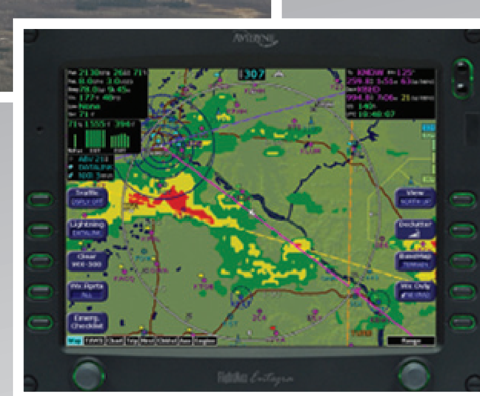
The Pilot's Manual

Access to Flight

Integrated Private and Instrument Curriculum



Foreword by Alan and Dale Klapmeier

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Dale Klapmeier

Aviation Supplies & Academics, Inc.
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The Pilot's Manual: Access to Flight

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None of the material in this manual supersedes any operational documents or procedures issued by the Federal Aviation Administration, aircraft and avionics manufacturers, flight schools, or the operators of aircraft.

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Foreword

Dear fellow pilot,

There are few challenges more rewarding, and accomplishments more satisfying, than becoming a licensed pilot. As an aviator, you'll find your horizons expanded, your aesthetic senses stimulated, and a rich camaraderie that no matter where you land, odds are you'll always find a friend.

Every time I fly, I look down at highways full of cars and wonder, "Why don't more people fly?" Is it because they just don't know they can? Learning to fly is a life-changing, and life-defining, experience. Not only does it shrink the world, but it also creates opportunities; it brings people and places closer together, and it saves time.

People often look at learning to fly as an insurmountable challenge. Learning to fly can indeed be challenging, but it will also be fun, exciting, and fulfilling. Learning to fly is not just an event; it is a change in lifestyle.

In the past few years, the road to becoming a pilot and the philosophies used in pilot training have evolved to keep up with the avionics and systems of today's modern aircraft, such as the Cirrus. It is also important that a new and modern approach to training will reflect these new technologies and capabilities, and focus on helping to shape a pilot's decision making skills and judgment. So while an airplane is, really, still an airplane — the physics are the same — how we're flying them, and how we're learning to fly them, has grown more sophisticated.

The training curriculum in The Pilots Manual: Access to Flight blends both the private pilot and instrument pilot training courses into one, complete pilot education solution. It is designed to get you, the pilot, flying and enjoying aviation efficiently and safely. Once you experience the rich rewards of aviation, soon you too will be asking, "Why don't more people fly?"

Alan and Dale Klapmeier

Alan Klapmeier is a co-founder of Cirrus and has served as its CEO and Chairman since its inception in 1984. Mr. Klapmeier serves on several industry boards, including the General Aviation Manufacturing Association (GAMA) Board of Directors (and serves as its Chairman for 2008), the AOPA Air Safety Foundation Board of Visitors, the Board of Directors of the Small Aircraft Manufacturers Association, and the Ripon College Board of Trustees. Mr. Klapmeier holds degrees in Physics and Economics from Ripon College in Wisconsin. With over 5,500 hours of flight time, Mr. Klapmeier has been a licensed pilot for more than 30 years.

Dale Klapmeier co-founded Cirrus 23 years ago and currently holds the position of Vice Chairman. As Vice Chairman, Mr. Klapmeier is responsible for overseeing product development, including the eagerly awaited Cirrus SRSport, and product strategy. Mr. Klapmeier is also involved in Experimental Aircraft Association's Young Eagle Program and the Red Tail Project, which is restoring a Tuskeegee Airmen P51 Mustang. Mr. Klapmeier holds degrees in business administration and economics from the University of Wisconsin, Stevens Point. As a private pilot Mr. Klapmeier has logged more than 3,000 hours of flight time.

Dale and Alan Klapmeier have received the 2007 Dr. Godfrey L Cabot Award, the Experimental Aviation Association, (EAA) 2007 Freedom of Flight Award, Airport Journal 2006 "Living Legends" Aviation Entrepreneurs of the Year, EAA August Raspet Award, Air Safety Foundation 2005 Admiral de Florez Award, and 2004 Ernst and Young Entrepreneurs of the Year for Manufacturing. Since founding Cirrus 23 years ago in a dairy barn in Baraboo, WI, the Klapmeiers have grown Cirrus Design into a global brand, with a formidable international sales and service network. Cirrus manufactures three models of aircraft, which includes the best selling aircraft for five consecutive years, the SR22. Cirrus employs about 1,300 people in two facilities. Grand Forks, ND is home to a state-of-the-art, composite lay-up and curing facility. Duluth, MN is home to Cirrus' world headquarters and where bonding, final assembly and customer delivery of aircraft also take place.

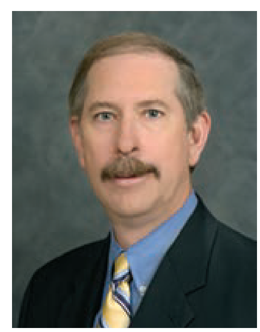
About the Editorial Team

David Robson

David Robson is a career aviator having been nurtured on balsa wood, dope (the legal kind) and tissue paper, and currently holds an Airline Transport Pilot certificate with instructor ratings. He served as a fighter pilot and test pilot for the Royal Australian Air Force, completed a tour in Vietnam as a forward air controller flying the USAF O-2A, and was a member of the Mirage formation aerobatic team, the Deltas. After retiring from the Air Force, he became a civilian instructor and lecturer for the Australian Aviation College, and editor for Aviation Safety Digest, which won the Flight Safety Foundation's international award. He was awarded the Australian Aviation Safety Foundation's Certificate of Air Safety.

Dr. Paul A. Craig

Paul A. Craig is a Professor of Aerospace at Middle Tennessee State University. He earned the Doctor of Education degree, holds the Airline Transport Pilot Certificate, and the Gold Seal Flight Instructor Certificate for Instrument, Multiengine and Seaplane. Craig is the author of numerous books, curriculum and journal articles on flight training and air safety. He is a two-time FAA District Flight Instructor of the Year and frequent speaker at pilot seminars. Craig worked with NASA on research pertaining to flight training in Technically Advanced Aircraft and won the 2005 NASA "Turning Goals into Reality" award. Craig won the 2004 University Aviation Association's Wheatley Award given yearly since the 1960s to the nation's most outstanding aviation educator. Craig is an active FAA Check Instructor, and currently works as a consultant and curriculum writer for Cirrus Design.



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Introduction

Becoming a Pilot in the 21st Century

Congratulations on beginning your journey into flight! Flying an airplane is one of the most rewarding accomplishments anyone can achieve.

Today's flight environment can be challenging, but this book, your flight training syllabus, and your flight instructor will work to make you a safe and competent pilot. As you progress in your study and in your flight lessons you will come to realize the awesome responsibility that comes with being a pilot. You will be responsible for your safety and the safety of your passengers. You will also be responsible for a great deal of fun and freedom. You will understand what it means to be Pilot in Command. In life there are very few times when you are totally and completely in charge of everything, but in an airplane you have that complete control.

We welcome you into this great tradition of aviators. You are in the same club with the Wright Brothers now and that's pretty good company.

This book incorporates a sequence of topics that is unlike other pilot training books and is especially designed to be used with new technologies of the 21st century. Airplanes and flight training did not change much from 1950 to 2000, however this is a new era with new airplanes, new technology in those airplanes and there are new ways to teach and learn in the modern flight environment. This book is specifically designed to meet the challenges of today's world and should be used as a companion to a combined Private Pilot and Instrument Rating course.

Why Combine the Private Pilot and Instrument Curriculum Together?

Traditionally the Private Pilot certificate and the world of Visual Flight Rules (VFR) were separate from the Instrument Rating and the world of Instrument Flight Rules (IFR). The Private Pilot certificate was for fair weather flying, for fun, or for the weekend. The Instrument Rating was the step toward serious flying, for business, or for the work week. The two worlds remained separated for all of the last century. Then at the beginning of the 21st century an explosion took place. Technology advances that had taken place over time in other industries arrived in aviation virtually overnight.

Single-engine trainer airplanes were just not being built during the last twenty years of the 1900's. The technology available to general aviation in 1995 was identical to the technology used in 1975—often it was the very same airplanes!

While the world's technology moved from the phonograph to the ipod, the magnetic compass, vacuum driven gyros and the airplane's round dials remained frozen in time. Then everything changed and changed fast. Manufacturers, with new liability laws on the books began to make airplanes again and new technology was waiting to be applied in aviation. It was a perfect storm.

A computerized or "glass" cockpit airplane hit the market and it was a revolution. Imagine going from a 1978 Commodore 64 computer to the 2008 Mac Air in one step. Airline captains retired early because they could not make the transition. Fleets of flight school airplanes were instantly obsolete. Everyone had to play catch-up. New airplanes called Technically Advanced Aircraft (TAA) were arriving on flight lines before pilots learned how to use them. Flight Instructors, many who gained their experience during the previous years of stagnation now had to learn to teach in a brand new environment.

With radically changing trends, flight instructors had to consider several things. For instance, what topics, which had been taught for a generation were no longer needed? Was there still value in teaching Automatic Direction Finder? What topics which were never taught before are now in desperate need? There was no such thing as "automation management" in an airplane built in 1975.

Aviation curriculum writers scrambled to meet unique challenges. And then there is the Federal Aviation Administration (FAA). The FAA is a deeply bureaucratic organization that is anything but nimble. The revolution caught the FAA off guard more than anyone else. In a February 2003 document, the FAA admitted: *"New small general aviation aircraft systems and technologies that do not fit neatly into the currently approved training programs are being produced faster than the FAA's resources can react to them."* The FAA needed lead time for changes, but the perfect storm happened too fast leaving the aviation training industry in a time of transition. We are teaching in technically advanced aircraft (TAA), but our tests—even the kinds of pilot certificates we have—are designed for the past. The FAA might be slow, but they are not blind.

In 2003 the FAA recognized that changes were needed. One of the training approaches that "might not be adequate" in this age of TAA is the continued separation of VFR and IFR operations.

The TAA makes it possible to blend VFR and IFR training in ways that were not possible before. The airspace in which we fly is more and more complex which in turn requires more capability from the aircraft and the pilot.

In 2030 will we still have VFR flying? The answer is probably yes. But it will be much different than VFR today. Even in Visual Meteorological Conditions (VMC), the aircraft and pilot will have to comply with certain Required Navigational Performance (RNP) standards for aircraft separation. This means that the airplane and the pilot must be able to guarantee a tight tolerance for position. The plane and pilot must follow a path that is so precise that it allows other airplanes to be closer than we are used to without fear of collision.

Today in a space where only two airplanes can fly, tomorrow there will be three airplanes or more! This would further utilize our airspace, but a more tightly packed airspace will place greater demands on the airplane's capabilities. RNP doesn't care how you make your airplane fly with this extra precision (with GPS or combination of ground based equipment) it just requires that you do it. The precision of IFR flight is no longer a luxury that VFR pilots can choose to take or leave. What we think of as VFR and IFR can no longer have separate training, separate certificates and be separate worlds as they were in the past.

One of the most significant steps the FAA has taken in this new direction is one that might not be obvious. In October of 2004, the Sport Pilot certificate and the Light-Sport Aircraft category became law.

The Sport Pilot certificate makes it easier for people who have always had a fascination with flight to become pilots in less time and with less money. Yet there are significant limitations. Sport Pilots cannot fly at night. They cannot fly in instrument conditions. Plus, they must remain in Class G and E airspace.

Sport Pilots can carry only one passenger and they must fly an aircraft that is in the Light Sport category. Although these limitations are great, they would not prevent a person from experiencing the thrill of flight and you can have a great deal of fun in Class G and E airspace. The Sport Pilot certificate fills a niche. It will be the pilot certificate of choice for those who want to fly in fair weather and for fun. In other words, the Sport Pilot will become what the Private Pilot certificate once was and the function of the Private Pilot certificate will change.

The Private Pilot certificate will be for those who fly for fun, as well as for those who need to fly in the airspace system and use the airplane as a business and personal transportation solution. For that function, the pilot must have IFR skills and the airplane must have the capabilities required for the IFR system. At that point VFR and IFR will be joined forever and the Private Pilot certificate with Instrument Rating will be one in the same.

Another reaction to technology in general aviation was a change in teaching strategy. Looking back across the history of aviation, every time new technology has been introduced, accidents spike. Would the introduction of new technology, which is the largest leap aviation has ever taken be followed by the largest leap in accidents as well? In each previous case there had been nothing wrong with the new technology. The fault was with the pilots who were not prepared to use the new technology. In an effort to "train-out" accidents before they happened, new airplanes, along with new technology demanded a new teaching method.

It is now possible and commonplace for skilled pilots in TAA to make longer flights at higher altitudes and across large weather patterns. Pilots today work inside the same system with corporate jet pilots and veteran airline captains. Pilots today have unprecedented access to information in flight and this has changed the role of pilot from just a controls manipulator to an information manager. Teaching pilots a set of non-applicable maneuvers alone is now dangerously out of step with reality. The pilot will always be required to control the airplane with skills—sometimes called "stick and rudder" skills—and that will never change, although today it takes more to operate in the system safely. A pilot flying his or her family across country for a vacation or a business trip will face countless challenges that a pilot would not be prepared for with flight maneuvers alone. New teaching strategies take this fundamental shift in the flight environment into account.

The new teaching method relies on three tenets that are each unique to flight training. First, the method uses a scenario-based, problem-solving approach that brings "real world" flight operations into the training. The idea is to train like you fly and fly like you train. Since today's technologically advanced airplanes have the capability to blend VFR and IFR, this book blends VFR and IFR into one teaching set. Flying a TAA, but using it for VFR alone would be like buying a flat panel, plasma screen television and only watching programs in black and white!

Second, the pilot in training becomes highly involved in their own learning and progress. This strategy uses a Learner Centered Grading approach that will involve the pilot at every step. The student pilot and flight instructor work as a team and the student's input, questions, and interests are solicited.

Last, the method teaches Single Pilot Resource Management (SRM). TAA airplanes offer pilots a new level of safety and information. But to turn the "available" safety of the TAA airplane into "actual" safety, the pilot must learn not only to fly the airplane, but to also be a manager of all the information that is available in the airplane. This strategy has been used and tested in a NASA sponsored program that came from the Small Aircraft Transportation System (SATS) initiative. The method of training this book uses and the original training syllabus of the project won the NASA "Turning Goals into Reality" award which was like winning an Academy Award for flight training!

Teaching pilots in the new century with new airplanes and new technology require a new approach. We must rely more on the pilot to physically fly the airplane safely, but also evaluate information, prioritize that information and make consistent and competent decisions based on that information. The pilot must be aware of all the factors that will challenge the safety of the flight. He or she must understand the limitations of the human body in flight must know how to acquire and maintain situational awareness. It's a big challenge for you as you begin your flight training experience, but those who dare to follow their dreams of flight always find a way to rise to the challenge.

A Few Points on Studying

Keep your study periods short and intense. Quietness, good lighting, and a clear and fresh mind are important to effective study. Occasional walks and breaks for relaxation are beneficial. Every person has different study habits and a study comfort level that is most effective for them. We suggest that you find your comfort level and then be diligent in your study.

Work closely with your personal flight instructor and integrated Private and Instrument syllabus, both which will guide your study within this book. The sections and chapters may not be studied in the exact order presented in the book. Ask your instructor what topics are coming next and what sections you should be reading as your flight training moves along.

Each chapter has helpful review questions. These reviews are designed to build your confidence in your own knowledge and ability while giving you practice for the Private Pilot and Instrument Rating Knowledge Exams. FAA Knowledge Exams consist of multiple-choice questions which are quick and easy to process. However, multiple-choice questions are not a good learning aid as they present you with a choice of answers, some of which are wrong. To continuously read incorrect statements is confusing, so in our reviews we question you in a more positive manner, while retaining some multiple-choice questions in the FAA exam style for your practice.

Our advice when working with multiple-choice questions is prior to reading the selections of possible answers, think in your own mind what the answer should be. Then read through the choices and quite often you will find the answer that you already have in mind is among them. If not, proceed to eliminate the obviously incorrect statements.

Conclusion

Access to Flight is designed to develop an in-depth understanding of the main facets of aviation and to be a companion with your personal flight instructor and flight training syllabus. Not only will this book help you pass the FAA Knowledge Exams easily, it will provide an excellent basis for becoming a competent and safe pilot.

—Paul Craig

The Pilot

Airmanship 1

The idea of Airmanship is complex. It encompasses all the facets that make up a competent and safe pilot. To have Airmanship is to be able to fly an airplane with skill and precision but the idea means more. To have Airmanship is to be a savvy decision maker and in the 21st century it means having the ability to acquire, prioritize, and utilize information during flight. Pilots with Airmanship can be trusted to make decisions that will insure the safety of flight with confidence.

Sometimes a pilot with Airmanship says no to a flight even when the decision is not popular with passengers and alternate plans would be inconvenient. Sometimes a pilot with Airmanship says yes to a flight and conducts that flight with the greatest level of safety in situations that might be dangerous for other pilots who do not have Airmanship. So the goal of every pilot is to work on obtaining and maintaining their Airmanship because by doing so they insure safety for all and guarantee the fun and excitement of flying.

Airmanship is the sound acquaintance with the principles of flight, the ability to operate an airplane with competence and precision, and the exercise of sound judgment that results in optimal operational safety and efficiency.

Across the world pilots fly together in teams or crews, but pilots are initially trained to fly alone without the aid of a second pilot on board. This means that all the tasks required to make a flight safe must be accomplished by a single pilot.

The pilot is never really alone however. Today vast amounts of information is available in the airplane while in flight. There are many people on the ground who assist pilots while in flight. Assistance by the airplane's radio, air traffic controllers, weather observers and forecasters, and even airplane maintenance personnel can be considered the "crew" of a single pilot. How the pilot manages all these resources is called Single-Pilot Resource Management (SRM).

Single Pilot Resource Management

Single Pilot Resource Management (SRM) is defined as the art and science of managing all the resources (both on-board the aircraft and from outside sources) available to a single-pilot (prior and during flight) to ensure that the successful outcome of the flight is never in doubt. SRM includes the concepts of Aeronautical Decision Making (ADM), Risk Management (RM), Task Management (TM), Automation Management (AM), Controlled Flight Into Terrain (CFIT) Awareness, and Situational Awareness (SA). SRM training helps the pilot maintain situational awareness by managing the automation and associated aircraft control and navigation tasks. This enables the pilot to accurately assess and manage risks and make accurate and timely decisions.

The ability to identify problems, analyze the information, and make informed and timely decisions is one of the most difficult tasks for the pilot. If pilots can accomplish these tasks confidently and consistently then they are maintaining their Situational Awareness and SA leads to Airmanship.

Situational Awareness

We tend to think of piloting an airplane as a physical skill. However, there is more to it—much more. Aircraft control, the manipulation of controls to achieve a desired performance, is important, but it is only one element of the pilot's total task. The pilot must assemble information, interpret the data, assess its importance, make decisions, act, communicate, correct and continuously reassess. We call this total process *piloting.* But let's start with the control process so that, once the aircraft is under control, we can be sensitive to and more aware of the bigger picture.

Where am I, where am I going, when will I get there, with how much fuel, at what time, what will the weather be like, how well is the aircraft performing, how tired am I, how well are the passengers, how do I get to the town after I land, how to avoid weather, how to avoid airspace, what calls I have to make . . . this is situational awareness. It is a total appreciation of where you are, where you want to be and how best to get there safely and on time.

How You Process Information

The main feature of your brain, as a central decision-maker, is that it can only function as a *single-channel* computer, which means that you can consider only one problem at a time. Conscious decisions are therefore not made simultaneously, but sequentially. They are placed in a queue according to a priority—but not always logically.

How the brain processes information is fascinating. There are six fundamental stages:

- *stimulation* and *sensation* where sensors receive a signal;
- *perception* for recognition, classification and remembering;
- *analysis* to work out what to do (make a decision);
- *action* for doing something (or nothing);
- *feedback* to check results; and
- *correction* to achieve acceptable standards of accuracy.

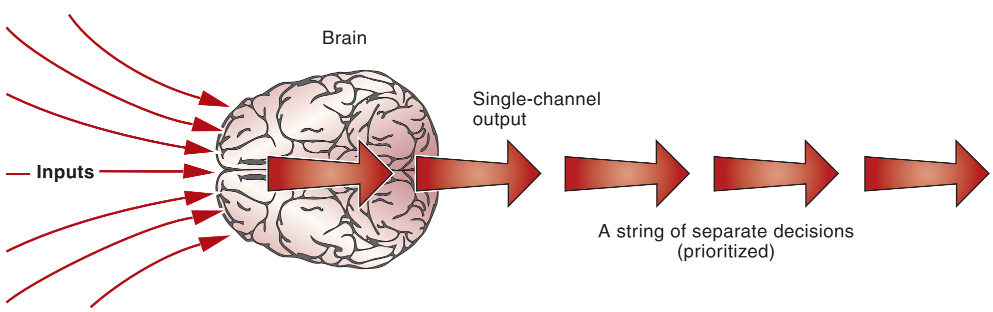


Figure 1-1 Single-channel processing.

Assembling the Big Picture

The pilot's task involves two processes:

- being in *control* of the airplane; and
- being in *command* of the situation.

Situational awareness is the process whereby the pilot gathers data from his or her own senses via sight, hearing, smell, taste, touch, and feel. For a pilot, the eyes and ears are the primary sensors—although control feel and " seat-of-the-pants" are important cues for aircraft control. In addition to direct sight and sound, the eyes and ears are used to gather information from the instruments, radios, and NAVAIDs so that the pilot can build and maintain an awareness of position, time, fuel, weather, traffic, and aircraft status. From these data, the pilot can prioritize the importance of the information, anticipate trends, assess the need for urgency, and make decisions. The primary task of being the pilot in command is decision making. The quality of the decision depends upon the quality, completeness, and timeliness of the data—and is affected by pilot aptitude, training, fatigue, stress, and personality.

The process of assembling data, making a decision, acting and correcting is called the pilot's *control loop.*

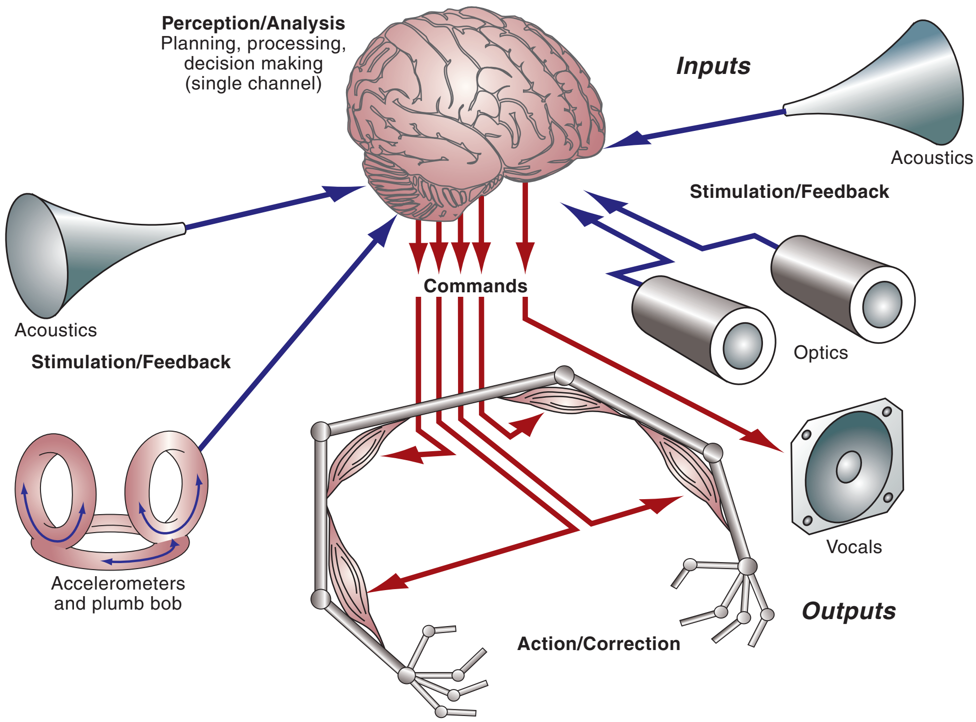


Figure 1-2 The pilot's central role in the control loop.

Flying as a Learned Set of Skills

While a student pilot is concentrating on learning to fly safely and accurately, the central decision-maker will be almost fully occupied. There will be very little spare capacity for other tasks such as navigation and radio calls—or even listening to the instructor. Once the student has learned the motor skills and practiced them until they are second nature, flying the airplane will occur with little conscious thought. In this case, a string of activities is run autonomously in the brain, leaving the central decision-maker available for higher-level decisions. Strings (or sets) of skills are often initiated by the central decision-maker. You might make a decision to get up and walk toward the door, but once this decision has been made, the central decision-maker can drop out of the picture temporarily and let the motor program run the activity. As well as initiating the activity, the central decision-maker will also

Figure 1-3
The primary pilot-airplane interface.

return to monitor the motor program from time to time, to check that the proper skill sequence is in use, and to check progress and decide when to stop.

If skills are not used regularly, they deteriorate, and an activity that was once run automatically by a single thought may now have to be managed by conscious decision-making. This will occupy the central decision-maker and, as a result, you can expect a temporary deterioration in the performance of other tasks. Professional pilots returning from a holiday break notice this, as do musicians and others who have to perform skilled tasks. We can certainly *do* more than one thing at a time, thanks to skill programming, but we can only *think* about one thing at a time.

Response Time

The time it takes for any initial stimulus to be perceived, considered, and acted upon can take between a fraction of a second and several seconds, depending upon the complexity of the decision to be made, the action to be taken and the acceptability of the degree of deviation. In a control loop, such as an autopilot, this is known as the *gain*—high gain means a quick response to any deviation, and low gain is a sluggish response. High gain is less tolerant of deviations but can mean a rough ride and so autopilots have a soft-ride or half-bank mode for less disturbances and a more comfortable flight.

Responding to a stimulus often requires a series of sequential decisions to be made: this of course needs time due to the single-channel nature of the brain's central decision-maker. On approach to land, for instance, the landing gear has been selected down and a horn unexpectedly sounds.

Some of the decisions that now need to be made are the following:

- *establish a safe flight path*—in this case, a go-around is essential to gain time and place you into a position where you can sort out the problem. Continuing with the approach is pushing you to a higher workload, with more critical demands on time;
- *silence the horn to remove the distraction*—the horn has been heard and the warning has been noted;
- *what does the horn mean?*—is it landing gear not down, or something else? It means that the landing gear has been selected down, but is not actually down;
- *radio call*—declare emergency to tower, ATC or other traffic; and
- carry out checklist items.

Throughout the decision-making process following a very simple unexpected event, you must continue to switch attention through the tasks of aviating, navigating, and communicating to allocate priorities and to trigger skilled responses. In a situation like that above, you removed the pressure of time by deciding to make a missed approach, and then allowing the learned skill to fly the aircraft. Once the safe response was seen to be in progress, the conscious mind then established the next priority. Time was thus made available to solve the problem. In other situations, you may not have that luxury—e.g. in a takeoff that is rejected at a high speed on a limiting runway. This will require a split-second decision and immediate actions. If the pilot of a large aircraft suspects a problem during the takeoff run, especially as the decision speed is approached, there is only two seconds to decide what to do: *stop or go?* Stopping may not be possible if a tire has blown and reduced the wheel-braking capability. Continuing the takeoff may not be possible if the problem is with the flight controls, or if the problem is multiple engine failure due to bird strikes. The enormous pressure of limited time between input and a necessary decision can sometimes lead to a faulty decision and response.

The risk of making a poor decision, no decision, or an incorrect response is minimized by maintaining a high level of knowledge, and by practicing a maneuver frequently so that it becomes a conditioned response. The decision/response is thus based on the probability of the best course of action and accepting the smallest odds. Simulators can play a big role here, particularly when practicing critical maneuvers.

Mental Workload

Best performance is achieved by a combination of high levels of skill, knowledge, and experience (consistency and confidence), and with an optimum degree of arousal. Skill, knowledge and experience depend upon the training of the pilot; the degree of arousal depends not only upon the pilot's flying ability but also upon other factors, such as the design of the cockpit, air traffic control, as well as upon the environment, motivation, personal life, weather, and so on. Low levels of skill, knowledge and experience, plus a poorly designed cockpit, bad weather, and poor controlling will lead to a high mental workload and a poor performance. If the mental workload becomes too high, decision making will deteriorate in quality, or maybe not even occur. This could result in concentrating only on one task (sometimes called *tunnel vision*) **with excessive or inappropriate load-shedding**. You can raise your capability by studying and practicing, and by being fit, relaxed and well rested.

The pilot's tasks need to be analyzed so that at no time do they demand more of the pilot than the average, current and fit pilot is capable of delivering. There should always be some reserve capacity to allow for handling unexpected abnormal and emergency situations. At the aircraft design stage, the pilot is taken to be of an average standard. On this basis, skills and responses are established during testing so that the aircraft can be certificated as compliant. But there is some argument that the specimen should not be the average pilot, because half of the pilot population would be below this standard.

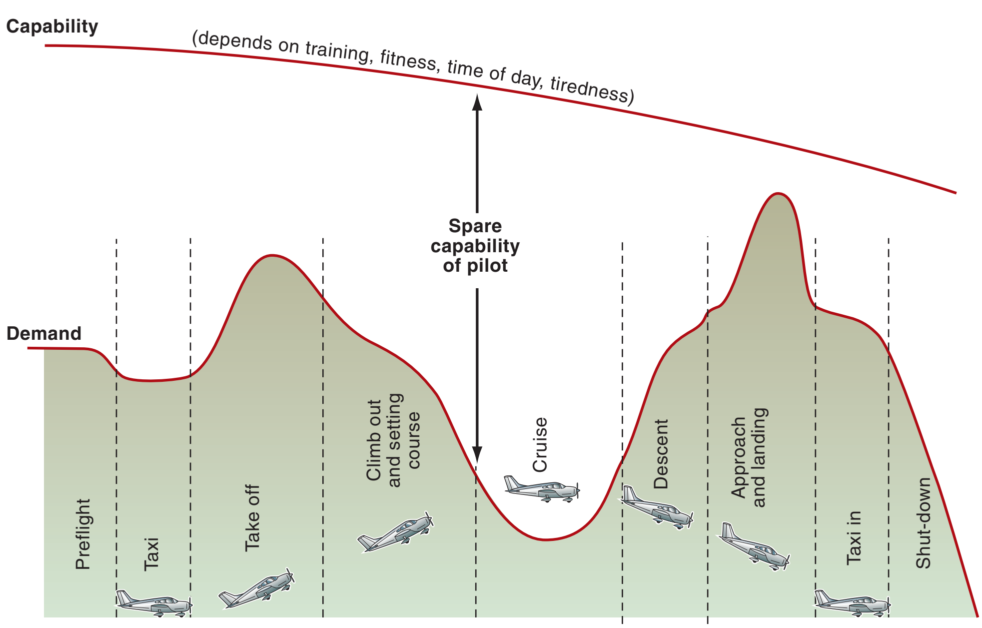


Figure 1-4 Reserve capability.

The legislators establish the minimum acceptable standards for licensing but the marginal pilot, who maintains only the minimum required standard, is not really of an acceptable standard. You can each ensure that you are at an acceptable standard by honestly reviewing the demand that the aircraft and the flight placed upon you. If your capabilities, mental or physical, were stretched at all, then you need more practice, more study or more training—at least in those aspects that challenged you. Many pilots feel that under normal conditions they should be able to operate at only 40–50% of capacity. The exception to this is during takeoffs and landings when capacity might rise to 70%. This leaves some capacity to handle abnormal situations.

Aeronautical Decision Making

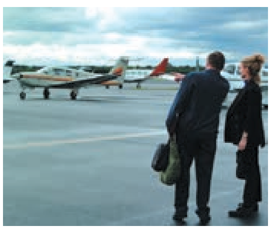


Figure 1-5
Make conscious decisions.

The essential, fundamental role of the pilot is to make decisions—reliably, safely and timely. But fortunately or unfortunately, pilots are only human.

Information Processing

The decision-making process is one of assembling data, assessing its importance and urgency, making the optimum decision (based on experience and training) and then taking the appropriate action. The quality of this action reflects the pilot's aptitude, skill, discipline, training and recent experience (on the aircraft type, in certain conditions and for the particular phase of flight). The quality of the decision depends very much on having complete and recent data (such as position, weather and traffic) for both existing conditions and the likely trends. This big picture is called *situational awareness.* Then there is the dimension that must have a high priority in the pilot's mind: the "fourth dimension."

The Fourth Dimension

An airplane operates in four dimensions:
- three-dimensional space; and
- time.

Everything in flight is changing, and the rate of change varies enormously. Learning to fly is very much a process of being conditioned to the rate at which things happen.

The other aspect of time is that it is finite. You run out of fuel, daylight and clear weather. You become tired. You may have limited time and space in which to make a decision or to maneuver the aircraft.

Thus situational awareness for a pilot is knowing more than where you are. It is knowing the aircraft's position, environment and status, all in the context of time—time gone, time to go and time available.

Emotions in Decisions

Emotion plays a significant, often a dominant role, in the decision-making process. We often decide on the basis of what we want to happen rather than what is most likely to happen. What we hope instead of what is likely. What we expect can also be ambitious or cautious, especially if we have pushed the boundaries and got away with it previously. Thus decisions also depend on personality and confidence. What are the chances I wrongly perceive rather than correctly know what the odds really are? Do I by nature err on the positive side or the negative? And in terms of safety, the negative is not a bad thing. It is cautious and survival-oriented rather than goal/success oriented. *I made it!* You must learn to make as much of a song-and-dance about sensible, reserved decisions and actions as you do about taking a risk and getting away with it.

Decisions and Stress

Internal Stressors

Decisions not taken cause stress. While you are deciding, and are under pressure to decide, the level of stress can become unreasonable. Avoiding a decision also causes stress because you know that ultimately the problem will have to be addressed. It won't go away. The solution is to make the decision and go for it. Stress is relieved by action, either fight or flight.

Keep stress down by: avoiding high risk flights; knowing your personal limits; staying proficient in your aircraft; concentrate on flying the aircraft, first and foremost.

External Stressors

External pressures have a significant effect on your decisions. You have human wants, needs and fears: wanting to please, wanting to impress friends or siblings, wanting to earn more money or be promoted, needing to be loved, needing to be noticed, needing to be rewarded, fearing criticism or ridicule, fearing job loss, or fearing injury. A completely rational decision is made in isolation and such decisions can often only be made retrospectively: what you should have decided rather than what you did decide. Accident investigations are largely of this ilk because they do not—cannot—know the pressures under which the particular decision was made. We can rationalize why the pilot should have made the correct decision when we read the accident report. It's obvious. What is not obvious is the emotional strings attached to that decision. Making correct decisions sometimes takes considerable courage or, to use the old term, *moral fortitude.*

Destination Obsession

Destination obsession (also known as "get-there-itis") is getting there, today, at all costs. It seems not to be the result of a conscious, foolish decision, but more likely the result of delaying the decision to turn back and land while it is safe to do so. Illusions and misinterpretation of the seriousness of a deteriorating situation complicates the decision.

Low Cloud, Pressing On

The problem with pilots pressing on under lowering cloud is well-known within the aviation industry, and yet it just doesn't go away. Fatal accidents continue to occur due to this problem. The solution is elusive. The process involved obviously affects judgment of distances—distance from cloud and height above the terrain. Incredibly visual meteorological conditions (VMC) do not require a visual horizon! True we can estimate the horizontal by perceiving the vertical—by looking down—but this is not always reliable. What if the terrain is not level?

With fewer cues available, those that can be read are given greater importance. They appear more pronounced, more compelling in their meaning. They invite greater reliance on what they are telling you. The main effect will be to deny a proper and accurate assessment of height above terrain, and distance from obstacles and cloud. This results in a false appreciation of level attitude.

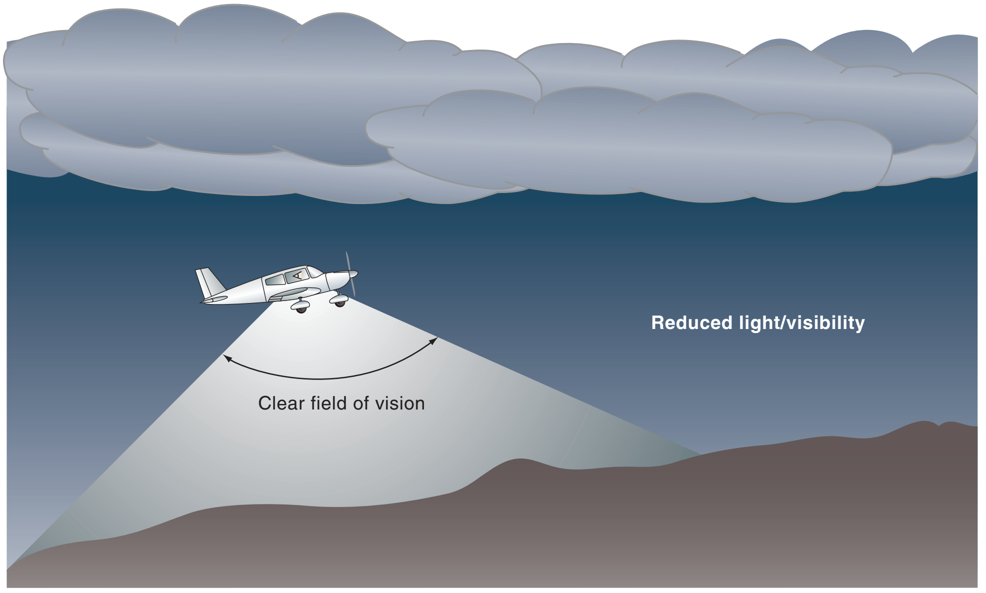


Figure 1-6 Limited cone of vision.

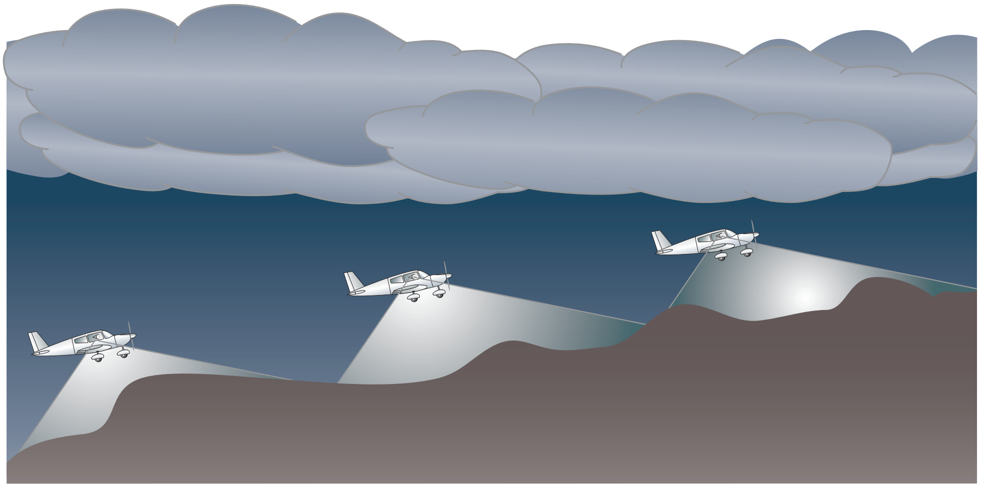


Figure 1-7 Rising terrain—false horizontal.

With restricted forward visibility, your judgment of height and distance will be so distorted it will be useless. You could become very close to the trees or ground without realizing. But, by then, it's far too late. We've all heard news reports of aircraft engine noise low overhead, often for long periods before the actual crash.

This adds up to the unsurprising conclusion that most, if not all, pilots who do go too far under cloud have no idea how low they are actually flying until they hit something—or wind up in the "soup" itself, blind in cloud. The destination obsession affecting their decision making and distorting their judgment must have been very powerful indeed. Moreover, there is one more influence: *visual illusion*.

Many aircraft that have crashed under cloud into rising terrain having stalled while under full power. With the limited field of view, there is a tendency to use the ground as reference for level flight. The closer you get to the ground without a strong nose attitude vs. horizon reference, the more prone will you be to seeing the fuselage being parallel to the earth's surface as an indication of level flight. As the slope increases so will the climb angle, until the inevitable stall.

It's the same phenomenon as not being able to judge height, anymore — too few visual clues available to make a correct assessment. The further you go pressing on, the less you'll appreciate just how close you are to the cloud and the tree tops. But, of course, you should never have got there in the first place. Unfortunately pilots do.

Personality and Matters of Choice

One of our defenses against being discomforted by situations like these is the confidence that, "It won't happen to me." On the other hand, most of us do know people who we would rate as more-likely-than-most to do such a thing. Thus, the idea that some types are more prone to taking higher risks than others is not especially controversial. The sort or type of person is usually defined by a hazardous attitude.

Five Hazardous Attitudes

The FAA defines five types of hazardous mental attitudes for pilots. They include:

- *antiauthority (don't tell me!).* People who don't like others to tell them what to do are often resentful of wise advice and prone to disregarding the rules. *The antidote to antiauthority is: Follow the rules; they are usually right*;
- *impulsivity (do something, quickly!).* People who don't stop to think before they act are impulsive. They often do the first thing that comes to mind. *The antidote is: Not so fast. Think first*;
- *invulnerability (it won't happen to me).* We all know accidents happen, but some feel it could never happen to them. They are far more likely to take chances and risks. *The antidote is: It could happen to me*;
- *macho (I can do it).* Now, here's a person with something to prove and he or she will probably take risks to show off. *The antidote is: Taking chances is foolish*; and
- *resignation (what's the use?).* Resigned pilots figure that the flight went well because they were lucky. If the flight goes poorly, however, it isn't their fault, there's nothing they can, or will do to change things. *The antidote to this attitude is: I'm not helpless. I can make a difference.*

Formal Decision-Making Processes

You can learn to make better decisions by itemizing the correct decision-making process:

Pilots must assess the risks involved in any flight. Good judgment and decision-making skills can be learned.

1. identify the decision to be made or problem to be solved;
2. collect relevant information;
3. generate alternatives;
4. analyze alternatives;
5. decide the most acceptable alternative;
6. action the alternative; and
7. monitor the outcome: if satisfactory, proceed; if not, repeat steps 2-7.

While this may seem to be time consuming, it gives structure and method to the process and ensures no jumping to conclusions. Most airlines use these steps in crew resource management (CRM), decision making and training. It is a valid way to make decisions and to check if your normal process covers all options. But there is another important element: how much time you have to make the decision.

The other problem is not making a decision, i.e. deferring the decision until it is too late. You are forced into a situation where there is no decision to make. You are then committed with no escape route.

D Detect a change.
E Estimate the need to react.
C Choose an outcome.
I Identify actions.
D Do the necessary action.
E Evaluate the effect.

There is a well-known model for decision making based on the mnemonic DECIDE. This model implies the decision is a reaction to circumstances, a situation or a change in events. A better way to make decisions is to anticipate—to be *pro* active rather than *re* active. Have the decision made before it is needed—on standby—like you practice emergency procedures so you can anticipate a decision point and have most of the work done.

Crises? Decisions should ideally not be made under duress—in a crisis situation. They should be made under controlled conditions and be stored—ready for use. A different model is based on the mnemonic ACTION:

A Anticipate and assess the possible scenarios.
C Consider actions and outcomes.
T Time—if available, immediate decision or nominate decision point (go/no-go point) and criteria.
I Implement decision—make a control input, transmission etc.
O Observe the result and correct—fine tune.
N Nominate the next milestone, decision point or potential hazard.

Many problems are due to no decision or a delayed decision. Decisions are easy to defer. Deferring decisions is only acceptable if a nominated decision point is made and adhered to.

Assembling What-If's

Sesame Street (Envisioning Outcomes)

A fabulous episode of Sesame Street involved a child who was encouraged to imagine outcomes before crossing the road:
- what if I run onto the road without warning . . . ?
- what if I run out in front of a school bus . . . ?
- what if I run across the road and trip . . . ?
- what if I cross without looking in both directions . . . ?

This is exactly the what-if attitude a pilot needs to develop.

Choosing the Best Option

Priorities

The first priority must surely be to arrive safely, but we often neglect that or compromise it for "must arrive today," "must get to a meeting on time," "must land before dark," "haven't time to top off the tanks, complete a fuel check, complete an engine run-up check," etc.

Bets and Betters

We endlessly evaluate bad decisions but what about some examples of good decisions? It is better to spend a cold night in a sleeping bag in a tent under the wing of the airplane than flying into deteriorating weather and impacting terrain. It is better to arrive late, even the next day or next week, than not at all.

If you have to be there, have an alternative plan: "I will leave early enough so that if the weather deteriorates over the mountains, I can land at . . . and take the bus and pick up the airplane on the way home."

It's better to accept the rebuke, criticism and complaints of a passenger or employer by refusing to overload the airplane or exceed the CG limits than crash on takeoff. Saying "I told you so" is no consolation in the eddying seconds of the flight as you inevitably impact the trees. (Incidentally, passengers and employers expect you to protect them from themselves). It is better to land and leave your family safely on the ground rather than risk injuring all of them because you have to get to a business meeting. But then shouldn't you also stay on the ground with them? It is better to pay several hundred dollars for taxis and hotel rooms at an unplanned stop than miss your daughter's wedding and have them attend your hospital bed instead. It is better to be called a chicken than to be decimated and burned in the wreck of an airplane that stalled and spun trying to attempt a low pass after takeoff. It is better to go around and accept the extra time and expense than land when the runway is occupied or when your threshold speed is too high. You bet!

On Def Ears

Two common situations lead to dangerous situations. They are:
- deference; and
- deferral.

Deference is when you relinquish the decision to someone or allow their views to dominate. Such as when you avoid discussion and possible conflict, or when you want to please by saying what others want to hear or do what they want despite your inner feeling that the option is risky. Deferral is avoiding making a decision—until later perhaps until its too late. This is the reason you have to set your own milestones, gates and go/no-go points and stick to them.

Choosing When to Implement a Decision

As important as the decision is the timing (when to implement it). But when is the right time?
- Immediately?
- Before sunset?
- Before reaching the point of no return (PNR)?
- Before becoming fatigued?
- Before becoming stressed due to weather or terrain?

Mostly a decision is needed now. But there are some occasions when a gate or milestone can be set. For example:
- I will proceed until the PNR, but at that point, if I have any doubts about the weather at the destination, I will turn back. (The decision is already made and the criteria set. The decision point is also set—it is non-negotiable);
- I will maintain minimums until overhead the airfield and if I cannot see the runway lights I will divert to the alternate. (I will not descend);
- I will continue while I can maintain safe terrain clearance. I have a defined horizon and I have at least a 500-foot vertical separation from cloud. If I lose the horizon, if I feel squeezed between ground and cloud, I will immediately turn right (least risk); and
- I will continue until an intermediate landing point and if I do not reach there by a certain time, which guarantees I will reach the ultimate destination by sunset, I will land.

Operational Airmanship–The "5P" Check

Single pilot resource management, situational awareness and aeronautical decision making all sound good on paper; however, pilots need a way to understand and deploy these skills in their daily flights. This practical application is called the "Five P's" (5P's) The 5P's consist of "the Plan, the Plane, the Pilot, the Passengers, and the Programming." Each of these areas consists of a set of challenges and opportunities that face a single pilot. Each can substantially increase or decrease the risk of successfully completing the flight based on the pilot's ability to make informed and timely decisions. The 5P's are used to evaluate the pilot's current situation at key decision points during the flight or when an emergency arises. These decision points include: preflight, pretakeoff, hourly or at the midpoint of the flight, pre-descent, and just prior to the final approach fix or for VFR operations, just prior to entering the traffic pattern.

The 5P's:
The Plan
The Plane
The Pilot
The Passengers
The Programming

The 5P's are based on the idea that pilots have essentially five variables that impact their environment which can cause the pilot to make a single critical decision, or several less critical decisions that when combined can create a critical outcome. These variables are the Plan, the Plane, the Pilot, the Passengers, and the Programming.

The 5P concept relies on the pilot to adopt a "scheduled" review of the critical variables at points in the flight where decisions are most likely to be effective. For instance, the easiest point to cancel a flight due to bad weather is before the pilot and passengers board the aircraft. So the first decision point is preflight in the flight planning room, where all the information is readily available to make a sound decision, and where communication and fixed base operator (FBO) services are readily available to make alternate travel plans.

The second easiest point in the flight to make a critical safety decision is just prior to takeoff. There is no such thing as an "emergency takeoff". While the point of the 5P check is to help you fly, the correct application of the 5P before takeoff is to assist in making a reasoned go/no-go decision based on all the information available. That decision will usually be to "go" with certain restrictions and changes, but may also be a "no-go." The key component is that these two points in the process of flying are critical go/no-go points on each and every flight.

The third place to review the 5P's is at the mid point of the flight. Often, pilots may wait until the Automatic Terminal Information Service (ATIS) is in range to check weather, yet at this point in the flight many good options have already passed behind the aircraft and pilot. Additionally, fatigue and low altitude hypoxia rob pilots of their energy by the end of a long and tiring flight day. This leads to a transition from a decision-making mode to an acceptance mode on the part of the pilot. If the flight is longer than 2 hours, the 5P check should be conducted hourly.

The last two decision points are just prior to decent into the terminal area and just prior to the final approach fix, or if VFR just prior to entering the traffic pattern, as preparations for landing commence. Most pilots execute approaches with the expectation they will land out of the approach every time. A healthier approach requires the pilot to assume that changing conditions (the 5P's again) will cause the pilot to divert or execute the missed approach on every approach. This keeps the pilot alert to all conditions that may increase risks and threaten the safe conduct of the flight. Diverting from cruise altitude saves fuel, allows unhurried use of the autopilot and is less reactive in nature. Diverting from the final approach fix, while more difficult, still allows the pilot to plan and coordinate better, instead of executing a futile missed approach. Now let's look in detail at each of the "Five P's."

The Plan

The "Plan" can also be called the mission or the task. It contains the basic elements of cross-country planning, weather, route, fuel, publications currency, etc. The "Plan" should be reviewed and updated several times during the course of the flight. A delayed takeoff due to maintenance, fast moving weather, and a short notice Temporary Flight Restriction (TFR) may all radically alter the plan.

The "plan" is not just about the flight plan, but the entire days events surrounding the flight and allowing the pilot to accomplish the mission. The plan is always being updated and modified and is especially responsive to changes in the other four remaining P's. If for no other reason, the 5P check reminds the pilot that the day's flight plan is real life and subject to change at any time.

Obviously the weather is a huge part of any plan. The addition of real-time datalink weather information gives the Technically Advanced Airplane pilot an added advantage in inclement weather, but only if the pilot is trained to retrieve and evaluate the weather in real time without sacrificing situational awareness. And of course, weather information should drive a decision, even if that decision is to continue on the current plan. Pilots of aircraft without datalink weather should get updated weather in-flight through a Flight Service Station and/or Flight Watch.

The Plane

Both the plan and the plane are fairly familiar to most pilots. The plane consists of the usual array of mechanical and cosmetic issues that every aircraft pilot, owner, or operator can identify. For example, whether or not everything is working properly; if the fuel situation is where you expect it to be at that point; and if you will need to use anti-ice equipment. However, with the advent of the Technically Advanced Aircraft (TAA), the plane has expanded to include database currency, automation status, and emergency backup systems that were unknown a few years ago. Much has been written about single pilot IFR flight both with and without an autopilot. While this is a personal decision, it is just that, a decision. Low IFR in a non-autopilot equipped aircraft may depend on several of the other "P's." Pilot proficiency, currency, and fatigue are among them. The TAA offers many new capabilities and simplifies the basic flying tasks, but only if the pilot is properly trained and all the equipment is working as intended.

The Pilot

This is an area in which all pilots are learning more and more about each day. Flying, especially when used for business transportation, can expose the pilot to high altitude flying, long distance and endurance, and more challenging weather. Technically Advanced Aircraft (TAA), simply due to their advanced capabilities can expose a pilot to even more of these stresses. The combination of late night, pilot fatigue, and the effects of sustained flight above 5,000 feet may cause pilots to become less discerning, less responsive to critical of information, less decisive and more compliant and accepting.

Just as the most critical portion of the flight approaches (for instance a night instrument approach, in the weather, after a four hour flight) the pilot's guard is down the most. The "5P" process emphasizes that pilots recognize the physiological situation they are placing themselves in at the end of the flight, before they even take off, and continue to update their condition as the flight progresses. Once identified, the pilot is in an infinitely better place to make alternate plans that lessen the effect of these factors and provide a safer solution.

The Passengers

One of the key differences between Crew Resource Management (CRM) and Single-Pilot Resource Management (SRM) is the way passengers interact with the pilot. In the airline industry the passengers have entered into a contractual agreement with the pilot's company with a clearly defined set of possible outcomes. In corporate aviation, the relationship between crew and passengers is much closer, yet is still governed by a set of operating guidelines and the more formal lines of corporate authority. However, the pilot of a highly capable single engine aircraft has entered into a very personal relationship with the passengers. In fact, they sit within an arms reach all of the time.

It may be easy, especially in business travel, for passengers to make airline connections or important business meetings to enter into the pilot's decision-making loop. If this is done in a healthy and open way, it is a very positive thing. However, this is not always the case. For instance, imagine a flight to Dulles Airport and the passengers, both close friends and business partners, need to get to Washington D.C. for an important meeting. The weather is VFR all the way to southern Virginia then turns to low IFR as the pilot approaches Dulles. A pilot employing the 5P approach might consider reserving a rental car at an airport in northern North Carolina or southern Virginia to coincide with a refueling stop. Thus, the passengers have a way to get to Washington, and the pilot has an out to avoid being pressured into continuing the flight if the conditions do not improve.

Pilots need to know that non-pilots may not understand the level of risk involved in the flight. There is an element of risk in every flight. That's why SRM calls it risk management not risk elimination. While a pilot might feel comfortable with the risk present in a night IFR flight, the passengers might not and possibly communicate this during the flight. The human reaction to fear and uncertainty is varied. Some become quiet, some talk incessantly, and in extreme cases anger and fear are strongly manifested. This is potentially the last thing the pilot needs to deal with while shooting the ILS to 400 feet with 1 mile visibility at midnight.

A pilot employing SRM should ensure that passengers are involved in decision-making and are given tasks and duties to keep them involved. If, upon a factual description of the risks presented, the passengers decide to buy an airline ticket or rent a car, then a good decision has generally been made. This discussion also allows the pilot to move past what he or she thinks the passengers want to do and find out what they actually want to do. This removes a load of self-induced pressure from the pilot.

The Programming

The Technically Advanced Airplane adds an entirely new dimension to the way general aviation aircraft are flown. The glass cockpit, GPS, and autopilot are tremendous aids that reduce pilot workload and increase pilot situational awareness. But unlike the analog instruments they replace, they tend to capture the pilot's attention and hold it for long periods (like a computer or television). To avoid this phenomenon, the pilot should plan in advance when and where the programming for approaches, route changes, and airport information gathering should be accomplished, as well as times it should not. Pilot familiarity with equipment, routes, the local air traffic control environment and their own capabilities with regards to the automation should drive when, where, and how the automation is programmed and used.

The pilot should also consider what his or her capabilities are in response to last minute changes of the approach (and the reprogramming required) and ability to make large-scale changes (a re-route for instance) while hand flying the aircraft. Since formats are not standardized, simply moving from one manufacturer's equipment to another should give the pilot pause and require more conservative planning and decision making.

The SRM Decision Process

The SRM process is simple. At least five times, before and during the flight, the pilot should review and consider the "Plan, the Plane, the Pilot, the Passengers, and the Programming" and make the appropriate decision required by the current situation. Remember, that failure to make a decision is a decision. Under SRM and the 5P's, even the decision to make no changes to the current plan is made through a careful consideration of all risk factors present.

Conduct the 5P check 5 times during each flight.

Review 1

Airmanship

1. What are the steps of the DECIDE model?
2. Apply the DECIDE model to a specific in-flight situation.
3. The FAA has identified five attitudes that could be hazardous to a pilot's judgment and decision-making skills. What are the five attitudes and their antidotes?
4. In a time of crisis where decisions must be made without time for contemplation it is recommended the ACTION model be used. What are the steps of the ACTION model?
5. Apply the ACTION model to a specific in-flight situation.
6. The overall aid to obtaining and maintaining Situational Awareness is the Five P Check. What are the 5P's?
7. When should the 5P check be used?

Answers are given on page 763.

The Human in the Cockpit 2

Human factors, as it relates to flying an aircraft, is the interaction between the pilot, the flying environment, and the aircraft. The area defined by human factors is complex and is where most errors occur. To safely operate an aircraft, you need to develop an awareness of not only the physiological aspect of flying, but also those that influence workload and fatigue, decision making, and situational awareness. It is vital that you, as a pilot, understand and appreciate how these factors affect your everyday flying.

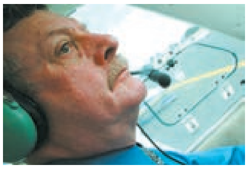


Figure 2-1
The pilot is human.

This chapter will discuss the following elements of the human in the cockpit:

- the physical pilot;
- the flight environment;
- health and well-being;
- vision and visual illusions;
- hearing and balance;
- situational awareness; and
- decision making.

The Physical Pilot

Circulatory System

The circulatory, or cardiovascular, system moves blood around the body, carrying oxygen and nutrients to the cells, and takes away waste products such as carbon dioxide. Blood is composed of plasma that carries red and white blood cells, or corpuscles. The red blood cells contain the iron-rich pigment hemoglobin, the principal function of which is to transport oxygen around the body. The white blood cells, of which there are various types, protect the body against foreign substances and are involved in the production of antibodies. The antibodies attack any substance that the body regards as foreign or dangerous. Platelets in the blood function to form clots when necessary to stop loss of blood from an injury.

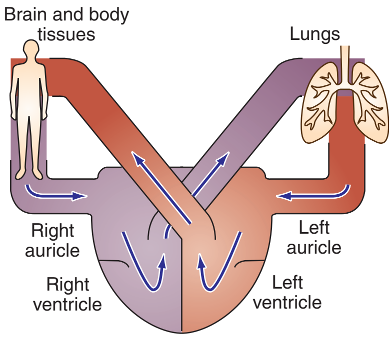


Figure 2-2 Circulatory system.

Heart

The heart is a muscular pump, about the size of a closed fist, that is divided into two sides, each with two chambers. The muscles of the heart contract in a double-action pulse, forcing blood through the one-way heart valves and through the network of arteries. This pump stroke causes a pressure pulse which can be felt at various parts of the body where the arteries are near the surface (such as the wrist and the side of the neck). Blood pressure is a measure of the pressure of the blood against the walls of the main arteries. It is necessary for the blood to be continuously replenished with oxygen, which it gives out to the tissues, and at the same time rid itself of the carbon dioxide that it acquires.

Circulation

On long flights you may be seated and stationary for very long periods. You can improve circulation by contracting and relaxing your stomach diaphragm as well as the leg and buttock muscles. Without the physical demand of activity, the heart will go into a dormant mode and the circulation slows down. This leads to sleepiness and loss of concentration. The muscles atrophy and you could suffer cramps. It is important to change your seating position and, if possible, exercise individual muscles by stretching and straightening the joints, and occasionally shaking a leg or twisting to improve circulation.

Respiratory System

The process of respiration brings oxygen into the body and removes carbon dioxide. The body has a permanent need for oxygen; it is used in the energy-producing burning process that goes on in every cell of the body tissues. The body is unable to store oxygen permanently and hence the need for continuous breathing. Any interruption to breathing lasting more than a few minutes may lead to permanent physical damage, especially of the brain, and to possible death.

Flight Environment

Atmosphere

Air is made up of 21% oxygen, 78% nitrogen, and 1% carbon dioxide and other inert gases.

The earth is surrounded and protected by a life-giving layer called the atmosphere. The atmosphere consists of a transparent mixture of gases that we call air. The atmosphere is held to the earth by the force of gravity and, because air is compressible, it packs in around the earth's surface. As altitude is gained, the air thins with fewer and fewer molecules in the same volume, but the percentage of each of the components of the air does not change. Total air pressure falls with altitude, as does the partial pressure of each of the gases in the air. (Total air pressure is a sum of all of the partial pressures.)

The International Standard Atmosphere

So that we have a common reference, scientists have agreed on average atmospheric conditions called the *International Standard Atmosphere* (ISA) or, simply, standard atmosphere. Like the "average" person, it never exists, but it is an essential yardstick used for comparisons, especially of aircraft performance. The standard atmosphere is as follows:

- sea level temperature: 59°F (15°C);
- lapse rate: -3.5°F (-2°C) per 1,000 feet;
- freezing level (32°F/0°C): 7,500 feet;
- sea level pressure: 29.92 in. Hg (1,013.2 hectopascals);
- tropopause: 36,080 feet; and
- temperature at the tropopause: -56°C.

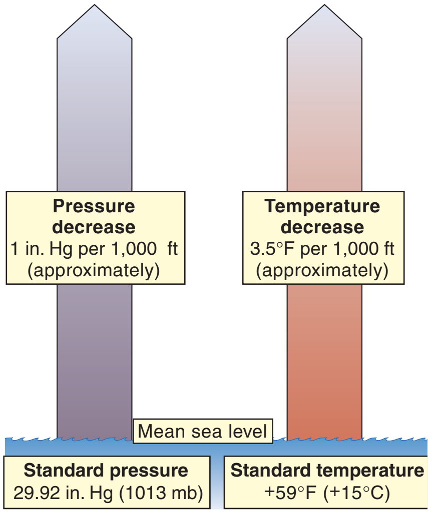


Figure 2-3 Standard atmosphere.

Flying at Altitude

The human body is designed to function in the lower levels of the atmosphere, where the air is fairly dense. Aircraft may operate at quite high altitudes where the air density is very low, exposing the pilot to possible oxygen deficiency and other problems such as low ambient temperatures. There are three major effects of altitude on the human body brought about by pressure changes:

- lower external pressure causes gases inside body cavities to expand;
- lower oxygen pressure causes hypoxia; and
- dissolved gases form bubbles in the blood, also due to decreased external pressure.

Hypoxia

Hypoxia is a deficiency of oxygen in the body.

Hypoxia is a condition in which oxygen concentration in the tissues is less than normal. Total absence of oxygen is called *anoxia*. Hypoxia is a lack of oxygen and may be caused by:

- a lack of oxygen in the air (called *hypoxic hypoxia*);
- a partial pressure of oxygen that is too low; or
- an inability of the blood to carry oxygen (called *anaemic hypoxia*) due to a medical condition (anaemia) or to carbon monoxide poisoning in the blood (from, say, a faulty engine exhaust system or smoking cigarettes).

Air pressure and density decrease with altitude; approximately 18,000 feet is where atmospheric pressure is at 50% of sea level (1,000 mb versus 500 mb). As an airplane climbs, the density of the air in which it is flying gradually reduces. The less dense the air, the lower the mass of oxygen taken into the lungs in each breath. In addition, the lower partial pressure of oxygen at altitude (i.e. fewer percentage of molecules), further reduces the amount of oxygen that will diffuse across the alveoli membranes into the bloodstream. A high cabin altitude therefore means less oxygen will be transported around the body, and less energy will be generated (including in the brain). Hypoxia is subtle and it sneaks up on you, like the effects of that extra glass of wine. Rapid rates of ascent can allow higher altitudes to be reached before severe symptoms occur. In these circumstances, unconsciousness may occur before any or many of the symptoms of hypoxia appear. At 9,000 feet, the partial pressure of oxygen in the air is about *half* that at sea level.

The initial symptoms of hypoxia may hardly be noticeable to the sufferer, and in fact they often include feelings of euphoria. The brain is affected quite early, so a false sense of security and well-being may be present. Physical movements will become clumsy, but the pilot may not notice this. Difficulty in concentrating, faulty judgment, moodiness, drowsiness, indecision, giddiness, physical clumsiness, headache, deterioration of vision, high pulse rate, blue lips and fingernails (cyanosis), and tingling of the skin may all follow, ending in loss of consciousness. Throughout all of this pilots will probably feel euphoric and as if doing a great job.

In this oxygen-deficient condition, a pilot is less able to think clearly and perform physically. The body attempts to compensate by increasing the pulse rate, and the rate and depth of ventilation. Pilots between 25 and 50 years who are in good physical condition and regularly exposed to low oxygen levels have a higher tolerance. Above about 8,000 feet cabin altitude, the effects of oxygen deprivation may start to become apparent in some pilots, especially if the pilot is active or under stress. At 10,000 feet, most people can still cope with the diminished oxygen supply, but above 10,000 feet supplementary oxygen is required (i.e. oxygen supplied through a mask), if a marked deterioration in performance is not to occur. At 14,000 feet without supplementary oxygen, performance will be very poor and, at 18,000 feet, the pilot may become unconscious. This will occur at lower altitudes if the pilot is a smoker, or is unfit or fatigued.

Avoid hypoxia by using supplemental oxygen at high cabin altitudes (above 10,000 feet).

In general terms, 10,000 feet is considered to be the critical cabin altitude above which flight crew should wear an oxygen mask (5,000 feet at night). The effects of oxygen deprivation are very personal in that they may differ from person to person and become apparent at different cabin altitudes. Some people are more resilient than others; however, the event of oxygen deprivation will eventually produce the same effects. For instance, night vision will generally start to deteriorate at a cabin altitude of above 4,000 feet.

Susceptibility to hypoxia is increased by anything that reduces the oxygen available to the brain, such as a high cabin altitude (of course), high or low temperatures, illness, stress, fatigue, physical activity, or smoke in the cockpit. The reduction of the oxygen-carrying capacity of the blood by smoking has the same effect as increasing the cabin altitude by 4,000–5,000 feet and this effect intensifies as the airplane climbs to higher altitudes. The preference of hemoglobin for carbon monoxide, as opposed to oxygen, means that a person who has been smoking has less oxygen circulating than would have been the case had CO not been absorbed. The onset of symptoms of hypoxia will occur at a lower altitude in that person. However, a smoker is acclimated to being hypoxic and may be more tolerant—to a degree.

Tolerance to hypoxia can be reduced by a loss of blood, as is the case after a person has made a blood donation. It is therefore recommended that active pilots do not donate blood. Should you decide you do want to give blood, it is recommended not to fly for 24 hours afterward.

Time of Useful Consciousness. If a person is deprived of an adequate supply of oxygen, unconsciousness will ultimately result. The cells of the brain are particularly sensitive to a lack of oxygen, even for a brief period. Total cessation of the oxygen supply to the brain results in unconsciousness in six to eight seconds and irreversible damage ensues if the oxygen supply is not restored within four minutes. The time available for pilots to perform useful tasks without a supplementary oxygen supply, and before severe hypoxia sets in, is known as the *time of useful consciousness* (TUC), or *effective performance time* (EPT). TUC/EPT reduces with increasing altitude.

Altitude above sea level	Sudden failure of oxygen supply	
	Moderate activity	Minimal activity
18,000 feet	20 minutes	30 minutes
22,000 feet	5 minutes	10 minutes
25,000 feet	2 minutes	3 minutes
28,000 feet	1 minute	1¼ minutes
30,000 feet	45 seconds	1¼ minutes
35,000 feet	30 seconds	45 seconds
40,000 feet	12 seconds	15 seconds

Table 2-1 Time of useful consciousness (effective performance time).

Barotrauma

Another effect of increasing cabin altitude is that gases trapped in parts of your body—such as the stomach, intestines, sinuses, middle ear, or in a decaying tooth—will want to expand as external pressure decreases. Either they will be able to escape into the atmosphere, or they may be trapped and possibly cause pain known as *barotrauma*. Pain is most severe on ascent with teeth and intestines and on descent with ears and sinus. Foods such as legumes and leafy greens known to produce gas should be avoided when flying.

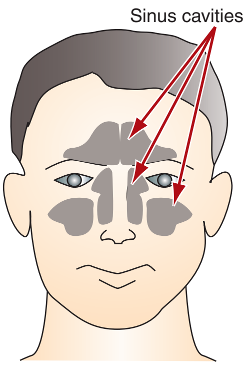


Figure 2-4
Sinus cavities in the skull.

Barotrauma of the Ears. You hear sound because waves of air pressure move a membrane within your ear (eardrum). The cavity behind the eardrum has a small tube (the Eustachian tube) that is open through the nose and allows air pressure on the inside to be balanced with outside air pressure. If you have a head cold or sinusitis, this tube can become restricted or even totally blocked. If this is the case, as the aircraft climbs, the air inside the ear easily escapes through the tube because that is the normal direction of fluid movement. However, when you descend again, you end up in a situation where the air on the outside of the drum is at a higher pressure than the air inside. It may collapse the tube. Because of this restriction, air cannot pass through to balance the pressure and so the eardrum is pushed in. This can be painful or even damaging. The pressure can usually be helped to equalize and open the Eustachian tube by swallowing, chewing, or by blowing with the mouth and nose held shut.

Decompression Sickness (The Bends)

Gas bubbles in the body will cause great pain and some immobilization in the shoulders, arms and joints. This serious complaint is known as *decompression sickness* or *the bends*. The remedy is to subject the body to a region of high pressure for a lengthy period of time (in a *recompression* chamber, for example), and then gradually return it to normal pressures over a period of hours or days. In an aircraft, the best you can do if the bends is suspected is to descend to a low altitude, where air pressure is greater. Even landing may not provide a sufficient pressure increase to remedy the problem, in which case seek medical assistance without delay. Sometimes low altitude pressure will cause nitrogen to form bubbles; however, this is unlikely below 18,000 feet.

Decompression sickness can follow scuba diving.

Scuba Diving. Decompression sickness can result from flying after scuba diving. When the body is deep under water it is subjected to strong pressures, and certain gases, such as nitrogen, are absorbed into the blood under pressure, because the air cylinders have to be pressurized above the local water pressure so the lungs can inhale increasing the partial pressure of nitrogen. The deeper and longer the dive, the more this absorption occurs. If the pressure on the body is then reduced too quickly—say, by rapidly returning to the surface from a great depth or, even worse, by then flying in an airplane at high cabin altitudes—the gases (especially nitrogen) will come out of the blood solution and form bubbles in the bloodstream and tissues, especially the joints. (You can see the same effect caused by a sudden reduction in pressure when the top is removed from carbonated drinks and bubbles of gas come out.)

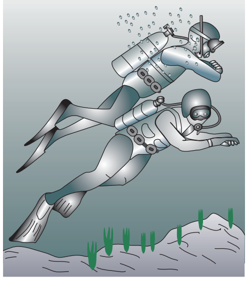


Figure 2-5
Do not fly within 24 hours of scuba diving.

Rules regarding scuba diving and flying vary slightly from country to country. The current Diver's Alert Network's recommendation is that you do not fly for 12 hours after any single dive without decompression stops. A greater surface interval is needed after multiple dives or dives with decompression stops. Ask your instructor for advice.

Decompression stops are necessary if a dive is deeper than 33 feet. At this depth, the pressure is twice that at sea level, and the amount of nitrogen dissolved increases appreciably.

Snorkeling will not cause decompression sickness as you are not taking in air under pressure. The risk of suffering decompression sickness increases with the depth to which you dive, the rate at which you resurface, how soon after you fly, how high you fly, how quickly the cabin altitude increases, your age, obesity, fatigue, and reexposure to decompression within 24 hours.

Hyperventilation

Hyperventilation is an involuntary and inappropriate increase in breathing rate, and is usually a symptom of psychological distress.

Hyperventilation occurs when the body over breathes due to some psychological distress such as fear or anxiety (gasping for breath). It is most likely to occur with inexperienced pilots in new situations. It is a self-perpetuating cycle, in which a feeling of breathlessness and dizziness develops—one is unable to catch one's breath and so one becomes more stressed—and continues even if the triggering influence is removed.

Carbon Monoxide Poisoning

Engine smells in the cabin are a warning that carbon monoxide may be present.

Carbon monoxide is produced during combustion. It is present in engine exhaust gases and in cigarette smoke, both of which can sometimes be found in the cockpit. Its entry into the cockpit may be from a faulty heating system. Carbon monoxide is a colorless, odorless, tasteless and poisonous gas for which hemoglobin in the blood has an enormous affinity. If carbon monoxide molecules are inhaled, then the hemoglobin will transport them in preference to oxygen, causing the body and the brain to suffer oxygen starvation, even though oxygen is present in the air. Hence, the first cigarette can cause light-headedness. Carbon monoxide poisoning is insidious and can be ultimately fatal. Recovery, even on pure oxygen, may take several hours.

Susceptibility to carbon monoxide poisoning increases as the cabin altitude increases because there is already an oxygen deficiency. Many cabin heating systems use warm air from around the engine and exhaust manifold as their source of heat. Any leaks in the engine exhaust system can allow carbon monoxide to enter the cabin in the heating air and possibly through open windows and cracks. To minimize the effect of any carbon monoxide that enters the cockpit in this way, fresh air should always be used in conjunction with cabin heating. Regular checks and maintenance of the aircraft are essential. Even though carbon monoxide is odorless, it may be associated with other exhaust gases that do have an odor. Engine smells in the cabin are a warning that carbon monoxide may be present. Symptoms of carbon monoxide poisoning include the following:

- headache, dizziness and nausea;
- deterioration in vision;
- impaired judgment;
- personality change;
- impaired memory;
- slower breathing rate;
- cherry-red complexion;
- loss of muscular power;
- convulsions; and
- coma and eventually death.

Carbon monoxide poisoning is serious and can be fatal!

If carbon monoxide is suspected in the cabin, carry out the following actions:

- shut off the cabin heat;
- stop all smoking;
- increase the supply of fresh air through vents (except exhaust ones) and windows; and
- land as soon as possible.

Many operators place carbon monoxide detectors in the cockpit. The most common type contains crystals that change color when carbon monoxide is present. These detectors are inexpensive and are a wise investment, but they do have a limited life, so check the expiration date. If the detector is date-expired, it is not reliable. Indeed, the crystal-type detector may not be as reliable as first thought. Increasingly, the more costly, but more effective, electronic detectors are being recommended. Be aware that carbon monoxide is not the only toxic chemical to which you may be exposed in aircraft operations (agricultural pilots especially). Vapors and fumes from fuels and lubricants, poorly packed dangerous goods, and other products of combustion may produce a range of symptoms including skin, eye and lung irritation, dizziness, drowsiness, confusion and loss of consciousness.

Dehydration

Dehydration is not only associated with hot days and intense sporting activities when you don't drink enough. It is also a problem when sitting relatively still when flying. As you climb, the atmosphere becomes less dense and is much colder. Both decreased density and temperature means less water is available in the atmosphere. So just by breathing, you are going to lose moisture from your lungs at a greater rate than you would at sea level. On large aircraft, the pressurization and air conditioning tend to reduce the moisture content of the air still further. Aircraft manufacturers incorporate humidifiers in these systems to keep the cabin environment comfortable. On any flight of more than an hour or so and especially in summer, always carry drinking water and sip it regularly. Don't wait until you are thirsty. Dehydration can quickly affect the brain's ability to function rationally.

Condition	Cause/ Altitude	Common Symptoms	Notes	Actions
Hypoxia	Rare below 10,000 feet.	Euphoria, visual disturbances, dizziness, light-headedness, confused thinking, apprehension, sense of well-being.	May be unaware of condition due to decreased partial pressure of oxygen.	Descend. Use oxygen. 10,000-33,700 feet—air-oxygen mix. 33,700-40,000 feet—100% oxygen.
Hyper-ventilation	Anxiety. Any altitude.	Light-headedness, dizziness, tingling, numbness, visual disturbances, confused thinking, tremors, faintness.	Overbreathing reduces carbon dioxide level in the blood.	Control breathing rate. Breathe into hand or bag. If above 10,000 feet, suspect hypoxia.
Carbon monoxide poisoning	Faulty exhaust heating. Smoking. Any altitude.	Headache, breathlessness, sluggishness, impaired judgment, feeling of warmth, cherry-red skin.	Hemoglobin has greater affinity for CO than for oxygen. (Smoking makes night vision poor.)	Immediate fresh air. Oxygen. Land and seek medical attention.
Decompression sickness	Flying after diving. Unlikely below 18,000 feet.	Headache, pain (joints), paralysis, choking, skin irritation.	Nitrogen forms bubbles in lungs (chokes), joints (bends), skin (creeps), central nervous system (paralysis).	Do not fly for 4 hours for dives less than 30 feet; wait longer if deeper dive.
Dehydration	Workload. Radiant heat. Perspiration.	Darker urine, dryness.	Carry drinking water in the cockpit. Cover exposed skin.	Sip water regularly in-flight.

Table 2-2 Summary of symptoms.

Health and Well-Being

General Health and Well-Being

The effects of flight on the human body and mind are representative of an average human in good health. Obviously, ill physical or psychological health adversely affects all of your capabilities, capacities, stamina, concentration, memory, and tolerances to the stresses of flight.

Health Indicators

You are the result of two primary influences: heredity (*nature*) and environment (*nurture*). One of the most reliable indicators of general health is the parentage from which you are born. If your parents were healthy and lived long lives then all you need to worry about are the environmental factors.

Blood Pressure

There are two levels of blood pressure:
- *systolic*, which is when the heart pumps (should be around 120 mm Hg); over
- *diastolic*, which is when it pauses (should be around 80 mm Hg).

The resting (diastolic) blood pressure is a good indicator of potential problems. High blood pressure can pertain with no apparent, underlying cause. It can be controlled with medication. If identifiable, the cause of the high blood pressure (*hypertension*) should also be addressed, whether it be physical or psychological.

Cholesterol

Cholesterol is formed by the body in response to dietary intake. There are two levels of cholesterol in the blood:
- low-density lipoprotein (LDL), which is related to animal fats; and
- high-density lipoprotein (HDL), which is related to exercise.

The former is not good and should be controlled by diet and exercise.

Obesity

You should maintain a reasonable degree of physical fitness. It allows better physical and mental performance during flight, and, in the long term, improves your chances of a long and healthy life. Physical fitness helps pilots cope better with stress, fatigue, and the reduced availability of oxygen. Diseases that have been directly related to obesity include osteoarthritis, hypertension (and risk of cardiovascular problems), and gout.

Medical Fitness

Disqualifying Illnesses

Disqualifying illnesses are conditions likely to restrict or deny the issue of a medical certificate either temporarily or permanently. They include heart attack, stroke, diabetes, kidney stones and ulcers.

Debilitating Illnesses

Migraines and Headaches. Headaches can be compromising due to stress, pain, distraction and reduced attention. Migraine headaches are due to the constriction of the arteries in a particular part of the brain. They can be totally incapacitating if accompanied by vision impairment, nausea, vomiting, oversensitivity to light and sound, and severe pain. Rarely, migraine attacks are accompanied by temporary, partial paralysis (one arm or one side of the body). They seem to be triggered by allergic reactions to certain foods such as cheese or chocolate, by stress, or by the removal of stress. Many are short lived and may be related to temporary circumstances, but do seek medical advice. There are treatments that are sometimes, but not always, effective. Heredity seems to be a significant factor in your susceptibility to migraine attacks.

Viruses/Colds/Flu/Middle-Ear Infections. Each eardrum has ambient pressure from the atmosphere or cabin on one side and air pressure in the middle ear on the other side, the middle ear being connected to ambient air via the Eustachian tube. During a climb, atmospheric pressure decreases and the differential pressure across the eardrum forces out the eardrum, as well as causing air to flow from the middle ear through the Eustachian tubes into the throat. In this way, the pressure differential is equalized. Any prevention of this equalization process is hazardous because of the pain and the potential to perforate the membrane of the eardrum.

Most pressurized aircraft have a low rate of climb (500 feet per minute or less) for the cabin and cockpit, allowing adequate time for pressure equalization to occur through the Eustachian tubes. This means that ear problems during the climb are generally not serious. During descent, however, difficulties with the ears may be more serious due to high rates of descent and problems with pressure equalization within the middle ear (the air finds it easier to escape through the collapsed tubes during the climb but cannot pass through the collapsed tube during the descent).

Further, the greatest proportional pressure differential occurs at lower altitudes and so the first few thousand feet on the way up and the last few on the way down are the difficult ones. Although the cockpit may be kept at 5,000 feet, the pressure change is very significant. Moreover, a depressurization with blocked Eustachian tubes could be overwhelming. High rates of descent worsen the situation. Pain in the ears can be debilitating, and there is a danger of the eardrums collapsing inward as the external pressure builds up, giving rise to a loss of hearing that may be permanent. In extreme cases, the balance mechanisms could be affected—a situation known as *pressure vertigo*. Blocked ears can sometimes be cleared by holding the nose and blowing hard (a technique known as the *Valsalva maneuver*), by chewing, swallowing or yawning. It is best not to risk flying with a head cold if you have difficulty clearing your ears. Problems can also arise in the sinuses, the cavities in the skull connected by narrow tubes to the nasal/throat passages. Blockages can cause severe pain, equivalent to the most severe headache, such that you cannot concentrate on flying.

Gastroenteritis. Gastrointestinal disorders are the most common cause of in-flight incapacitation. They may result from an improperly prepared meal (food poisoning), impure drinking water, or infection. Onset may be almost immediate following consumption of the food or drink, or it may not become evident for some hours. Even then, onset may be very sudden. The stomach pains, nausea, diarrhea and vomiting that accompany food poisoning can make it physically impossible to perform pilot duties. Some of the reflexes are uncontrollable (projectile vomiting and diarrhea, sometimes simultaneously). A wise precaution is never to have the same meal as your crew.

For the day prior to flight, avoid foods that are associated with food poisoning, including shellfish, fish, mayonnaise, creams, overripe and thin-skinned fruits, uncooked foods such as salads and raw foods, and old, tired food (e.g. food that has been cooked, then stored for some time or reheated several times). If you suspect that some symptoms of food poisoning are present or forthcoming, don't take a chance—don't fly. After the event, you will be dehydrated and weak—very weak indeed. You should not fly for at least 72 hours after the last symptoms of even a mild case of food poisoning. Gastroenteritis, flu, food poisoning, and dysentery can leave you sitting on the toilet and vomiting simultaneously. You cannot possibly fly with those symptoms. You are literally and totally incapacitated.

Cardiovascular Diseases. Diseases affecting the heart and circulatory system include the following:

- *thrombosis*—a *coronary thrombosis* is caused by blood clots (*embolisms*) obstructing the flow of blood to the heart. The heart muscle may go into irregular spasms (*fibrillation*);
- *myocardial infarction* (*heart attack*)—sudden blockage may result in the death of heart tissue;
- *angina*—part of the heart may be deprived of oxygen by a reduced blood flow when demand is increased. It is felt as pain in the chest, neck, shoulders and arm, especially the left, that comes and goes with exercise. If untreated, angina causes heart inefficiency and gradual or sudden heart failure;
- *arteriosclerosis*—the arteries can be blocked by fats, often as a the result of high cholesterol due to poor diet and lack of exercise;
- *aneurism*—a bursting of an artery, generally in the brain; and
- *stroke*—the blood flow in some part of the brain may be interrupted, leaving loss of sensation or paralysis in any part of the body but commonly on one side of the face.

Cardiovascular risk factors, in order of priority, appear to be: family history of heart disease, smoking, high blood pressure, high cholesterol, obesity, lack of exercise, diabetes and stress. Excessive alcohol consumption may also be an influence, but moderate consumption may actually be beneficial in controlling stress and cholesterol. All the above factors relate to inheritance or lifestyle, and pilots particularly need to manage the latter.

The normal electrocardiogram, or resting ECG, is a sensor that measures the heartbeat at 12 locations. It is carried out while the body is resting to check whether there is a deficiency in the action of the heart muscle. It is a here-and-now indicator that shows congenital or preexisting defects, but it cannot predict future problems.

Physical and Mental Fitness

Exercise

Keeping fit takes some effort, and this effort must be continually maintained for fitness to be retained; but it can also be good fun and very recreational. Walking, jogging, digging in the garden, cycling, swimming, in fact anything that steadily raises your pulse rate, will improve your fitness. If you are grossly unfit or obese, then allow yourself several diet-conscious months with moderate exercise that is gradually increased, and consider medical supervision. It might seem like a long haul, but the quality of life and your self-esteem will improve along with your fitness.

Fatigue and Sleep Deprivation

Fatigue, tiredness and sleep deprivation can lower a pilot's mental and physical capacity quite dramatically. Fatigue can become deep-seated and chronic. If personal, psychological or emotional problems are not resolved, they prevent deep rest and good sleep over a prolonged period. Chronic fatigue won't be cured until the problems are resolved, or at least are being addressed, and the person can relax and unwind. You should prohibit yourself from flying if the distress is distracting.

Do not fly when fatigued. It shows poor judgement.

Short-term fatigue can be caused by overwork, mental stress, an uncomfortable body position, a recent lack of sleep, living-it-up a little too much, lack of oxygen or lack of food.

Stress

Stress is part of our lifestyle. It is inevitable but manageable. Management of stress is relatively easy, once learned. You have to learn a way that best suits you. You need to find the particular technique that tickles your own fancy. The objective is not to confront stress head on. Like a kite it will climb against the wind and become even more challenging. The idea is to defuse it—to divide it into bite-size chunks—and remind yourself that it is temporary. It will pass and there is a future. Alcohol doesn't defuse stress: it defers it and then it is added to the next day's lot.

Stress management includes the following:
1. *Identifying hazardous attitudes.*
2. *Learning to modify your behavior.*
3. *Recognizing and coping with stress.*
4. *Developing a method to assess risks.*
5. *Using all your resources.*
6. *Being able to evaluate your performance.*

Coping/defusing techniques include:

- *exercise/sports*—physical demands that take your mind off mental problems are good for you. Physical demand that also requires mental concentration is even better; for example, golf, skiing or sailing are more diverting and therefore relaxing than jogging;
- *fresh air*—the wide world around you keeps everything in perspective and reinforces your hope and realization that you are both small and large in the scheme of things;
- *diversions/hobbies*—the mental and manipulative occupation of hobbies are a marvellous relaxant as their appeal usually claims one's total concentration; and
- *relaxation therapy and meditation*—these use the same technique of mental occupation and diversion so the build-up of stress is deflated by inattention. It is not the same as lying in the sun and snoozing as the brain dwells on the problem. They are effective and easy to learn techniques for focusing the single-channel processor of the conscious mind on a trivial routine symbol.

Diet and Nutrition

We are what we eat. Diet concerns what you eat, how much and in what proportions. It receives much attention in the media these days because in western society our dietary intake is poorly managed: too much animal fat, too much processed sugar, too few vegetables, cereals and fruit. In all, too much quantity and too little exercise. The suggested eating pattern is to have smaller, more varied servings often, rather than larger serves less frequently. Snacks, such as fruit, muesli bars and cereals, keep the hunger at bay and avoid the temptation to eat a large meal too quickly. Eating slowly allows the digestive system to process the food and to feel satisfied with a lesser quantity.

Water is best. Drink lots of it. Don't wait until you feel thirsty. The color of your urine should be light straw or paler. Any darker means potential dehydration. Too much fruit juice can cause bowel problems and also adds calories. Mineral-enriched health drinks are for athletes. Use them for severe exercise; otherwise, drink water. Avoid too much of the sugary soft drinks, as they make you even thirstier.

Tea and Coffee.

Caffeine is a drug and stimulant. Coffee contains the most, especially espresso. Caffeine increases the pulse rate, prevents sleep, increases urination and therefore fluid loss (it is a diuretic), causes headaches and increases the level of stress. It may wake you up but it won't let you rest. There are also withdrawal symptoms when you stop consuming it.

Dependencies

Alcohol

Do not fly under the influence of alcohol.

Even small quantities of alcohol in the blood can impair one's performance, in addition to the danger of relieving anxiety so that the person believes he or she is performing marvelously. Alcohol severely affects a person's judgment and abilities. Reduced oxygen worsens the effect. Alcohol is a depressant. It lowers the body's natural sensitivities, cautions and fears (shown as overconfidence) and, at the same time, it lowers capabilities—a deadly combination as demonstrated by the road accident statistics. It also represses social mores and allows emotions, that would otherwise be controlled, to run free, such as aggression, anger, passion, violence, showing-off and taking risks. In some personalities, it causes depression and low self-esteem.

It takes time for the body to remove alcohol. As a general rule, a pilot must not fly for at least 8 hours after drinking small quantities of alcohol and increase this time if greater quantities are consumed. After heavy drinking, alcohol may be present in the blood 24 hours later. Sleep will not speed up the removal process; in fact, it slows the body processes down and the elimination of alcohol may take even longer. Exercise is better. Having coffee, soup or water between drinks only helps if they are taken *instead* of an alcoholic beverage. Otherwise, the body receives the same total amount of alcohol in the same time, so it takes the same time for it to be discarded and for its effects to be removed.

Tobacco

Smoking is detrimental to good health, both in the short term and long term. Smoking also significantly decreases a pilot's capacity to perform by reducing the amount of oxygen carried in the blood, replacing it with the useless, poisonous byproducts of cigarette smoke. A pilot does not have to be the active smoker to suffer the effects. Second-hand smoke is also detrimental.

Drugs and Medication

Recreational drugs such as marijuana, cocaine and LSD must never be mixed with flying. Persons who are dependent on such drugs are not permitted to hold a pilot certificate.

All drugs affect the body (as well as the disease they are taken to combat). They may be incompatible with flying. Sedatives, and their side effects, are a prime example of this, also antihistamines. Some drugs may have long *half-lives*; that is, their concentration stays too high for too long, e.g. certain sleeping pills. Other drugs, called potentiating agents, change or exaggerate the effect of other drugs taken in combination with them, especially alcohol. Until cleared by a doctor, it is safest to assume that *any* drug or medication will temporarily ground you. *Don't accept or use non-prescribed drugs.*

Toxic Substances

Some pilots will come in contact with toxic substances—fuel additives, cleaning agents, aerial agriculture sprays and powders, defoliants, compressed gases and extinguishants. Don't ever take shortcuts. Observe the special precautions and protections required for each. If in doubt, don't fly.

Vision and Visual Illusions

Eyes provide the brain with a visual image of the environment. Each eye acts as a natural and very sophisticated digital camera. Its basic function is to collect light rays reflected from an object, using the lens to focus these rays into an image on a screen (the retina), and then converting this image into electrical signals that are sent via the optic nerve to the brain. This is how you *see*. The brain matches the image to previously stored data so you recognize (*perceive*) the object. The connection of the optic nerve to the brain is so close and integral, and the importance of the messages sent to the brain is so dominant, that the eyes can almost be considered an extension of the brain.

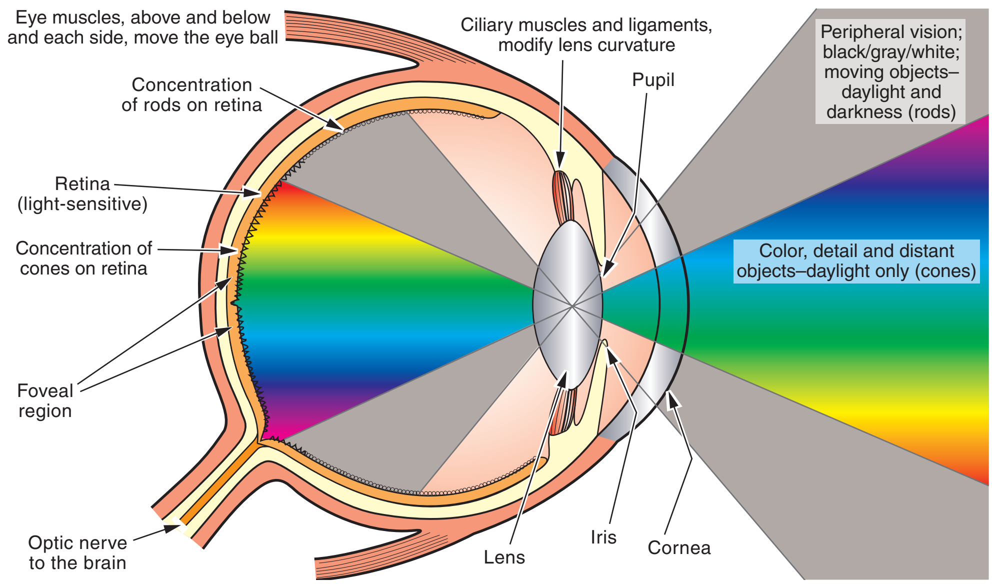


Figure 2-6 Structure of the eye.

Binocular Vision

Binocular vision describes the process whereby optical information is received and processed from two eyes. To track a moving object with both eyes, they need to move in harmony, and this means coordinated control of the two sets of muscles by the brain. In a fatigued person, this coordination sometimes fails, and the result is quite different images from each eye resulting in double vision.

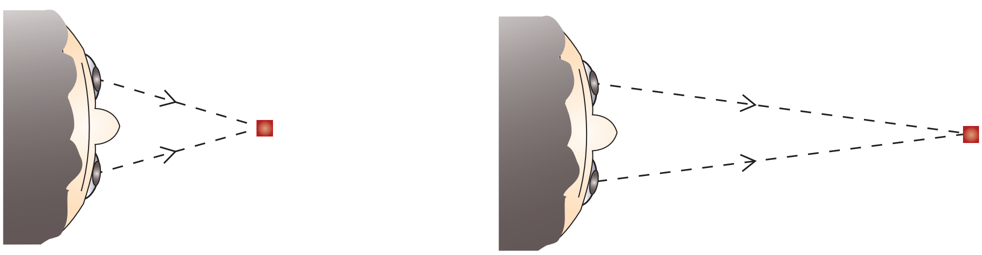


Figure 2-7 Binocular vision.

Blind Spot

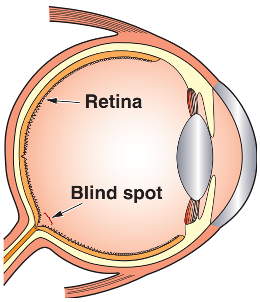


Figure 2-8
Blind spot.

Rods and cones are the nerve endings that feed the optic nerve.

Absolute distance can only be judged by triangulation (the convergence of sight lines) and this is the prime reason for binocular vision. The other reason is to compensate for the blind spot in each eye. The blind spot is the small area on the retina of the eye where the nerve fibers from the light-sensitive cells (rods and cones) on the retina lead into the optic nerve. At this point, there is no coating of light-sensitive cells, and hence any light falling here will not register; that is, it is literally a blind spot. However, it is not possible for an image to fall on the blind spot of both eyes simultaneously because it will be in different relative position for each. Even when an image falls on the blind spot of one eye, and is therefore not registered, the brain will receive a message from the other eye and so the object will still be seen.

You can observe the existence of the blind spot in each eye by viewing figure 2-9. Hold the page at arm's length, cover your right eye, and then with your left eye focus on the airplane on the right. It will be clearly recognizable as a biplane because it will be focused on your retina. Move the page closer and as you still focus on the biplane, you will notice that the helicopter will eventually disappear. Its image has fallen on the position on the retina occupied by the optic nerve. In practice you must be careful when you are scanning the sky that another aircraft is not blocked from view by the magnetic compass or some part of the windshield structure. If it is blocked from the view of both eyes, you will not see it at all; if it is blocked from the view of only one eye, you will lose the blind-spot protection provided by binocular vision.

Figure 2-9 Example of blind spot.

Vision Limitations

Rods and cones are the endings of the optic nerve. As an extension of the brain, they will be affected by anything that affects the brain. With a shortage of oxygen (hypoxia), or an excess of alcohol, medication, or other drugs, sight is one of the first senses to suffer. High positive g-loadings, as in strenuous aerobatic maneuvers, will force the blood into the lower regions of the body and temporarily starve the brain and eyes of blood, leading to a grayout (black-and-white tunnel vision) or unconsciousness (blackout).

Vision Defects

With normal vision, the lens focuses an inverted image of the object on the rear of the eyeball (the retina). The shape of the lens changes to adjust for the distance of the object from the lens to ensure the visual data is focused on the retina. Inability to focus may result naturally from a lens that has become less flexible with age, or it may result from a lens or eyeball that is not shaped correctly. In almost all cases, artificial lenses in the form of spectacles or contact lenses can be made to correct the specific deficiency and restore sharp vision, just like the focus of a camera. Since good eyesight is essential for safe flight, professional assistance is required whenever there is a problem.

Visual Acuity (Clarity or Focus of What We See)

Visual acuity is the ability of the eye to see clearly and sharply. Perfect visual acuity (focus) means that the eye sees the object exactly as it is, clearly and without distortion, no matter how distant the object is. The degree of visual acuity varies between different people and also between the two eyes of any one person, as well as for the single eye at different times. This depends upon whether the person is fatigued, suffering hypoxia (lack of oxygen), or under the influence of alcohol or some other drug. To describe differences in visual acuity, the standard is considered to be what a normal eye is capable of seeing clearly at a particular distance. The eye test chart usually has lines of letters readable for a normal eye from 120, 80, 60, 40, 30, 20 and 16 feet respectively.

The standard testing distance between the eye and the eye chart is 20 feet; the normal eye is capable of clearly seeing letters of a certain size at this distance. If another eye at 20 feet cannot read the 20-foot line clearly, and can only identify letters on the chart that a normal eye can see clearly at 30 feet, then the abnormal eye is said to have 20/30 vision. This is compared with the 20/20 vision of the so-called normal eye. As a rule of thumb, pilots should be able to read a car license plate at a distance of approximately 130 feet.

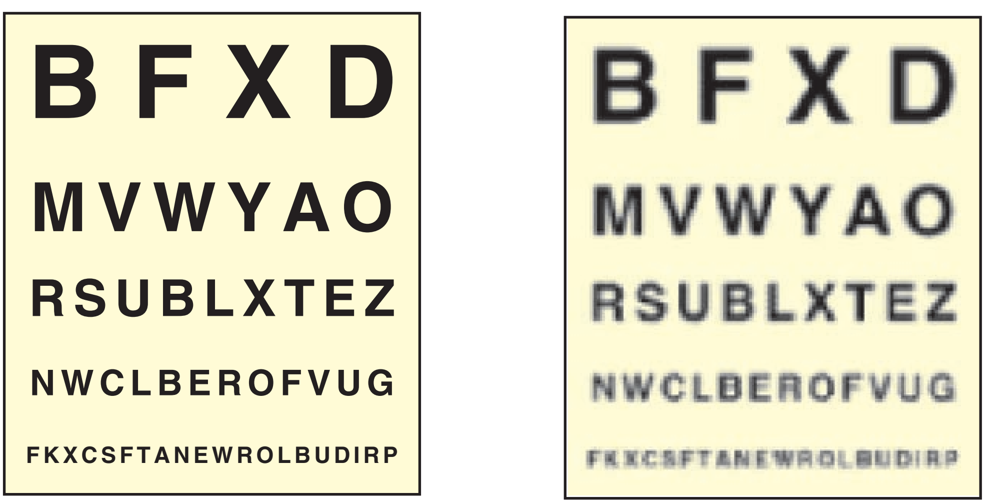


Figure 2-10 An eye chart seen with 20/20 vision and 20/30 vision.

Perfect visual acuity within the individual eye occurs when the image is focused sharply by a high-quality cornea and lens onto the central foveal region of a healthy retina, where the cone receptors predominate. The cone receptors are very sensitive to small details and send very sharp, colorful images to the brain. Light rays that are focused on the retina away from the central foveal region in areas where there are not so many cone receptors but more rod receptors will not be seen as clearly nor will they be in color. Visual acuity (focus) will therefore be less for these images. To illustrate the difference between central and peripheral vision, look at the words on this page. You must move your eyes so that the image of the word that you want to read falls on the central foveal region. While you can clearly read the word you are looking at right now, you will not be able to read words some distance away from it—up, down, or sideways from it—unless you move your eyeball so that the image of that word falls on the central high visual acuity area of the retina.

Color Vision

Colors are detected in the central foveal region of the retina by the cone receptors, which are only active in fairly bright light. There are some eyes that cannot distinguish any colors at all, even in bright light. Males are more susceptible to color blindness. Defective color vision shows up as difficulty in distinguishing between red and green. It may cause problems during night flying, as well as in poor visibility, with the white, red and green navigation lights of other aircraft used for recognition, with red or green taxiway or threshold lighting, and also with visual light signals from the control tower used in a radio-failure situation instead of radio voice messages (an uncommon event nowadays).

Night Vision

Cockpit lighting should be dimmed at night.

Adaptation of the Eyes to Darkness. At night, there are some special considerations regarding vision. Your attention during night flying is both inside and outside the cockpit. It takes the eyes some minutes to adapt to a dark environment, as experienced when walking into a darkened cinema stumbling over other patrons in an attempt to find an empty seat. As mentioned, night vision is susceptible to hypoxia: it is affected by cabin altitudes above 4,000 feet. The time it takes for the eyes to adapt depends, to a large extent, on the contrast between the brightness of light previously experienced and the degree of darkness of the new environment. Conversely, when the lights are turned on at the end of a movie the opposite effect takes place. Whereas the cones, concentrated in the central region of the retina, adjust quickly to variations in light intensity (about seven minutes to return to normal), the rods (which are most important for night vision) take some 30 minutes to adapt fully to darkness. In dim light, the cones become less effective, or even totally ineffective, and there is a chemical change in the rods to increase their sensitivity. Thus we adapt more quickly to brightening lights rather than dimming light.

Adapt your eyes to darkness before night flying by avoiding bright lights for at least 30 minutes before flight.

Protecting Night Vision. It is a common misconception that, at night, you are using your night vision in the cockpit or looking at the runway. When you are looking at something that is well illuminated, you are using normal vision. The night fighter pilots of World War II sat blindfolded in darkened rooms and used red cockpit lighting (and ate carrots) so they could look for other aircraft or ground features not illuminated due to the blackout. The only equivalent situation for today would be when you are looking for ground features like lakes or coastlines or the shadows of hills on a moonlit night; otherwise, you use normal vision. The disadvantage of red lighting is that red lines or tints on maps do not show up.

Keep the internal lighting to an acceptably low level to minimize reflections and to allow best transmission of light through the transparencies. It's the same as other natural process; the transmission depends on the energy difference—outside to in. More light outside and less light inside provides best transmission of light through the windows. Even wear a dark-colored shirt for night flying as the traditional white pilot's shirt adds considerably to the reflections off the face of the instrument glass. Avoid brilliant lights as they temporarily reduce the sensitivity of the eyes to less well-lit objects. Be especially careful of viewing sunsets and then trying to see down-sun at the darkened earth. Exposure to glare and bright sunlight should be avoided before night flights, possibly by wearing sunglasses. Vision is also affected by reduced oxygen levels and so, at night in an unpressurized aircraft, avoid smoking and use supplemental oxygen (recommended above 5,000 feet).

Protection of Vision

Safety Glasses. A pilot's vision is precious. Always wear eye protection for sports, when using tools, or when gardening.

Sunglasses. When flying into a rising or setting sun or above cloud layers, the pilot is exposed to very high intensity light coming from all angles. The eyes are protected from light coming from above by the forehead, eyebrows, eyelashes, and strong upper eyelids, they are not so well protected from light coming from below. Bright sunlight reflected from cloud tops, for instance, can be particularly bothersome because of this lack of natural protection. In conditions of glare, it is advisable to protect your eyes by using high quality sunglasses that reduce glare but not your visual acuity. The contrast between the glare of a very bright outside environment and the darker cockpit interior may also make it difficult for the eyes to adjust quickly enough to read instruments and charts inside the cockpit. Sunglasses should be impact resistant, having thin metal frames. They should transmit 10 to 15% of the light, filtering out damaging ultraviolet rays. They should not be worn in decreased light.

When landing directly facing the sun, 100% of your vision can be lost at the moment of flare. Even when the sun is 40° to the side, vision is reduced by 42%.

Visual Scanning

Scanning by Day

The central (foveal) region of the retina provides the best vision, and in full color but only during reasonable daylight. Objects are best seen by day if you can focus their image on the foveal region, and you do this by looking directly at them. The most effective method of scanning for other aircraft for collision avoidance during daylight hours is to use a series of short, regularly spaced eye movements to search each 10° sector of the sky. Systematically focusing on different segments of the sky for short intervals is a better technique than continuously sweeping the sky. This is sometimes called the *saccade/fixation cycle*, where the saccade or movement takes about one-third of a second.

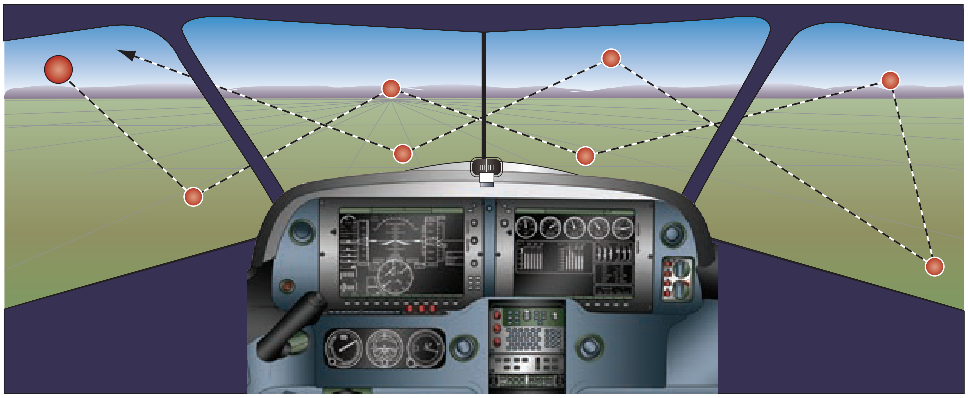


Figure 2-11 Methodical scan.

Relative Movement. If there is no apparent relative motion between you and another aircraft, you may be on a collision course, especially if the other aircraft appears to be getting bigger and bigger in the windshield. Due to the lack of movement across your windshield, an aircraft on a collision course with you will be more difficult to spot than one that is not on a collision course.

Any relative movement of an object against its background usually makes it easier to notice in your peripheral vision. The image of the other aircraft may not increase in size much at first, but, shortly before impact, it would rapidly increase in size. The time available for you to avoid a collision may be quite brief, depending upon when you see the other aircraft and the rate of closure.

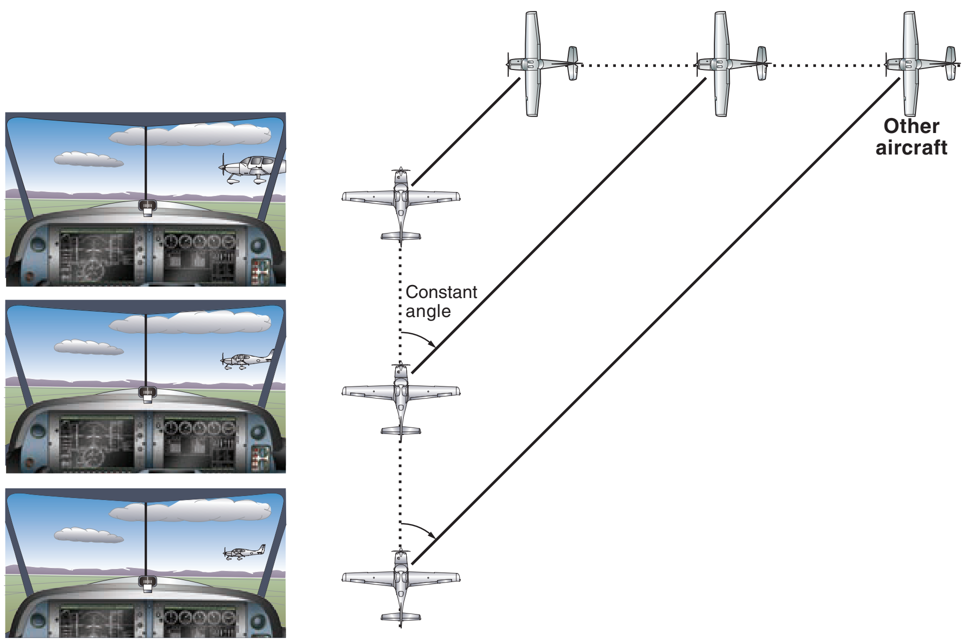


Figure 2-12 Constant relative position = collision course.

If you are flying at 100 knots and it is flying at 500 knots in the opposite direction, the rate of closure is 600 knots, i.e. ten nautical miles per minute. If you spot the other aircraft at a distance of one nautical mile, you only have 1⁄10 of a minute (six seconds) to potential impact. If you are a vigilant pilot and spot it at 3 nautical miles you have eighteen seconds in which to act.

In hazy conditions, objects may be closer than they appear.

In hazy or low-visibility conditions, your ability to see other aircraft and objects with edges that might be blurred will be diminished and, if you can see them, they may appear to be further away than their actual distance. You might be closer than you think.

Empty-Field Myopia. When trying to search for other aircraft in an empty sky, the natural tendency of a resting eye is to focus at about six feet. Consequently, distant aircraft may not be noticed. To avoid this empty-field myopia, you should focus on any available distant object, such as a cloud or a landmark, to lengthen your focus. If the sky is empty of clouds or other objects, then focus briefly on a relatively distant part of the airplane like a wing tip as a means of lengthening your focus. Having spotted an airplane in an otherwise empty sky, be aware that it could be closer to you than it appears to be, because you have no other object with which to compare its size.

Specks. A small, dark image formed on the retina could be a distant aircraft, or it could be a speck of dirt or dust, or an insect spot, on the windshield. Specks, dust particles, a scratch, or an insect on the windshield might be mistaken for a distant airplane. Simply moving your head will allow you to discriminate between marks on the windshield and distant objects.

Figure 2-13 Specks?

Scanning by Night

At night, scan slowly using your peripheral vision.

The central (foveal) region of the retina containing mainly cones is not as effective at night, causing an area of reduced visual sensitivity in your central vision. Peripheral vision, provided by the rods in the outer band of the retina, is more effective albeit color blind. An object at night is more readily visible when you are looking to the side of it by ten or twenty degrees, rather than directly at it. Color is not perceived by the rods, and so your night vision will be in shades of gray. Objects will not be as sharply defined (focused) as in daytime foveal vision.

The most effective way to use your eyes during night flight is to scan small sectors of sky more *slowly* than in daylight to permit off-center viewing of objects in your *peripheral vision,* and to deliberately focus your perception (mind) a few degrees from your visual center of attention (that is, *look at* a point but *look for* objects around it).

Since you may not be able to see the aircraft shape at night, you will have to determine its direction of travel making use of its visible lighting:

- the flashing red beacon;
- the red navigation light on the left wing tip;
- the green navigation light on the right wing tip; and
- a steady white light on the tail.

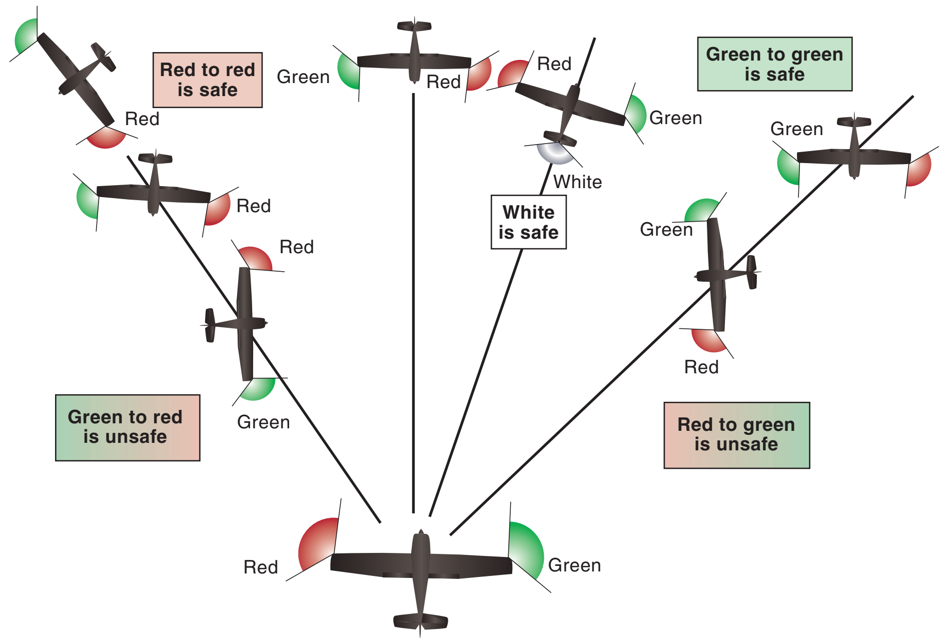


Figure 2-14 Position lights.

Visual Judgment on Approach

The eyes and brain use many clues and stored images of known objects to help in judging distance, size and height. The relative size and relative clarity of objects give clues to their relative distances: a bigger object is assumed to be nearer than a smaller one and a more clearly defined object nearer than a blurry one. When the object is near, binocular vision (the slightly different images of a nearby object relative to its background seen by each eye) assists in depth perception.

Texture also assists in depth perception: the more visible the texture, the closer the object appears to be. On final approach as you near the aim point, the surface texture will appear to flow outward in all directions from the point on which you are focused.

This is one means by which you can visually maintain the flight path to the aim point: adjust the attitude and heading so that the point from which the texture appears to be moving outward remains the desired aim point.

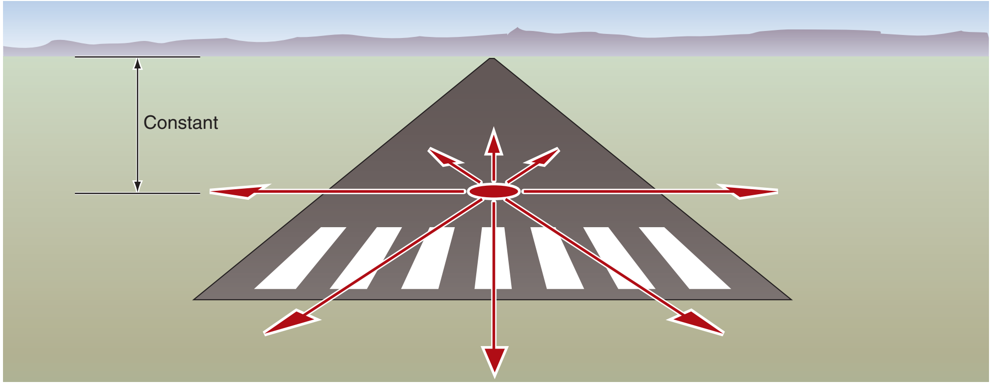


Figure 2-15 Aim point.

Texture is also used for the estimation of height; for instance, as you approach flare height for a landing, the actual texture of the runway or the grass passing by the cockpit becomes increasingly noticeable. Relative motion also aids in depth perception. Near objects generally appear to pass by faster than more distant objects. This helps a visual pilot estimate height above the runway before and during the flare: the closer the airplane is to the runway, the faster the runway surface and the surrounding environment appears to pass by.

Depth perception can be difficult in hazy or misty conditions, where edges are blurred, colors are muted, and light rays may be refracted unusually. This gives the impression of greater distance, an impression reinforced by the fact that we often have to look at distant objects through a smoggy or hazy atmosphere. This illusion is referred to as *environmental perspective*. In hazy conditions, the object might be closer than it seems; in very clear conditions, the object might be further away than it seems. On hazy days, you might touch down earlier than expected; on very clear nights, you might flare a little too soon.

Visual Illusions

Sometimes what we perceive in our brain (what we think we see) is not actual because images sent from the eyes can sometimes be misinterpreted by the brain.

Autokinesis

The visual illusion of autokinesis (self-motion) can occur at night if you stare continuously at a single light against a generally dark background. It will appear to move, perhaps in an oscillating fashion, after only a few seconds of staring at it, even though in fact it is stationary. You could lose spatial orientation if you use it as your single point of reference. The more you try to concentrate on it, the more it may appear to oscillate. You can guard against autokinesis at night by maintaining movement of your eyes in normal scanning, and by monitoring the flight instruments frequently to ensure correct attitude.

Unless you have a distant object in view at night, your eyes will tend to focus at a point about three to six feet ahead of you, especially if you are an older person, and you may miss sighting distant objects. This empty-field myopia or night myopia (shortsightedness) can be combated by searching for distant lights and focusing briefly on them. Beware also of false horizons at night (see later in this chapter).

Haze

In hazy conditions, you may be closer to the runway than you appear to be, an illusion that may lead to an unnecessarily hard landing if you are not prepared for the effect of haze on your vision. This also has an effect on your ability to estimate distances to the airport or checkpoints. The effect of haze over featureless terrain or over water virtually eliminates any reference to the horizon.

On hazy days, objects appear closer.
On clear days, objects seem farther away.

False Horizons

Sloping layers of cloud by day, angled lines on the ground, lights along a coastline at night, or areas of lights by night can present a pilot with a false horizon, which can be very misleading. This is not uncommon with a ragged, lowering cloud base and associated drizzle or rain obscuring the horizon.

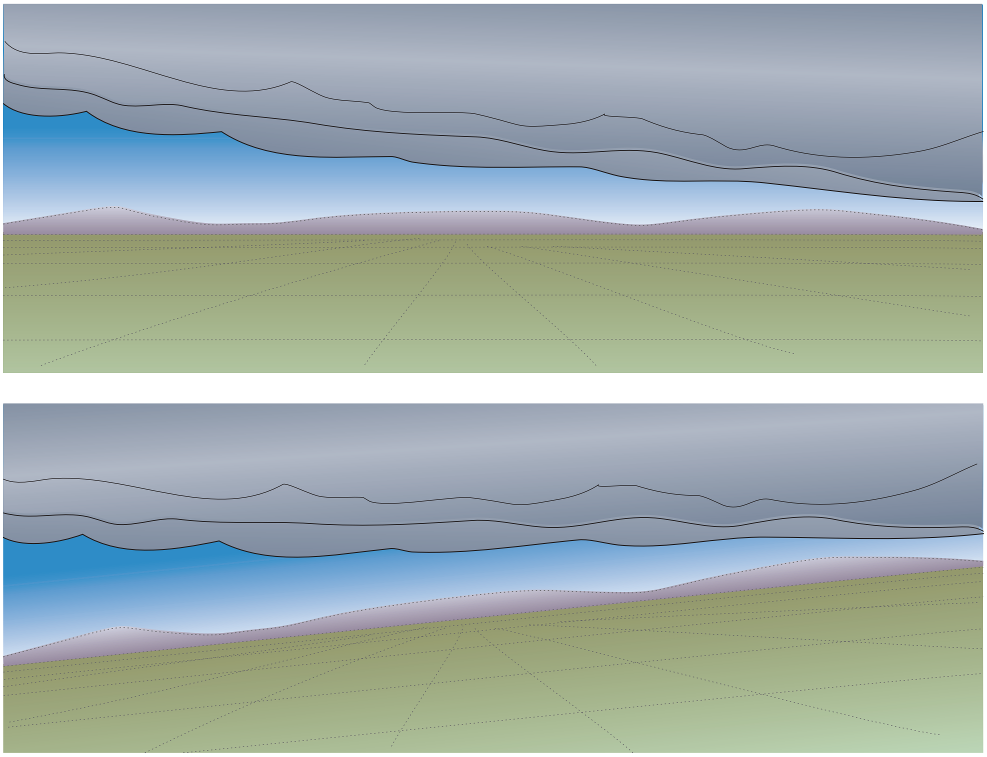


Figure 2-16 False horizon.

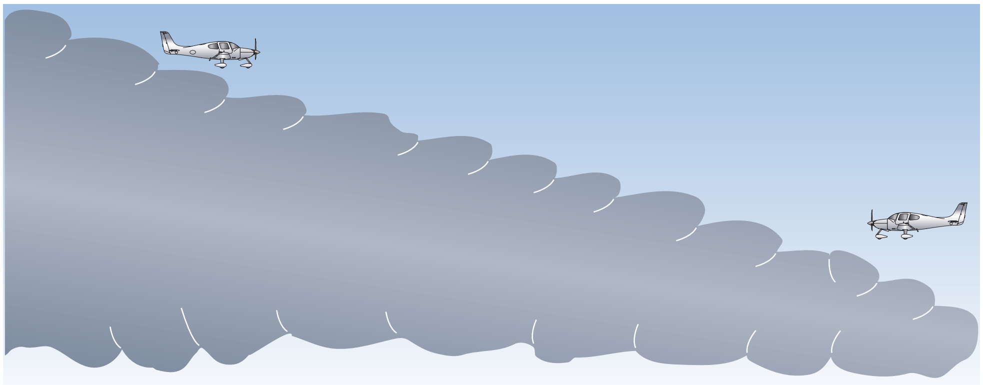


Figure 2-17 False level.

Visual Illusions in the Pattern

Visual Estimation Of Height. A pilot flying a right traffic pattern may get the impression that the aircraft is higher than normal. This illusion could occur to a pilot who has developed the habit of visually judging pattern altitude and position by relating the position of the runway lights to some feature of the aircraft, such as a particular position in a side window. Such a rule of thumb that worked satisfactorily for the more typical left patterns could lead a pilot to descend lower to achieve the same picture when making right traffic patterns. Like most habits, such a practice could happen unconsciously.

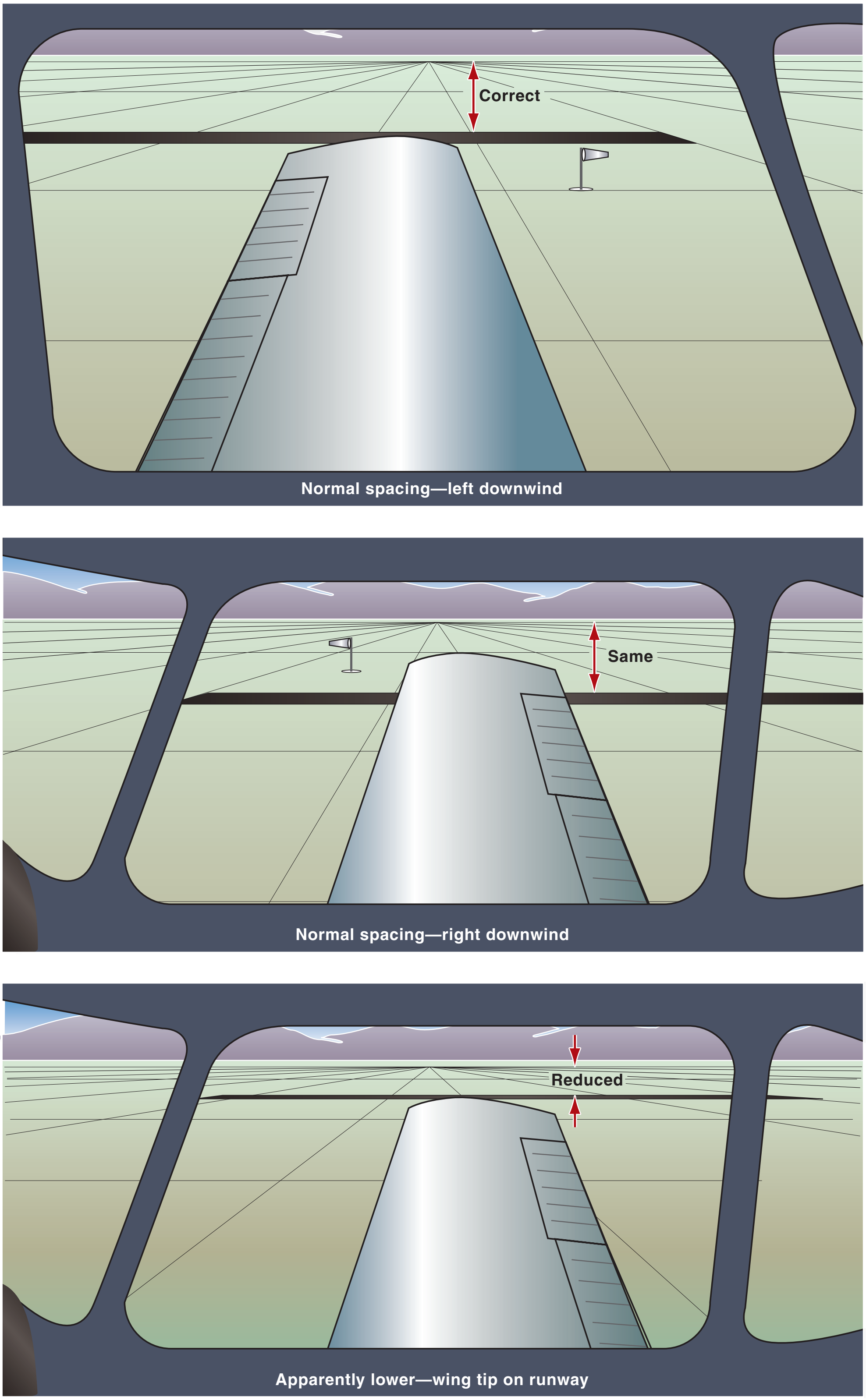


Figure 2-18 Downwind spacing in the traffic pattern.

Visual Illusions on Approach

Runway Slope. Most runways are of standard width and on flat ground. On every approach, you should try to achieve the same flight path angle to the horizontal, to which your eyes will become accustomed, allowing you to make consistently good approaches along an acceptable approach slope merely by keeping your view of the runway through the windshield in a standard perspective.

When approaching a sloping runway, however, the perspective will be different. A runway that slopes upward will look longer, and you will feel that you are high on slope, when in fact you are right on slope. The tendency will be for you to go lower or make a shallower approach.

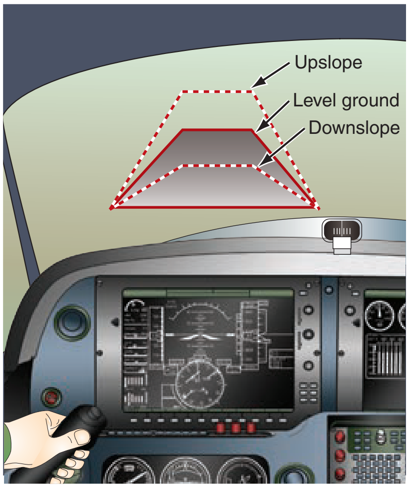


Figure 2-19 Runway slope.

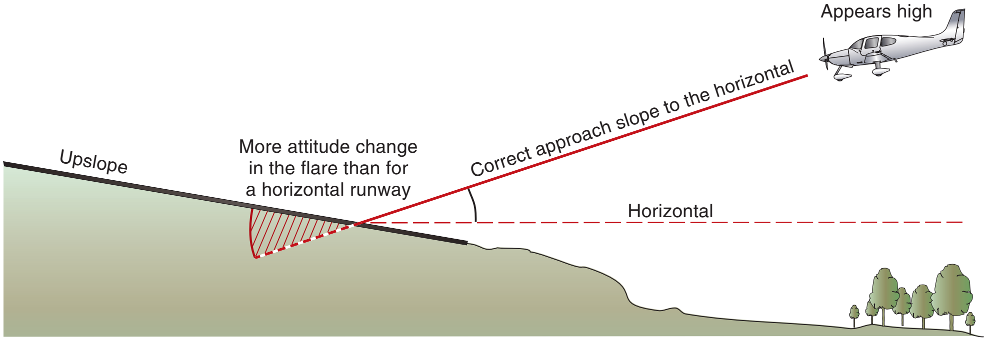


Figure 2-20 Upsloping runway.

A runway that slopes downward will look shorter, and you will feel that you are low when in fact you are on the correct path. The tendency will be for you to go higher and make a steeper approach.

If you know the runway slope, you can allow for it in your visual estimation of whether you are high or low on approach.

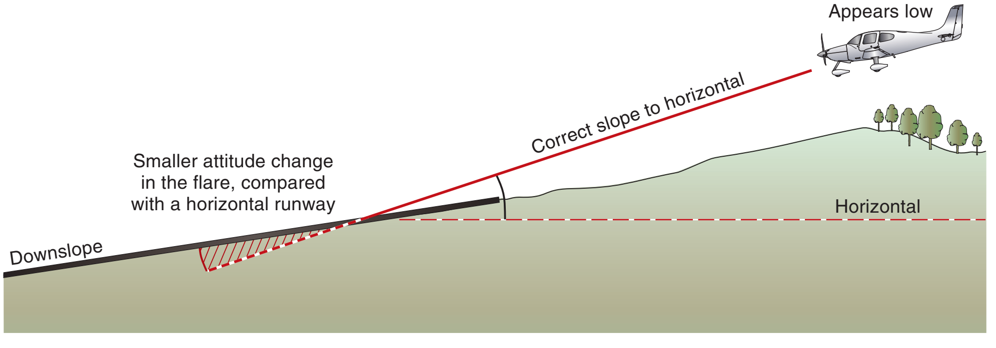


Figure 2-21 Downsloping runway.

Runway Width. A runway that is wider than usual will appear to be closer than it really is. Conversely, a runway that is narrower than usual will appear to be further away than it really is. A wide runway, because of the angle at which you view it peripherally in the final stages of the approach and landing, will also cause an illusion of being too low, and you may flare and hold off too high as a result. This may lead to "dropping in" for a heavy landing.

Conversely, a narrow runway will cause an illusion of being too high, and you may delay the flare and make contact with the runway earlier (and harder) than expected. If you know that the runway is wider or narrower than what you are familiar with, then you can allow for this in your visual judgment of flare height.

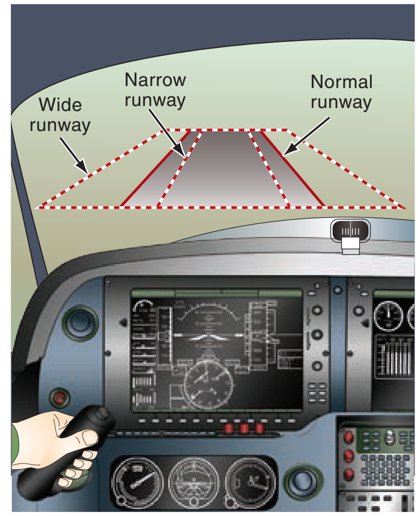


Figure 2-22 Runway width.

Night Approach. A powered approach is preferred. Power gives the pilot more precise control, a lower rate of descent and a shallower approach path. The approach to the aim point should be stabilized as early as possible (constant airspeed, path, attitude, thrust and configuration). Use all the available aids, such as the runway lighting and a visual approach slope indicator (VASI).

If the runway edge lighting is the only aid, correct tracking and slope is achieved when the runway perspective is the same as in daylight. On centerline, the runway will appear symmetrical.

Guidance on achieving the correct approach slope is obtained from the apparent spacing between the runway edge lights and the distance of aim point below the horizon. If the aircraft is low, the runway lights will appear to be closer together or closing. If above slope, the runway lights will appear to be further apart and separating. VASI will provide correct indications, but the perspective provided by runway edge lighting may be misleading due to runway slope or width.

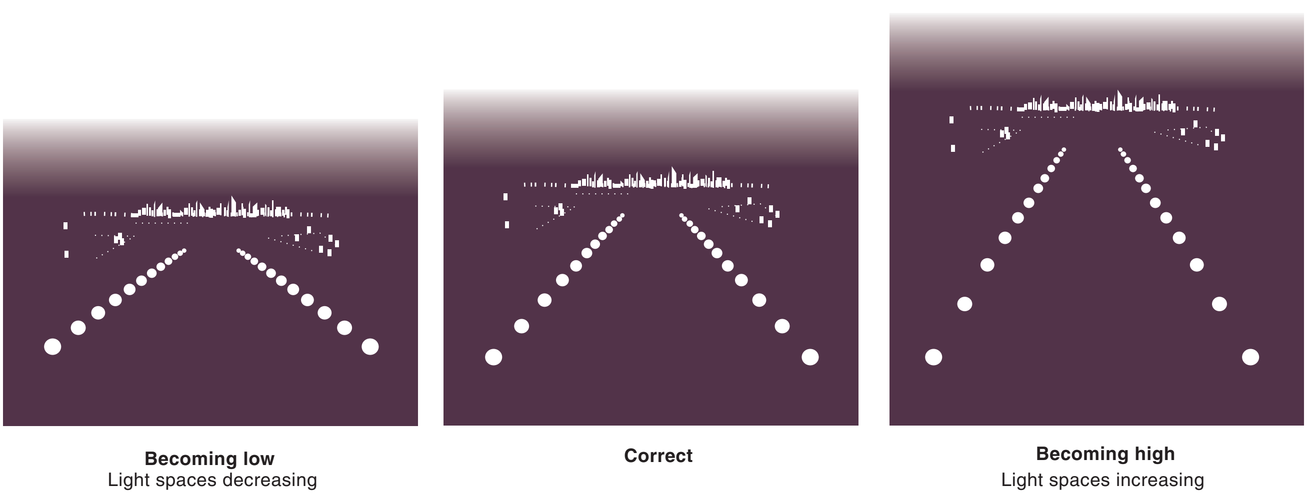


Figure 2-23 Night runway aspect.

Black-Hole Approach. Flying an approach to a runway with no other visible references can often be difficult. This can occur when approaching a runway on a dark night where the only lights visible are the runway edge lights, with no town lights or street lights to be seen, and no indication of the nature of the surrounding terrain. This is what is known as a *black-hole approach*. Alternatively, there could be city lights in the area beyond the airfield but no visual cues near the threshold. Black-hole approaches also occur on tropical atolls, at remote desert airfields, or on approaches to runways that are surrounded by water.

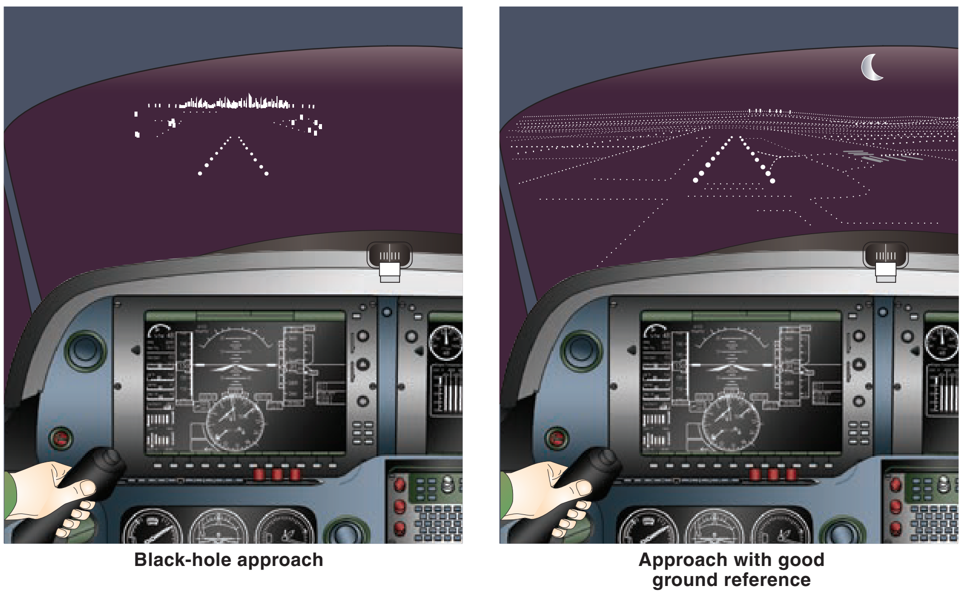


Figure 2-24 Black-hole approach.

The tendency is to think that you are higher than in fact you are, resulting in an urge to fly down and to fly a shallower approach—to sink into the abyss, the black hole.

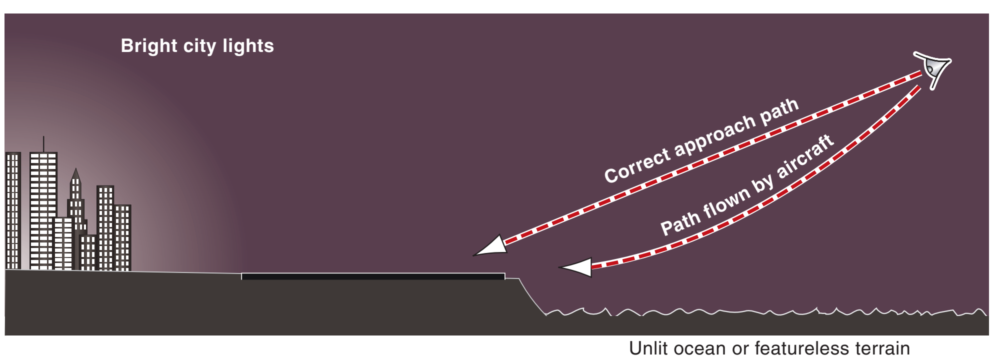


Figure 2-25 Black hole with high-contrast illumination.

The worst black-hole problem of all is to be found in remote airfields on a dark night (say, under cloud) where there is no other light source or any ground texture, and autokinesis might generate an impression of movement when there is none. Rely on the instruments, not your eyes, to maintain horizontal and vertical navigation plots.

If VASI is not available, crosscheck the vertical speed indicator (VSI) to ensure that the rate of descent is proportional to the approach speed (V_{REF}). As a guide, the rate of descent should be close to five times the groundspeed for a 3° approach. The glidepath is approximately 300 feet of altitude AGL for every mile from the runway, i.e., you should be at 900 feet AGL if you are on a three-mile final. Target an altitude of 300 feet one mile from the runway with a rate of descent of approximately 450 feet per minute with a 90-knot approach speed (use DME or GPS distance from the threshold, if available, to better plan descents).

Similar situations to a black-hole approach arise in conditions where the ground is covered with snow, making it featureless (white-out approach). The lack of a horizon and details around the runway threshold make depth and slope perception much more difficult.

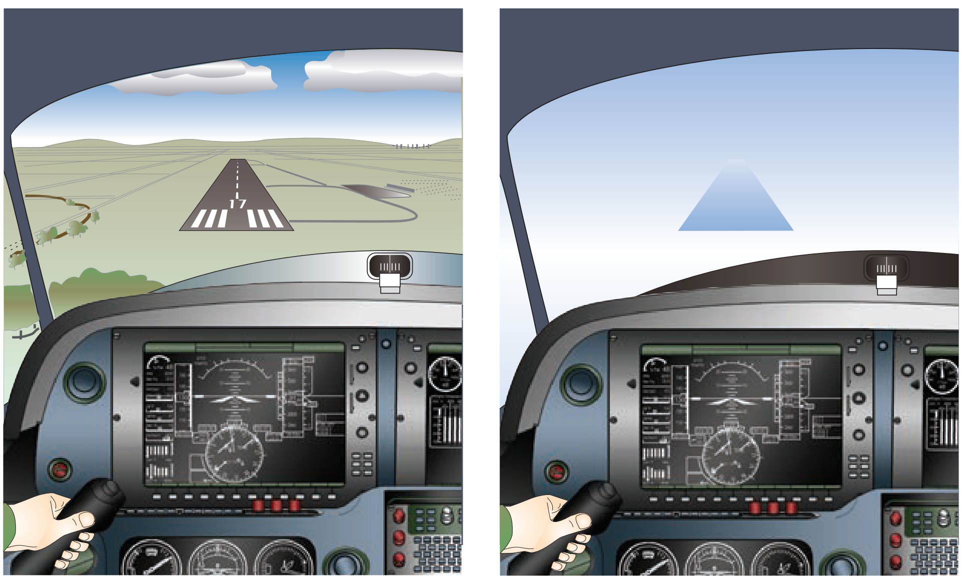


Figure 2-26 Reduced visibility.

A variety of atmospheric and terrain conditions may produce visual illusions on approach. When you encounter such situations, anticipate and compensate for them.

<table>
<tr><th>Situation</th><th>Illusion</th><th>Result</th><th></th></tr>
<tr><td>Upslope runway or terrain</td><td>Greater height</td><td>Lower approaches</td><td rowspan="5">Shallower</td></tr>
<tr><td>Narrower-than-usual runway</td><td>Greater height</td><td>Lower approaches</td></tr>
<tr><td>Featureless terrain</td><td>Greater height</td><td>Lower approaches</td></tr>
<tr><td>Rain on the windshield</td><td>Greater height</td><td>Lower approaches</td></tr>
<tr><td>Haze</td><td>Greater height</td><td>Lower approaches</td></tr>
<tr><td>Downslope runway or terrain</td><td>Less height</td><td>Higher approaches</td><td rowspan="3">Steeper</td></tr>
<tr><td>Wider-than-usual runway</td><td>Less height</td><td>Higher approaches</td></tr>
<tr><td>Bright runway and approach lights</td><td>Less distance</td><td>Higher approaches</td></tr>
</table>

Table 2-3 Visual illusion on approach.

Hearing and Balance

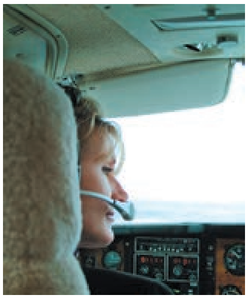


Figure 2-27 Ears aren't only for hearing.

The ears provide two senses: hearing and balance. Hearing allows you to perceive sounds and to interpret them; the sense of balance lets you know which way is up and whether you are accelerating or not. Balance is the next most important sense for a pilot after vision.

Sound is defined as energy that you can detect with your ears. It is often very useful and pleasant, as with voice messages and music; however, excessive sound may be annoying and fatiguing, and can even lead to damage within the ear. Irregular, unwanted and unpleasant sound is called noise and is best filtered out. Sound signals are caused by pressure waves traveling through the air, and these cause the eardrum to vibrate. The inner ear converts these pressure vibrations into electrical signals that are sent via the auditory nerve to the brain where they are interpreted.

Similarly, balance and acceleration signals from the balance mechanism in the inner ear pass to the brain as electrical signals for interpretation. The interpretation is sometimes tricky in the case of an airborne pilot, since the brain is accustomed to the person generally being upright and slow moving on the earth's surface.

Structure of the Ear

The ear is divided into three areas: the outer, middle, and inner ear.

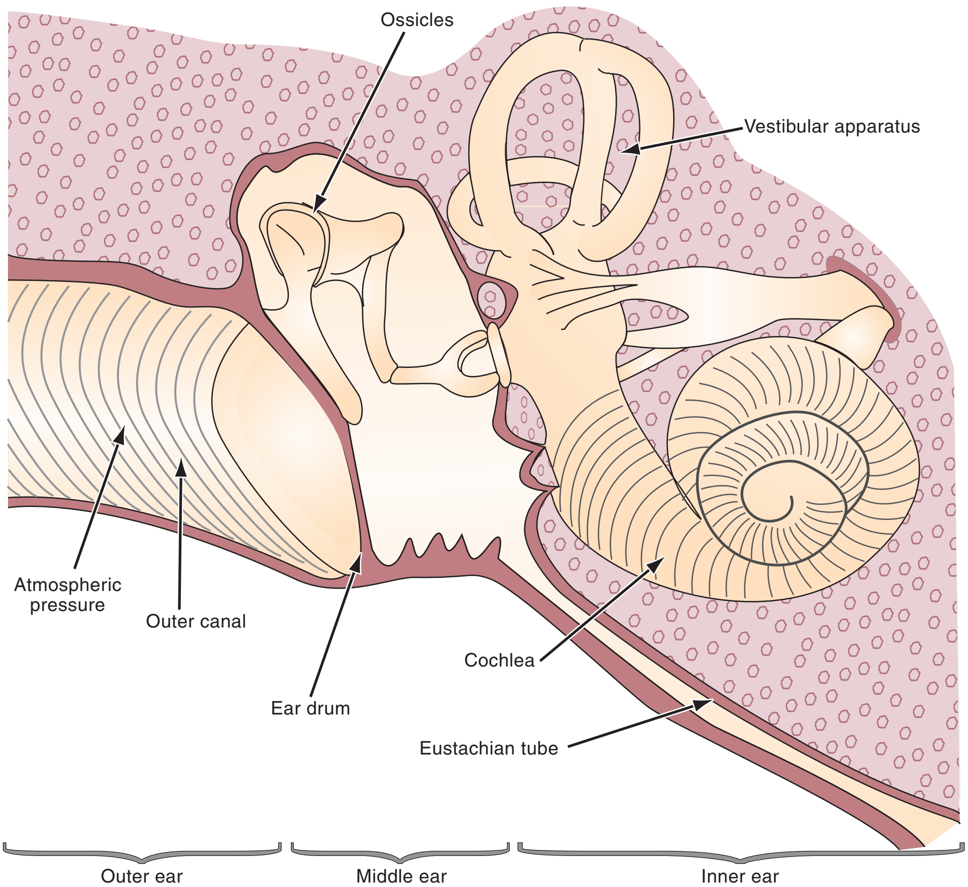


Figure 2-28 Structure of the ear.

Hearing

The ear is never switched off. Loud or particular noises to which you have a conditioned response can always stir you from the deepest sleep. A quiet room is essential for sound sleep. It is also interesting to note that you can extract messages important for you out of a noisy background; for instance, a radio message directed at you, the sound of your own child on a crowded beach, or your own name mentioned in a distant conversation can all be discerned. This is known as the *cocktail party effect*.

The region of the middle ear has much to do with your sensations of movement and balance. It is for that reason that people with middle-ear infections often lose their sense of balance. Furthermore, disturbed signals from these sensors lead to a feeling of nausea. In extreme cases, *vertigo*, the total loss of balance with massive and disturbing disorientation, results. The comments that follow apply to the hearing aspects of the ear; balance is discussed later in the chapter.

Sound is what you hear, and each sound can be defined by the following qualities:

- *frequency* or *pitch*, which is the number of pressure waves per second (or hertz, Hz) that the sound source produces. Perfect human hearing is in the range of 20 Hz to 20,000 Hz, and voices use the frequency range 500 Hz to 3,000 Hz;
- *loudness* or *intensity*, which is the strength or amplitude of the pressure waves, measured in decibels (dB), a logarithmic scale where an increase of 20 dB signifies an increase in intensity of ten times. (20 dB is ten times as loud as 0 dB, the threshold of hearing; 40 dB is ten times louder again, i.e. 100 times as loud as 0 dB; 60 dB is 1,000 times as loud as 0 dB and 100 times as loud as 20 dB); and
- *duration*, which is how long the sound lasts.

Fatigue and Damage From Noise

Unwanted sound, especially if it is loud and disagreeable, is *noise.* It can be mentally fatiguing through its effect on our ears, but it also affects the rest of our body, especially if it is associated with vibration as is often the case. Noise can interfere with communications, and with concentration. Extreme noise levels can also do permanent physical damage to our ears, with duration and recurrence of exposure being as important as loudness.

Loss of Hearing

A person can experience a temporary hearing loss after exposure to noise. The noise of an engine, for instance, may no longer be heard after a while even though the engine noise is still there. Some factory workers lose the ability to hear frequencies they are subjected to all day long. A temporary hearing loss may disappear after a few hours.

Exposure to high noise levels (greater than 80 dB) for long periods can also lead to a permanent hearing loss, especially in the high-frequency range. This is a risk area for pilots who are exposed to a noisy work environment for long periods. Put it together with visits to the car races, noisy night clubs, plus a top set of speakers at home and you are in a high-risk environment from the point of view of your hearing.

Very, very gradually, and imperceptibly, a person can lose the ability to hear certain sounds clearly, speech becomes more difficult to comprehend and radio communications become more difficult. Sudden, unexpected loud noises (greater than 130 dB), such as an explosion or the sound of an impact, can cause damage to hearing, possibly even physical damage to the eardrum or to the small and delicate ossicles.

Level (dB)	Situation
130	Standing near a jet aircraft (noise becoming painful).
120	Standing near a piston-engine aircraft (noise becoming uncomfortable). Several hours per day for three months could lead to deafness.
110	Maximum recommended for up to thirty minutes' exposure.
100	Maximum recommended for two hours' exposure.
90	Maximum recommended for eight hours' exposure (a working day).
80	Standing near heavy machinery. Above 80 dB for long periods can lead to temporary or permanent hearing loss.
60	Loud street noise, trucks, etc.
50	Conversation in a noisy factory.
40	Office noise.
30	Quiet conversation.
20	Whispering.
0	The threshold of hearing.

Table 2-4 Noise levels of typical sounds.

Aircraft Type	Takeoff	Cruise	Landing
Aero Commander 680	102	92	83
Beechcraft A36	97	86	75
Cessna 172	94	89	75
Piper Pawnee	103	102	89
Bell 206	91	92	89

Table 2-5 Indicative cockpit noise levels (decibels).

Hearing loss can also result from:

- problems in the conduction of the sound due to a blocked outer canal (ear wax), or fluid or pressure problems in the middle ear, e.g. barotrauma or damaged ossicles (known as *conductive hearing loss*);
- loss of sensitivity of the hair cells in the cochlea due to exposure to noise, infection, or age (known as a *sensory* or *noise-induced hearing loss*);
- *presbycusis*, a natural loss of hearing ability with increasing age, especially in the higher frequencies (down about 5% by age 60 and 10% by age 70); and
- excessive use of alcohol or medications.

Precautions for Minimizing Hearing Loss. A noise-induced hearing loss may develop gradually over a period of years without the person noticing. It is something that cannot be reversed, hence the need for prevention rather than cure. As a pilot, you are lucky in that you will have regular audiometry tests that can be compared over the years to look for any gradual loss of hearing, especially in the higher frequencies. Wear hearing protection when in noisy areas. A good noise-canceling headset is highly recommended for the cockpit, and earplugs or earmuffs for when you are moving around outside the aircraft. Earplugs can reduce noise by about 20 dB, and good earmuffs by about 40 dB. The radio headset, especially if it is well sealed, will block out background noise. Unprotected, close exposure to jet-engine noise can be hazardous to the balance mechanism in the ears also, which is another reason to wear hearing protection on the tarmac.

Balance

The sense of balance makes it possible for you to remain upright. The most powerful reference is visual. If you can see, you can tell directly whether you are vertical (if there is a vertical or horizontal reference). If you close your eyes, things are not so easy. Try standing on one leg and closing your eyes.

The secondary sensing mechanisms are those devices (other than vision) from which your brain might be sent orientation messages. The secondary signals are very feeble indeed, compared to visual cues. They really only supplement visual perception. In other words, they can only make sense in partnership with the vastly more powerful visual picture. These sensory mechanisms were designed for three-dimensional orientation but not three-dimensional motion or accelerations. However, if you have no visual horizon, these other sensors will supply fall-back information, but it is not totally reliable.

In the absence of a powerful visual cue, your system will crave orientation signals and accord them equal weight. The secondary sensing mechanisms will be sensed very strongly indeed, but they are always misleading. You cannot rely on any of them. You must never use them to judge your flight path. You can only guard against that by knowing what they will try to tell you, and by becoming familiar with their illusive signals. To be confident and competent in cloud requires training, experience and recency in cloud or in a motion simulator.

Spatial Orientation

Orientation is the ability to determine your position and alignment in space. It is usually achieved by a combination of three senses:

- vision, the most powerful sense;
- balance, the *vestibular* sense (gravity, acceleration, and angular acceleration); and
- "seat-of-the-pants" (bodily feel or the *proprioceptive* sense).

Avoid spatial disorientation by looking outside or by looking at the flight instruments. Do not rely on body signals.

The brain uses all information that it has available to assemble a picture. If there are conflicting signals, vision is given first priority. In most situations, each of the three senses reinforce the others; however, in flight, this is not always the case. Each of these senses can sometimes have its messages misinterpreted by the brain. Not knowing your attitude (i.e. which way is up) is *spatial disorientation*. When you are denied external vision, and flying is solely by reference to the instruments, a range of false sensations can be perceived. Hence, the need to rely totally on your flight instruments (but also scan to check that they agree with each other).

Human Balance Mechanism: The Vestibular Apparatus

The balance mechanism is designed to keep you upright—i.e. vertical and balanced—while standing or moving without input from the eyes. In the absence of visual references, the inner ear can sense what it believes is vertical by two means:

- sensing tilt angle; and
- sensing tilting motion (backward/forward or left/right).

The angle of tilt is sensed by the equivalent of a pendulous mass (which senses gravity as vertical) and the tilting motion by the fluid-filled semicircular canals.

Sensing Gravity (Verticality)

Your body can sense accelerations (g-forces).

Gravity is detected by sensory hairs in a sac filled with gelatinous material, commonly known as the *otolithic organ* or *utricle*. The sac's outer membrane is studded with small crystals of calcium carbonate. These are called *otoliths* and give the organ its name.

The otolithic organ has a resting position when the head is upright. The brain interprets the message sent from the small hairs at this time as *up*; that is, the sac is affected by a 1g force directly downward. If the head is tilted to one side, or forward or backward, then the otoliths act as weights moving the sac under the force of gravity and taking up a new position, thus bending the hairs, which sends a different signal to the brain.

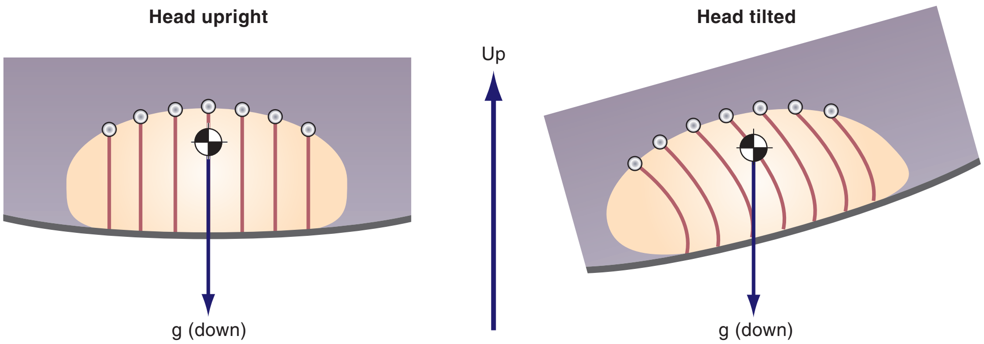


Figure 2-29 Sensing vertical.

Figure 2-30 Pendulous effect.

The otolithic organ detects the direction of g-forces but cannot distinguish their origin; that is, it cannot tell whether it is the force of gravity or a centripetal force pulling you into a coordinated turn. You must remember that the body was designed for fairly slow motion on the face of the earth, with a consistent 1g force of gravity exerted on it, and not for the three-dimensional forces you experience in flight (or zero g for that matter). In a turn, it will recognize the direction of the total load factor as a false vertical.

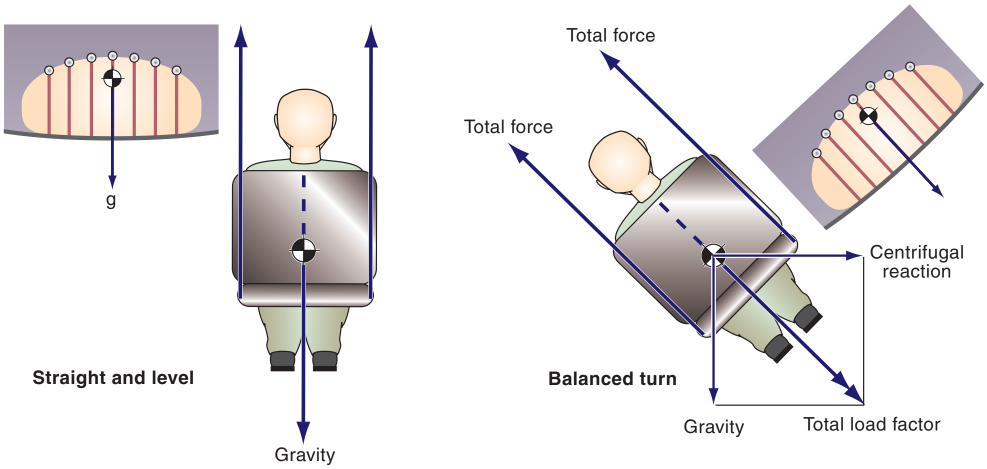


Figure 2-31 Apparent vertical -- straight and turning flight.

Sensing Angular Movement (Rotation).

The three semicircular canals of the inner ear—the vestibular apparatus—contain fluid. These three semicircular canals are at right angles to each other (they are orthogonal) like the pitch, roll and yaw planes of an airplane, and therefore they can detect angular accelerations (change in the rate of rotational speed) in pitch, roll and yaw.

The *cupula* is a saddle-shaped chamber at the base of each canal as depicted in the diagram opposite. It has a cluster of fine hairs that protrudes into the fluid. Movement in the fluid is sensed by these hairs. Nerve endings at their base send corresponding signals to the brain for interpretation (perception).

The semicircular canals are *not* designed to detect linear changes in motion or linear acceleration, because the upper and lower volumes of fluid are self-canceling. For example, if the fluid at the top of the semicircular canal tries to move counterclockwise around the canal due to an acceleration forward, then the fluid at the bottom will try to move around clockwise to the same degree. The net effect is no relative movement of the fluid and the sensory hairs of the cupula will remain straight.

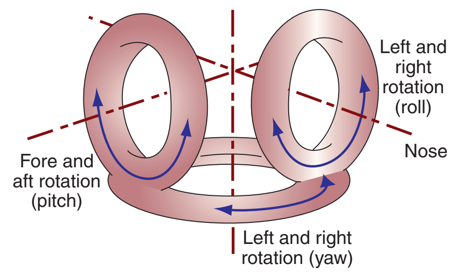


Figure 2-32 Semicircular canals.

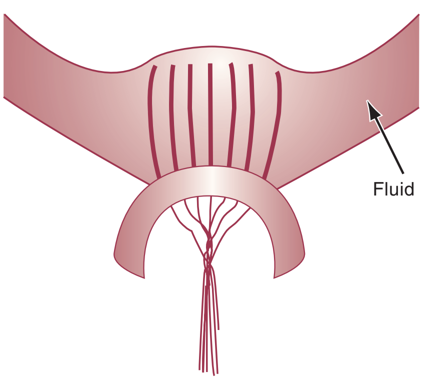


Figure 2-33 Cupula.

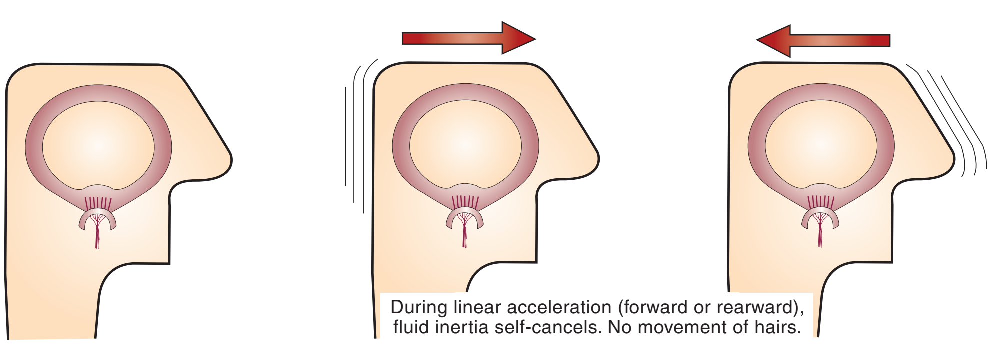


Figure 2-34 Linear acceleration.

The vestibular apparatus senses angular acceleration by recognizing changes in rotary motion due to the lag of the viscous fluid. During angular acceleration, the relevant semicircular canal moves around a mass of fluid that lags. This lag in the fluid bends the sensory hairs to send a signal to the brain that the head is rolling, yawing or pitching (three dimensions—three channels—three canals). Once the rate of roll steadies—that is, there is no more angular acceleration—the fluid will catch up with the surface of the semicircular canals, straightening the sensory hairs of the cupula. This means you will detect the entry to the roll but not its continuing steady state. Similarly, you will sense the opposite acceleration as you stop the roll (decelerate) at the required bank angle.

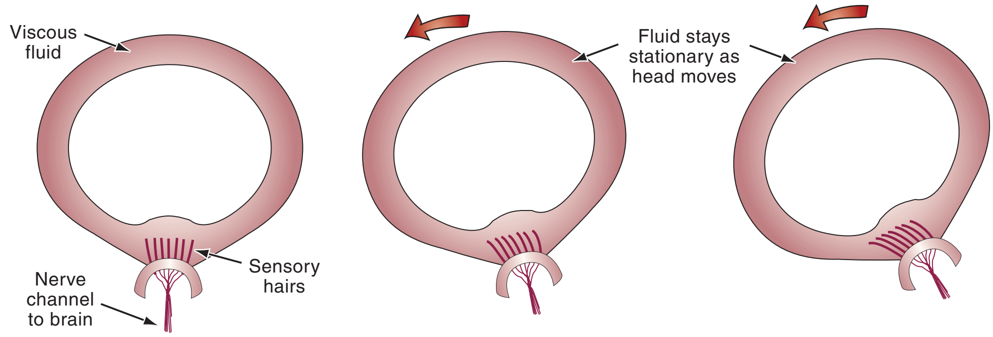


Figure 2-35 Angular acceleration -- rotation.

In flight, the sensory mechanisms are suppliers only of crude and potentially deceptive messages (compared to the direct orientation images flowing through the sight channel). As is the case with any stimulus or sensation, there is a threshold below which movement will not be detected. For example, you will sense a rapid change in roll rate, but not a gentle one. In reality, you do not necessarily detect the angular acceleration that commences the roll as a rolling sensation. You may feel the entry into the roll as a rolling sensation if the roll is rapid enough. Similarly, you may sense the rotary deceleration that stops the roll at the selected bank angle. You may also sense rolling signals from adjustments to the control input while adjusting either roll rate or angle of bank. However, in many flight regimes, your control inputs will be so gentle that you will not detect any rolling sensation at all. The potential for confusion is serious.

Sensations in Turning Flight. In a balanced turn, a full glass of water on top of the instrument panel will remain unspilled; it will remain level with respect to the glass. It is as if the weight of the fluid is acting through the aircraft's vertical axis. It is. The apparent weight is the result of gravity and centrifugal reaction.

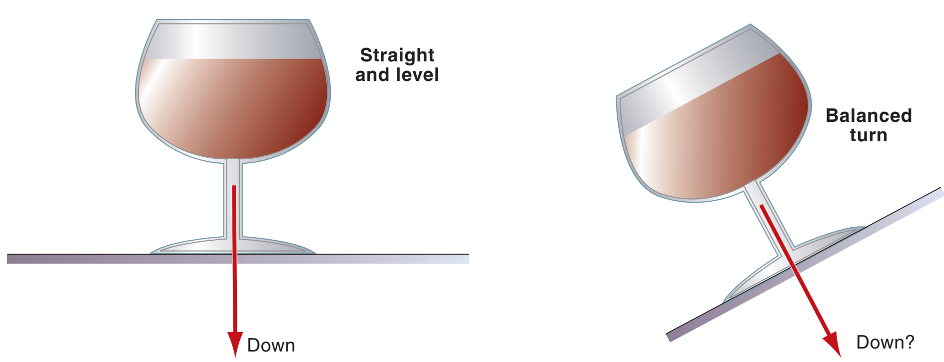


Figure 2-36 Sensed vertical.

Your body will also sense up and down as acting in that same axis. There will no longer be any rolling sensation, nor is there any other sensation source other than seat-of-the-pants. In other words, once you are established in a turn, you will feel that you are in straight and level flight. And that feeling will be the same regardless of the bank angle, except that the load factor is increased. When you bring together this feeling of certainty of where down is and the sensation of rolling, things can become very confusing, a condition generally known as *the leans*. The leans can profoundly interfere with your mental equilibrium, but only if you let them.

Disorientation and Illusions

The Leans

Let's look at another situation. If the turn entry is very gentle, it is not sensed by the semicircular canals, but the stop-roll deceleration is detected. The end result is quite discomforting:

- the gentle onset of roll into the turn is not perceived;
- next, no sensation is available during the steady-state roll;
- but, when the stop-roll control movements are made briskly, the angular deceleration that stops the roll and establishes the bank angle is felt—strongly;
- however, it is felt as a roll to the left; and
- as there is no canceling sensation available, the sensation of rolling—continuous rolling—persists, though it will slowly dissipate as the fluid stops moving and the sensory hairs get to stand up straight again.

In entering this turn, the only sensation perceived was the stop-roll angular deceleration. The signal sent to your brain is read as a roll to the left. With no corresponding canceling sensation, it will be a sensation of continuously rolling. When you then roll out of the turn, and the rollout is briskly commenced (enough to be detected), you will then experience the sensation that the left-roll movement has become faster.

Perception of rapid roll rates can quickly produce strong sensations of disorientation. You can get the leans from turn entries or exits. That is:

- you might be wings level and yet absolutely convinced you are rolling into or established in a turn; or
- equally, you can be in the turn and certain that your wings are level.

Slow rates of roll (or movement around the other two axes) will not be detected. Brisk control inputs will induce sensations, and the brisker, the stronger. A common leans scenario is the following:

- you slowly let a wing drop then suddenly notice the wing-low condition;
- you spontaneously and rapidly roll to wings level (and perhaps be looking down at a map or over your shoulder for the runway after a night takeoff); and
- you feel a strong rolling sensation.

Nose-Up Pitch Illusion of Linear Acceleration

The otoliths are tiny weights on the membrane enclosing the utricle sac and its sensing hairs. When you tilt your head back, or lean backward, the weights cause the sac to slump in that direction. The corresponding sensor-hair movement tells your brain that your vertical axis is now inclined rearward.

The same sensation is caused by linear acceleration. Under acceleration, the sac lags behind, and sensor hairs send a message of tilting backward. This sensation of the nose rising as you accelerate is known as the *somatogravic illusion* (*somato* meaning originating in the body, *gravic* meaning sense of gravity). The greater the acceleration, the stronger the feeling. Obviously, it is not a problem when there are clear visual cues, but it can have very serious consequences when there are few, or none, as on a dark night. The forward acceleration through takeoff and then to climb speed will be sensed as backward tilt or, rather, as a higher nose-attitude and pitch-up than actually exists. There is a temptation to lower the nose with sometimes fatal consequences.

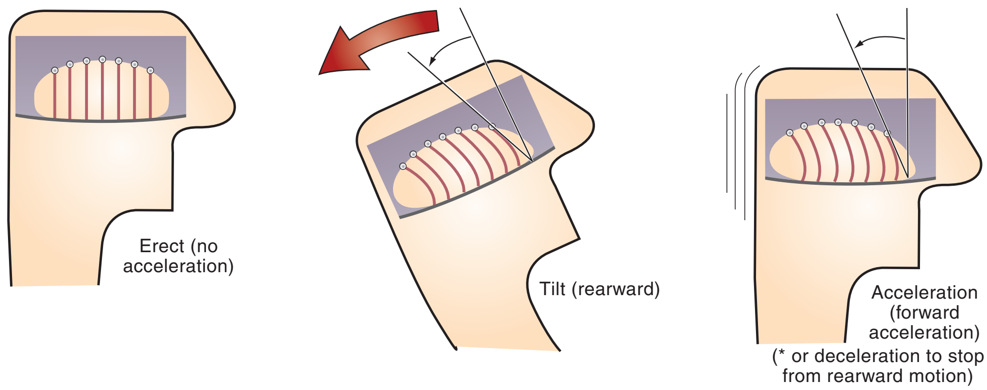


Figure 2-37 Rearward tilt or acceleration?

Nose-Down Pitch Illusion of Linear Deceleration

There is a converse to the somatogravic illusion, but not as serious, as it is less likely to happen near the ground. Deceleration in flight is sensed as tilting forward. It is particularly noticeable in higher performance aircraft when reducing thrust and extending the speed brakes. If the aircraft is already descending, the deceleration will be sensed as a steepening descent.

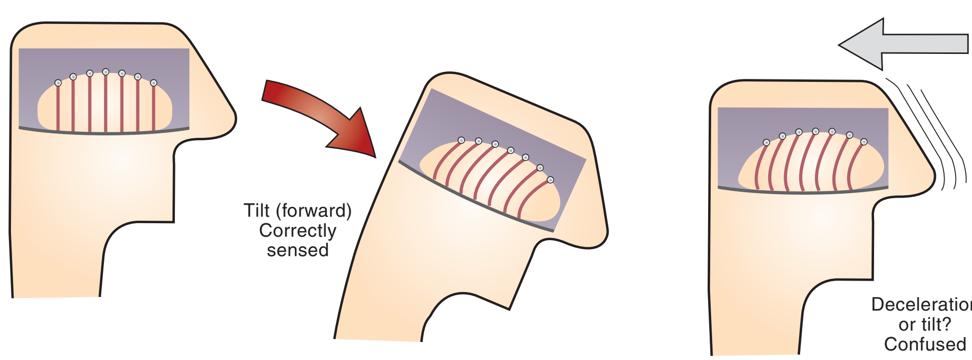


Figure 2-38 Forward tilt or deceleration?

Again, if there is clear visual reference, the sensation is hardly noticeable. If the horizon is less clear, then they are more powerful. Fly attitude as depicted on your flight instruments.

Motion Sickness

Motion sickness is usually caused by the balance mechanisms of the inner ear being overstimulated by motion. This can be caused by turbulence, or maneuvers such as steep turns or spins, in which forces other than the normal will be experienced, especially if there is no clear horizon. A hot, smelly cockpit does not help. Psychological aspects can also play a role in the onset of motion sickness. Anxiety, in particular, will make the condition worse by causing the sufferer to lose control over where he or she looks and focuses attention. Visual scanning is likely to become purposeless, random or fixed.

The visual channel is, by far, the most powerful spatial orientation reference. If the messages coming in through non-visual channels—the balance organs—are accorded priority, the sensory confusion causing airsickness will predominate. If the airsick person focuses on the horizon, the visual messages will be given a chance to assert their authority and to tone down the strength of the signals coming from other sources.

Many pilots have experienced airsickness, especially early in their training when stress levels are higher, and unusual attitudes and g-forces are encountered perhaps for the first time, so do not be discouraged if you experience it occasionally.

To avoid airsickness:

- anticipate and avoid areas of turbulence, known from weather forecasts and any local effects such as the side of hills (if not a local, seek the views of someone who is);
- eat lightly before flight, but do eat something (don't fly on an empty stomach);
- fly the airplane smoothly, gently and maintain trim and balance;
- focus on the horizon as much as you can;
- avoid maneuvers involving unusual g-forces; and
- ventilate the cabin with a good supply of cool, fresh air.

If turbulence is encountered:

- fly at best speed;
- relax, don't fight, and maintain attitude;
- occupy a potentially airsick passenger in the flight, especially with looking outside the airplane into the distance or at the horizon;
- as a last resort, recline the airsick passenger's seat to reduce the effect of the vertical accelerations and keep an airsickness bag handy; and
- land as soon as is reasonably possible (if necessary).

Load Factor

Speed has relatively little effect on the human body, whereas acceleration or deceleration may produce pronounced effects ranging from the fatiguing characteristics of flight to a complete collapse of the cardiovascular system. In aviation, acceleration is usually expressed in multiples of the acceleration due to gravity of 32.2 fps^2 (9.81 m/s^2) and is represented by the symbol g.

The brain and eyes need a continuous supply of oxygen. They have little storage capacity, so strong or prolonged g-forces, which reduce the supply, lead to reduced visual acuity, loss of color vision, loss of sight and even unconsciousness. When the acceleration is centripetal, as in turn or pitching maneuvers, it is felt by the pilot as an increase in weight. In a 60°-banked level turn, you will experience +2g, or feel you are twice as heavy.

All parts of the body are affected by g-force. The blood, for instance, will also get heavier. It therefore is harder to pump and circulate, and tends to pool in the legs and lower abdomen. At higher load factors of, say, +3.5g and upward, this can produce physiological symptoms.

Reduced blood circulation diminishes the transport of oxygen and sugar to the head. That is manifested as less blood supply and reduced local blood pressure. As there is very little stored oxygen and sugar in the head (as opposed to muscles, which have some storage capacity), the reduced blood supply can cause an immediate effect.

The first to notice anything is the eyes. As the eyeballs must remain balls—as opposed to being squashed by surrounding tissue—they are inflated to positive internal pressure (they feel hard to the touch.) A side-effect of this necessary condition is that blood flow to the eyes, and the oxygen and sugar supply it carries, is inhibited. It's an uphill slope.

If g-force is reducing the blood pressure in the head, then the eyes will be affected first because of this pressure gradient. The supply of oxygen and sugar is necessary to process sight signals. As g increases, sight becomes affected, with color vision the first to go. If you are not used to high load factors, this stage of the phenomenon might occur at +3.5 to +4.5g. It is called *grayout*. All images are seen as shades of gray and white.

If the g keeps building, the field of view will begin to shrink, starting from the sides. This limiting vision effect is called tunnel vision. Still increasing g-forces will lead to total loss of vision, or blackout. At this point, the pilot is temporarily blind, though still conscious. Further g increase will inevitably lead to insufficient oxygen and sugar supply to keep the brain functioning—loss of consciousness.

So far, we have only talked about positive g—the plane is the right way up. If the aircraft is inverted, the effect of negative g is not only uncomfortable, it is potentially dangerous. It's one thing for large amounts of blood under higher pressure to be accumulating in the legs and lower abdomen, surrounded by tough and flexible muscle. To have that happening in the head around all that delicate machinery is another thing altogether.

Most pilots, once they have accommodated to aerobatic maneuvering, can withstand up to negative 2.5g. If, however, you push beyond that, you will encounter the phenomenon called *redout*. When you red out, the impression is of total loss of sight, because a red veil is in the way. The reason for it is that your lower eyelid muscles have evolved to match the human bodies needs. As we mostly stand erect, blinking requires the lower eyelid to move only upward. Gravity will organize the return journey. There is no corresponding muscle group to "unblink" the lower eyelid. So if you are inverted, and push to a certain negative g limit, the lower eyelid will drop, covering the pupil, and you cannot force it out of the way.

Many pilots will never experience any of these g-related phenomena. However, some will go on to learn aerobatic maneuvers, or to fly military jets capable of high g-forces in turns and maneuvering. For those who do, there is an especially insidious potential trap: *g-induced loss of consciousness* or *g-loc*.

We saw earlier how positive g-force brings on a sequence of sight-related changes before getting to the point of unconsciousness—grayout, tunnel vision, blackout. As all of these occur while conscious, they can be controlled and relieved. Relaxing the back pressure on the controls will bring nearly instantaneous relief from the degraded sight condition. Indeed, in the case of blackout, the reaction to diminish the g-force by easing the control forces is nearly reflexive. However, g-loc occurs with high rates of onset of g where the warning symptoms are overruled.

As the graph in figure 2-39 shows, the grayout to blackout phenomena acts as a threshold or warning of unconsciousness. It enables forewarning and the chance to reduce the control pressure. There is appreciable delay before the effects are felt and therefore time to return to normal. That is what happens at the normal rate of g onset.

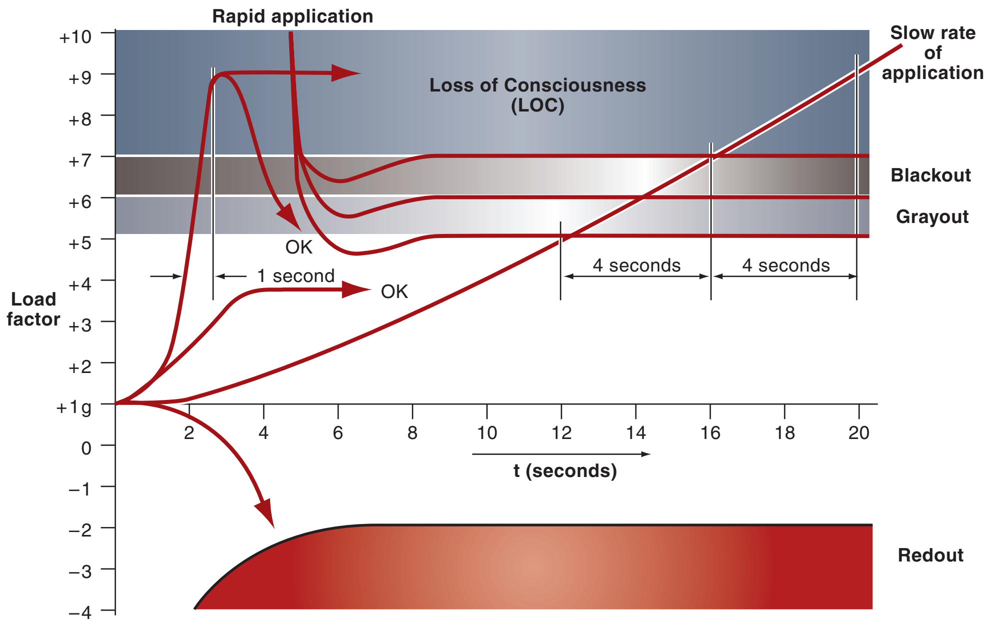


Figure 2-39 Physical response to load factor.

If, however, the rate of onset of g is rapid, the warning signals of degraded sight will be bypassed. The pilot will become instantly unconscious. If you blackout, you will, intuitively relax the control pressure to reduce the g, and immediately regain full sight and you remain conscious throughout. However, if you lose consciousness, it takes at least 15 seconds to recover. Loss of consciousness is a debilitating experience. Think of the last time you saw someone faint: recall how disoriented and incapable they were during the ensuing period. Momentary loss of consciousness in an aircraft can never be safe. Being out of control for 15 seconds will often prove fatal. However, only aerobatic aircraft have the structure and control power for flight capable of causing g-loc.

Coping With High Load Factors

Your personal resistance to g-forces is highest not only if you are physically fit but also toughened—hardened by regular exposure. Serious exercise is a good idea for all pilots, but it is especially so for those who want to be good at aerobatics. On the other hand, no matter how fit you are, there will be times in your life (or day) when your resistance levels are down, like when recovering from illness, tired after a long day, under domestic stress or suffering work problems.

A-loc

Another term that has been recently coined is *a-loc.* A-loc is *almost* loss of consciousness due to g. The reason for the differentiation is that, even if the pilot does not lose consciousness, there is a temporary period of confusion and even euphoria, where the pilot either does not recognize, or does not care about, the seriousness of the situation. It is momentary, but it is believed to have caused some otherwise unexplained pilot lack-of-response during recovery from high-g maneuvers.

Review 2
The Human in the Cockpit

Am I Fit to Fly?

1. You have consumed a small amount of alcohol. You should not fly for at least how many hours?
2. What is Hypothermia?
3. The FAA prescribes a method for evaluating risk and reducing stress. What is it?
4. List at least two ways you can keep your stress levels down when planning a flight or during a flight.

Respiration

5. What is hypoxia?
6. What is hyperventilation?
7. What effect does hyperventilation have on the body?
8. What is the main cause of hyperventilation?
9. Name a common symptom of hyperventilation.
10. Why is a faulty exhaust system potentially dangerous?
11. Susceptibility to carbon monoxide poisoning increases as:
- **a.** air pressure increases.
- **b.** altitude decreases.
- **c.** altitude increases.

Balance

12. What is spatial disorientation?
13. What should you rely on in order to interpret airplane attitude in poor visibility conditions?
14. To best overcome the effects of spatial disorientation, a pilot should:
- **a.** rely on body sensations.
- **b.** increase the breathing rate.
- **c.** rely on aircraft instrument indications.

Vision

15. The retina contains rods and cones. Describe where each are located in the eye.
16. True or false? Cones are most effective at night.
17. Are rods color-sensitive?
18. What is your peripheral vision provided by?
19. What is the most effective method of scanning for other aircraft in daylight?
20. True or false? In daylight, other aircraft are most clearly seen in your central vision.
21. Another aircraft remains in view in the same position in your windshield. Is there a possibility that you are on a collision course?
22. True or false? At night, other aircraft are most clearly seen in your central vision.
23. The most effective method of scanning for other aircraft for collision avoidance during nighttime hours is to use:
- **a.** regularly spaced concentration on the 3, 9, and 12 o'clock positions.
- **b.** a series of short, regularly spaced eye movements to search each 30° sector.
- **c.** peripheral vision by slowly scanning small sectors and utilizing off-center viewing.

24. How can you determine if another aircraft is on a collision course with your aircraft?
25. Is it possible for other objects to be closer than they appear to be in hazy conditions?
26. If you are exposed to bright lights prior to flight, how long is it recommended you wait before undertaking a night flight?
27. During a night flight, you observe a steady red light and a flashing red light ahead and at the same altitude. What is the general direction of movement of the other aircraft?
28. What illusion can an upward sloping runway give?
29. What illusion can a narrow runway give?

Answers are given on page 763.

Aviation Regulations 3

Chapter 14 of the Code of Federal Regulations (14 CFR) is designed to regulate aviation and to keep flying safe and efficient. These regulations are almost always universally called the Federal Aviation Regulations (or FARs), although this is not the proper term. This chapter is a sample of paraphrased and abbreviated regulations relevant to private and instrument pilots.

As a pilot, it is your responsibility to comply with all regulations, even though many of the details you encounter will be fairly complex. Therefore, this discussion is intended to introduce you, the beginning aviator to the intricacies of FARS in a context more easily understandable. As you begin flying you should study and use the actual regulations. As a responsible pilot you should have in your personal library a copy of the current 14 CFR and the Aeronautical Information Manual (AIM), obtainable from the FAA and most pilot shops. These are the official documents on which aviation is based and they are updated continuously. Study these documents in conjunction with this chapter.

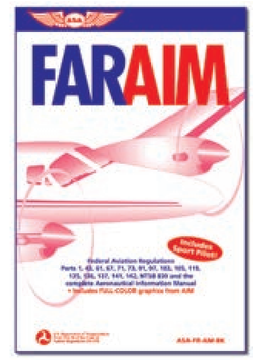


Figure 3-1
Example of FAR/AIM book.

Definitions and Terminology

To ensure that all aviators speak the same technical language it is necessary to define certain terms, such as aircraft, night and operator. Part 1.1 is where you'll find legal definitions of aviation terminology applicable to Chapter 14 of the CFR. Some terms have expanded definition and those definitions are applicable to a particular subpart of the regulations. In other words, some words may mean more than one thing, depending upon which part of the rules you are applying. You will see an example of this in the discussion of "night" for different purposes. Other commonly used aviation terms such as *above ground level*, or *instrument landing system*, are abbreviated. Part 1.2 defines these abbreviations.

Some useful definitions from Part 1.1 are outlined below. Some of these definitions are not in Part 1.1:

- *Night* is the time from the end of evening civil twilight and through the hours of darkness until the beginning of morning civil twilight. As you know, darkness does not descend immediately at sunset, but rather after a period of twilight. Similarly, there is a period of twilight in the morning before the sun can actually be seen.
- An *air traffic clearance* means an authorization by air traffic control (ATC) for the purpose of preventing a collision between known aircraft and to proceed under specified traffic conditions in Class A, B, C, D or E airspace.
- An *authorized instructor* is an instructor who has a valid ground instructor certificate or current flight instructor certificate with appropriate ratings issued by the administrator or any other person authorized by the administrator to give instruction.
- An *airplane flight simulator* is a device that is a full-sized airplane cockpit replica of a specific type of airplane or make, model, and series of airplane. It includes the hardware and software necessary to represent the airplane in ground and flight operations, including a force cueing system (motion sensations) and a visual cueing system. The simulator must be evaluated, qualified and approved by the administrator.

- A *flight training device* is a full-sized replica of instruments, equipment, panels and controls of an airplane or rotorcraft in an open flight deck area or an enclosed cockpit. It includes the hardware and software necessary to simulate the airplane or rotorcraft in ground and flight operations, but it does not have a force cueing system or a visual cueing system. It must be evaluated, qualified and approved by the administrator.
- A *PCATD* is a flight training device that combines a personal computer and flight simulation software, along with appropriate hardware necessary to simulate an airplane in ground and flight operations. Some visual cues may be available although no force cues are necessary. PCATDs may be used in lieu of and for not more than 10 hours of time which ordinarily may be acquired in a flight simulator or flight training device that is authorized for use under Part 61 or Part 141 towards an initial instrument rating. The FAA has not authorized the use of PCATDs for conducting practical tests or for the purpose of accomplishing the recent flight experience requirements. The device must be approved by the administrator.

If you intend to log simulator or flight training device time as part of the time required for a certificate or rating, or as time required for maintaining your currency and proficiency, be sure you do so on a piece of equipment that has been approved by the Administrator.

Abbreviations and Symbols

There are various airspeeds that are important when flying. Some target airspeeds to provide best performance. Others limit airspeeds to protect the airplane's structural integrity. Many of these airspeeds are symbolized as *V-speeds.* These are found in Part 1.2. Some examples are given in figure 3-2.

V_S	Stall speed or minimum steady flight speed at which the airplane is controllable.
V_{SO}	Stall speed or minimum steady flight speed in the landing configuration. (An easy way to remember this is to think of the "0" as "flaps Out").
V_{S1}	Stall speed or minimum steady flight speed in a specific configuration (for instance, flaps up and landing gear retracted).
V_{NO}	Maximum structural cruise speed (marked by intersection of green and yellow arcs on airspeed indicator).
V_{NE}	Never-exceed speed (red line on airspeed indicator).
V_{FE}	Maximum flap extended speed (high-speed end of the white arc on airspeed indicator).
V_F	Design flap speed.
V_{LO}	Maximum landing-gear operating speed.
V_{LE}	Maximum landing-gear extended speed (faster than V_{LO} in some airplanes becaus e of the greater structural strength once the gear is lowered).
V_X	Speed for best angle of climb (used to clear obstacles by achieving the steepest possible climb-out gradient).
V_Y	The speed for best rate of climb (used to gain altitude as quickly as possible).

Figure 3-2 V speeds.

Rules for Pilots: Pilot Certification

Certificates and Ratings

Pilot certificates that may be issued include:

- Student pilot
- Sport pilot
- Recreational pilot
- Private pilot
- Commercial pilot
- Airline transport pilot

A *flight instructor* and *ground instructor certificate* may also be issued. *Ratings* may be placed on pilot and flight instructor certificates as:

- An aircraft category rating (airplane, rotorcraft, glider, lighter-than-air, powered-lift)
- An airplane class rating (SEL, MEL, SES, MES); a rotorcraft class rating; or a lighter-than-air class rating
- An aircraft type rating for advanced and/or large aircraft—examples: a B757 (Boeing 757) type rating; a CE500 (Cessna Citation) type rating
- An instrument rating

Pilot Qualifications

Requirements for Certificates, Ratings and Authorizations

To operate as pilot-in-command under instrument flight rules (IFR) or in weather conditions less than the minimums prescribed for VFR flight, you are required to hold an *instrument rating*. Since an IFR clearance is required to operate in Class A airspace, you must hold an instrument rating to do this.

Upon request from the FAA Administrator, an authorized representative of the National Transportation Safety Board (NTSB) or any federal, state or local law enforcement officer, you must present your pilot certificate for inspection.

Category and *class* are two terms that you will often hear, but they have different meanings depending on whether they are being used in reference to airmen (pilot certificates, ratings, privileges, and limitations) or in reference to the certification of aircraft.

Category

Category, when used for *pilot* qualification purposes (certification of airmen), is a broad classification of aircraft into families such as:

- Airplane (fixed-wing and heavier-than-air)
- Rotorcraft (heavier-than-air and supported by rotor-generated lift. For example, helicopters and gyroplanes)
- Glider (heavier-than-air and not depending on an engine)
- Lighter-than-air (airships and balloons supported by a gas weighing less than air)
- Powered-lift (such as a tilt rotor)

Class

Class, when used for *pilot* qualification purposes, is a further classification of aircraft within a category having similar operating characteristics. Examples of *airplane* class ratings (Part 61.5) that may be earned and placed on a pilot certificate are:

- Single-engine land (SEL)
- Multi-engine land (MEL)
- Single-engine sea (SES)
- Multi-engine sea (MES)

General Limitations

Unless you hold a *category and class rating* for that aircraft, you may not act as pilot-in-command of an aircraft that is carrying another person or is operated for compensation or hire. An exception is when you are taking a practical test with an examiner or when you hold a logbook or certificate endorsement for solo operations in training for a rating and you are supervised by an authorized instructor.

No person may act as pilot-in-command of a *tailwheel airplane* unless that person has received and logged flight training from an authorized instructor in a tailwheel airplane and has received a recorded logbook endorsement from an authorized instructor who found the person proficient in the operation of a tailwheel airplane. The flight training must include at least the following maneuvers and procedures:

- Normal and crosswind takeoffs and landings
- Wheel landings (unless the manufacturer has recommended against such landings)
- Go-around procedures

If you hold a private or commercial pilot certificate then, to act as pilot-in-command of a *high performance airplane,* you must receive and log ground and flight training from an authorized flight instructor who certifies (endorses) in your logbook that you are proficient to fly airplanes with an engine of more than 200 horsepower. To act as pilot-in-command of a *complex airplane*, you must receive and log ground and flight training from an authorized flight instructor who certifies in your logbook that you are proficient to fly airplanes with retractable landing gear, flaps, and a controllable propeller.

To act as pilot-in-command of a *pressurized airplane*, you must receive and log flight training from an authorized flight instructor in normal cruise flight operations while operating above 25,000 feet MSL; proper emergency procedures for simulated rapid decompression without actually depressurizing the aircraft; and emergency descent procedures. The ground training must include at least the following subjects:

- High-altitude aerodynamics and meteorology
- Respiration
- Effects, symptoms, and causes of hypoxia and any other high-altitude sickness
- Duration of consciousness without supplemental oxygen
- Effects of prolonged usage of supplemental oxygen
- Causes and effects of gas expansion and gas bubble formation
- Preventive measures for eliminating gas expansion, gas bubble formation, and high-altitude sickness
- Physical phenomena and incidents of decompression
- Any other physiological aspects of high-altitude flight

You must hold a specific *type rating* to act as pilot-in-command of:

- A large aircraft (more than 12,500 pounds certificated takeoff weight, other than lighter-than-air)
- A helicopter for operations requiring an airline transport pilot certificate
- A turbojet-powered airplane

Glider Towing

To act as pilot-in-command of an aircraft towing a glider, you must:

You must be properly qualified to tow gliders.

- Hold a private pilot certificate or higher with a powered aircraft category rating
- Have an endorsement in your logbook from an authorized instructor certifying that you:
  - Have received ground and flight instruction in gliders
  - Are proficient in the techniques and procedures essential to the safe towing of gliders
- Have logged at least three flights as the sole manipulator of the controls of an aircraft towing a glider or simulating glider-towing flight procedures while accompanied by a suitably qualified pilot
- Have logged at least 100 hours of pilot-in-command time in the aircraft category, class, and type that the pilot is using to tow a glider
- Within the preceding 12 months made at least three actual or simulated glider tows while being accompanied by a qualified pilot or have made at least three flights as pilot-in-command of a glider towed by an aircraft

Private Pilot Privileges and Limitations

A private pilot may not act as pilot-in-command of an aircraft that is carrying passengers or property for compensation or hire, nor may he or she be hired or compensated to act as pilot-in-command of any aircraft. But a private pilot may share operating expenses with a passenger, although he or she may not pay less than the *pro rata* (equal) share of the operating expenses of the flight. The expenses shared may involve only fuel, oil, airport expenditures, or rental fees. A private pilot can carry passengers on business trips if the flight is only incidental to that business or employment. A private pilot who is an aircraft salesman and who has at least 200 hours of logged flight time may demonstrate an aircraft in flight to a prospective buyer.

Under certain strict constraints, including FAA notification and a donation to the charitable organization concerned, a private pilot who has logged at least 200 hours may carry paying passengers on an airlift for a charitable organization.

Required Pilot Documents

Requirements Regarding Pilot and Medical Certificates

To act as pilot-in-command (or as a required pilot flight crew member), you must have in your personal possession or readily accessible in the aircraft a current pilot certificate issued under Part 61, a current medical certificate issued under Part 67, and a photo ID. You are required to present your pilot or flight instructor certificate and medical certificate for inspection on the request of the FAA Administrator or representative, an authorized representative of the Safety Board (NTSB), or law enforcement officer.

Pilot and Flight Instructor Certificates Duration

The student pilot certificate and flight instructor certificate both expire at the end of the 24th month after the month in which they were issued or renewed. All other pilot certificates do not have a specific expiration date.

The student pilot certificate is valid for 2 years to the end of the month.

The medical certificate for a Private Pilot Certificate lasts for 5 years to the end of the month for pilots less than 40 years old.

Higher class medical certificates can be used as a lower class after expiration of the certificate for its original level of authority; i.e. after 12 months, a 2nd class certificate can be used as a 3rd class certificate.

Duration of Medical Certificates

A third-class (or higher) medical certificate, which is required for operations requiring a private, recreational, or student pilot certificate expires at the end of the 60th month after the month of the date of examination shown on the certificate if the holder is less than 40 years old on the date of the examination. If the pilot is age 40 or above, on the date of the examination, the certificate is valid for 24 months.

A second-class (or higher) medical certificate, which is required for operations requiring a commercial pilot certificate, expires at the end of the 12th month after the month of the date of examination shown on the certificate. A first-class medical certificate, required for Airline Transport Pilots, expires at the end of the 12th month after the month of the examination shown on the certificate if the holder is less than 40 years old on the date of the examination. If the pilot is age 40 or above, on the date of the examination, the certificate is valid for six months.

Change of Address

Unless you notify the FAA Airman Certification Branch in Oklahoma City in writing of any change to your permanent mailing address, you may not exercise the privileges of your pilot certificate after 30 days from the date you moved.

Pilot Logbooks—General

Part 61 of the Regulations instructs pilots on how to log flight time. Flight time begins when an aircraft moves under its own power for the purpose of flight and ends when the aircraft comes to rest after landing.

Figure 3-3 Pilot logbook.

The aeronautical training and experience used to meet the requirements for a certificate or rating or the recent flight experience requirements must be logged. The *pilot-in-command* has final authority and responsibility for the operation and safety of the flight; has been designated as pilot-in-command before or during the flight; and holds the appropriate category, class, and type rating, if appropriate, for the conduct of the flight.

You may log as *pilot-in-command* only that flight time during which you are:

- The sole manipulator of the controls of an aircraft on which you are rated
- Flying solo
- When acting as pilot-in-command of an aircraft requiring more than one pilot

You may log as *second in command* time all flight time during which you act as second-in-command of an aircraft requiring more than one pilot. You may log *solo time* only when you are the sole occupant of the aircraft. All time logged as instructional must be certified by the authorized instructor from whom it was received.

All instrument approaches logged must include the place and type of approach completed, whether conditions were simulated or actual, and in the case of simulated conditions, the name of the safety pilot. When a flight simulator or flight training device is used, the type of device should be logged.

Pilot Logbooks—Specific

The aeronautical training and experience to meet the requirements for a certificate or rating, or the recent flight experience requirements must be shown by a reliable record. The logging of other flight time is not required.

A pilot may log as *instrument flight* time only that time during which the pilot operates the aircraft solely by reference to instruments under actual or simulated instrument flight conditions. Each entry must include:

- Total time of flight or flight lesson
- The place or points of departure and arrival (except for simulated flight)
- Type and identification of aircraft, flight simulator, or flight training device
- Type of pilot experience or training
- Pilot-in-command or solo
- Second in command
- Flight instruction received from an authorized flight instructor
- Instrument flight instruction from an authorized flight instructor
- Pilot ground trainer instruction
- Participating crew (for lighter than air aircraft)
- Other pilot time
- Instruction in a flight simulator or in a flight training device
- Conditions of flight
- Day or night
- Actual instrument time
- Simulated instrument conditions in actual flight, in a flight simulator or a flight training device
- The place and type of each instrument approach completed
- The name of the safety pilot for each simulated instrument flight conducted
- An instrument flight instructor may log as instrument time that time during which the pilot acts as instrument flight instructor in actual instrument weather conditions
- All time logged as instruction must be certified by the authorized instructor from which it was received

Flight Simulators and Flight Training Devices

If you intend to log simulator or flight training device time for the purposes of a rating or currency, the training device or simulator must be qualified and approved by the administrator.

Flight Instruction, Simulated Instrument Flight and Certain Flight Tests

To operate in simulated instrument flight (under the hood), you must have a *safety pilot* occupying the other control seat. The safety pilot must possess at least a private pilot certificate with category and class ratings appropriate to the aircraft being flown. The safety pilot must have adequate vision forward and to either side of the aircraft or vision must be complemented by another competent observer in the aircraft. Additionally, the aircraft must be equipped with functioning dual controls, however the safety pilot is permitted to make a determination that a single, throw-over control is adequate provided certain conditions are met.

Part 142 Schools

If the flight school at which you're training uses flight simulators and flight training devices extensively for both pilot training and for checkrides, the odds are that you are training at a school governed by 14 CFR Part 142 rules. Schools that operate under these rules can use simulators and flight training devices extensively in their syllabi and can certify pilots for private, instrument and commercial ratings in less flight time than schools operating under 14 CFR Part 61 or 14 CFR Part 141. The rules are geared toward hi-tech pilot training programs using standardized training. Most Part 142 facilities train airline and corporate turbojet and turboprop pilots.

Currency Requirements: Am I Qualified to Fly VFR, IFR or at Night?

Recent Flight Experience: Pilot-in-command

To carry passengers by day, you must have made three takeoffs and three landings within the preceding 90 days in an aircraft of the same *category* and *class* (or *type* if a type rating is required). For tailwheel airplanes, the landings must be to a full stop (because steering "taildraggers" on the ground is more difficult compared with steering nosewheel aircraft).

To carry passengers *at night*, you must have made three takeoffs and three landings to a full stop in the hours between one hour after sunset to one hour before sunrise within the preceding 90 days in an aircraft of the same category, class, and, if required, type. Note that for *recency of experience* the definition of night is different to that in Part 1.1 of the Regulations. The requirement for three *full-stop* landings at night applies to both nosewheel and tailwheel airplanes. The takeoffs and landings may be performed in an approved simulator at a Part 142 training facility.

Night Experience

If you intend to carry passengers at night, you must have made at least three takeoffs and three landings to a full-stop at night as the sole manipulator of the flight controls in an aircraft in the preceding 90 days in the category and class of aircraft to be used. The takeoffs and landings may be performed in an approved flight simulator at a Part 142 training facility.

Instrument Experience

To act as pilot-in-command under IFR, or in weather conditions less than the minimums prescribed for VFR you must have, within the previous six calendar months, logged at least six instrument approaches under actual or simulated IFR conditions, as well as holding patterns and tracking and intercepting through the use of navigation systems. The approaches may have been in either an aircraft or a simulator.

If you run out of IFR-currency, you have six calendar months thereafter to achieve the above requirements in order to regain your IFR privileges. For instance, suppose you logged six approaches and one holding pattern on January 1, and then navigation and tracking on July 7. You would be instrument-current until July 31. At any time in the next six calendar months following July 7 (until the end of January), you could regain instrument currency by adding to the navigation on July 7 with holding and six approaches. This would keep you instrument-current until January 31. Keep in mind you must always look at the last six calendar months to ensure your instrument currency.

If the above conditions cannot be met an alternative way to remain current for IFR is to pass an *instrument proficiency check* (IPC) in the category of aircraft involved. This will be conducted by an FAA inspector, an FAA-designated examiner, or a certificated instrument flight instructor (CFII). An instrument proficiency check qualifies you as current for IFR flight for the upcoming six months. You can, of course, submit yourself to an instrument proficiency check at any time.

Flight Review

To act as pilot-in-command, you must have, since the beginning of the 24th month prior to this flight, successfully completed, and have endorsements in your logbook for either:

Flight reviews and proficiency checks are valid for 2 years to the end of the month.

- A (biennial) flight review (consisting of at least one hour of flight instruction and one hour of ground instruction)
- A proficiency check for a pilot certificate or rating

The flight review lasts for two years to the end of the month. Instrument proficiency checks are valid for six months. Afterwards the pilot must meet currency requirements or receive another instrument proficiency check.

A flight simulator or flight training device may be used to meet the flight review or proficiency check requirements if:

- It has been approved for that purpose by the administrator (FAA)
- It is being used in accordance with an approved course conducted by a training center that operates under Part 142 of the Regulations
- It represents an aircraft or set of aircraft for which the pilot is rated

National Transportation Safety Board

The U.S. National Transportation Safety Board (NTSB) is charged with investigating aircraft accidents and incidents. The procedures that a pilot should use to report such matters are specified in document 49 CFR Part 830.

49 CFR Part 830

NTSB Part 830 covers rules pertaining to the notification and reporting of aircraft accidents or incidents and overdue aircraft, and preservation of aircraft wreckage, mail, cargo, and records. An *accident* involves the death or serious injury of a person or substantial damage to an aircraft between the time any person boards the aircraft with the intention of flight and the time they disembark. An *incident* is an occurrence other than an accident associated with the operation of an aircraft, which affects or could affect the safety of operations.

An accident must be reported immediately to the nearest NTSB field office, followed by a written report within 10 days. The following serious incidents must also be reported immediately, however a written report is only required on request from the NTSB:

- A flight control system malfunction or failure
- The inability of a required flight crewmember to perform normal flight duties as a result of injury or illness
- Failure of a turbine (jet) engine
- An in-flight fire
- An aircraft collision in flight
- Significant damage to other property by the aircraft operation
- An overdue airplane believed to have been involved in an accident (a written report is required after seven days if an overdue airplane is still missing).
- Prior to the time the NTSB (or its authorized representative) takes custody of aircraft wreckage, mail, cargo and records, it must not be disturbed or moved except to the extent necessary to remove persons injured or trapped, to protect the wreckage from further damage, or to protect the public from injury.

Rules for Aircraft and Aircraft Certification

Category

Category, when used for *aircraft* certification purposes is a grouping of aircraft based on *intended use* or *operating limitations*, such as:

- Transport
- Normal (all maneuvers except aerobatics and spins)
- Utility (normal category maneuvers plus limited aerobatics, including spins)
- Acrobatic
- Limited
- Restricted
- Provisional

For an airplane to be flown, it must have a current Airworthiness Certificate (except in certain abnormal situations). An Airworthiness Certificate, once issued, remains in force as long as any maintenance or alteration of the aircraft is performed as required by the Regulations (Part 21). An airplane should only be flown in the permitted maneuvers. For instance, a *utility category* airplane may fly all normal maneuvers plus limited acrobatics, including spins, but cannot fly acrobatic maneuvers such as loops and rolls (Part 23).

Class

Class, when used for *aircraft* certification purposes, is a broad grouping of aircraft having similar characteristics of propulsion, flight, or landing, such as:

- Airplane
- Balloon
- Rotorcraft
- Land plane
- Glider
- Seaplane
- Powered-lift

Required Aircraft Documents

Civil Aircraft Flight Manual, Marking, and Placard Requirements

You must operate within the limitations specified in the approved Flight Manual, on markings and placards, or as otherwise prescribed. Within the aircraft, there should be an approved Flight Manual or Pilot Operating Handbook (and this will include weight-and-balance information).

Note. The required documents can be remembered using the acronym AROW:

A	airworthiness certificate
R	registration certificate
O	operating limitations (Flight Manual, POH, placards, etc.)
W	weight-and-balance information (in the Flight Manual, POH, or separate)

Certificate of Airworthiness

When a new type or model of airplane is designed and built, the manufacturer applies for and, after suitable tests on the original test airplanes have been passed, is granted a Certificate of Type Approval. This document is issued to the manufacturer by the aviation authority in the country of manufacture (Federal Aviation Administration (FAA) in the United States).


UNITED STATES OF AMERICA
DEPARTMENT OF TRANSPORTATION—FEDERAL AVIATION ADMINISTRATION
STANDARD AIRWORTHINESS CERTIFICATE

1 NATIONALITY AND REGISTRATION MARKS	2 MANUFACTURER AND MODEL	3 AIRCRAFT SERIAL NUMBER	4 CATEGORY
N723BB	CIRRUS SR22	1298	NORMAL

5 AUTHORITY AND BASIS FOR ISSUANCE
This airworthiness certificate is issued pursuant to the [illegible] Act of [illegible] and certifies that, as of the date of issuance, the aircraft to which issued has been inspected and found to conform to the type certificate therefor, to be in condition for safe operation, and has been shown to meet the requirements of the applicable comprehensive and detailed airworthiness code as provided by Annex 8 to the Convention on International Civil Aviation, except as noted herein.
Exceptions:
NONE

6 TERMS AND CONDITIONS
Unless sooner surrendered, suspended, revoked, or a termination date is otherwise established by the Administrator, this airworthiness certificate is effective as long as the maintenance, preventative maintenance, and alterations are performed in accordance with Parts 21, 43, and [illegible] of the Federal Aviation Regulations, as appropriate, and the aircraft is registered in the United States.

DATE OF ISSUANCE	FAA REPRESENTATIVE	DESIGNATION NUMBER
February 3, 2005	Paul R. Sitko	DMIR-410373-CE

Any alteration, reproduction, or misuse of this certificate may be punishable by a fine not exceeding $1,000, or imprisonment not exceeding 3 years, or both. THIS CERTIFICATE MUST BE DISPLAYED IN THE AIRCRAFT IN ACCORDANCE WITH APPLICABLE FEDERAL AVIATION REGULATIONS.

FAA Form 8100-2 (8-82) U.S. GPO-2001 - 668-456

Figure 3-4 Certificate of Airworthiness.

Engineering and safety requirements, reliability and many other factors are considered in detail, and many inspections and flight tests are carried out prior to the issue of a Type Certificate. Once it is obtained, the manufacturer commences production and a new airplane type comes onto the market. The pilot does not see the Type Certificate, which is retained by the manufacturer.

The airworthiness requirements for airplanes are specified in the Federal Aviation Regulations. A large number of documents are involved in the airworthiness system, but those of most immediate importance to the individual pilot are the:

- Certificate of Registration (Part 91)
- Certificate of Airworthiness (Part 91
- Approved Flight Manual (Part 91)

The Certificate of Airworthiness is issued by the FAA for an individual airplane. This may be American or an American approval of a foreign certificate. The Certificate of Airworthiness is normally granted for an unlimited period—its validity being subject to regular inspections. In some cases, the Certificate of Airworthiness may be issued for only a specified period. It should be carried in the airplane and prominently displayed.

The Certificate of Airworthiness is issued by the FAA for an individual airplane to operate in a particular category, provided it complies with the appropriate airworthiness requirements. Categories and their authorized purposes include transport, experimental, normal, limited, utility, restricted, acrobatic, and provisional.

A private pilot is likely to fly airplanes in the following categories, which are defined in Part 23 of the Federal Aviation Regulations:

- *Normal category*—below 12,500 pounds and non-acrobatic maneuvers limited to stalls (but not whip stalls), lazy eights, chandelles and steep turns of 60°. Typical limit load factors are +3.8g and -1.52g

- *Utility category*—same as a normal category, plus limited acrobatics (aerobatics), which may include spins. Typical limit load factors are +4.4g and -1.76g. Note that some airplanes in the normal category may be allowed to operate in the utility category within certain specified weight-and-balance limits, usually with fuel/passenger restrictions
- *Aerobatic category*—airplanes in this category are fully aerobatic but may have some limitations based on flight test results. Typical limit load factors are +6.0g and -3.0g.

Never intentionally carry out inappropriate maneuvers for the category of your airplane as structural damage or destruction is a very real possibility. The Certificate of Airworthiness has other documents associated with it, in particular, the approved Flight Manual.

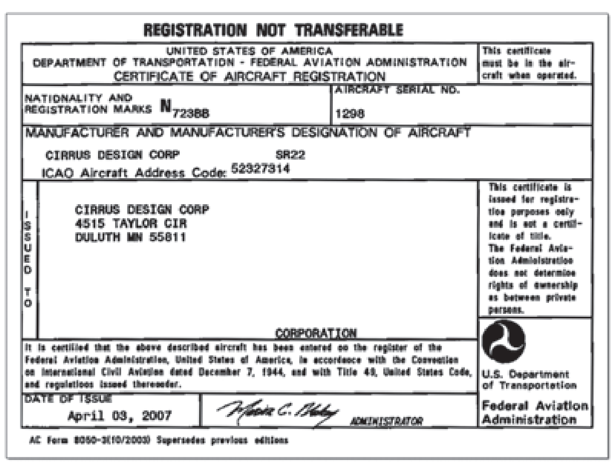
Civil Aircraft Airworthiness

The pilot-in-command is responsible for determining whether that aircraft is in condition for safe flight and should not operate an aircraft that is not in airworthy condition. As pilot-in-command, you are responsible for determining this. You should discontinue a flight when un-airworthy mechanical, structural or electrical conditions occur.

Certificate of Registration

The Federal Aviation Regulations require that an American-owned or operated airplane be on the Register of Aircraft. When this is done for an individual airplane, the FAA issues a Certificate of Registration to the owner. The airplane is given a registration number to follow the letter "N," which is the United States nationality marking. For example N4713P which must be displayed prominently on the airplane in specific sizes and positions. Examples of other aircraft nationality markings are: "D" for Germany (Deutschland), "F" for France and "G" for Great Britain.

The Certificate of Registration must be carried and prominently displayed in the airplane. Before flight it is important to verify the airplane is registered.



REGISTRATION NOT TRANSFERABLE

UNITED STATES OF AMERICA
DEPARTMENT OF TRANSPORTATION - FEDERAL AVIATION ADMINISTRATION
CERTIFICATE OF AIRCRAFT REGISTRATION

This certificate must be in the aircraft when operated.

NATIONALITY AND REGISTRATION MARKS N 723BB

AIRCRAFT SERIAL NO. 1298

MANUFACTURER AND MANUFACTURER'S DESIGNATION OF AIRCRAFT
CIRRUS DESIGN CORP SR22
ICAO Aircraft Address Code: 52327314

ISSUED TO
CIRRUS DESIGN CORP
4515 TAYLOR CIR
DULUTH MN 55811

CORPORATION

This certificate is issued for registration purposes only and is not a certificate of title. The Federal Aviation Administration does not determine rights of ownership as between private persons.

It is certified that the above described aircraft has been entered on the register of the Federal Aviation Administration, United States of America, in accordance with the Convention on International Civil Aviation dated December 7, 1944, and with Title 49, United States Code, and regulations issued thereunder.

DATE OF ISSUE April 03, 2007

ADMINISTRATOR

U.S. Department of Transportation
Federal Aviation Administration

AC Form 8050-3(10/2003) Supersedes previous editions

Figure 3-5 Certificate of Registration.

Approved Flight Manual (AFM)

The flight manual for each airplane must be approved by the FAA. The AFM comes in various forms, including the Pilot's Operating Handbook (POH) for modern airplanes, and the Owner's Manual for older aircraft. These documents must contain the latest valid information for the airplane.

The information in the flight manual is presented in a standard format as given in figure 3-6.

The pilot must comply with all of the requirements, procedures, and limitations with respect to the operation of the airplane as set out in its approved flight manual. Placards placed in the cockpit will often reflect the flight manual limitations and have the same status.

1.	General Section;
2.	Limitations Section;
3.	Emergency Procedures;
4.	Normal Procedures;
5.	Performance;
6.	Weight and Balance;
7.	Description and Operation of the Airplane and its Systems;
8.	Handling, Service and Maintenance; and
9.	Supplements (optional systems and equipment not provided with the standard airplane).

Figure 3-6
Sections of the Flight Manual.

Operating Limitations

Restricted Category Civil Aircraft

You may not operate a restricted category civil aircraft:

- For other than the special purpose for which it is certificated (for example, crop dusting, seeding, banner towing)
- To carry persons or property for compensation or hire
- Over a densely populated area
- In a congested airway
- Near a busy airport used by passengers

You may not ride in a restricted category aircraft unless you are a required crew member or crew member trainee, or your skills are specially required for that flight. Other limitations may also apply (see Part 91).

Experimental Aircraft Certificates

You may not operate an aircraft that has an experimental certificate:

- For other than the purpose for which the certificate was issued
- To carry persons or property for compensation or hire
- Over a densely populated area or in a congested airway unless authorized by the administrator

Pilots must advise their passengers with clearly displayed placarding that the aircraft they are riding in is experimental. Other limitations may also apply (see Part 91).

Primary Category Aircraft

No person may operate a primary category aircraft carrying persons or property for compensation or hire. You may not operate a primary category aircraft that is maintained by the pilot-owner under an approved special inspection and maintenance program unless you are the pilot-owner or a designee of the pilot-owner.

Limited Category Civil Aircraft

You may not operate a limited category civil aircraft to carry persons or property for compensation or hire.

Maintenance

The owner or operator of an airplane is responsible for maintaining it in an airworthy condition. Specific FAA requirements for maintenance may be found in Parts 91 and 43 of the Federal Aviation Regulations. Each owner or operator of an aircraft shall ensure that prescribed inspections and maintenance of Parts 91 and 43 are carried out. They should also ensure that maintenance personnel make appropriate entries in the aircraft maintenance records to indicate the aircraft has been approved for return to service.

Preventive Maintenance and Alterations (General)

The owner or operator of an aircraft is primarily responsible for maintaining that aircraft in an airworthy condition. Part 43 of the Regulations details what maintenance pilots may perform on their own aircraft.

Required Inspections

You may not operate an aircraft unless within the preceding 12 calendar months it has had either:

1. An annual inspection
2. An inspection for the issuance of an Airworthiness Certificate

As a general rule, you may not operate an aircraft carrying persons for hire or give flight instruction for hire unless within the preceding 100 hours the aircraft has received:

1. An annual inspection
2. An inspection for the issuance of an Airworthiness Certificate
3. a 100-hour inspection

The *annual inspection* is a requirement and is the normal inspection that is done during the life of the airplane following the initial airworthiness inspection. The annual inspection is more thorough than the 100-hour inspection and can replace it (but not vice versa). With FAA approval, a series of progressive checks through the year may replace the annual/100-hour inspections. People who own their own airplanes and operate them privately—and not for hire—typically do not have 100-hour inspections.

The 100-hour limitation may be exceeded by not more than 10 hours while en route to reach a place where the inspection can be done but this excess time must be included in computing the next 100 hours of service.

For example, if a 100-hour inspection is due when the tachometer reads 1,395.3, the next inspection is due at 1,495.3 hours. If the actual inspection is done at 1,497.3 hours (2 hours later than the due time) because of a three-hour flight to the place where the inspection was done, the next 100-hour inspection will still be due at 1,595.3 hours. The two hours overdue becomes part of the next 100 hours and the next 100-hour inspection is due 100 hours from the prior due time.

Annual inspections occur every 12 calendar months, so an aircraft that had an annual inspection performed on July 9 this year is due for another annual inspection no later than July 31 next year. Normally an Airworthiness Certificate remains in effect as long as the maintenance, preventive maintenance, and alterations are performed in accordance with the Regulations and are entered correctly in the maintenance records.

Maintenance Records

The owner or operator of an aircraft should keep records of:

- Maintenance, preventive maintenance and alterations
- 100-hour inspections, annual inspections, progressive inspections
- any other required or approved inspections

Preventive maintenance is defined in Part 1.1 as simple or minor preservation operations and the replacement of small standard parts not involving complex assembly operations. Preventive maintenance items that the *pilot* may perform are found in Part 43 and include such items as oil changes, replenishing hydraulic fluid, and servicing the landing gear wheel bearings. It does not include structural work on the airframe or major adjustments to the engine.

Maintenance records apply to each aircraft (including airframe), each engine, each propeller, rotor, and each appliance of the aircraft. The records must include:

- A description of the work performed and the date of completion
- The signature and certificate number of the person approving the aircraft for return to service
- Total time in service of the airframe, engine and propeller
- Current status of life-limited parts
- Time since last overhaul of all items requiring overhaul on a specified time basis
- Current inspection status including time since the last inspection required
- Current status of applicable Airworthiness Directives (ADs) which must be complied with for the aircraft to remain airworthy
- Copies of the forms prescribed by Part 43 for each major alteration

Rebuilt Engine Maintenance Records

An aircraft engine rebuilt by the manufacturer or its agent may have a new maintenance record (that is zero hours) without previous operating history, but it should specify the date of rebuilding and each change as required by Airworthiness Directives (ADs) and specified Service Bulletins.

Operations after Maintenance, Preventive Maintenance, Rebuilding or Alteration

After an aircraft has undergone maintenance, preventive maintenance, rebuilding or alteration for the Airworthiness Certificate to remain valid:

- Applicable maintenance record entries in the aircraft logbooks must be made
- The aircraft should not be operated until it has been approved for return to service by an authorized person
- If the flight characteristics or operation in flight have been altered appreciably passengers may not be carried until the aircraft is test flown satisfactorily by an appropriately rated pilot with at least a private pilot certificate

Additional Inspections

ATC Transponder Tests and Inspections

A transponder must have been tested and inspected satisfactorily within the preceding 24 calendar months. For example, if this is carried out on any day in November it is valid until the last day of November, two years to the end of the month.

Altimeter System and Altitude Reporting Equipment Tests and Inspections

To operate under IFR each static pressure system, each altimeter instrument, and each automatic pressure altitude reporting system must have been tested and inspected satisfactorily within the preceding 24 calendar months. You may not operate under IFR at an altitude above the maximum at which the systems were tested.

VOR Equipment Check for IFR Operations

To use the VOR under IFR, the aircraft's VOR receiving equipment must either:
- Be maintained, checked and inspected under an approved procedure
- Have been operationally checked within the preceding 30 days and found to be within the permissible limits. The accuracy for the VOR equipment is covered in Chapter 17 and is specified in this regulation.

Each person making an operational check of the VOR should enter in the aircraft log or other permanent record:
- Date
- Place
- Bearing error
- Signature

Malfunction Reports: Operation under IFR in Controlled Airspace

Any loss of navigation or air/ground communications capability must be reported immediately to ATC. This report should include:
- Aircraft identification
- Equipment affected
- Any impairment of IFR capability
- The nature and extent of ATC assistance desired

Portable Electronic Devices

Portable electronic devices which may cause interference with the navigation or communication system may not be operated on aircraft being flown in commercial operations. Items excluded from this include portable voice recorders, hearing aids, heart pacemakers and electric shavers.

Instrument and Equipment Requirements

Powered civil aircraft with a standard category United States airworthiness certificate must satisfy the following instrument and equipment requirements:

VFR by Day

- Airspeed indicator
- Altimeter
- Magnetic direction indicator (magnetic compass)
- Tachometer for each engine
- Oil pressure gauge for each engine using pressure system
- Temperature gauge for each liquid-cooled engine
- Oil temperature gauge for each air-cooled engine
- Manifold pressure gauge for each altitude engine
- Fuel gauge indicating the quantity of fuel in each tank
- Landing gear position indicator (for retractables)
- Approved flotation gear for each occupant, and at least one pyrotechnic signaling device (if aircraft is operated for hire over water beyond the power-off gliding distance from shore)
- Approved safety belts for all occupants two years or older
- Approved shoulder harness for each front seat (for small civil airplanes manufactured after July 18, 1978)

VFR by Night

As above, plus:

- Approved position lights
- An approved anti-collision light (aviation red or aviation white)
- At least one electric landing light (if the airplane is operated for hire)
- An adequate source of electrical energy for all installed electric and radio equipment
- One spare set of fuses or three spare fuses of each kind required

IFR

As above (for day or night flight as appropriate), plus:

- A two-way radio communications system and navigation equipment appropriate for ground facilities (including DME for all flights at and above 24,000 feet MSL within the 50 states and the District of Columbia for which VOR is required. These altitudes are within Class A airspace, and IFR operations are therefore required at all times).
- A gyroscopic rate-of-turn indicator (turn coordinator or turn-and-balance indicator)
- A slip-skid indicator (balance ball)
- A sensitive altimeter, adjustable for barometric pressure
- A clock displaying hours, minutes, and seconds with a sweep second pointer or digital presentation
- Gyroscopic bank and pitch indicator (attitude indicator or artificial horizon)
- Gyroscopic direction indicator (heading indicator)

Inoperative Instruments and Equipment

You may not take off in an aircraft with an inoperative instrument or inoperative equipment unless 14 CFR 91 permits it and unless the equipment is properly placarded as inoperative, any required maintenance is performed and that maintenance is recorded in the aircraft maintenance logs.

In general, flight is not permitted if the inoperative instrument or equipment is part of the VFR-day required instruments and equipment or for an IFR flight, part of the IFR-required instruments and or equipment. Under certain stringent conditions the FAA may issue a special flight permit.

Additional Equipment Needed in Certain Situations

Supplemental Oxygen

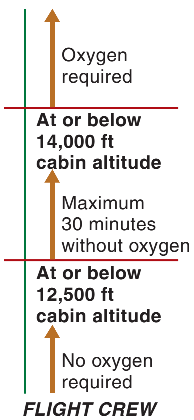


Figure 3-7
Oxygen requirements.

Crew oxygen requirements for operations under Part 91 Regulations:

- Crew members are not required to use oxygen up to a cabin pressure altitude of 12,500 feet MSL.
- At cabin pressure altitudes above 12,500 feet up to and including 14,000 feet. The required minimum flight crew may fly without supplemental oxygen for up to 30 minutes. Supplemental oxygen must be provided and used for at least the time in excess of 30 minutes at these cabin pressure altitudes.
- At cabin pressure altitudes above 14,000 feet, the required minimum flight crew must be provided with and use supplemental oxygen during the entire time at those cabin altitudes.

For passenger oxygen requirements, at cabin pressure altitudes above 15,000 feet, each occupant (flight crew and passengers) must be provided with supplemental oxygen.

ATC Transponder, Altitude Reporting Equipment and Use

A Mode C (Mode 3/A 4096 code capability, or the newer and more advanced Mode S) transponder is required to be turned on in all aircraft operating:

- In Class A airspace (at and above 18,000 feet MSL)
- In all airspace of the 48 contiguous states and the District of Columbia at and above 10,000 feet MSL, except at and below 2,500 feet AGL

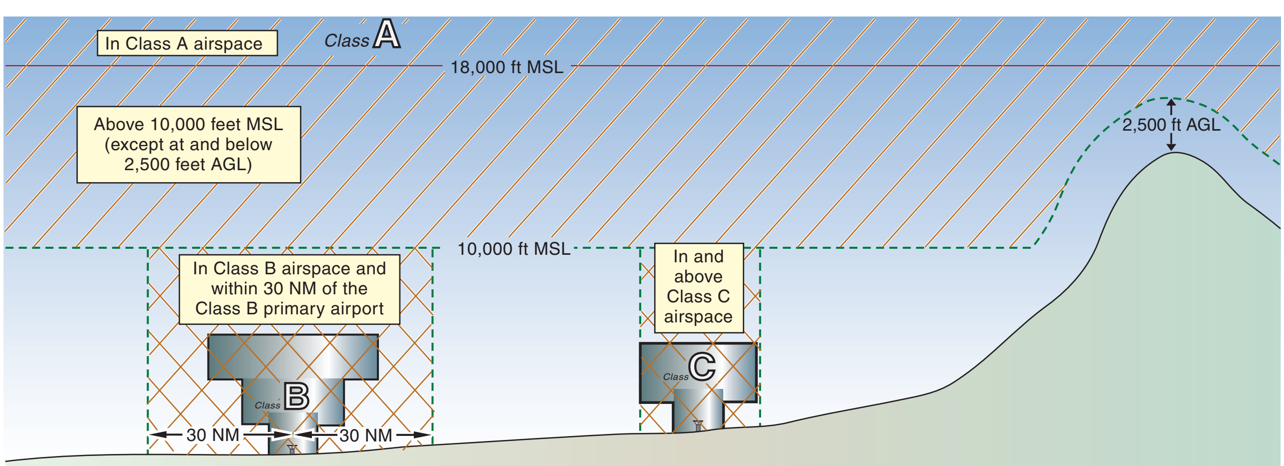


Figure 3-8 A transponder is required in the shaded airspace.

- In Class B airspace and within 30 nautical miles of any airport listed in Part 91, Appendix D, Section 1, from the surface up to 10,000 feet MSL (this list contains most major US airports — Class B airspace primary airports such as: Atlanta, Denver, Los Angeles, Miami, Minneapolis, both New York airports, San Francisco, St Louis, and both Washington airports)
- In Class C airspace, and above it to 10,000 feet MSL
- From the surface to 10,000 feet MSL within a 10 NM radius of any airport listed in Part 91, Appendix D, Section 2, except the airspace below 1,200 feet AGL that is outside the lateral boundaries of the surface area of the airspace designated for that airport.

A functioning Mode C or Mode S transponder is not required in Class D, E or G airspace unless one of the above applies For example, operating within 30 nautical miles of San Francisco International but outside of the Class B and C airspace areas. Exceptions to this transponder-equipment regulation are also listed in Part 91 and includes aircraft without original electrical systems, balloons and gliders in certain circumstances.

If your transponder fails in flight and you are, or will be operating in airspace where it is required equipment, you should notify ATC immediately. ATC may authorize deviation from the requirement to have an operating transponder to allow you to continue to the airport of your ultimate destination, including any intermediate stops, or to proceed to a place where suitable repairs can be made, or both. For a continuing waiver you should make a request to ATC at least one hour before the proposed flight.

Operations in Class B Airspace

To operate in Class B airspace, you require the following communications and navigation equipment:

- An operable VOR receiver (for IFR operations, but not required for VFR operations)
- An operable two-way radio capable of communications with ATC
- A Mode C (altitude-reporting) 4096 transponder. A new Mode S transponder is also acceptable.

Having satisfied the equipment requirements, you also require prior authorization from ATC to operate in Class B airspace (an ATC clearance).

Equipment Required for Practical Tests

You must supply an aircraft appropriate and qualified for the practical test you are about to take. For example, if the test is for a multi-engine rating, you must supply a multi-engine airplane for the test. If the test is for a commercial rating, the airplane used must be complex. If you are taking the test for an instrument rating be sure to arrive with a view limiting device. Required equipment for each practical test is listed in the Practical Test Standards for that rating or certificate.

Emergency Locator Transmitters

The batteries in an emergency locator transmitter (ELT) must be replaced or recharged when the ELT has been used for more than one cumulative hour or 50% of the battery's useful life. ELTs transmit an audible tone on the emergency frequencies 121.5 MHz and 243.0 MHz. A short ELT ground test should be conducted only in the first five minutes after any hour, and then for only three cycles. To check that an ELT has not been inadvertently activated for instance, by a hard landing, you should monitor the emergency frequency 121.5 MHz (see AIM for details). It is good airmanship to do this before normal engine shutdown at the conclusion of each flight.

Aircraft Lights

An aircraft operating on the ground or in flight between sunset and sunrise should have lighted *position lights* (sometimes called navigation lights). In Alaska, where twilight hours in summer can be long and bright the lighting requirements are different.

U.S.-registered civil aircraft must have an approved aviation red or aviation white anti-collision light system. If the anti-collision light system fails you may continue to a location where repairs or replacement can be made. The anti-collision lights need not be lit when the pilot-in-command determines that due to operating conditions it would be in the interest of safety to turn the lights off.

Parachutes and Parachuting

Each occupant of an aircraft must wear a parachute for maneuvers that exceed 60° bank angle or 30° nose-up or nose-down. Parachutes are not required for spin training with a flight instructor, designated examiner or Airline Transport pilot. Modern parachutes (including chair-types) carried for emergency use must have been packed by a certificated and appropriately rated parachute rigger within the preceding 120 days.

Towing: Other than Gliders

To tow anything other than a glider (for example, a banner) requires a *Certificate of Waiver* issued by the administrator of the FAA.

Rules for Flight: General Operating and Flight Rules

Responsibility and Authority of the Pilot-in-command

The pilot in command of an aircraft is directly responsible for that aircraft and has the final authority of its operation.

In the event of an in-flight emergency requiring immediate action, the pilot-in-command may deviate from the Regulations to the extent required to meet that emergency. On the request of the administrator (of the FAA), a written report of the deviation should be sent to the FAA.

Dropping Objects

No object should be dropped from an aircraft in flight which creates a hazard to persons or property. You may drop an object if reasonable precautions are taken to avoid injury or damage to persons or property.

Alcohol and Drugs

Alcohol and other drugs are not compatible with flying.

No person may act, or attempt to act, as a crewmember:

- Within 8 hours after the consumption of any alcoholic beverage
- While under the influence of alcohol
- While using any drug that affects their faculties in any way contrary to safety
- While having 0.04% by weight or more of alcohol in the blood

You may be asked by a law enforcement officer or by the administrator to submit to a blood alcohol test if they suspect you are intoxicated. Except in an emergency, a pilot may not allow an intoxicated person or a person under the influence of drugs (other than a medical patient under proper care) to be carried on that aircraft.

Preflight Action for VFR or IFR Flight

Before beginning a VFR flight each pilot-in-command should become familiar with all available information concerning that flight. This information must include:

- Runway lengths at the airports of intended use
- The airplane's takeoff and landing distance data for any flight not in the vicinity of an airport
- Weather reports and forecasts
- Fuel requirements
- Alternatives available if the planned flight cannot be completed
- Any known traffic delays

VFR Flight Plan—Information Required

Unless otherwise authorized by ATC, each person filing a VFR flight plan shall include the following information:

(1) The aircraft identification number and if necessary, its radio call sign.

(2) The type of aircraft or in the case of a formation flight, the type of each aircraft and the number of aircraft in the formation.

(3) The full name and address of the pilot in command or in the case of a formation flight, the formation commander.

(4) The point and proposed time of departure.

(5) The proposed route, cruising altitude (or flight level), and true airspeed at that altitude.

(6) The point of first intended landing and the estimated elapsed time until over that point.

(7) The amount of fuel on board (in hours).

(8) The number of persons in the aircraft, except where that information is otherwise readily available to the FAA.

(9) Any other information the pilot in command or ATC believes is necessary for ATC purposes.

(10) Cancellation. When a flight plan has been activated, the pilot in command, upon canceling or completing the flight under the flight plan, shall notify an FAA Flight Service Station or ATC facility.

IFR Flight Plan—Information Required

When filing an IFR Flight Plan, you must include all the information listed above that is required for a VFR Flight plan, plus include an *alternate airport* unless at the first airport of intended landing:

1. There is a prescribed standard instrument approach
2. For at least one hour before and one hour after the estimated time of arrival, the weather reports or forecasts or any combination of them indicate the ceiling will be at least 2,000 feet above the airport elevation and visibility will be at least three statute miles. (This is the 1-2-3 requirement to avoid naming an alternate.)

To be suitable as an alternate, the current weather forecasts must indicate that at the estimated time of arrival at the alternate airport the ceiling and visibility will be at or above the following alternate airport weather minimums:

1. If an instrument approach procedure has been published for the proposed alternate airport:

The alternate airport minimums specified in the instrument approach procedure for that alternate airport; or if no alternate airport minimums are so specified, the following minimums:

i. precision approach procedure (ILS): ceiling 600 feet, visibility 2 statute miles
ii. non-precision approach procedure: ceiling 800 feet, visibility 2 statute miles

2. If no instrument approach procedure has been published for the proposed alternate airport, the ceiling and visibility minimums are those allowing descent from the minimum en route altitude (MEA), approach and landing, all under basic VFR.

Note. *Alternate minimums* listed above are those required to be met for you to select the airport as a suitable alternate airport. These alternate minimums are significantly better conditions than the *landing minimums* so you should be able to approach and land at the alternate even if conditions deteriorate a little below the alternate minimums while you are en route. Having selected it as alternate, and then diverted to it, you may make an approach and landing at the alternate airport provided the landing minimums for the approach to be used are met.

ATC Clearance and Flight Plan Required

To operate in controlled airspace under IFR you must (1) file an IFR flight plan; and (2) receive an appropriate ATC clearance.

Fuel Requirements for Flight in VFR Conditions

After considering wind and forecast weather conditions, you must ensure that there is enough fuel to fly to the first point of intended landing plus sufficient reserve fuel to fly for an additional 30 minutes by day, or 45 minutes at night at normal cruise speed.

Fuel Requirements for Flight in IFR Conditions

The fuel required to operate in IFR conditions must be sufficient to:

1. Complete the flight to the airport of first intended landing
2. Fly from that airport to the alternate airport (see below)
3. Fly after that for 45 minutes at normal cruising speed

Item 2 does not apply if the first airport of intended landing has a standard instrument approach procedure, and for at least one hour before and one hour after the estimated time of arrival the weather reports and/or forecasts indicate:

- The ceiling will be at least 2,000 feet above the airport elevation
- Visibility will be at least three statute miles

This can be remembered as 1-2-3: ETA ±1 hour, 2,000 feet, three miles. Additional fuel should also be carried for any known traffic delays.

Weather Minimums

Basic VFR

The basic weather minimums required for you to fly VFR are stated in terms of flight visibility and distance from clouds (horizontally and vertically). For VFR operations within Class B, C, D and E surface areas around airports with an operating control tower, you require:

- Cloud ceiling at least 1,000 feet AGL
- Ground visibility at least three statute miles (usually measured by ATC but, if not available, flight visibility at least three statute miles as estimated by the pilot)

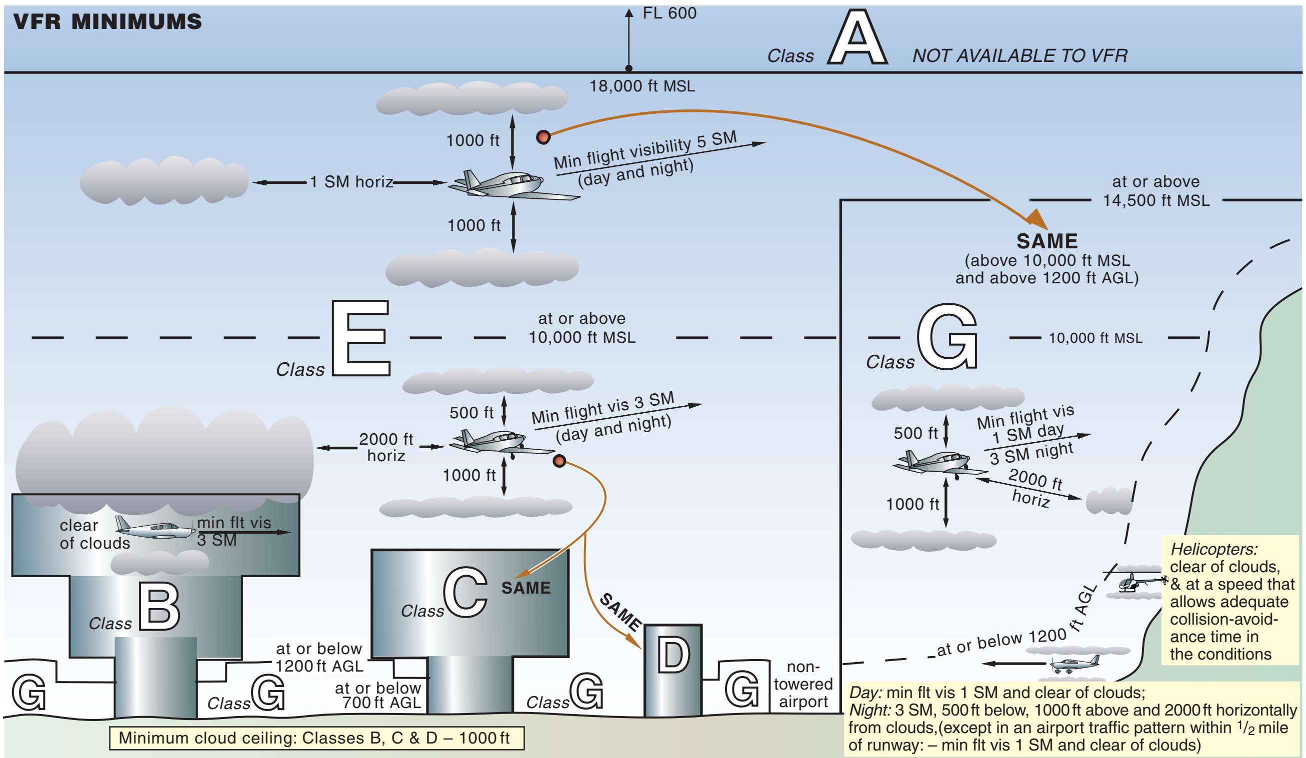


Figure 3-9 VFR weather minimums.

	Class A Airspace	Class B Airspace	Class C Airspace	Class D Airspace	Class E Airspace	Class G Airspace
VFR minimum visibility	Not applicable (IFR only)	3 statute miles	3 statute miles	3 statute miles	*3 statute miles	**1 statute mile
VFR minimum distance from clouds	Not applicable (IFR only)	Clear of clouds	500 feet below; 1,000 feet above; and 2,000 feet horizontal	500 feet below; 1,000 feet above; and 2,000 feet horizontal	*500 feet below; 1,000 feet above; and 2,000 feet horizontal	**500 feet below; 1,000 feet above; and 2,000 feet horizontal

**Different visibility minimums and distance from cloud requirements exist for operations above 10,000 feet MSL in Class E airspace.*

***Different visibility minimums and distance from cloud requirements exist for night operations, operations above 10,000 feet MSL, and operations below 1,200 feet AGL in Class G airspace.*

Figure 3-10
VFR weather minimums.

This can seem very confusing and not just to the beginning pilot. Yet it really is pretty simple for most general aviation pilots, because below 10,000 feet, the following rules comply with all airspace ceiling and visibility requirements. Maintain 3 SM visibility:

- 500 feet below clouds
- 1,000 feet above clouds
- At least 2,000 feet lateral separation from the clouds

The requirements are slightly less restrictive in Class G airspace, with a less-restrictive daytime visibility below 10,000 feet MSL (1 statute mile only) and below 1,200 feet AGL by day a less-restrictive separation from clouds (clear of clouds with no distance-from-cloud requirements).

In Class B airspace aircraft are required to remain clear of clouds. In Class C, D, E and at night, Class G airspace, aircraft are required to maintain a minimum distance of 1,000 feet above, 500 feet below and 2,000 feet horizontal from clouds. Also, in Class G airspace, when the visibility is less than three statute miles but not less than one statute mile during night hours, an airplane may be operated clear of clouds if operated in an airport traffic pattern within one-half mile of the runway.

Special VFR

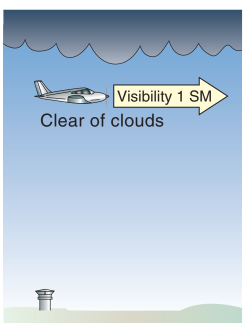


Figure 3-11
ATC may issue a special VFR clearance.

A pilot operating below 10,000 feet MSL in or above the airspace designated on the surface for an airport may be issued an ATC clearance to operate under special VFR, which reduces the normal requirements down to:

- Flight visibility one statute mile (and ground visibility 1 statute mile for takeoff and landing)
- Clear of clouds

To take off or land at any airport in Class B, C, D and E airspace under special VFR, the ground visibility at the airport must be at least one statute mile. If ground visibility is not reported then the flight visibility during takeoff or landing must be at least one statute mile. A non-instrument-rated pilot may be issued a special VFR clearance by day, but to operate under special VFR *at night*, he or she must be instrument-rated, instrument-current and flying in an IFR-equipped airplane.

Airports in Class B, C or D airspace have a control tower from which you can request a special VFR clearance. Airports in Class E airspace do not have a control tower, however your request for special VFR can be relayed via Flight Service Station to the ATC facility responsible for that Class E airspace (only ATC, and not a Flight Service Station, can issue an ATC clearance, although a Flight Service Station may relay it to you). Special VFR is prohibited at some airports (see 14 CFR, Part 91).

Flight Crewmembers at Stations

During takeoff and landing, and while en route, each required flight crewmember shall be at their station with the safety belt fastened. The shoulder harness should be fastened during takeoff and landing, but is not required en route.

Crew members are permitted to leave their stations to attend to other duties in connection with the operation of the aircraft or because of physiological needs.

Use of Safety Belts, Shoulder Harnesses, and Child Restraint Systems

The pilot must ensure that all persons on board are:

- Briefed on how to fasten and unfasten their safety belt and shoulder harness if fitted
- Notified that they must wear their safety belt and shoulder harness if fitted, during taxi, takeoff and landing
- Wearing their safety belt and shoulder harness if fitted, during taxi, takeoff and landing (except for infants under 2 years of age held on an adult's lap, parachutists sitting on the floor or someone aiding in floatplane operations on the water)
- Children under two years of age not held by an adult should be occupying an approved child restraint system (such restraint system are placarded as approved for aircraft use) and must be accompanied during the flight by a designated guardian adult.

Operating Near Other Aircraft

You must not operate an aircraft so close to another as to create a collision hazard. You must not operate an aircraft in formation flight except by arrangement with the pilot in command of each aircraft in the formation, and you must not carry passengers for hire when flying in formation.

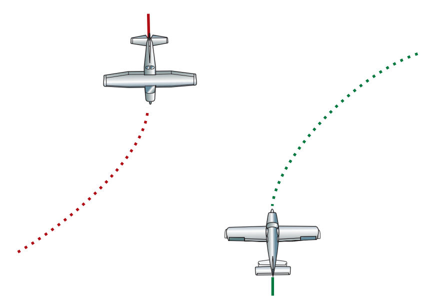


Figure 3-12
Approaching head-on, turn right.

Right-of-Way

Each person operating an aircraft should be vigilant so as to see and avoid other aircraft. If a rule gives another aircraft right-of-way, then you should give way to that aircraft and not pass over, under, or ahead of it unless:

- An aircraft in distress has right-of-way
- When aircraft are approaching head-on or nearly so, each shall turn right
- When two aircraft of different categories are converging at approximately the same altitude the more maneuverable aircraft must give way to the less-maneuverable in this order: airplanes or rotorcraft, airships, gliders, balloons

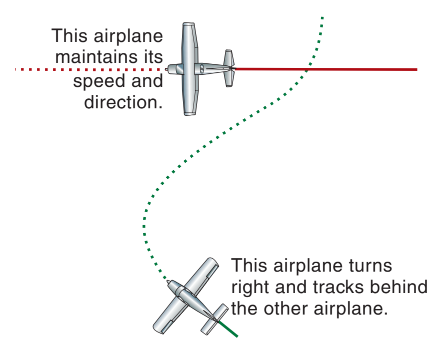


Figure 3-13
Give way to the right.

For instance, an airplane must give way to an airship, glider, or balloon. A glider must give way to a balloon, but has right-of-way over a powered airplane:

- When two aircraft of the same category are converging, the aircraft to the other's right has right-of-way. Airplanes and rotorcraft (for example, helicopters) are considered to be equally maneuverable and therefore have equal rights. An aircraft that is towing or refueling other aircraft has the right-of-way over all other engine-driven aircraft.
- An airplane being overtaken has right-of-way, and the overtaking airplane shall alter course to the right to pass
- An aircraft landing or on final approach to land has right-of-way over aircraft in flight or operating on the surface but it should not take advantage of this rule to force an aircraft that has just landed off

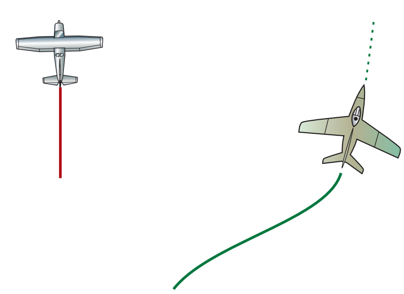


Figure 3-14
Overtaking, keep right.

the runway. If two aircraft are approaching an airport for the purpose of landing, the lower aircraft has right-of-way but it should not take advantage of this rule to cut in front of another aircraft on final approach to land or to overtake that aircraft.

Similar right-of-way rules apply to *water operations*, with seaplanes and vessels on crossing courses giving way to the right.

Aircraft Speed

Maximum indicated airspeed below 10,000 feet MSL is 250 KIAS or 288 mph (unless otherwise authorized). This speed also applies in Class B airspace. Maximum indicated airspeed at or below 2,500 feet AGL within four nautical miles of the primary airport of a Class C or Class D airspace area is 200 KIAS or 230 mph (unless otherwise authorized or required by ATC, or unless the operation is within Class B airspace, in which case 250 KIAS applies). A maximum indicated airspeed limit of 200 KIAS also applies to the airspace underlying Class B airspace or in a VFR corridor through Class B airspace. If minimum safe airspeed for your airplane exceeds these speeds, ATC should be notified and the aircraft should be operated at the minimum safe speed.

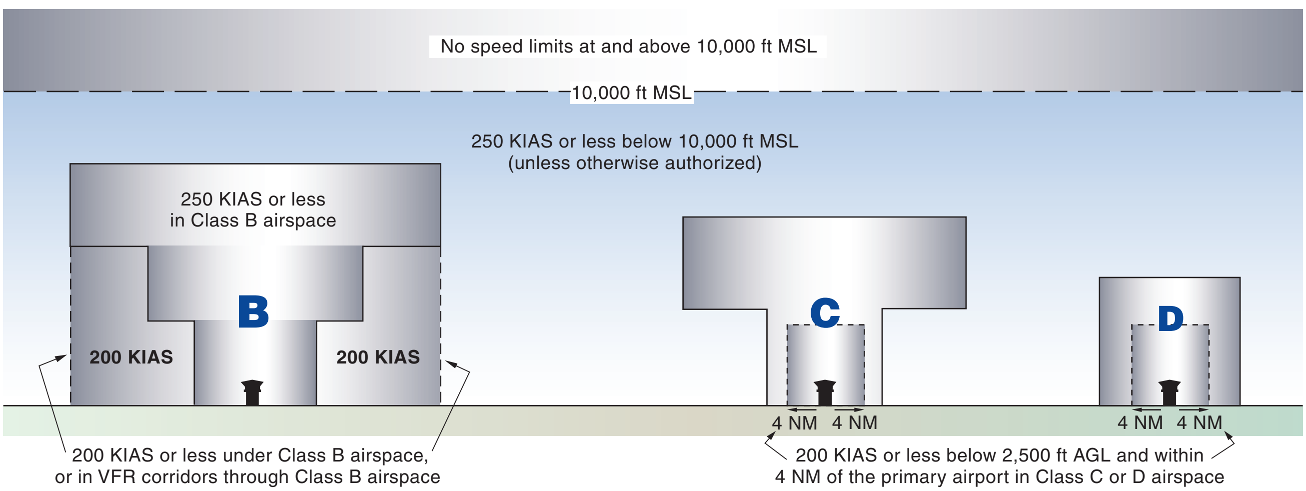


Figure 3-15 Speed limitations.

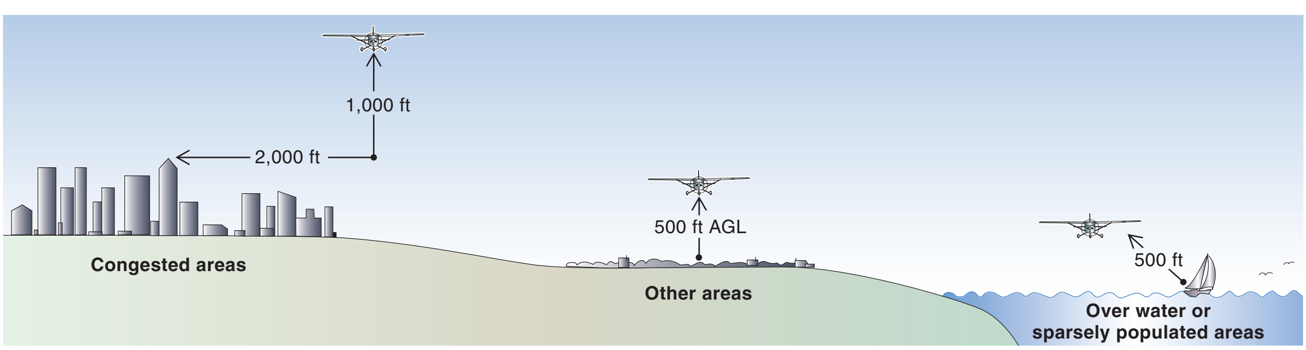


Figure 3-16 Minimum safe altitudes.

Altitudes for Flight

Minimum Safe Altitudes

Except when taking off or landing, no person may operate an airplane below the following altitudes:

- *Anywhere*—an altitude allowing, if an engine fails, an emergency landing without undue hazard to persons or property on the surface
- *Over congested areas*—over any congested area of a city, town, or settlement, or over an open-air assembly of persons, an altitude of 1,000 feet above the highest obstacle within a horizontal distance of 2,000 feet of the aircraft
- *Over other than congested areas*—an altitude of 500 feet above the surface, except over open water or sparsely populated areas (be careful the area is indeed not "congested"—less than a few buildings should be around). In those cases, the aircraft may not be operated closer than 500 feet to any person, vessel, vehicle, or structure.

VFR Cruise Altitude or Flight Level

VFR cruise altitudes or flight levels, when more than 3,000 feet AGL, are:

- On a magnetic course of magnetic north to magnetic 179: *odds+500 feet*—for example, 3,500 feet MSL, 15,500 feet MSL
- On a magnetic course of magnetic 180 to magnetic 359: *evens+500 feet*—for example, 4,500 feet MSL, 16,500 feet MSL

(You can memorize this as "West Evens, East Odds, plus 500 feet," or "WEEO+500.")

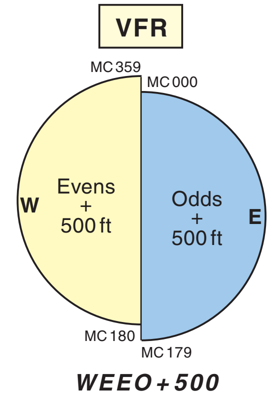


Figure 3-17
VFR cruise altitudes and flight levels above 3,000 feet AGL.

IFR Cruising Altitude or Flight Level

An IFR flight should plan to cruise:

- On a magnetic course of north to MC 179: *odds* – 5,000 feet MSL, 15,000 feet MSL, FL190, FL230
- On a magnetic course of MC 180 to MC 359: *evens* – 4,000 feet MSL, 16,000 feet MSL, FL180, FL280

In controlled airspace maintain the altitude or flight level assigned by ATC. If ATC assigns you a VFR-on-top clearance you should maintain a VFR altitude or flight level. This regulation applies up to FL290.

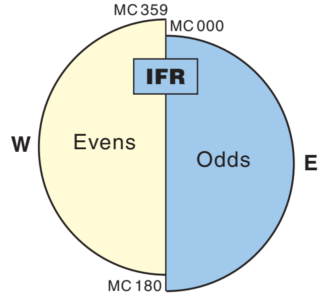


Figure 3-18
IFR cruise levels "WEEO" (west evens, east odds).

Minimum Altitudes for IFR Operations

You may not operate under IFR below a prescribed minimum altitude. If both an MEA (minimum en route altitude) and a MOCA (minimum obstruction clearance altitude) are prescribed for a particular route or route segment you may operate below the MEA down to, but not below, the MOCA within 22 NM (25 SM) of the VOR concerned—based on your reasonable estimate of that distance. The MEA assures obstruction clearance and NAVAID reception; MOCA is lower and only assures obstruction clearance, plus NAVAID reception within 22 NM (25 SM) of the aid.

If no applicable minimum altitude is prescribed, then you must maintain a clearance height above the highest obstacle, within a horizontal distance of four nautical miles of the course to be flown of:

- 2,000 feet in designated mountainous areas (shown in 14 CFR Part 95: IFR Altitudes subpart B); otherwise 1,000 feet

You should climb to a higher minimum IFR altitude immediately after passing the point beyond which that minimum altitude applies, except when ground obstructions intervene the point beyond which the higher minimum altitude applies shall be crossed at the applicable MCA (minimum crossing altitude).

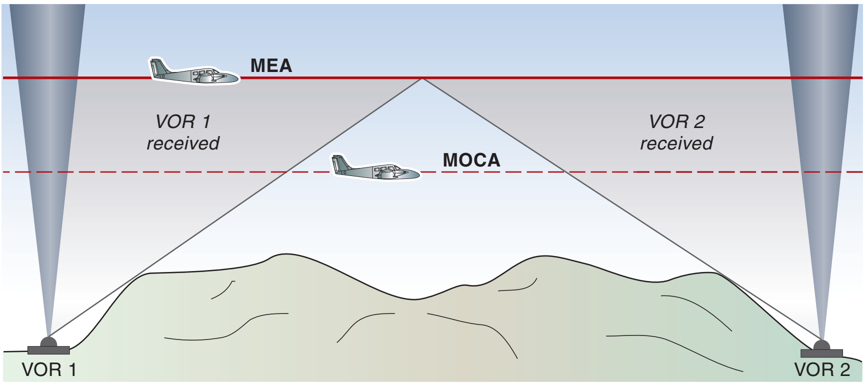


Figure 3-19 MEA and MOCA.

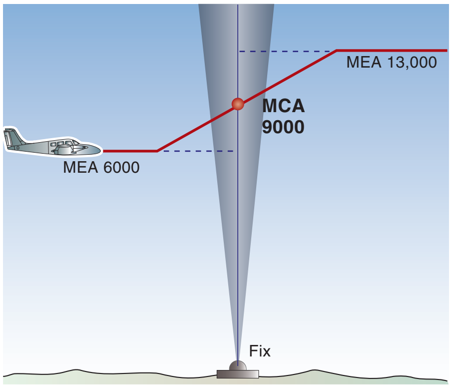


Figure 3-20 MCA.

Altimeter Settings

Cruise altitude below 18,000 feet MSL should be maintained with reference to an altimeter that has its pressure window set to the current reported altimeter setting of a station along the route and within 100 nautical miles of the aircraft (or, if not available, an appropriate available station). In a no-radio aircraft, you should set the altimeter to the departure airport elevation prior to takeoff or set an appropriate altimeter setting available before departure in the pressure window.

- Below 18,000 feet MSL: the current reported altimeter setting of a station along the route and within 100 NM of the aircraft (at altitudes) or at or above 18,000 feet MSL: 29.92 in.Hg (at flight levels).

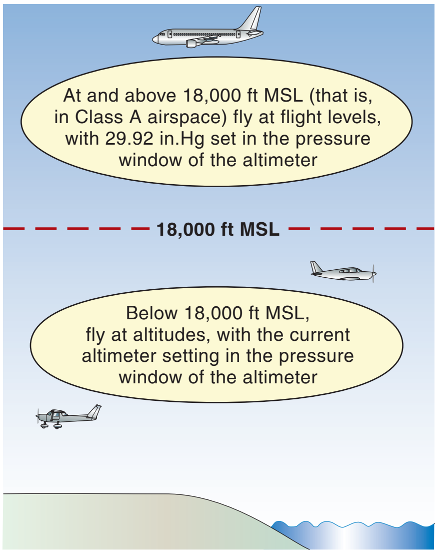


Figure 3-21
Use the current altimeter setting when flying below 18,000 feet MSL.

Course to be Flown

As discussed earlier, VFR courses are selected based on the altitude to be flown with reference to the magnetic course. See figure 3-17 for the hemispheric rules.

Unless otherwise authorized by ATC, in controlled airspace, under IFR you should:

- Fly along the centerline of an airway (±4 NM from airway centerline when within 51 NM of the VOR) or on any other route, directly between fixes. Note: You may maneuver the aircraft to pass well clear of other traffic.

Takeoff and Landing Under IFR

Takeoff Minimums

Takeoff weather minimums for each runway are published with the instrument approach charts and departure procedures otherwise standard minimums apply. For one and two-engine airplanes involved in 14 CFR Part 135 (Commuter and On-Demand) operations, the standard takeoff minimum is visibility one statute mile.

Instrument Approaches

When an instrument approach to a civil airport is necessary, you should use a published standard instrument approach procedure (SIAP) unless otherwise authorized.

Use of Radar During Instrument Approaches

ATC may issue radar vectors as course guidance through the segments of an approach procedure to the final approach fix (FAF). When you have received an approach clearance, you should hold the last altitude assigned until established on a segment of a published route or the IAP after which the published altitudes apply within each succeeding route or approach segment (unless a different altitude is assigned by ATC).

Authorized DA or MDA

The authorized *decision altitude/decision height* (DA/DH) or *minimum descent altitude* (MDA) is the higher of:

- The DA/DH or MDA prescribed for the pilot-in-command and the DA/DH or MDA for which the aircraft is equipped.

Operation Below DA or MDA

You may not operate the aircraft below the authorized DH or MDA unless:

- The aircraft is continuously in a position from which a safe landing may be made using normal maneuvers
- The flight visibility is not less than the prescribed visibility in the standard IAP
- One of the following visual references for the intended runway is distinctly visible and identifiable to the pilot (except for Category II or III approaches):
  - the approach light system;
  - the threshold, threshold markings or threshold lights, or the runway end identifier lights (REIL)
  - the visual approach slope indicator (VASI)
  - the touchdown zone, touchdown markings or touchdown zone lights
  - the runway, runway markings or runway lights or the aircraft has reached the specified visual descent point (VDP) for certain non-precision IAPs

Landing

You may not land when the flight visibility is less than the visibility prescribed in the standard IAP being used.

Missed Approach

You shall immediately execute a missed approach if at the DA/DH or below on a precision approach or below the MDA on a non-precision approach the above visibility requirements are not met, or if you lose sight of the airport environment (except in normal banked turns when maneuvering).

Comparable Values of Runway Visual Range (RVR) and Visibility

RVR 2,400 feet = H statute mile; RVR 5,000 feet = 1 statute mile.

Limitations on Procedure Turns

In the case of a radar vector to a final approach course or fix, a timed-approach from a holding fix, or an approach for which the procedure specifies "NoPT" or when a barbed procedure turn is not depicted, you may not make a procedure turn unless cleared to do so by ATC.

IFR Radio Communications

You shall maintain a continuous radio watch on the appropriate frequency when flying IFR and report by radio as soon as possible:

- Time and altitude at each designated reporting point except when under radar control
- Any unforecastweather conditions encountered and any other information relating to the safety of the flight.

IFR Operations—Two-Way Radio Communications Failure

If when operating under IFR, two-way radio communications fail, you are required to take the following action:

- In VFR conditions: remain in VFR and land as soon as practicable.
- In IFR conditions:

1. Route:

Follow the route in the last ATC clearance received. If being radar vectored by the direct route from the point of radio failure to the fix, route or airway specified in the vector clearance. In the absence of an assigned route, by the route that ATC has advised you to expect in a further clearance, otherwise the route filed in the flight plan.

2. Altitude:

At the highest of the following altitudes or flight levels for the route segment being flown:

The altitude or flight level in the last ATC clearance received the minimum altitude for IFR operations. The altitude or flight level that ATC has advised you to expect in a further clearance.

3. Leave Clearance Limit:

When the clearance limit is a fix from which the approach begins, commence descent or descent and approach as close as possible to the *expect further clearance* (EFC) time if one has been received or if one has not been received as close as possible to the estimated time of arrival (ETA) as calculated from the filed or amended (with ATC) estimated time en route. If the clearance limit is not a fix from which an approach begins, leave the clearance limit at the EFC time if one has been received or, if none has been received, upon arrival over the clearance limit, and proceed to a fix from which an approach begins, and commence descent or descent and approach as close as possible to the ETA as calculated from the filed or amended (with ATC) estimated time en route (ETE).

Note 1. In cases of radio communications failure, make use of your transponder to alert radar controllers by squawking code 7600. If you divert to an alternate airport and you have not filed route or altitude you should fly the published airways and minimum en route altitude (MEA).

Note 2. If two-way radio failure occurs while flying in Instrument Meteorological Conditions, pilots should attempt to re-establish two-way communications in any way possible. Today this includes the use of a cell phone. In normal situations, cell phones are not to be used in flight, but lost communications in the clouds is not normal—and considered an emergency.

Using the pilot-in-command authority, a pilot could use a cell phone to re-establish communication. While in flight the pilot would not know the telephone number of the nearest air traffic control facility therefore the best practice would be to call the Flight Service Station on their nationwide number of 1-800-WX-BRIEF. The FSS cannot control traffic, but can contact ATC and become the liaison between a controller and a pilot to re-establish communication. This would be a slow and awkward method to communicate, but much better than no communications at all. Pilots should never go into the clouds without a fully charged cell phone within reach.

Note 3. Although cell phone use in flight is not allowed, text messaging is allowed, but the current FSS computers and telephones cannot accept text messaging therefore this information is not helpful in this situation.

Compliance with ATC Clearances and Instructions

You shall not deviate from an ATC clearance except in an emergency or if the deviation is in response to a traffic alert and collision avoidance system resolution advisory. If you do deviate from an ATC clearance in an emergency, then you shall notify ATC of that deviation as soon as possible.

If you are given priority by ATC in an emergency (even though you may not have deviated from any rules), you shall, on request, submit a detailed report of that emergency to the manager of that ATC facility within 48 hours.

ATC Light Signals

If you experience radio communications failure, ATC may use light signals originating in the control tower to communicate basic commands.

Color and Type of Signal	Meaning with respect to Aircraft on the Surface	Meaning with respect to Aircraft in Flight
Steady Green	Cleared for takeoff	Cleared to land
Flashing Green	Cleared to taxi	Return for a landing (followed by a steady green at the proper time to indicate cleared to land)
Steady Red	Stop	Give way to other aircraft and continue circling
Flashing Red	Taxi clear of runway in use	Airport unsafe — do not land
Flashing White	Return to starting point on airport	Not applicable
Alternating Red and Green	Exercise extreme caution	Exercise extreme caution

Figure 3-22 ATC light signals.

Aerobatic Flight

Aerobatic flight means intentional maneuvers involving an abrupt change in aircraft attitude, an abnormal attitude, or abnormal acceleration that is not necessary for normal flight. You may not perform aerobatics:

- Over any congested area of a city, town, or settlement
- Over an open air assembly of persons
- Within or above the lateral boundaries of the surface areas of Class B, C, D or E airspace designated for an airport
- Within four nautical miles of the centerline of any Federal airway
- Below an altitude of 1,500 feet AGL
- When the flight visibility is less than three statute miles

Review 3
Aviation Regulations

Definitions and Pilot Qualifications

1. Define "night."
2. What does ATC clearance provide?
3. With respect to the certification of aircraft, what is:
   a. a utility?
   a. an airplane?
4. How long are airworthiness certificates valid for?
5. Where can you find the legal definitions of air traffic control and air traffic clearance?
6. What does V_{LE} stand for?
7. What does V_{FE} stand for?
8. Define V_{S0}.

Part 61—Pilot Certification

9. Name three documents that must be in your possession any time you fly as pilot in command.
10. Does a private pilot certificate have a specific expiration date?
11. For private pilot operations, a third-class or second-class medical certificate issued on July 15, this year is valid until midnight on which date?
12. What is the exception to the rule that a private pilot may not act as pilot in command of an aircraft carrying passengers or property for compensation or hire?
13. Describe the requirements for carrying passengers, including any special considerations for tailwheel aircrafts.
14. Recency of experience requirements for night flight have not been met and official sunset is 1830. What is the latest time passengers may be carried?
15. As one requirement to act as pilot in command of an aircraft towing a glider, at least how many actual or simulated glider tows do you need to have made while accompanied by a suitably qualified pilot within the previous 12 months?

Part 91—General Operating and Flight Rules

16. Who has final authority as to the operation of an airplane?
17. Who is responsible for determining if an aircraft is in condition for safe flight?
18. There is an in-flight emergency requiring immediate action. Can the pilot in command deviate from the regulations to the extent required to meet that emergency? If so, must a written report of the deviation be sent to the FAA?
19. Where may an aircraft's operating limitations be found?
20. Which documents should be carried onboard an aircraft?
21. What is the blood alcohol limit for a person to act as a crewmember even if they have not consumed alcohol in the previous 8 hours?
22. May a medical patient under the influence of drugs be carried on an aircraft?
23. May people under the influence of drugs or alcohol be carried on an aircraft?
24. During which phases of flight are flight crew members required by the regulations to keep their seat belts and shoulder harnesses fastened?
25. Which category of aircraft must give right-of-way to all others in normal circumstances?
26. Which aircraft has the right-of-way over all other air traffic?
27. Does an airplane refueling another have right-of-way over a glider?
28. What action is required when two aircraft of the same category converge, but not head-on?
29. An airplane is converging at an angle with a helicopter on its left. Which one has right-of-way?

30. A glider and an airplane are on a head-on collision course. What action should be taken?
31. An airship and an airplane are converging, with the airship left of the airplane's position. Which aircraft has the right-of-way?
32. When two or more aircraft are approaching an airport for the purpose of landing, the right-of-way belongs to which aircraft?
33. In an overtaking situation, does the aircraft being overtaken have right-of-way?
34. An aircraft being overtaken should expect to be passed on which side?
35. What is the maximum speed below 10,000 feet MSL for all aircraft?
36. What is the maximum speed in Class B airspace for all aircraft?
37. What is the maximum speed in Class C or D airspace within 4 nautical miles of the primary airport for all aircraft?
38. Except when necessary for takeoff or landing, an aircraft may not be operated closer than what distance from any person, vessel, vehicle, or structure?
39. Except when necessary for takeoff or landing, what is the minimum safe altitude for a pilot to operate an aircraft anywhere?
40. When would a pilot be required to submit a detailed report of an emergency which caused the pilot to deviate from an ATC clearance?
41. What does an alternating red and green light signal directed from the control tower to an aircraft in flight indicate?
42. What does a flashing white light directed from the control tower to an aircraft on the ground mean?
43. While on final approach for landing, the control tower directs an alternating red and green light at you, followed by a flashing red light. What actions should you take?
44. You are approaching to land at an airport in Class G airspace. All turns should be made in which direction (unless otherwise indicated)?
45. You are operating from a satellite airport located in Class D airspace. When must two-way radio communications be established with ATC?
46. Is an ATC clearance required to operate at an airport located in Class D airspace?
47. What minimum radio equipment is required to operate in Class C airspace?
48. Operations in which class(es) of airspace require an encoding altimeter?
49. What fuel is required for:
    a. a VFR flight by day?
    b. a VFR flight at night?
    c. an IFR flight?
50. In what airspace may a special VFR clearance be issued by ATC?
51. What are the visibility and distance-from-clouds requirements for special VFR clearances?
52. What is the next higher appropriate cruise altitude or flight level to 5,000 feet MSL for a VFR flight along an airway whose magnetic course is MC 180?
53. How often do the batteries in an emergency locator transmitter (ELT) need to be replaced or recharged?
54. Except in Alaska, when should you display position lights?
55. When operating an aircraft at cabin pressure altitudes above 12,500 feet MSL up to and including 14,000 feet MSL, when should supplemental oxygen be used?
56. An operable 4096-code transponder with an encoding altimeter is required in which airspace?
57. What is the minimum altitude and flight visibility for aerobatic flight?
58. An annual inspection was due at 1,259.6 hours, but was actually done at 1,261.2 hours. When is the next 100-hour inspection due?
59. Can the annual inspection replace a 100-hour inspection?
60. Where is the expiration date of the last annual aircraft inspection found?
61. May aircraft wreckage be moved prior to the time the NTSB takes custody?
62. If you undertake a forced landing because of piston-engine failure, does this need to be immediately reported to the nearest NTSB field office?
63. The operator of an aircraft has been involved in an accident. He or she is required to file an accident report within how many days?

64. An aircraft that is overdue for an inspection is involved in an accident. Does this fact need to be immediately reported to the nearest NTSB field office?

IFR Operations

65. To operate under IFR, an operational check of the aircraft VOR equipment must have been accomplished within what time period?
66. When making an airborne check of a dual VOR system, what is the maximum tolerance between the two indicators when set to identical radials of a VOR?
67. What four items should be entered in the aircraft log, or other permanent record, by each person who carries out the VOR operational check?
68. What is the maximum tolerance allowed for an operational VOR equipment check when using a VOT?
69. What minimum conditions must exist at the destination airport to avoid listing an alternate airport on an IFR flight plan when a standard instrument approach is available?
70. Is an alternate required for a destination airport which has an instrument approach procedure, and which has a ceiling forecast of 1,500 feet, and a forecast visibility of 3 miles? Justify your answer.
71. If conditions requiring an alternate are forecast to improve above alternate conditions 45 minutes prior to your ETA, do you need to carry an alternate?
72. If excellent weather conditions at your destination are forecast to deteriorate below alternate minimums 55 minutes after your ETA, do you need to carry an alternate?
73. Is an alternate required for a destination airport served by an instrument approach with a ceiling forecast of 2,500 feet and a forecast visibility of 3 miles? Justify your answer.
74. Is an alternate required for a destination airport not served by an instrument approach with a ceiling forecast of 2,500 feet, and a forecast of 3 miles? Justify your answer.
75. Your destination airport has a ceiling forecast of 2,000 feet and forecast visibility of 3 miles. Is an alternate required? Justify your answer.
76. The destination airport has a ceiling forecast of 1,500 feet, and a forecast visibility in excess of 3 miles. Is an alternate required? What minimum fuel must you carry?
77. The destination airport has a ceiling forecast of 3,000 feet and a forecast visibility in excess of 3 miles. Is an alternate required?
78. There are known traffic delays of 30 minutes. Should you carry 30 minutes additional fuel?
79. The weather at the destination airport is currently good, but the ceiling is forecast to drop to 1,500 feet approximately 50 minutes after your estimated time of arrival. Is an alternate required?
80. The weather at the destination airport is currently good, but the ceiling is forecast to drop to 1,500 feet approximately one hour after your ETA. Is an alternate required?
81. The weather at the destination airport is currently good, but the ceiling is forecast to drop to 1,500 feet approximately 90 minutes after your estimated time of arrival. Is an alternate required?
82. The weather at your destination airport is ceiling 1,500 feet, visibility 2 miles but is forecast to improve to ceiling 2,500 feet, visibility 4 miles approximately 75 minutes after your ETA. Is an alternate required?
83. If the weather at your destination airport is currently ceiling 1,500 feet, visibility 2 miles, but is forecast to improve to ceiling 2,500 feet, visibility 4 miles approximately 45 minutes before your ETA, is an alternate required?
84. What are the alternate minimums that must be forecast at the proposed alternate airport in the following situations:
    - **a.** if it has only a nonprecision approach procedure?
    - **b.** if it has a precision approach procedure?
    - **c.** if it has only a VOR approach procedure?
    - **d.** if it has published VOR and ILS approach procedures?

85. The alternate minimums apply to:
  a. the ETA at the alternate airport.
  b. the ETA +/- 1 hour at the alternate airport.

86. What needs to be indicated in the current weather forecast for an airport without an authorized instrument approach procedure for that airport to be included on an IFR flight plan as an alternate?

87. You have diverted to the alternate airport. When making an approach to land at this airport, which minimums are you restricted to?

88. Do you need to file a flight plan to operate in controlled airspace (Class A-E) under IFR?

89. Do you need an ATC clearance to operate in controlled airspace (Class A-E) under IFR?

90. Do you need to file an IFR plan to operate in instrument conditions (IMC) in controlled airspace?

91. Do you need to file an IFR plan to operate in IMC in Class G airspace?

92. Do you need to have an instrument rating to operate as PIC in IMC in Class G airspace?

93. When departing in IMC from an airport located in Class G airspace, must you file a flight plan and receive an ATC clearance before takeoff?

94. When departing in IMC from an airport located in Class G airspace, must you file a flight plan and receive an ATC clearance before entering IFR conditions?

95. When departing in IMC from an airport located in Class G airspace, must you file a flight plan and receive an ATC clearance before arriving at the enroute portion of the flight.

96. When departing in IMC from an airport located in Class G airspace, must you file a flight plan and receive an ATC clearance before entering controlled airspace?

97. When departing in IMC from an airport located in Class G airspace, you must file a flight plan and receive an ATC clearance before which of the following?
  a. takeoff.
  b. entering IFR conditions.
  c. entering controlled airspace.
  d. arriving at the enroute portion of the flight.

98. Does the MEA ensure obstruction clearance?

99. Does the MEA ensure radio navigation air reception?

100. What does MOCA stand for?

101. Does the MOCA ensure obstruction clearance?

102. Does the MOCA ensure radio navigation aid reception?

103. Is the MOCA higher than the MEA?

104. What does MCA stand for?

105. On a particular route segment, the MEA is 7,000 feet and on the next route segment, after passing an intersection, it is 9,500 feet. When is the latest you may start your climb if you are initially cruising at 7,000 feet and the airplane can achieve a climb of 500 fpm? No MCA is noted at the intersection.

106. On a particular route segment, the MEA is 6,000 feet and on the next route segment, after passing an intersection, it is 12,000 feet. When is the latest you may start your climb if you are initially cruising at 7,000 feet and the airplane can achieve a climb of 500 fpm? An MCA of 8,500 feet is noted at the intersection for this route.

107. If no applicable minimum altitude is prescribed for your route, which is in designated mountainous area, what clearance should you plan to maintain?

108. If no applicable minimum altitude is prescribed for your route, which is not in a designated mountainous area, what clearance height should you plan to maintain?

109. Should you plan to fly directly between fixes on an IFR flight plan?

110. May you continue with an approach to land if an excessive rate of descent to the runway is required?

111. May you continue with an approach to land if a steep turn is required to align the aircraft with the runway?

112. May you continue to maneuver below the MDA for a landing if you lose sight of the airport environment behind a cloud bank?

113. What is the landing minimum specified as?

114. If you decide to discontinue an approach at or below the DH/DA of a precision approach, or below the MDA of a nonprecision approach, what procedure should you follow?

115. What are the standard takeoff minimums for a one- or two-engine airplane carrying people for 14 CFR Part 135 operations? What are the standard takeoff minimums for flights operated under Part 91?

116. What is the equivalent visibility in statute miles for RVR 2,400 feet?

117. What is the equivalent visibility in statute miles for RVR 5,000 feet?

118. Are you required to make a radio call at a compulsory position reporting point designated on your chart when you are under radar control?

119. Are you required to make a radio call at a compulsory position reporting point designated on your chart when you are not under radar control?

120. Are you required to report any unforecast weather encountered, such as a thunderstorm, by radio?

121. What action should you take if you experience two-way radio communication failure in VFR conditions?

122. You enter a holding pattern at a fix, which is not the approach fix, and receive an EFC time of 1620Z. At 1610Z you experience a complete two-way communications failure. What actions should you take?

123. If you are in IFR weather conditions and experience a two-way radio communications failure, what action can you take with the transponder to alert ATC? What altitude and route should you follow?

Answers are given on page 764.

Aerodynamics

4 Forces Acting on an Airplane
5 Stability and Control
6 Aerodynamics of Flight

Forces Acting on an Airplane 4

Like all things, an airplane has *weight*, the force of gravity that acts through the center of the airplane in a vertical direction toward the center of the earth. While the airplane is on the ground, its *weight* is supported by the force of the ground on the airplane, which acts upward through the wheels.

During the takeoff roll, the task of supporting the weight of the airplane is transferred from the ground to the wings (and vice versa during the landing). While in level flight, the weight of the airplane is supported by the *lift* force, which is generated aerodynamically by the flow of air around the wings. In addition, as the airplane moves through the air it will experience a retarding force known as *drag*, which, unless counteracted, will cause the airplane to decelerate and lose speed.

In steady (unaccelerated) straight-and-level flight, the drag (or retarding force) is neutralized by the *thrust* (figure 4-1). In most smaller airplanes, thrust is produced by the engine-propeller combination; in pure-jet airplanes, the thrust is produced by the gas efflux, without the need for a propeller.

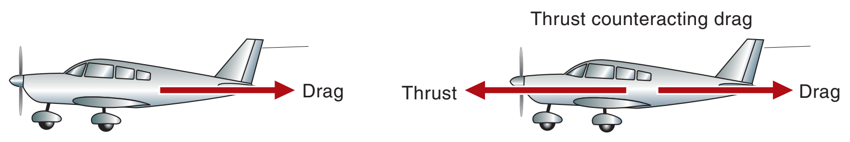


Figure 4-1 Drag counteracted by thrust.

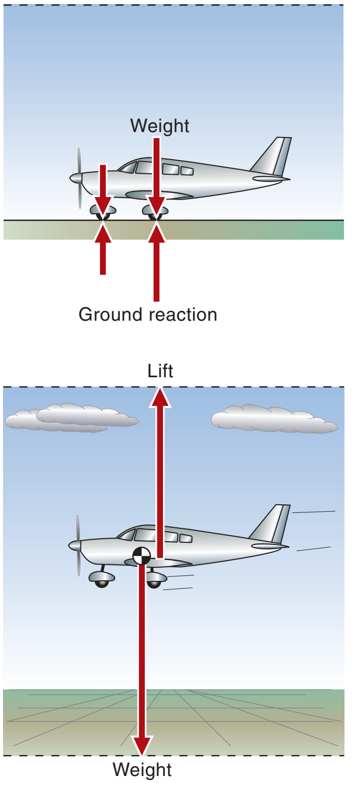


Figure 4-2
The airplane is supported by the ground, and in the air by lift.

In figure 4-3, the forces are equal and opposite, canceling each other out, so that the resultant force acting on the airplane is zero, and it will neither accelerate nor decelerate. In this situation the airplane is in a state of *equilibrium:*

- *weight* is equal to *lift*, and acts in the opposite direction; and
- *drag* is equal to *thrust*, and acts in the opposite direction.

During steady (unaccelerated) flight the four main forces are in equilibrium and the airplane will continue in level flight at the same speed.

For the type of airplane you are likely to be flying during your training, the amount of the lift (and therefore the weight) during cruise flight will be approximately 10 times greater than the drag (and thrust). This relationship of lift to drag is very important and is referred to as the *lift/drag ratio.* The L/D ratio in this case is 10 to 1.

If the airplane is to accelerate in level flight, the thrust must exceed the drag; if the airplane is to be slowed down in level flight, the thrust must be less than the drag. A state of equilibrium does not exist during acceleration or deceleration.

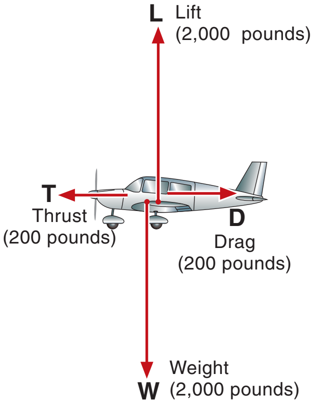


Figure 4-3 The four main forces are in equilibrium during unaccelerated flight.

Gravitational Force (Weight)

Gravity is the downward force attracting all bodies vertically toward the center of the earth. The name given to the gravitational force is *weight*, and for our purposes it is the total weight of the loaded airplane. This weight is called *gross weight*, and it may be considered to act as a single force through the *center of gravity* (CG).

The CG is the point of balance. Its position depends on the weight and position of the various parts of the airplane and the load that it is carrying. If the airplane were supported at its center of gravity, the airplane would be balanced.

The weight of an airplane varies depending on the load it has to carry (cargo, baggage, passengers) and the amount of fuel on board. Airplane gross weight will gradually decrease as the flight progresses and fuel is burned off. The magnitude of the weight is important and there are certain limitations placed on it—for instance, a maximum takeoff weight will be specified for the airplane. Weight limitations depend on the structural strength of the components making up the airplane and the operational requirements the airplane is designed to meet.

The balance point (center of gravity) is very important during flight because of its effect on the stability and performance of the airplane. It must remain within carefully defined limits at all stages of the flight.

The location of the CG depends on the weight and the location of the load placed in the airplane. The CG will move if the distribution of the load changes, for instance by transferring load from one position to another by passengers moving about or by transferring fuel from one tank to another. The CG may shift forward or aft as the aircraft weight reduces in flight, such as when fuel burns off or parachutists jump out.

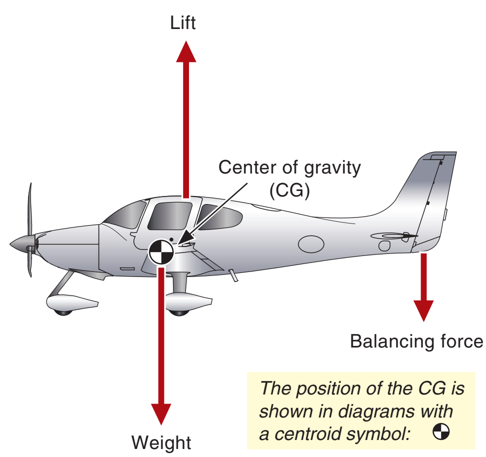


Figure 4-4
Weight acts downward through the center of gravity (CG).

Airflow and Airfoils

An airfoil is a surface designed to lift, control, and propel an airplane. Some well-known airfoils are the wing, the horizontal stabilizer (or tailplane), the vertical stabilizer (or fin), and the propeller blades. A wing is shaped so that as the air flows over and under, a pressure difference is created—lower pressure above the wing and higher pressure below the wing—resulting in the upward aerodynamic force known as lift. The wing also bends the free stream of air, creating downwash. The total reaction has a vertical component to lift the aircraft or change its flight path, and it has a rearward component, drag, which resists the movement of the wing through the air.

Figure 4-5
Airfoil shape.

The airplane's control surfaces—ailerons, elevator and rudder—form part of the various airfoils. You can move these to vary the shape of each airfoil and the forces generated by the airflow over it. This enables you to maneuver the airplane and control it in flight. These control surfaces also operate based on Newton's Third Law of Motion, which says that every action has an equal and opposite reaction. By deflecting the free stream of air that flows over them, control surfaces cause the airplane to roll, yaw or pitch as the reaction.

Figure 4-6
Left aileron.

The wing shape can also be changed by extending the flaps to provide better low-speed airfoil characteristics for takeoff and landing.

Figure 4-7
Vertical stabilizer and rudder.

Figure 4-8
Wing flaps.

Airflow Around an Airfoil

The pattern of the airflow around an airplane depends on the shape of the airplane and its attitude relative to the airflow. There are two airflow types: streamline flow and turbulent flow.

Laminar Flow

If successive molecules or particles of air follow the same steady path in a flow, then this path can be represented by a line called a *streamline*. There will be no flow across the streamlines, only along them. There is no turbulence or mixing, hence the name *laminar* (layered) flow. At any fixed point on the streamline, each particle of air will experience the same speed and pressure as the preceding particles of air when they passed that particular point. These values of speed and pressure may change from point to point along the streamline. A reduction in the speed of streamline flow is indicated by wider spacing on the streamlines, while increased speed is indicated by decreased spacing of the streamlines. The existence of streamline flow is very desirable around an airplane because streamlined flow offers the least drag.

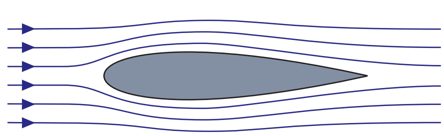


Figure 4-9 Laminar flow.

Turbulent Flow

In turbulent flow, the airflow does not follow a streamlined pattern. Succeeding particles of air may travel a path quite different to the preceding parcels of air. This turbulent flow is also known as unsteady flow, vortices or eddying, and is an undesirable feature in most phases of flight. The point where the airflow around a surface becomes turbulent is called the *transition point*. The point where the turbulence is so severe that the airflow separates from the surface of an airfoil is known as the *separation point* (see figure 4-10).

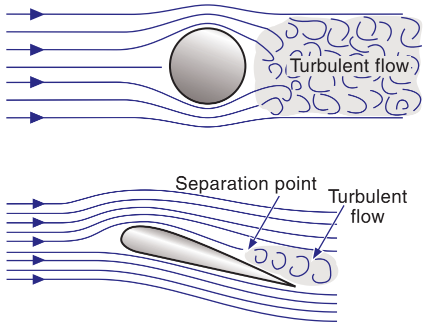


Figure 4-10 Turbulent flow.

The wing of an airplane pushes and induces the air downwards and forwards, because of its shape, angle of attack, and speed. The reaction is an upward/rearward force called the *total reaction*. The upward component of this reaction lifts the airplane (i.e. it overcomes gravity), and the rearward force (drag) is the force that must be overcome by the engine and propeller.

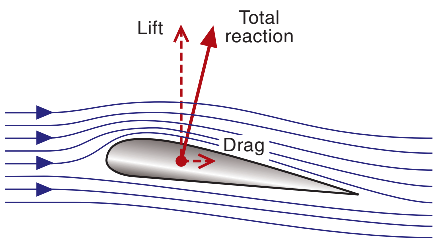


Figure 4-11 Total reaction.

How the wing generates the action and total reaction has been a subject of theoretical debate for many years. You may hear theorems of lift due to:

- Bernoulli's principle (pressure inequalities);
- circulation theory (vortices); and
- Coanda effect (downwash).

The end result of these is that the passage of the wing causes downwash, and the reaction causes lift and drag (Newton's third law). The most common explanation of lift is given by Bernoulli's principle, but this theorem is by no means the whole story.

Energy and Pressure

There are two types of energy:

- potential energy (due to height—for example, the pressure in a faucet is a function of the relative height of the water tank); and
- kinetic energy (due to speed).

An airplane at 10,000 feet has the potential to dive and accelerate. An airplane at low altitude and high speed has the capacity to zoom up to a higher altitude. Thus any body has a total bank of energy that can be exchanged as speed or height (with some losses in the exchange process).

For a gas, mass equates to density and energy equates to pressure. The pressure forces exerted by air are caused by:

- static pressure (a function of height); and
- dynamic pressure (due to speed).

Static pressure is caused by gravity. The stack of air molecules in the earth's atmosphere causes the lower molecules to be squashed (less volume, greater density) and the upper molecules to be relaxed (more volume, less density). *Dynamic pressure* is caused by air moving against an object (wind and turbulence) or by an object trying to move through the air.

The forces experienced by an aircraft are a combination of static and dynamic pressure. If the aircraft is stationary, it experiences only static atmospheric pressure (and any dynamic pressure due to wind). Static pressure is equal in all directions—up, down and all around. As soon as the airplane moves through the air, the static and dynamic pressures change, while the total pressure remains constant. Thus for any place on the aircraft when the dynamic pressure increases, the static pressure drops. If the dynamic pressure reduces, the static pressure increases. This is reflected around an airfoil, as shown in figure 4-12.

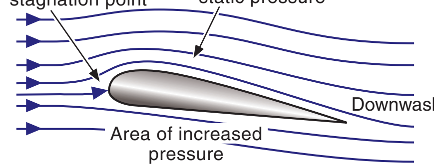


Figure 4-12
Pressure around an airfoil.

The dynamic pressure of a parcel of air moving relative to an object is a function of its density. This density (and velocity) generates a force on any object that tries to move through it. This force, when calculated per unit of surface area, is called *dynamic pressure*. If you hold your hand up in a strong wind or out of the window of a moving automobile, air pressure is felt because of the air striking your hand and flowing around it. This pressure is dynamic pressure—pressure caused by the relative movement between your hand and the air.

Dynamic pressure (represented by the symbol "q.") involves *air density* (mass per unit volume) which is denoted by the Greek letter *rho* (ρ). The more dense the air, the greater the dynamic pressure:

$$\text{Dynamic pressure (q)} = \tfrac{1}{2}\rho \times \text{velocity-squared} = \tfrac{1}{2}\rho V^2$$

The strength of dynamic pressure therefore depends on:

- the *velocity* (speed in a particular direction) of the body relative to the air; and
- the *density* of the air.

Bernoulli's Principle

The production of the lift force by an airfoil may be explained by *Bernoulli's principle*—also known as the *venturi effect*. Daniel Bernoulli (1700–82) was a Swiss scientist who discovered this effect. A fluid in steady motion has a total energy. Air is a fluid, and if we assume it to be incompressible, it behaves as a so-called "ideal" fluid. Bernoulli's principle states that for an ideal fluid the total energy in steady streamline flow remains constant. Therefore:

Bernoulli' s principle is the easiest non-mathematical way to understand the production of lift (and drag) by an airfoil.

$$\text{Potential energy} + \text{kinetic energy} = \text{constant total energy}$$

Within any steady streamline flow the total energy content will always remain constant, but the relative proportions of pressure energy and kinetic energy can vary. If kinetic energy increases because of a greater speed of flow, then potential energy will decrease accordingly. This is explained by Bernoulli as fluid flowing through a tube. The mass flow (total energy) is constant. If the opening is restricted (like the nozzle in a garden hose), the velocity is increased.

Total energy in a steady streamline flow remains constant.

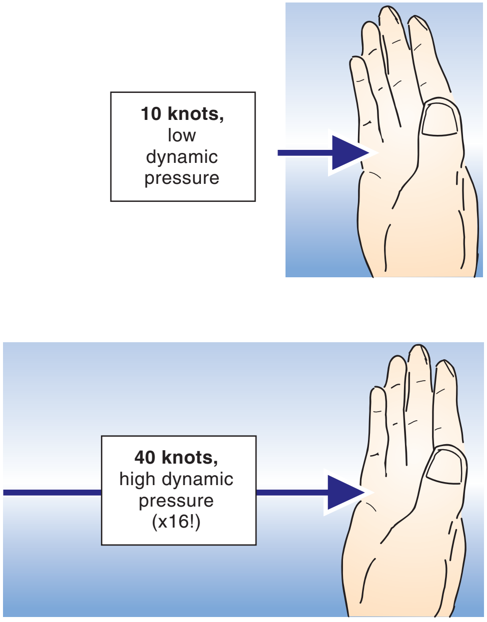


Figure 4-13
Dynamic pressure increases with airspeed.

The faster an automobile drives or the stronger the wind blows, the stronger the dynamic pressure that you feel on your hand. This is because of the greater number of air molecules that impact per second.

> **Note.** It is the *relative velocity* of the airplane and the airflow that matters. The force is the same whether it is the airplane moving through the air or the air is flowing over the airplane.

At the same speed, the denser the air, the more molecules per second that will strike your hand and so the greater the dynamic pressure. Density changes with altitude and temperature.

> **Note.** Bernoulli's principle may be used to explain many aspects of aerodynamics, but only if it is assumed that air is incompressible. At the private- and commercial-pilot level, such an assumption is valid because we are mainly concerned with airplanes that operate at relatively slow speeds and at altitudes below 10,000 feet. At higher speeds and altitudes, compressibility of air must be accounted for, but this is only applicable when you are studying at the Airline Transport Pilot (ATP) level.

Lift and Thrust

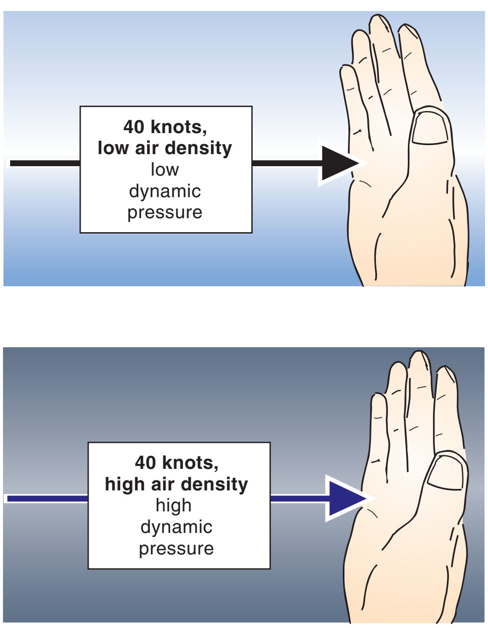


Figure 4-14
Dynamic pressure is greater in dense air.

Pressure is force per unit area—pounds per square inch (psi). This force around an airplane is significant. Static pressure alone acts on all sides of the airplane and thus cancels itself, until we use dynamic pressure and the resultant differences in static pressure to our advantage. It is an imbalance of forces that allows the airplane to fly. The propeller causes reduced static pressure ahead and increased static pressure behind. The force is called *thrust* and drives the airplane forwards. The airfoil section of the wing accelerates the air; this causes a downwash and a change in static pressure between the lower and upper surfaces. This is sufficient to carry the aircraft and to maneuver it (change its flight path). The control surfaces cause the change in flight path.

Airspeed

Dynamic pressure (q) and the term $\frac{1}{2}\rho V^2$ are very important in aviation. The airspeed indicator shows *indicated airspeed* (IAS), which is not a real speed but a measure of dynamic pressure. Since dynamic pressure is related to air density, the real speed of the airplane relative to the airflow can only be calculated if the change in density due to altitude or temperature is recognized. This corrected speed is known as *true airspeed* (TAS or V). Although indicated airspeed is of most concern to you when flying, you will need to calculate true airspeed for measuring time, fuel, and distance.

Airfoils

All parts of the airplane contribute positively or negatively to the total forces of lift and drag, but it is the *airfoil* of the wing that is specifically designed to provide the lift needed to support the weight of the airplane in flight. If a thin, flat metal plate is oriented parallel to a streamline airflow, it causes virtually no alteration to that airflow, and consequently experiences no reaction (aerodynamic force). If, however, the plate is inclined with respect to the airflow, it will experience a reaction that tends to both lift it up and drag it back. This is the same effect that you feel if you hold your hand out the window of a moving vehicle. The amount of reaction depends on the relative speed and the angle between the flat plate (or your hand) and the airstream.

Because of the angle of the plate to the airflow, the straight-line streamline flow of the air is disturbed. A slight *upwash* is created in front of the plate, causing the air to flow through a more constricted area, almost as if there was an invisible venturi above the plate. As it passes through this constricted area, the air speeds up. The velocity increase produces a decrease in static pressure (Bernoulli's principle).

The static pressure above the plate is now lower than the static pressure beneath the plate, causing a net upward and rearward reaction. After passing the plate there is a *downwash* of the airstream. Note that if the angle of the flat plate to the airflow becomes too large, the streamline airflow breaks down resulting in less lift and more drag. See figure 4-15.

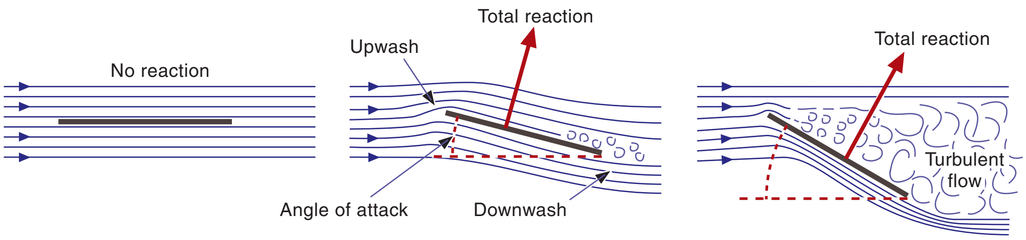


Figure 4-15 Airflow can lift a flat plate (but not efficiently).

The reaction, or aerodynamic force, on the plate caused by its disturbance of the airflow has two components:

- one at right angles to the relative airflow, known as *lift;* and
- one parallel to the relative airflow, opposing the relative motion, known as *drag.*

Airfoil Shape

A flat plate is not the ideal airfoil shape because it breaks up the streamline flow, causing eddying (turbulence), with a loss of lift and a great increase in drag. In addition, it is difficult to construct a thin, flat wing (no strength, no internal structure).

Figure 4-16 Examples of various airfoil shapes.

A cambered airfoil surface not only generates more lift and less drag compared to a flat plate, it is also easier to construct in terms of structural strength. Airfoils can have many cross-sectional shapes. Airplane designers choose the shape with the best aerodynamic characteristics to suit the role of the airplane.

Camber

Camber is curvature. Aviation pioneers, such as Wilbur and Orville Wright, experimented with different curved (cambered) shapes and found that the degree of curvature, the point of maximum curvature, and the ratio of thickness to length were critical. Later designers found that the shape of the upper curvature was more important than the lower curvature, and therefore they could have a thicker, lighter, stronger wing with internal storage capacity for fuel and structure with no aerodynamic penalty. Thick wings with a large camber have a good lifting ability, making them suitable for low-speed flight. The position of greatest camber is usually about 30 percent back from the wing leading edge. As camber increases, the airflow path lengthens, resulting in the airflow speeding up, static pressure reducing and lift and drag increasing.

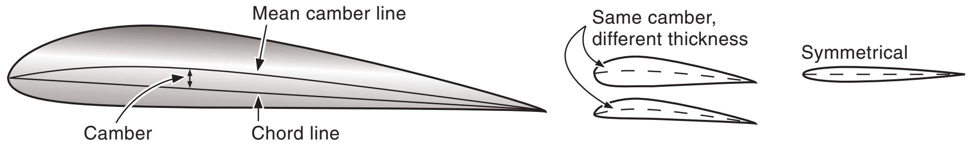


Figure 4-17 A cambered airfoil with internal structure.

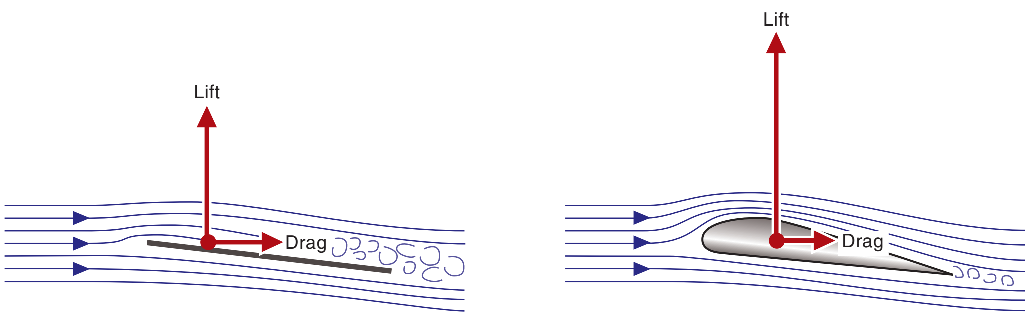


Figure 4-18 More camber, more lift, less drag.

Wings with less camber give a better cruise performance but a higher takeoff and landing speed (and distance). Aircraft and airfoil design is a compromise to suit customers' requirements.

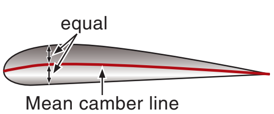


Figure 4-19 Mean camber line.

Mean Camber Line

The mean camber line is the line drawn halfway between the upper and lower surfaces of the airfoil cross-section. This line gives a picture of the average curvature of the airfoil.

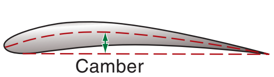


Figure 4-20 Camber.

Camber

The camber is the maximum distance between the mean camber line and the chord line.

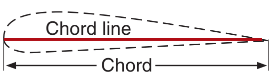


Figure 4-21 Chord line.

Chord Line

The chord line is the straight line joining the leading edge and the trailing edge of the airfoil or, in other words, the straight line joining the ends of the (curved) mean camber line.

The Chord

The length of the chord line is called the chord of the wing. It varies from the wing root to the wing tip, so we use the average (mean) chord.

Aerodynamic Forces

In normal flight, the static pressure over most of the upper surface of the airfoil is slightly reduced when compared with the normal static pressure of the airflow well away from the airfoil. The static pressure beneath much of the lower surface of the airfoil is greater than that on the upper surface, because a greater number of air molecules are impacting the airfoil's lower surface and the airflow is being slowed down. This pressure difference is the origin of the *total aerodynamic force* exerted on the airfoil, with the greater contribution coming from the upper surface.

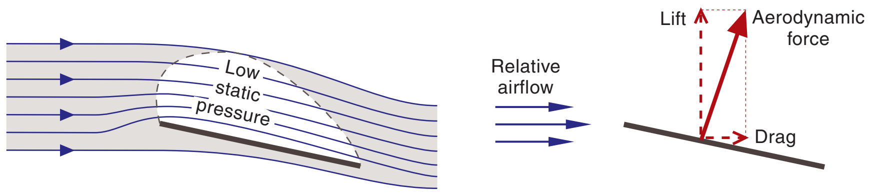


Figure 4-22 The production of lift and drag.

In the same way that the total weight of an airplane can be considered to act through a single point—the center of gravity—the aerodynamic forces on an airfoil can be considered to act through a single point known as the *center of pressure* (CP) or center of lift.

It is convenient for us to consider the aerodynamic force (*total reaction*) in its two components: lift and drag:

- *lift* is the sum total of the components of the aerodynamic force at right angles, or perpendicular, to the relative airflow; and
- *drag* is the total of the component of the aerodynamic force parallel to the relative airflow and opposing motion.

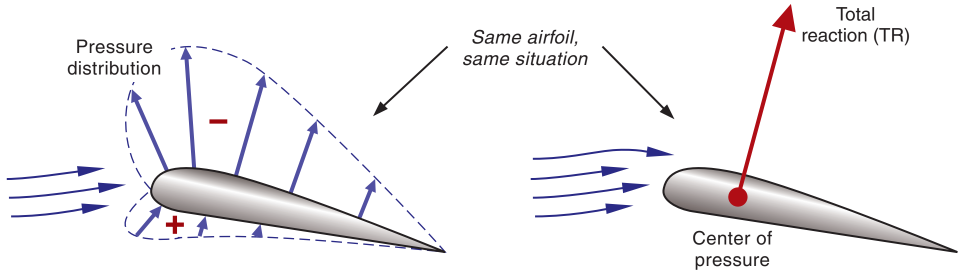


Figure 4-23
The aerodynamic force acts through a point on the wing called the center of pressure.

The *center of pressure* is the point through which the equivalent single force (TR) would act to cause the same effect as all the component forces distributed over the wing.

The *relative airflow*, or *relative wind,* refers to the relative motion between a body and the remote (free stream) airflow—that is, the airflow far enough away from the body not to be disturbed by it. The relative airflow is the direction opposite to the flight path of the airplane.

The *angle of attack* is the angle between the chord line of an airfoil or wing and the remote relative airflow. It is represented by the Greek letter α (alpha).

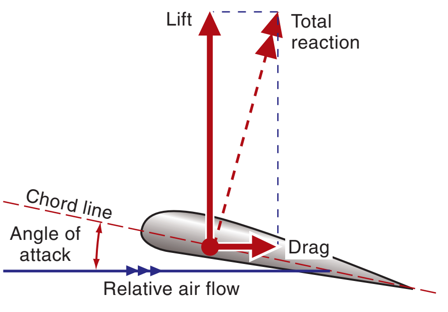


Figure 4-24 Relative airflow (measured relative to the "free-stream" airflow).

Note the following.

1. Do not confuse the *pitch attitude* of the airplane (relative to the horizontal) with the angle of attack of the airfoil (relative to the remote airflow). See figures 4-25 and 4-26.

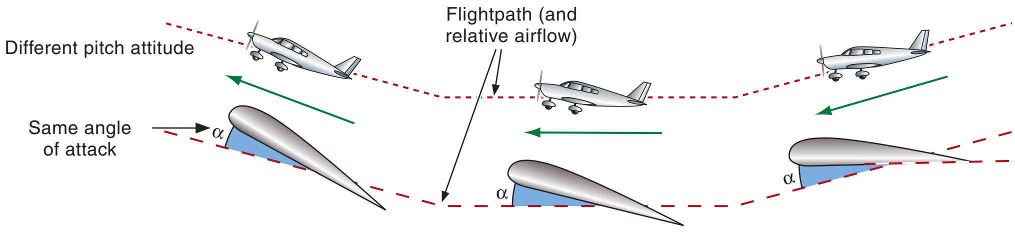


Figure 4-25 Same angle of attack, but different pitch attitudes.

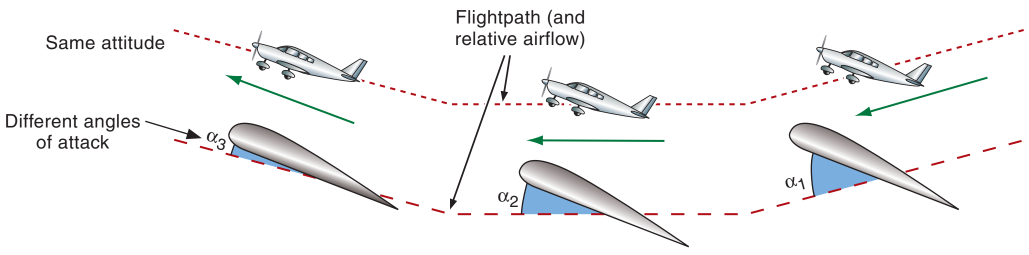


Figure 4-26 Same pitch attitude, but different angles of attack.

2. Do not confuse angle of attack with *angle of incidence*—the angle at which the wing is mounted onto the fuselage, relative to the longitudinal axis. The angle of incidence is fixed at construction (figure 4-27), while the angle of attack changes in flight.

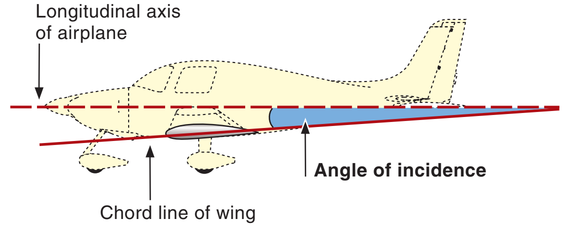


Figure 4-27 The angle of incidence is fixed during design and construction.

Pressure Distribution and CP Movement

Bernoulli's principle links a decrease in static pressure with an increase in velocity, which means a decreasing static pressure goes hand-in-hand with an accelerating airflow. The shape of the airfoil and its angle of attack determine:

- the acceleration of the airflow above and below the wing; and
- the distribution of the static pressures over the surface and the lifting ability of the airfoil.

If we reduce speed while flying straight-and-level, and we progressively increase the angle of attack, two important things occur.

1. The lifting ability of the wing increases, allowing the wing to produce the same amount of lift (required to counteract the weight) at a lower airspeed.
2. The center of pressure (CP) moves forward—the furthest forward is about ⅕ of the chord (20 percent) back from the wing leading edge.

At normal cruise speeds (about 4° angle of attack), the CP is located approximately ½ of the chord back from the wing's leading edge. As the angle of attack increases with the reduction in airspeed, the CP moves forward until a point is eventually reached where the airflow over the wing upper surface cannot follow the curved surface, but separates and becomes turbulent, and produces significantly less lift. This is known as the *critical* or *stall* angle of attack. At the critical angle of attack—about 16° where the streamline airflow over the wing upper surface breaks down—the CP moves rearward.

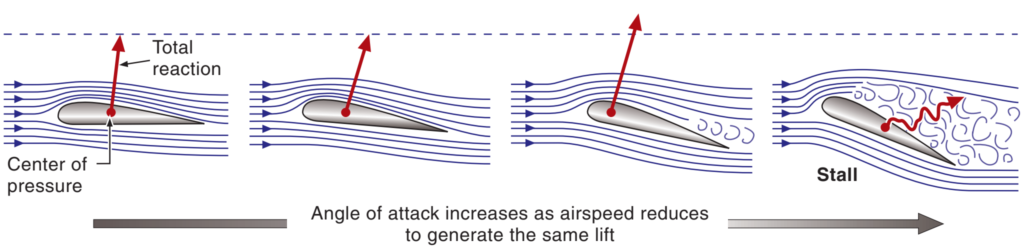


Figure 4-28 The size of the aerodynamic force and the CP position change at various angles of attack.

Changes in the size and location of the aerodynamic force produce a different *moment* (or *rotating effect*) in the pitching plane of the airplane, (this means that the airplane will want to rotate nose-up or nose-down to a new pitch attitude). The extent of this pitching moment depends on both the size of the aerodynamic force and the distance between the CP and the CG. You can normally neutralize this moment, and prevent the airplane from pitching nose-up or nose-down, by varying the aerodynamic force generated by the *horizontal stabilizer.* This is achieved by the forward and rearward movement of the control column, which controls the elevator (see also Chapter 5).

Past the stall angle, the significant rearward movement of the CP and the changed airflow over the horizontal stabilizer cause a nose-down pitching moment, and the nose of the airplane will drop, even with the control column held fully back (nose-up). This is a good safety feature because the nose-drop reduces the angle of attack below the stall angle. With appropriate stall recovery actions by the pilot, the angle of attack will remain below the critical (or stall) angle.

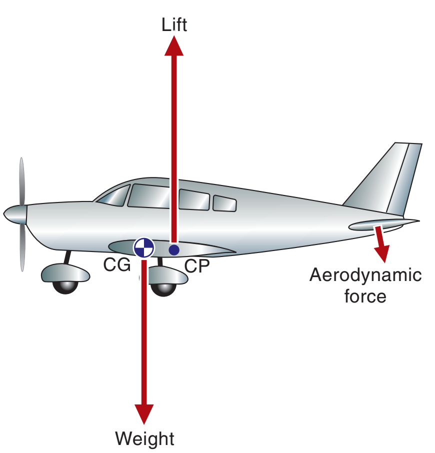


Figure 4-29
The elevator keeps the attitude constant.

Contamination of the Wings

Any contamination or damage to a wing, especially to its main lifting surface (the upper third rearward from the leading edge), will disrupt the smooth airflow over the airfoil and cause it to separate from the wing at a lower angle of attack than usual. This will cause decreased lift, increased drag, and may make it difficult, or even impossible, for the airplane to become airborne on takeoff.

Frost on a wing disturbs the airflow, reduces its lifting ability, and can prevent an airplane from becoming airborne.

If there is *frost*, *ice*, or any other *contamination* (such as the remains of insects or a build-up of salt from sea-spray, for example) on the wings, remove this contamination before flying.

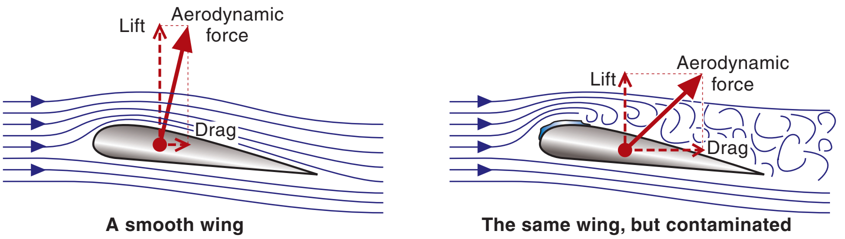


Figure 4-30
Contamination on the wings can seriously affect the lifting characteristics.

Drag

Drag is the aeronautical term for the air resistance experienced by the airplane as it moves through the air. It acts in the opposite direction to the motion of the airplane, and is the enemy of flight. Streamlining of shapes, flush riveting, polishing of surfaces and many design features are all attempts to reduce the drag force.

Drag opposes motion.

The function of the *thrust* produced by the propeller is to overcome the *drag*. The lower the drag, the less the thrust required to counteract it. The advantages of a lower thrust requirement are obvious: smaller (and possibly fewer) engines, lower fuel flow, less strain on the engine(s) and associated structures, and lower operating costs.

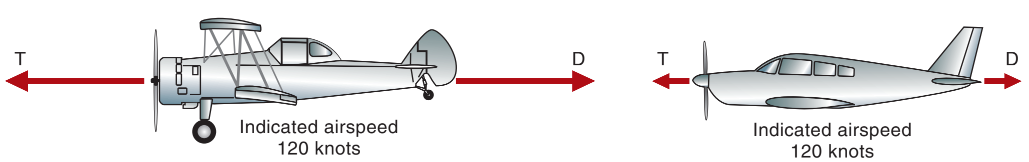


Figure 4-31 Low drag requires only low thrust to counteract it.

Total Drag

Total drag is the sum of induced drag and parasite drag.

The total drag is the sum total of the various drag forces acting on the airplane. A convenient way of studying these various types of drag forces is to break them up into two basic groups.

1. Those drag forces not directly associated with the development of lift—known as *parasite drag,* which includes form drag, skin friction and interference drag. (Form drag and skin friction are sometimes classified together under the name *profile drag*.)

2. Those drag forces associated with the production of lift, known as *induced drag* (manifested as vortices at the trailing edge of the wing and especially at the wingtips).

Parasite Drag

Parasite drag comprises *skin friction*, *form drag*, and *interference drag*.

Skin-Friction

Friction forces between an object and the air through which it is moving produce skin-friction drag. The magnitude of this component of parasite drag depends on:

- the surface area of the airplane—the whole surface area of the airplane experiences skin-friction drag as it moves through the air;
- roughness on a surface (including ice-accretion)—flush riveting and polishing are attempts to smooth the surface and reduce skin-friction drag; and
- airspeed—an increase in airspeed increases skin-friction drag.

Form Drag

When the airflow actually separates from the airfoil, disturbing the streamline flow and forming eddies, a turbulent wake is formed which increases drag. This is form drag.

Perhaps the easiest way to distinguish form drag from skin-friction drag is to consider a flat plate in two different attitudes relative to the airflow. At zero degrees angle of attack, the drag is all skin friction. When the flat plate is perpendicular to the airflow, the drag is all form drag.

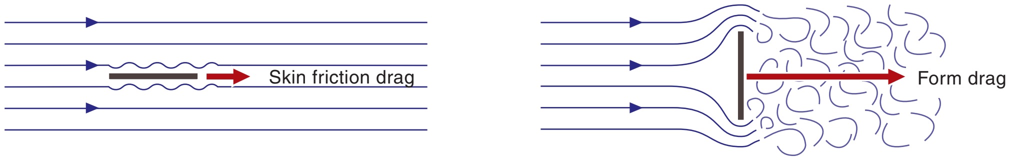


Figure 4-32 Skin friction and form drag.

The point at which the streamline airflow separates from the airfoil and becomes turbulent is known as the *separation point*. As the wing's angle of attack increases, the separation point moves forward and the turbulent wake becomes deeper. The size of the wake (caused by an airfoil, or indeed the entire aircraft) indicates the magnitude of the form drag—the larger the wake the greater the form drag.

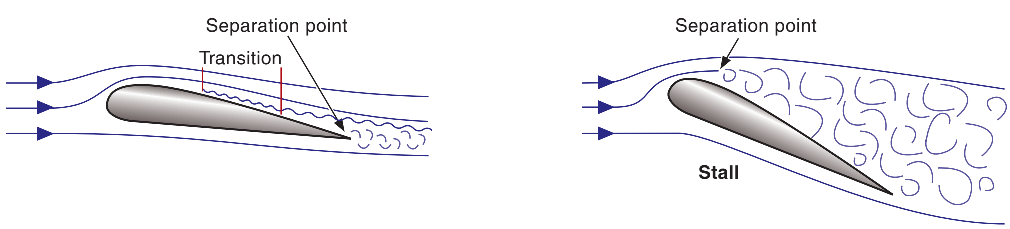


Figure 4-33 A stalled wing increases form drag substantially.

Streamlining reduces form drag by decreasing the curvature of surfaces. This delays the separation of the airflow, and thereby reduces the size of the turbulent wake. The designer may choose an airfoil of different *fineness ratio* (wing thickness/chord) to achieve better streamlining.

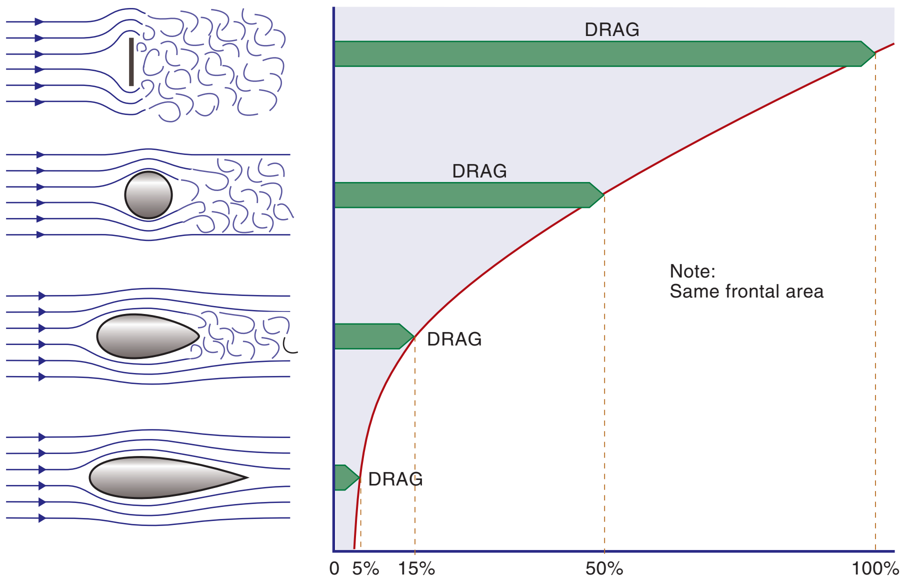


Figure 4-34 Streamlining, especially behind the shape, greatly reduces form drag.

Streamlining of other parts of the airframe can be achieved by adding *fairings*—parts of the external surface of an airplane that encourage streamline flow, thereby reducing eddying and decreasing drag (figure 4-35).

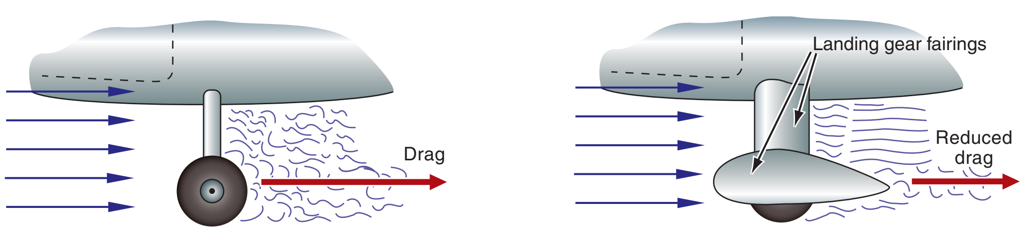


Figure 4-35 Streamlining reduces form drag.

Remember, streamlining may be ineffective if ice is allowed to form (figure 4-36).

Figure 4-36 Ice accretion on the airframe will increase drag.

Interference Drag

The total parasite drag produced by an airplane is greater than the sum of the skin friction and form drag. Additional drag is caused by the mixing, or interference of airflows, which converge at the junction of various surfaces, such as at the wing-fuselage junctions and the tail section-fuselage junctions. This additional drag is referred to as interference drag. As it is not directly associated with the production of lift, interference drag is a component of parasite drag. Smooth fairings at surface junctions reduce interference drag.

Parasite Drag versus Airspeed

At zero airspeed there is no relative motion between the airplane and the air. Therefore there is no parasite drag. As the airspeed increases, the skin friction, form drag and interference drag (which together make up parasite drag) all increase.

Airspeed has a powerful effect on parasite drag. Doubling the airspeed gives four times (2-squared, or $2 \times 2 = 4$) the parasite drag, while tripling the airspeed would give $3 \times 3 = 9$ times the parasite drag. Parasite drag is therefore of greatest significance at high speeds and is small at low speeds. However, there is another form of drag called induced drag, which increases with reducing airspeed (increasing angle of attack). An airplane flying at a speed just above the stall may have only 25 percent of its total drag caused by parasite drag, with most of the total drag caused by induced drag.

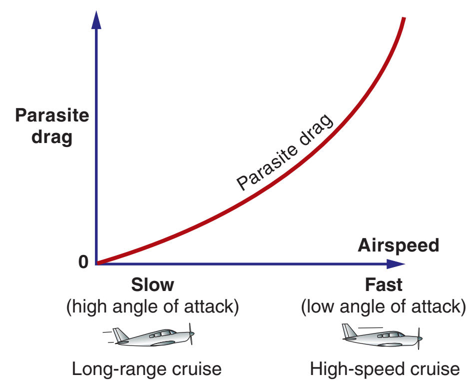


Figure 4-37
Parasite drag increases with airspeed.

Induced Drag

By definition lift is said to act at right angles to the remote free stream of air. It is the vertical component of the total reaction. At lower airspeeds, the angle of attack is higher, and the total vector is tilted rearwards. The increasing horizontal component is induced drag. It is an unavoidable cost for the generation of lift.

Induced drag occurs when lift is produced and is closely related to the angle of attack.

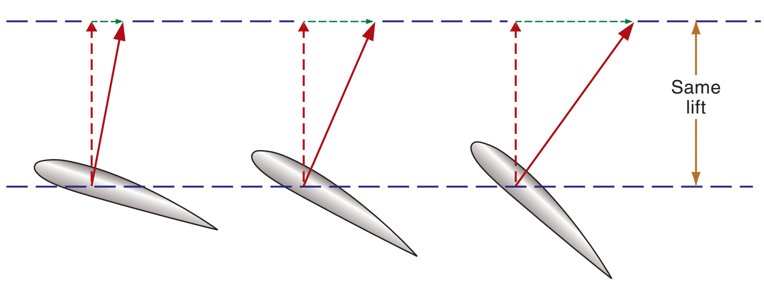


Figure 4-38 Induced drag increases as angle of attack increases.

Vortices

To produce lift, the static pressure on the upper wing surface will be less than that on the lower wing surface. The air flowing over the bottom surface of the wing tends to flow outward as well as rearward. The air flowing over the top surface of the wing has a lower pressure and tends to flow inward, toward the aircraft fuselage, as well as rearward.

When the two flows meet at the trailing edge they are flowing across, or at different angles to each other and a sheet of *trailing-edge vortices* rotating clockwise (when viewed from the rear) is formed. At the wingtips, where the spanwise flow is greatest, the strongest vortices are formed. These are known as *wingtip vortices*. A vortex is a whirling or twisting flow of air or some other fluid. Wingtip vortices are also discussed under *Wake Turbulence* on page 186.

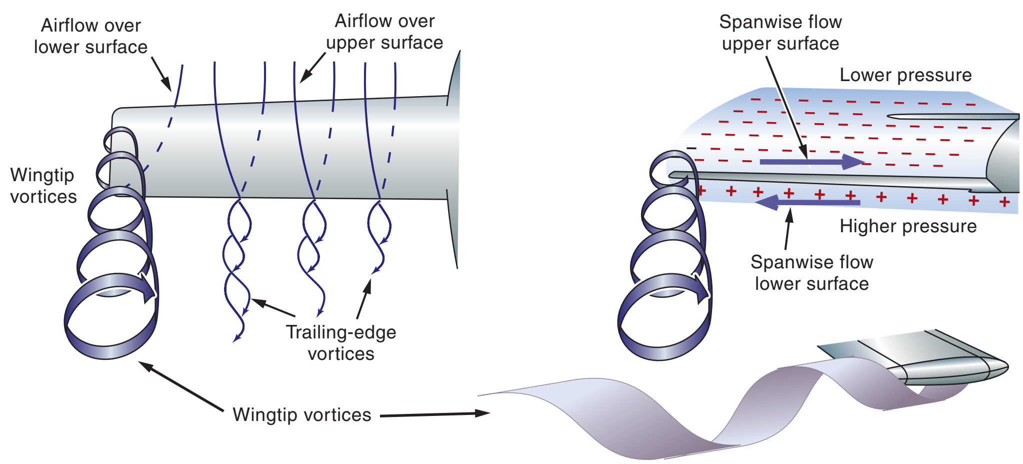


Figure 4-39 The production of lift creates wingtip vortices and induced drag.

Angle of Attack

The greater the lift produced, the greater the induced drag. Induced drag is therefore most significant when the wing is at high angles of attack, such as during low-speed flight or maneuvering. Near the stall speed in level flight, induced drag could account for 75% of the total drag (parasite drag making up the rest), yet at high speed in level flight the induced drag might provide only 1% of the total drag.

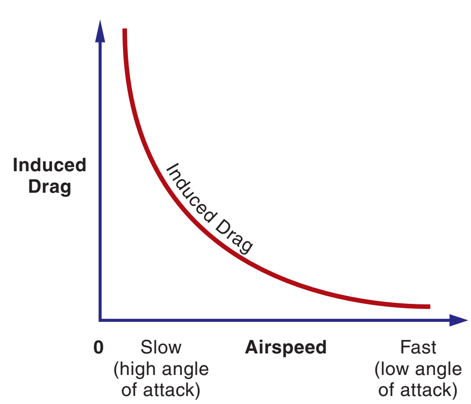


Figure 4-40
Induced drag is greatest at low speeds and high angles of attack.

Wing Design

Induced drag is affected by the span-to-chord ratio, known as the *aspect ratio*. Wings with a high aspect ratio (such as those on sailplanes) produce significantly less induced drag than short, stubby wings.

Figure 4-41
High aspect ratio.

The Total Drag on an Airplane

Total drag is the total of all the drag forces. As we have seen, total drag has two components:

- *parasite drag;* and
- *induced drag.*

If we combine the graphs of parasite and induced drag as they vary with airspeed, we end up with a graph that illustrates the variation of total drag with airspeed (for a given airplane in level flight at a particular weight, configuration, and altitude). This total drag graph (figure 4-42) of drag versus airspeed (angle of attack) illustrates an extremely important relationship. It is a summary of all we need to know about drag.

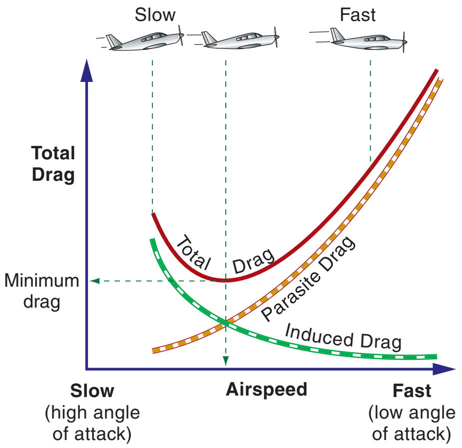


Figure 4-42 Total drag versus airspeed.

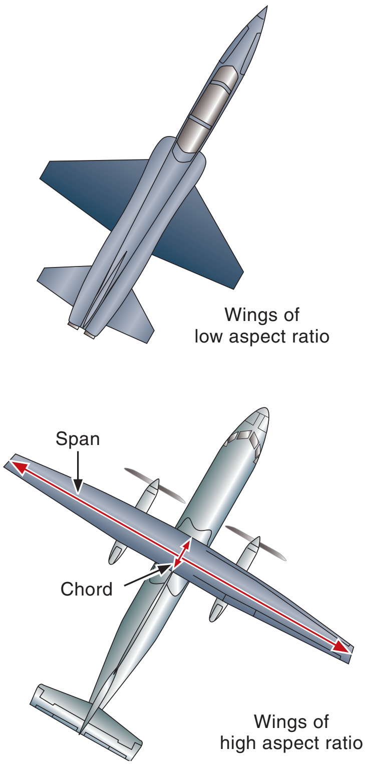


Figure 4-43 Aspect ratio.

The parasite drag increases with speed. The induced drag decreases as the speed increases. The graph shows how induced drag is predominant at low speed, while at high speed the parasite drag predominates. The total drag is least at the point where the parasite drag and the induced drag are equal. Many aspects of airplane performance are related to this *minimum drag speed.*

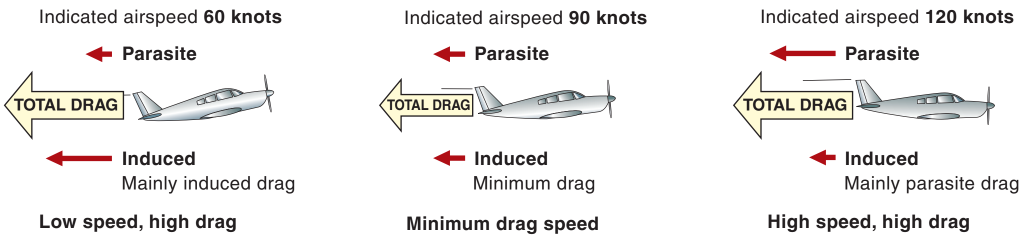


Figure 4-44 Minimum drag speed.

Lift/Drag Ratio

The *lift curve* shows a steady increase in the coefficient of lift as the angle of attack is increased, up to the stall angle, beyond which C_L decreases.

The *drag curve* shows that drag is least at small positive angles of attack and increases either side as angle of attack is increased or decreased. As the stall angle is approached the drag increases at a greater rate. At the stall the separation of streamline airflow and the formation of a turbulent wake causes a large increase in drag.

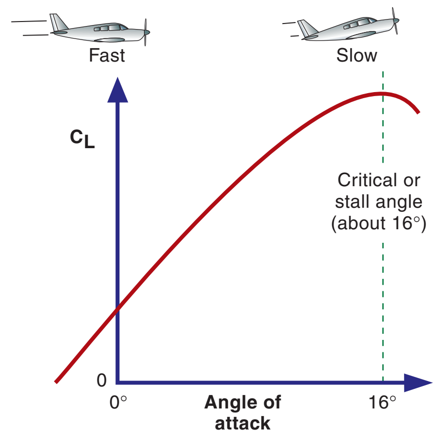


Figure 4-45 C_L versus angle of attack.

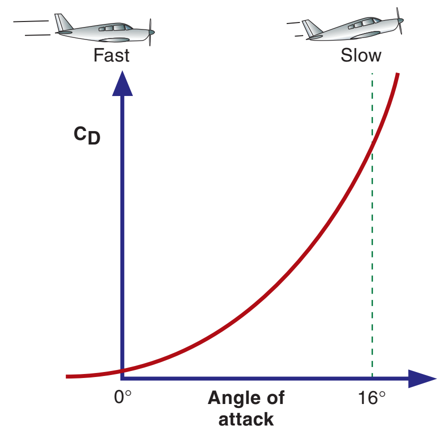


Figure 4-46 C_D versus angle of attack.

To determine the performance and efficiency of an airfoil at a particular angle of attack (and airspeed), both the lift and the drag need to be considered. The size of lift compared to weight is the *lift/drag ratio* and is very important.

The most efficient angle of attack is the angle that gives the maximum or best lift/drag ratio, typically 10:1. In most airplanes you do not have an instrument to indicate angle of attack, but the airspeed indicator is a good guide because airspeed is related to angle of attack. High angles of attack in steady flight are associated with low airspeeds (and vice versa).

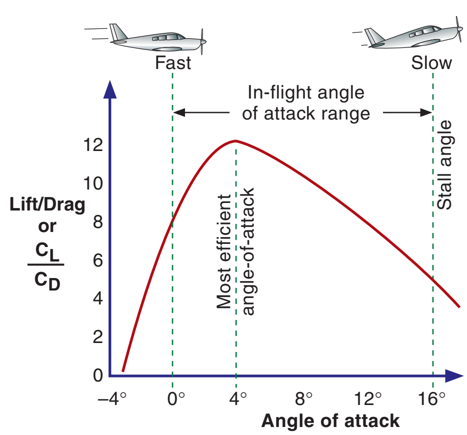


Figure 4-47 Lift/drag ratio versus angle of attack.

The angle of attack (and airspeed) for the best lift/drag ratio gives the required lift (to counteract the weight) for the minimum cost in total drag. At any other angle of attack there is a greater cost in terms of increased drag to obtain the same lift.

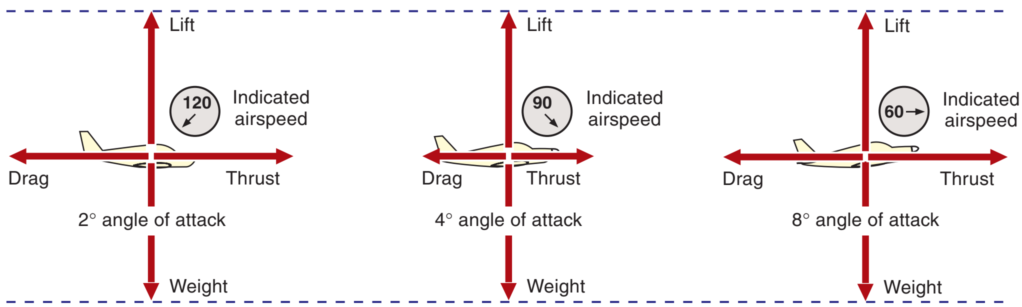


Figure 4-48 Same lift at a different cost in total drag.

In steady flight drag is counteracted by thrust. If the lift required to counteract the weight is obtained at the minimum cost in drag, then thrust can be kept to a minimum with the resulting benefits—smaller powerplant, better economy through lower fuel and maintenance costs, and so on.

The L/D ratio is greatest when the drag is least—this occurs at about 4° angle of attack. For a propeller-driven airplane some important in-flight performance characteristics are obtained at the best L/D ratio, such as the maximum cruise range and the maximum power-off glide range.

Wing Flaps

The type of wing flaps fitted to most airplanes are those mounted on the trailing edge of the main wings. They serve two purposes: to increase the lifting ability of the wing, and to increase drag:

- sometimes it is desirable to fly slowly, for instance when taking off and landing. The usual method to do this safely is to use the flaps to *increase the lifting ability* of the wing, enabling it to produce the required lift at a lower airspeed; and
- at other times it is useful to have *increased drag*—to help reduce the airspeed, or to increase the rate of descent and allow a steeper descent angle without increasing the airspeed.

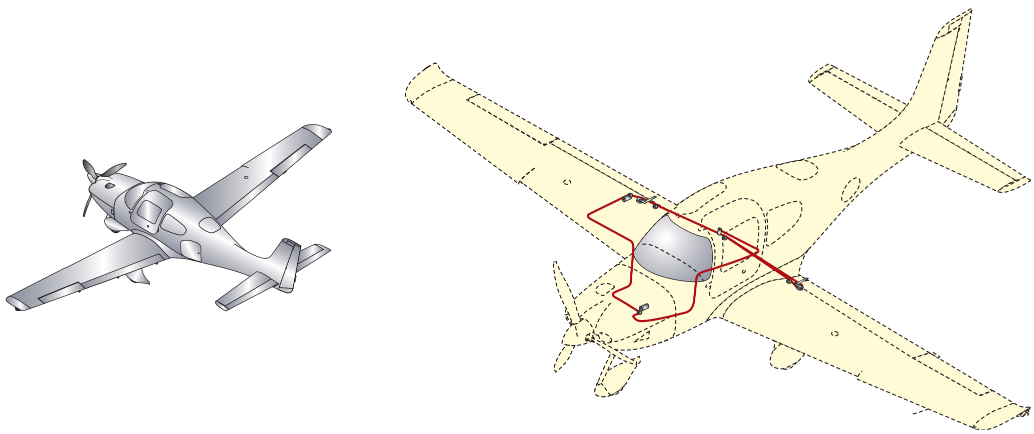


Figure 4-49 Typical flap installation—a Cirrus wing-flap system.

In straight-and-level flight the weight is counteracted by the lift:

lift	=	lifting ability of the wing	×	dynamic pressure	×	wing area
L	=	C_L	×	$\frac{1}{2}\rho V^2$	×	S

Wing flaps allow the pilot to change the basic airfoil shape to one which has an increased lifting ability (and also an increased wing area, in the case of Fowler flaps), enabling the required lift to be generated at much lower speeds.

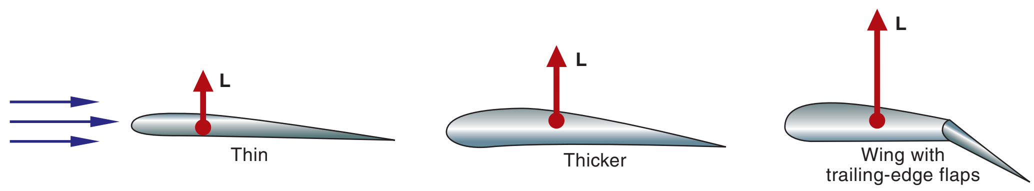


Figure 4-50 Same airspeed: increased camber and/or wing flaps give higher lift.

When the wing is near the stall angle of attack, the required lift with flaps extended will be generated at a much lower airspeed. When the stall angle is finally reached, the airspeed is much lower than that for flaps up. This means that all the other speeds which are factored from the stall speed, such as takeoff speed, approach speed, and landing speed, can be lower—a safer situation that allows shorter takeoff and landing distances.

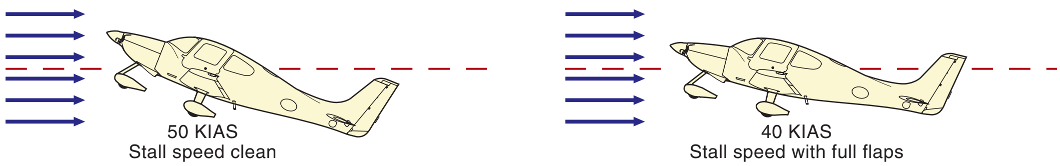


Figure 4-51 Flaps lower the stall speed (and nose attitude).

Lift/Drag Ratio

Trailing-edge flaps decrease the lift/drag ratio, and reduce glide range.

When the flaps are extended the lift increases, but so too does the drag. When we consider the angle of attack giving the best lift/drag ratio, the drag increase is proportionately greater than the lift increase, therefore the lift/drag (L/D) ratio decreases once the flaps are extended. As a result of a lower L/D ratio, the airplane will not glide as far with flaps lowered as it would when *clean* (flaps up)—nor will it climb at as steep an angle. Also, if you cruise with flaps lowered, more fuel will be required to travel the same distance.

Think of the trailing-edge flaps at their early extension as *lift* flaps (when the lifting ability of the wings is increased significantly for a moderate cost in drag), and when fully extended as *drag* flaps. The latter stages of trailing-edge flap extension give only a small increase in lifting capability for a large increase in drag. In both cases the L/D ratio will reduce, however the L/D ratio will decrease greatly with full flaps extended. When the flaps are extended, because the drag increases, the speed will decrease unless power is added or the rate of descent increased—or both.

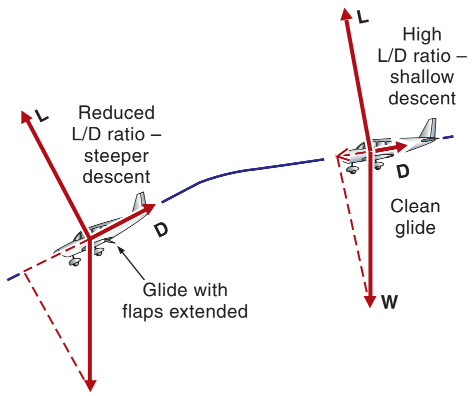


Figure 4-52 Effect of flaps on lift/drag ratio.

Approach

When flaps are extended the L/D ratio reduces, which enables the pilot to make a steeper approach without increasing airspeed.

Takeoff and Landing

One of the main functions of flaps, as previously stated, is to provide the same lift at a lower airspeed. This not only reduces takeoff and landing speeds (which is safer), but also shortens the length of runway required.

Ballooning

The initial effect of lowering the trailing-edge flaps is to produce an increased aerodynamic force because of the increased camber. With flaps extended, a lower pitch attitude is required to decrease the angle of attack, and prevent a short-lived climb called a *balloon.* It is only short-lived because the increased drag soon slows the airplane down, reducing the aerodynamic force. Conversely, raising the flaps can cause the airplane to *sink,* unless you raise the pitch attitude.

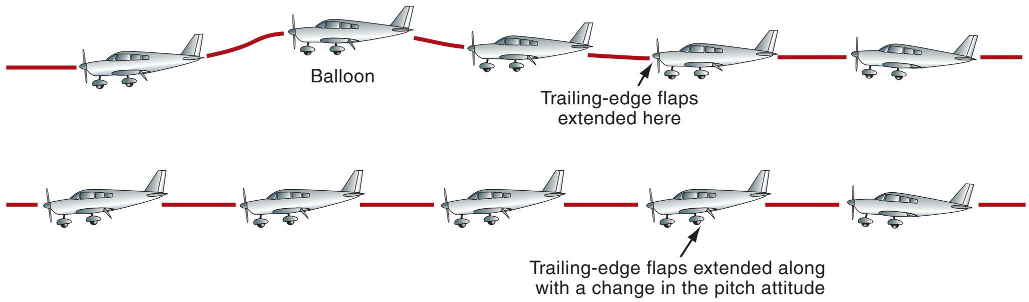


Figure 4-53 Lowering the flaps can cause the airplane to balloon unless you simultaneously adjust the pitch attitude.

Pitch Attitude

Because the increased camber resulting from extending the trailing-edge flaps occurs at the rear of the wing, the center of pressure moves rearward as the flaps are extended. The resultant pitching effect will vary between airplane types. Elevator pressure will be required to hold the desired pitch attitude, but you can trim this steady pressure off.

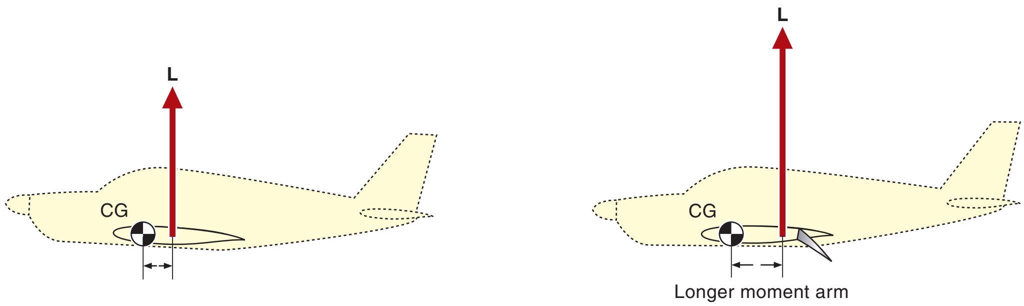


Figure 4-54 Extending the flaps may cause the nose to pitch.

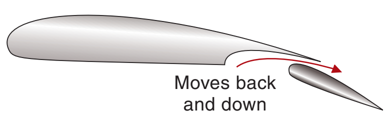


Figure 4-55 A Fowler flap.

Changing Wing Area

Increasing the wing area allows the same lift to be produced at an even lower airspeed. Some flaps, such as Fowler flaps (which extend rearward as well as downward), increase the wing area as they are extended. Other less complex flaps simply change the cross-section of the wing, increasing camber, as they are extended. All types of flaps change lift and drag, and consequently have an effect on the value of the L/D ratio.

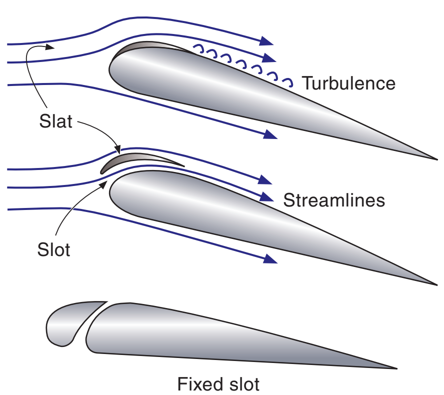


Figure 4-56
Slats and slots delay the stall.

Leading-Edge Devices

At high angles of attack, the airflow separates from the wing's upper surface and becomes turbulent. This leads to a stalled condition that destroys much of the lifting ability of the wing.

Some airplanes have leading-edge devices that allow some of the high energy air from beneath the wing to flow through a slot and over the upper surface of the wing, thereby delaying separation and the stall, allowing the airplane to fly at a higher angle of attack and a lower airspeed. This can be achieved with *slats* which form part of the upper leading edge of the wing in normal flight, but can be extended forward and/or down to form a slot.

Some wings have fixed *slots* built in to the wing leading edge, but this is less common because they generate high drag at cruise speeds. On a high performance airplane this would be unacceptable, so the more complicated extendable slat would be fitted.

Spoilers

Spoilers increase drag and reduce the L/D ratio.

Most advanced jet transports and most gliders have *spoilers* on the upper surfaces of their wings. These are hinged control panels which, when extended, disturb the airflow over the upper lift-producing part of the wing, thereby decreasing lift and increasing drag. Pilots use spoilers to reduce airspeed and/or steepen the descent path without increasing airspeed. On large jet airplanes, pilots deploy the spoilers after touchdown to dump the lift and get all of the weight onto the wheels, thus making the wheel brakes more effective.

Thrust

is one of the four main forces that act on an airplane. To maintain a steady straight-and-level speed, the thrust must equal the total drag of the airplane. To accelerate the airplane in level flight, thrust must be greater than drag; conversely, to decelerate in level flight, thrust must be less than drag.

A piston engine uses a propeller to convert the power output of the engine into thrust. Engine power is transmitted by a shaft to the propeller as *torque* or *turning effect*. This power is used to rotate the propeller, which converts most of the torque supplied by the engine into an aerodynamic force called *thrust*.

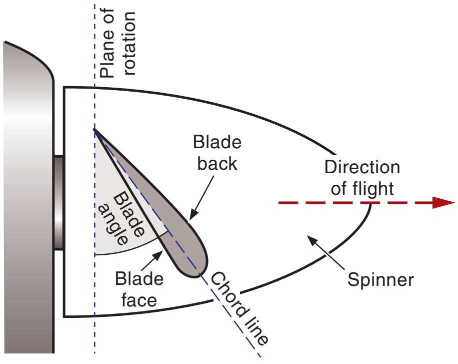


Figure 4-57 Propeller terminology.

The propeller blades are *airfoils* that generate aerodynamic forces in a similar way to other airfoils, such as the wings, by modifying the airflow around them. Notice how the cross-section of a propeller blade resembles the cross-section of a wing.

As the propeller blade rotates through the air, the acceleration of the airflow over the front cambered surface of the blade causes a reduced static pressure ahead of the blade (Bernoulli's principle). The result is a forward thrust force on the propeller blade which pulls the airplane along. Air density affects the efficiency of a propeller, as it does a wing. In addition, the less dense the air, the less the mass of air accelerated rearward, and the less effective the propeller, such as at high altitudes or on very hot days.

Consider just one *blade section,* or *blade element* as it is sometimes called, at some radial distance from the hub or the centerline of the propeller rotation. The blade section is an airfoil and it has a leading edge, a trailing edge, a chord line and a camber just like any other airfoil.

The angle which the chord line of a propeller section makes with the plane of rotation is called the propeller *blade angle.* As we shall soon see, the blade angle varies from a large angle at the root near the hub, and gradually becomes less toward the propeller tip. However, the rotating blade creates not only thrust but also many unbalanced forces. These are considered later in this chapter.

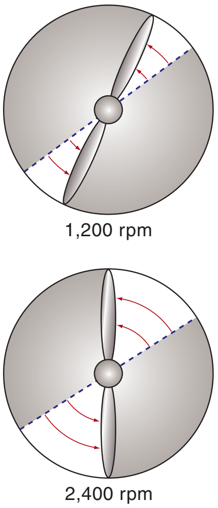


Figure 4-58 The speed of the blade section depends on the radius and RPM.

Propeller Motion

Rotational Velocity

If the airplane is stationary, the motion of the propeller section under consideration is purely rotational. The further out along the blade the section is, the faster its rotational velocity. Also, the higher the RPM (revolutions per minute) of the propeller, the faster the rotational velocity of the section.

Forward Velocity

As the airplane moves forward in flight, the propeller section will have a forward velocity as well as its rotational velocity. When this forward motion is combined with the rotational velocity, the overall *resultant velocity* of the propeller blade section through the air is obtained, as shown in figure 4-59. The angle between the resultant velocity (and therefore relative airflow) of the propeller blade and the plane of rotation is called the *helix angle* or the *pitch angle* or the *angle of advance.*

Helical Motion

Each propeller blade section follows a corkscrew path through the air—called a *helix*—as a result of the combined rotational and forward velocities. The easiest way to picture it is to consider the helix as the path which the trailing edge of the propeller section follows.

The blade section experiences a relative airflow directly opposite its own path through the air. The angle between the chord line of the propeller blade section and the relative airflow is its *angle of attack*. Notice that the angle of attack plus the helix angle (pitch angle) make up the blade angle.

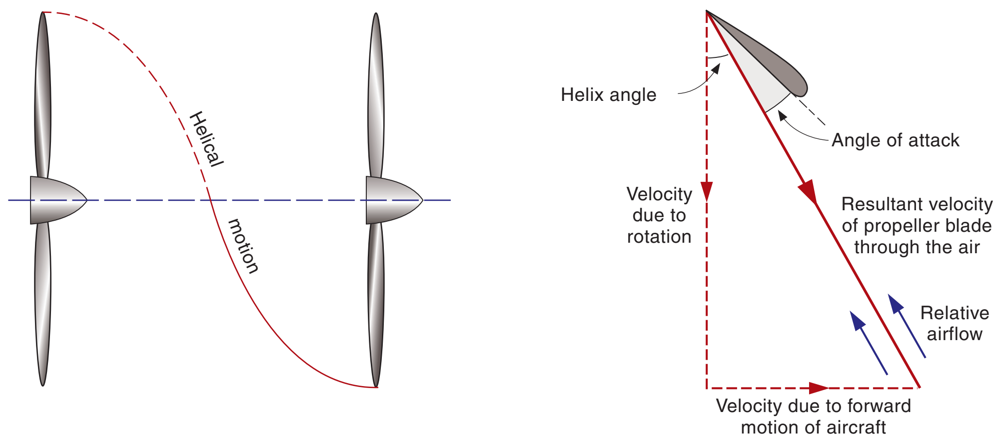


Figure 4-59 Each propeller blade-section follows its own path.

When the airplane is in flight each propeller blade section will have the same forward velocity component. What will differ, however, is the rotational component of velocity—the further each blade section is from the propeller shaft the faster it is moving. If the blade angle was the same along the whole length of the propeller (which we know is not the case), then the angle of attack would be different at all points.

For a propeller with the same blade angle along its length, the angle of attack would vary with distance from the propeller shaft, causing thrust to be produced in an inefficient manner.

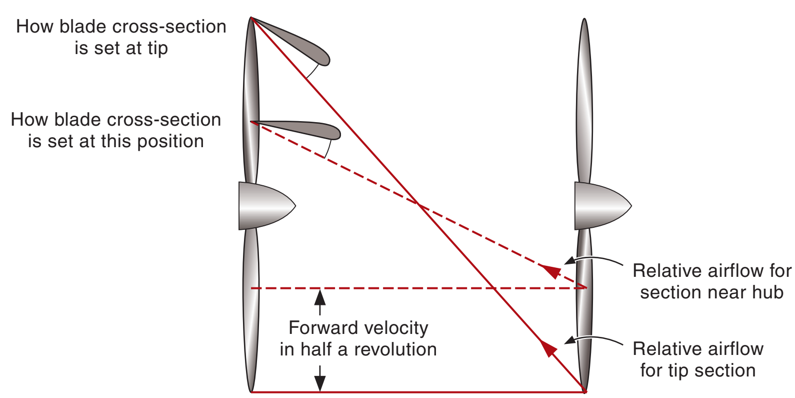


Figure 4-60
The propeller blade angle is made progressively larger from tip to hub to provide efficient angles of attack along its full length.

Like all airfoils, there is a most efficient angle of attack. If the propeller is designed to be most efficient at a certain airspeed of the airplane and RPM of the propeller, then the designer will aim to have this most efficient angle of attack along the whole length of the propeller blade when it is operating under the design airspeed and RPM conditions. To achieve this, the blade angle at the hub needs to be much greater than the blade angle at the tip. This is known as *blade twist* or *helical twist*.

A propeller has blade twist to maintain the same angle of attack along the length of the blade.

Forces on a Propeller Blade

When considering a wing, the total aerodynamic force is resolved into a lift component perpendicular to the relative airflow, and a drag component parallel to the relative airflow. For a propeller airfoil, however, each blade section has a different oriented relative airflow because of the different rotational velocities. It would therefore be complicated to resolve the aerodynamic forces into components parallel and perpendicular to the relative airflow. Therefore when considering the forces on a propeller blade it is much more convenient to resolve the total reaction into two components:

- one in the plane of rotation called *propeller torque* (which is resistance to motion in the plane of rotation); and
- another in the direction perpendicular to the plane of rotation called *thrust*.

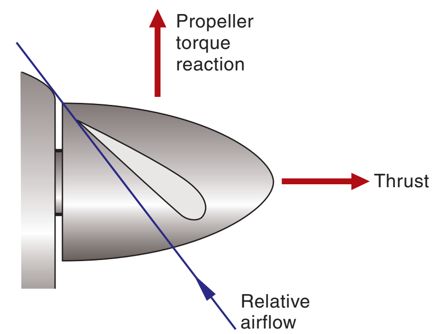


Figure 4-61
Forces on a propeller blade.

For a wing, drag must be overcome to provide lift. For a propeller, the propeller torque must be overcome or balanced by the engine for the propeller to provide thrust. Opening the throttle increases the engine power, overcomes the propeller torque, causes the propeller to rotate faster and generate more thrust.

Propeller Efficiency

An efficient propeller can convert a lot of the power produced by the engine (the brake horsepower) into thrust (that is, to thrust horsepower). A less-efficient propeller converts less of the engine power (brake horsepower or BHP) to thrust (thrust HP). Therefore:

$$\text{Propeller efficiency} = \frac{\text{thrust horsepower}}{\text{brake horsepower}}$$

Variation of Propeller Efficiency

Only part of the propeller blade is capable of producing thrust efficiently—this usually lies at some distance from the hub between 60 and 90 percent of the blade radius, with the greatest useful thrust produced at approximately 75 percent of the blade radius. Reference to blade angle, angle of attack, and so on, will refer to this most effective part of the propeller blade.

Now consider a well-designed fixed-pitch propeller blade. The term *fixed-pitch* means that the blade angle is fixed and unable to be changed, as on most training airplanes. If the propeller RPM is constant, then the direction of the relative airflow and the angle of attack will be determined by the forward speed.

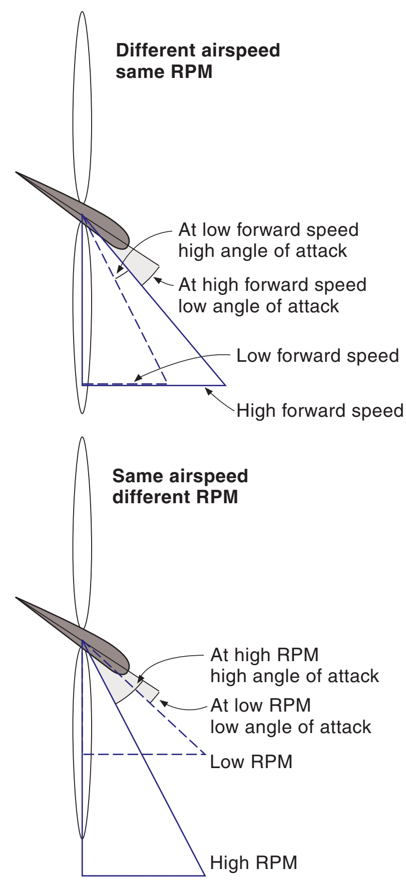


Figure 4-62
Fixed-pitch propeller -- the angle of attack varies with forward speed and RPM.

As the forward airspeed increases, the angle of attack of a fixed-pitch propeller turning at a constant RPM will decrease. At some high forward speed, the angle of attack of the blades will be such that little or no thrust will be produced. For a given RPM, there will only be one airspeed at which the fixed-pitch propeller will operate at its most efficient angle of attack.

The designer chooses a fixed-pitch propeller whose most efficient airspeed/RPM combination fits the tasks for which the airplane is designed. For an airplane whose primary purpose is to lift heavy loads off short runways and operate at low airspeeds, a low-pitch propeller (small blade angle) is most suitable. Airplanes designed for agricultural spraying or fire-bombing are typical examples. For an airplane whose primary purpose is cruising long distances at high speeds, a propeller of higher pitch (large blade angle) is more suitable.

A fixed-pitch propeller is most efficient at only one airspeed and RPM.

Although the fixed-pitch propeller can be designed for a specific role, its maximum efficiency is limited to just one airspeed/RPM combination. Faster or slower than this speed/RPM, propeller efficiency will reduce markedly. The constant-speed propeller overcomes this problem by varying the blade angle so that it operates at an efficient angle of attack at any airspeed. Most pilots will fly constant-speed propeller airplanes early in their careers.

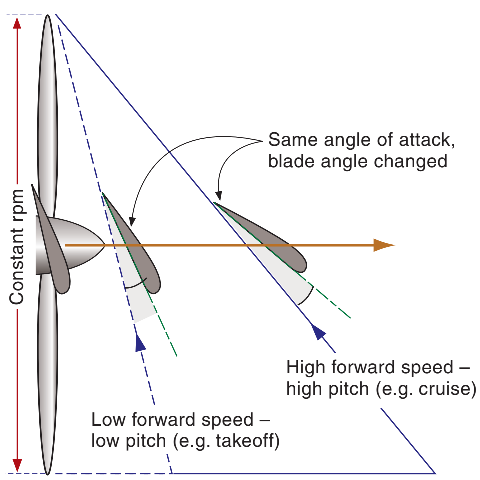


Figure 4-63 A constant-speed propeller maintains an efficient angle of attack over a wide speed/RPM range.

Variable-Pitch Propellers

An early development in improving propeller efficiency was the two-pitch propeller, which enabled the pilot to select a low pitch for takeoff and low-speed operations, and a high pitch for the higher airspeeds on the cruise and descent. More recently, the automatic *constant-speed propeller* was developed, with a blade angle that could take up any position between two in-flight limits at the *low* and *high* pitch ends of its range. This allows the propeller blade to maintain its most efficient angle of attack at all airspeed/RPM combinations.

At low airspeeds, the blade angle needs to be small for the angle of attack to be optimum. This is known as *fine pitch*. As the forward speed increases, the blade angle needs to increase toward *coarse* pitch for the angle of attack to remain optimum. The device used to achieve this is the *governor*, whose function is to regulate the propeller RPM to that selected by the pilot. It does this by automatically adjusting the blade angle so that the RPM is maintained irrespective of the airspeed and the power delivered by the engine, hence the term constant-speed propeller.

The pilot sets the recommended RPM for the operation (climb, cruise, or descent) with the propeller control. The aim is to have the propeller working close to its best angle of attack and maximum efficiency throughout its operating range, as advised by the manufacturer's operating procedures. In the extreme case of low engine power, the blade angle will reduce until it reaches the minimum limit, known as the low-pitch stop. From then on, the propeller acts as a fixed-pitch propeller, with further power reductions causing a drop in RPM because the governor cannot reduce the blade angle any further to maintain the RPM.

Takeoff

Fine pitch is used for takeoff so that the blade angle of the constant-speed propeller is at a small angle of attack. This enables the propeller to operate at maximum RPM as the throttle is advanced to the takeoff position, and so enable the engine to deliver maximum power.

Cruise

The throttle is mid-range and the propeller is set to medium pitch (low RPM) for best cruise fuel consumption.

Approach and Landing

When the airspeed and power are low, as on approach to land, the propeller blades are hard against the fine-pitch stop, and the RPM changes with throttle movements. However, in case a go-around is necessary, it is good airmanship to advance the prop control to high RPM on final approach so that the propeller can quickly and efficiently achieve maximum thrust when the throttle is advanced.

Figure 4-64
Engine instruments used with the Constant-speed propeller.

A constant-speed propeller is efficient over a range of RPM and airspeed conditions.

Constant-Speed Propeller Controls

The pitch-changing mechanism is usually operated hydraulically by governor-regulated oil pressure. In contrast to fixed-pitch propellers, where the throttle alone is used to control RPM with a constant-speed propeller there are two controls:

- the *propeller control* to control propeller RPM; and
- the *throttle* to control the manifold pressure in the engine.

The desired power is achieved by selecting certain combinations of propeller RPM and manifold pressure (see also Chapter 8). Some constant speed props employ a single lever power control that combines the prop and throttle levers.

Advantages of the Constant-Speed Propeller

A constant-speed (or variable-pitch) propeller enables the propeller to be at its most efficient angle of attack over a wide range of RPM and airspeed. In comparison, a fixed-pitch propeller only operates efficiently under the one set of RPM and airspeed conditions.

More complex constant-speed propellers used in multi-engine or turbine airplanes have other significant features, including:

- *beta range*, which is a range of very low pitch angles that reduce thrust and produce more drag for ground operations;
- *reverse thrust*—some propeller mechanisms can rotate the blades into reverse (or negative) pitch, which results in the propeller's thrust acting backwards; and
- *feathering*—on multi-engine airplanes, propellers can be feathered in flight to stop a windmilling prop, reduce drag and prevent further engine damage following an engine failure.

Unbalanced Effects of Propellers—Left Turning Tendencies

Slipstream Effect

A clockwise-rotating propeller (as seen from the cockpit) will impart a clockwise rotation to the slipstream as it flows back over the airplane, following a corkscrew path. This causes an asymmetric airflow over the vertical stabilizer and rudder. In the case of a single-engine airplane at high power, the slipstream will strike the left of the vertical stabilizer at an angle of attack, generating an aerodynamic force which pushes the tail to the right and makes the airplane *yaw left*. Some airplanes have an

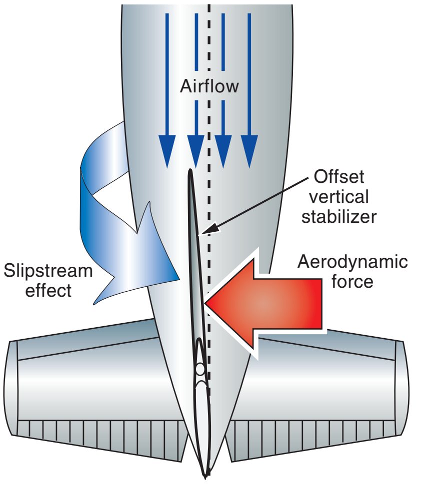


Figure 4-65 An offset fin helps counteract propeller-slipstream effect.

offset vertical stabilizer to help overcome this effect. It is most noticeable at high power and low airspeed.

Propeller Torque Effect

If the propeller rotates clockwise (when viewed from behind), the torque reaction will tend to rotate the airplane counterclockwise, which means the airplane will *roll left*. This effect is most pronounced under conditions of high power and high propeller RPM, and at low airspeeds when fixed-pitch propeller blades have a large angle of attack—for example, during takeoff.

On the takeoff ground run, the tendency to roll left is absorbed by the left mainwheel, which will have to support more load. This will increase the friction force, tending to slow it down, and consequently the airplane will *yaw left*. Notice that on the ground run this effect yaws the airplane in the same direction as the slipstream effect. Use right rudder to keep straight. A high-powered airplane, such as a P51, can roll uncontrollably if full power is applied suddenly at low airspeed (e.g. for a go-around).

Gyroscopic Effect

Gyroscopic effect is significant on the take-off run in a tailwheel airplane as the tail is raised.

Early in the takeoff run of a tailwheel airplane, the tail is lifted off the ground to place the airplane into a low drag and flying attitude. As the tail is being raised, a force is applied to the rotating propeller to tilt the rotating propeller disc forward. Because a rotating body tends to resist any attempt to change its plane of rotation, when such a change is imposed on it, a *gyroscopic precession* will be superimposed. See Chapter 10 for more on gyroscopic precession.

Gyroscopic effect causes any force applied to a spinning object to be displaced 90° in the direction of rotation. The action of *raising the tail* of the airplane on the takeoff run is like applying a forward force to the top of the rotating propeller disc. Gyroscopic precession causes an equivalent force to be applied 90° degrees in the direction of propeller rotation. With clockwise rotation, there will appear to be a force acting on the right side of the rotating propeller disc, causing the airplane to *yaw left*. The direction of yaw depends on the direction of propeller rotation. Right rudder must be applied to counteract this effect.

The extent of the gyroscopic effect depends on the propeller's *moment of inertia*. The moment of inertia depends on the mass of the propeller, how the mass is distributed along the blades and how fast the propeller is rotating. It also depends on how fast you try to change the plane of rotation—if you raise the tail quickly, the tendency to yaw left will be greater.

Raising the tail of a high-powered airplane like a P-51 Mustang on takeoff produces a much greater gyroscopic effect than raising the tail of a Piper Cub.

Asymmetric Propeller Blade Effect (P-Factor)

P-factor is present at high angles of attack (low airspeed) and high power.

P-factor occurs for tailwheel airplanes on takeoff and for all airplanes when flying at high angles of attack (low speeds). During the first part of a tailwheel airplane's takeoff run, the tail is still on the ground, the propeller shaft is inclined upward, and the plane of propeller rotation is not vertical. Because the airplane is moving horizontally, the down-going propeller blade has a greater angle of attack than the up-going blade. In addition, the down-going blade also travels further (and therefore faster) through the air than the up-going blade.

These two effects (greater angle of attack and higher blade velocity) combine to produce more thrust on the down-going half of the propeller disc than on the up-going half and the airplane will *yaw left*. P-factor is strongest at high power settings

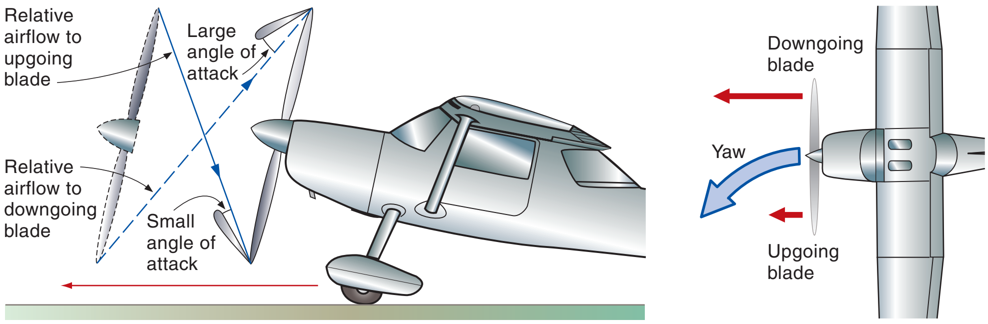


Figure 4-66 The down-going propeller blade produces more thrust when the airplane is in a nose-high attitude, causing P-factor.

and high angles of attack, both on the ground and in flight. In normal cruise flight, the P-factor is insignificant because the up-going and down-going propeller blades produce similar amounts of thrust when the angle of attack is low.

Summary

Prevent unwanted yaw with rudder.

On the takeoff ground run, the above four effects cause the airplane to *yaw left*. You can remain on the runway centerline by counteracting the yaw with right rudder. However, be cautious if there is any crosswind from the left. During flight, an increase in power will cause the airplane to yaw left due to slipstream effect and roll left due to the torque reaction. In addition, when flying slowly at a high angle of attack the airplane will yaw further left because of asymmetric blade effect.

Review 4
Forces Acting on an Airplane

4 Forces in Flight

1. Which force produced by the wings supports the airplane in flight?
2. Which force is produced by the engine–propeller?
3. Which force resists the motion of the airplane through the air?
4. Lift and weight are generally how much greater than thrust and drag in straight-and-level flight at a constant airspeed?
5. What relationships exist between lift and weight, and between thrust and drag, when the airplane is flying straight-and-level at a constant airspeed?

Airfoil Lift

6. Which surface is designed to create an aerodynamic lifting force as air flows over it?
7. What do you call a steady airflow around an airfoil in which succeeding parcels of air follow each other?
8. Where on an airfoil does the smooth boundary-layer flow separate from the airfoil surface and become turbulent?
9. Static pressure in the air is exerted in which direction(s)?
10. Which pressure is caused by motion?
11. What is total pressure energy the sum of?
12. In streamline flow, if dynamic pressure increases, what happens to the static pressure?
13. What does the expression "$\frac{1}{2}\rho V^2$" represent?
14. What line is drawn half-way between the upper and lower surfaces of the wing to give an indication of its curvature?
15. The wing shape and the angle of attack determine the profile that the airfoil presents to the airflow. What else do they determine?
16. True or false? The forces acting on an airfoil in flight, as a result of the changes in static pressure around it, may be considered to act through the center of pressure.
17. Describe how the relative airflow relates to the flight path of an airplane.
18. Define the term angle of attack.
19. If the angle of attack is gradually increased in normal cruise flight, what will happen to the lifting ability of the wing?
20. On a wing, the force of lift acts perpendicular to and the force of drag acts parallel to the:
    - **a.** chord line.
    - **b.** flight path.
    - **c.** longitudinal axis.
21. What does the angle of attack of a wing control directly?
22. What happens to the center of pressure as the angle of attack is gradually increased in the normal flight range?
23. True or false? Beyond the stall angle of attack, the lifting ability of the wing decreases significantly and the center of pressure moves rearward on the wing.
24. How will frost on the wings of an airplane affect takeoff performance?

Drag

25. What is drag?
26. True or false? If drag can be kept low, thrust can be kept low.
27. Describe the two basic groups of total drag.
28. True or false? As airspeed increases, drag caused by skin friction decreases.
29. How can form drag be reduced?
30. True or false? The spanwise flow of air on the upper wing surface is toward the wing root.
31. When is the formation of wingtip vortices and induced drag greatest?
32. When is the total drag at a minimum?
33. Why is the thrust requirement greater at high speeds and low angles of attack?
34. True or false? Minimum drag means minimum thrust to maintain airspeed.
35. What does the lift/drag ratio describe?

Wing Flaps

36. What effect does extending the flaps have on the camber of the wing?
37. Aside from lift, what do trailing-edge flaps increase?
38. The percentage increase in drag usually exceeds that in lift when the flaps are extended. Do flaps therefore increase the lift/drag ratio?
39. True or false? The extension of flaps on a glide approach allows a steeper approach path at a constant speed.
40. True or false? With flaps extended, the nose attitude of the airplane is higher.
41. True or false? Slots increase the angle of attack at which the wing stalls by delaying the separation of the smooth airflow over the upper surface of the wing.

Thrust from the Propeller

42. What does a propeller convert engine torque into?
43. True or false? At high altitudes, when the air is less dense, a propeller will be more efficient.
44. Why is a propeller blade twisted?
45. True or false? A fixed-pitch propeller is efficient at only one set of RPM and airspeed conditions.
46. True or false? A constant-speed propeller has a variable pitch angle and is efficient over a wide range of RPM and airspeed conditions.
47. As the forward speed of an airplane with a fixed-pitch propeller increases, with the RPM remaining constant, the angle of attack of the propeller blades:
    a. decreases as forward speed increases.
    b. increases as forward speed increases.
    c. remains unaltered as forward speed increases.
48. In an airplane with a clockwise rotating propeller, what does P-factor, or asymmetric blade effect cause the airplane to do?
49. During the takeoff roll in a single-engine airplane, the left tire will carry more load. Why?
50. When is torque effect greatest in a single-engine airplane?
51. How can you keep the airplane tracking straight down the runway during the takeoff roll in a single-engine airplane?

Answers are given on page 766.

Stability and Control 5

Stability

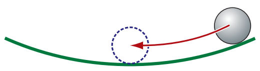


Figure 5-1
Tends to return to center.

Figure 5-2
No tendency to return.

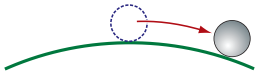


Figure 5-3
Tends to diverge.

Stability describes the initial response and subsequent behavior of an aircraft when it is disturbed from its trimmed condition by atmospheric effects, such as wind gusts or thermals. There are two stages:

- the initial response, which is called *static stability*; and
- the subsequent behavior, which is called *dynamic stability*.

Static Stability

If an aircraft tends to return to its trimmed condition, it has positive static stability or is statically stable, like a marble in a saucer (figure 5-1). If an aircraft has neutral static stability, it will tend to stay in its new condition, like a marble on a flat surface (figure 5-2). If an aircraft has negative static stability, it is unstable and will diverge further when disturbed, like a marble on a convex dish (figure 5-3).

Dynamic Stability

Dynamic stability describes the behavior of the aircraft after the disturbance. An aircraft is subject to many external forces. These are balanced in trimmed, steady flight. When the aircraft is disturbed, the forces change, and the dominant ones determine the behavior. An aircraft that is dynamically stable will experience an oscillation that is quickly damped.

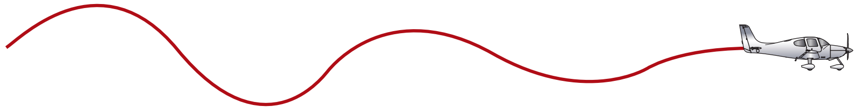


Figure 5-4 Damped oscillation—dynamically stable.

An aircraft with neutral dynamic stability will follow a continuing, undamped oscillation.

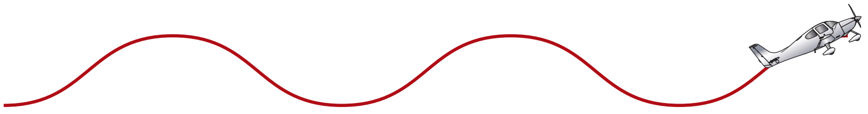


Figure 5-5 Undamped oscillation—dynamically neutral.

An aircraft that is dynamically unstable will have increasingly divergent oscillation.

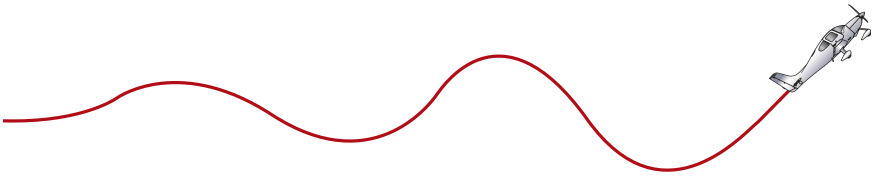


Figure 5-6 Divergent oscillation—dynamically unstable.

Stability and Maneuverability

There is a trade-off between stability and maneuverability.

An airplane with some positive stability is much easier to fly than an unstable airplane that shows a tendency to diverge from the trimmed flight attitude. The stability must not be so great, however, as to require unacceptably high control forces for maneuvering. An unstable airplane is difficult, if not impossible, to fly because of the continual need to apply control corrections. A stable airplane can almost be flown hands-off and only requires guidance rather than second-to-second control inputs by the pilot. The designer must achieve a compromise between stability and maneuverability, bearing in mind the qualities most desirable for the airplane's planned use. For instance, a passenger airplane would require more stability, whereas a fighter requires greater maneuverability.

Our examples so far have been drawn from the pitching plane, but stability in the other planes and about the other axes is just as important.

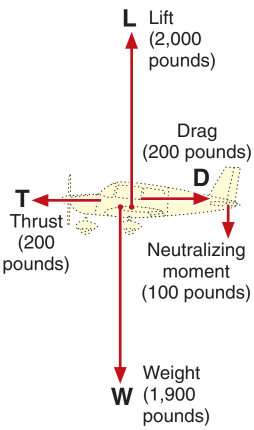


Figure 5-7 Lift counteracts weight, thrust counteracts drag in straight-and-level flight (moments neutralized by stabilizers and trim). Total weight includes download on the tail.

Airplane Equilibrium

An airplane is in a state of *equilibrium* when the sum of all forces and moments is zero. This means it will fly in a straight line at a steady airspeed. The airplane is *in trim* if all the moments in pitch, roll and yaw are zero.

As explained in the previous chapter, four main forces act on an airplane in flight: lift, weight, thrust and drag. For the airplane to remain in equilibrium in steady straight-and-level flight, the opposing forces must be equal so that they balance out, leaving an overall force of zero acting on the airplane.

Therefore:

- lift is equal to weight and acts in the opposite direction; and
- thrust is equal to drag and acts in the opposite direction.

There is usually a considerable difference between the two pairs of forces, with lift and weight being much greater in magnitude than thrust and drag in normal flight. For example, lift and weight may each be 2,000 pounds, with thrust and drag each 200 pounds (that is, a lift/drag ratio of $^{2,000}/_{200}$ = 10:1). The weight will gradually decrease as fuel is burned off, meaning that the lift required will also decrease. Thrust and drag will vary considerably depending on the angle of attack and airspeed.

Pitching Moments

The positions of the lift force acting through the center of pressure (CP), and the weight force acting through the center of gravity (CG), are not constant in flight. The basic CG position is established when the airplane is loaded, but will move as passengers or crew move around (noticeable in airliners as flight attendants walk down the cabin), if unsecured freight moves, and as fuel burns off. The CP changes position according to the angle of attack (and therefore airspeed).

A couple is a pair of equal, parallel forces acting in opposite directions which tends to cause rotation because the forces are acing along different axes.

Under most conditions of flight the CP and CG are not at the same point. The outcome is that the opposing forces of lift and weight, even though approximately equal in magnitude, will set up a *couple,* causing a nose-down pitching moment if the lift (CP) is behind the weight (CG), or a nose-up pitching moment if the CP is in front of the CG.

The different lines of action of the thrust force and the drag force produce another couple, causing a nose-up pitching moment if the drag line is above the thrust line, or a nose-down pitching moment if it is below the thrust line.

The pitching moments from the two couples should neutralize each other in level flight so that there is no *residual* (remaining) moment that would cause the airplane to pitch nose-up or nose-down.

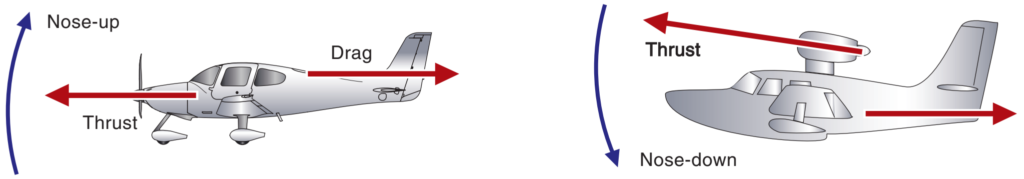


Figure 5-8 Thrust and drag form a pitching couple.

Ideally, the lines of action of the two couples are designed to be as shown in figure 5-9. With this arrangement the thrust-drag couple produces a nose-up pitching moment which approximately cancels the nose-down pitching moment of the lift-weight couple, and little or no elevator deflection or trim is required.

There is a very good reason for the lift-weight couple to have a nose-down pitching moment balanced by the thrust-drag nose-up pitching moment. If thrust is lost after engine failure, the thrust-drag nose-up couple is weakened and therefore the lift-weight couple will pitch the airplane nose-down, without any action by the pilot. The airplane will then assume a glide attitude without a tendency to lose flying speed.

It is rare to have the sum of moments exactly zero. The force generated by the horizontal stabilizer and elevator provides the final balancing force.

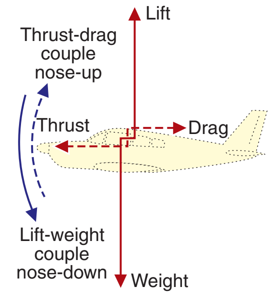


Figure 5-9 The lift-weight couple and the thrust-drag couple may be balanced.

The Horizontal Stabilizer

The horizontal stabilizer counteracts the residual pitching moments from the two main couples. It is simply an airfoil that can generate an aerodynamic force by being positioned at an angle of attack relative to the local airflow. The lift component of the aerodynamic force can act upward or downward as required by the pilot, and because of this the horizontal stabilizer usually has a symmetrical section.

If the residual moment from the four main forces is nose-down (as is most common), the horizontal stabilizer provides an aerodynamic force with a downward component on the tail section, which generates a nose-up pitching moment to balance the nose-down moment.

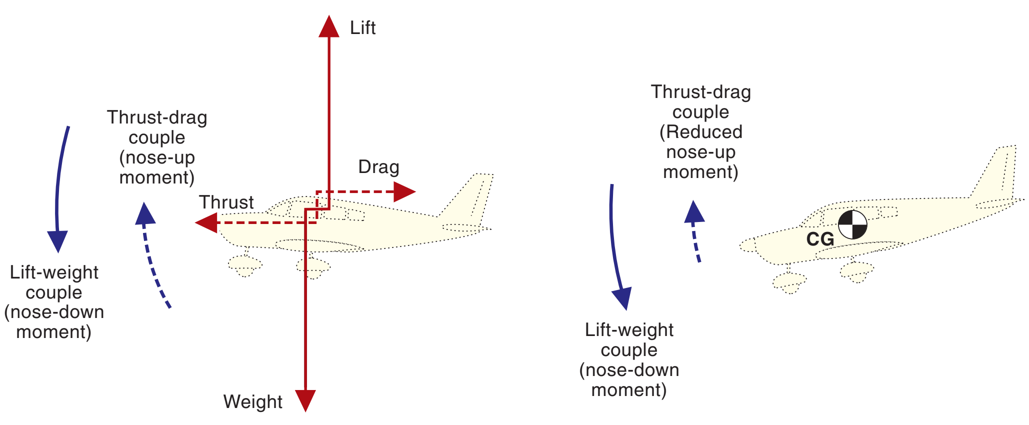


Figure 5-10 Following a loss of thrust the lift-weight couple pitches the aiplane nose-down.

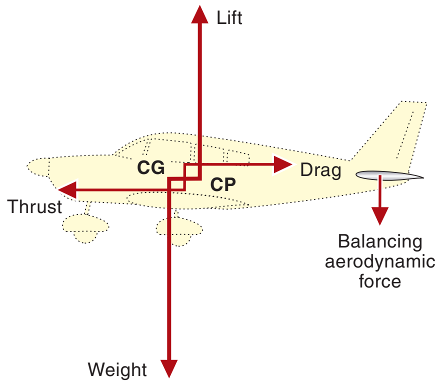


Figure 5-11 The horizontal stabilizer provides the final balancing moment.

Because the horizontal stabilizer is situated some distance from the center of gravity, its moment arm is quite long. The aerodynamic force provided by the horizontal stabilizer therefore needs only to be small to have a significant pitching effect. Consequently its size and aerodynamic capabilities are small compared with the wings.

Many airplanes are designed to operate most efficiently at cruise speed. By designing the couples to be at least in approximate equilibrium during the cruise, only small balancing aerodynamic forces are required from the horizontal stabilizer, thereby minimizing drag. Generally an airplane's center of pressure is designed to be aft of the center of gravity, with the horizontal stabilizer producing a small downward aerodynamic force.

The airplane will also pitch whenever the engine power setting is altered, because the speed of the slipstream over the horizontal stabilizer will change. When power is reduced, the slipstream over the horizontal stabilizer weakens, reducing the downward force and causing the nose to pitch down. Conversely, if the power is increased the slipstream over the horizontal stabilizer strengthens, increasing the downward force and causing the nose to pitch up. Therefore whenever power is changed you will need to retrim.

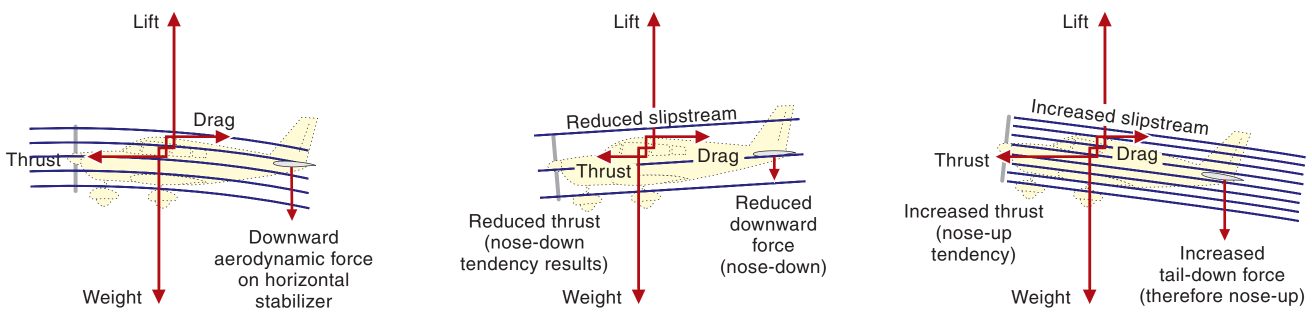


Figure 5-12 Propeller slipstream affects the force generated by the horizontal stabilizer.

Angular Movement

We may consider the motion of the airplane to occur about each of three reference axes. Each axis passes through the center of gravity and is mutually perpendicular, or at right angles, to the other two.

The *longitudinal axis* runs from front to rear through the center of gravity. Movement around the longitudinal axis is known as rolling. Stability around the longitudinal axis is known as *lateral stability,* because it is concerned with movement in the lateral or rolling plane. See figure 5-14. The *lateral axis* passes through the center of gravity across the airplane from one side to the other. Movement around the lateral axis is called pitching (nose-up or nose-down). Stability around the lateral axis is called *longitudinal stability,* because it is concerned with stability in the longitudinal or pitching plane. See figure 5-15. The *vertical axis* passes through the center of gravity and is perpendicular (normal) to the other two axes. Movement around the vertical axis is called yawing. Stability around the vertical axis is *directional stability,* because it is concerned with stability in the directional or yawing plane. See figure 5-16.

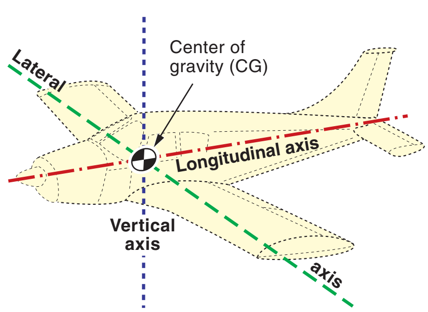


Figure 5-13 Angular movement can occur about three axes.

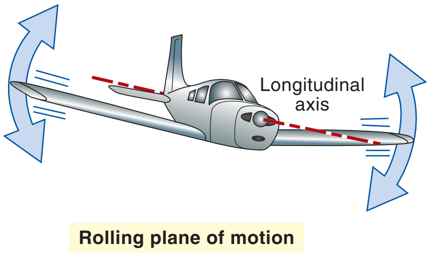


Figure 5-14
Rolling about the longitudinal axis.

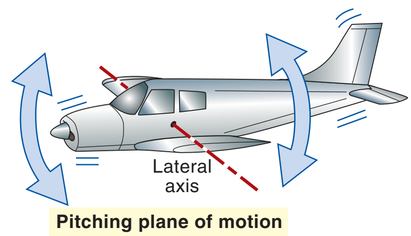


Figure 5-15
Pitching about the lateral axis.

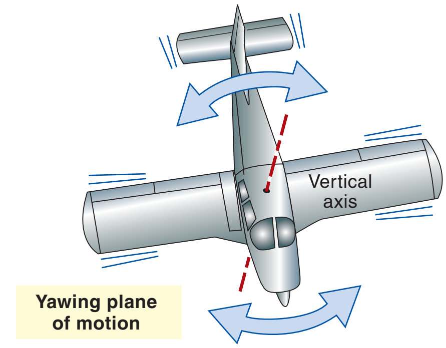


Figure 5-16
Yawing about the vertical axis.

Longitudinal Stability

Longitudinal stability is in the pitching plane and occurs about the lateral axis. To be longitudinally stable, an airplane must have a natural tendency to return to the same attitude in pitch after any disturbance. A longitudinally stable airplane tends to maintain the trimmed condition of flight and is therefore easy to fly in pitch.

The position of the center of gravity (CG) and the size of the horizontal stabilizer determines an airplane's longitudinal stability characteristics.

Let us consider a situation that is constantly occurring in flight, referring to figure 5-17. If a disturbance, such as a gust (1), changes the attitude of the airplane by pitching it nose-up, the airplane, because of its inertia, will initially continue on its original flight path and therefore present itself to the relative airflow at an increased angle of attack (2). This will cause the horizontal stabilizer to produce a greater upward force (or decreased downward force) than before the disturbance. The increased aerodynamic force acting about the CG will produce a nose-down pitching moment, causing the airplane to return to its original trimmed condition (3).

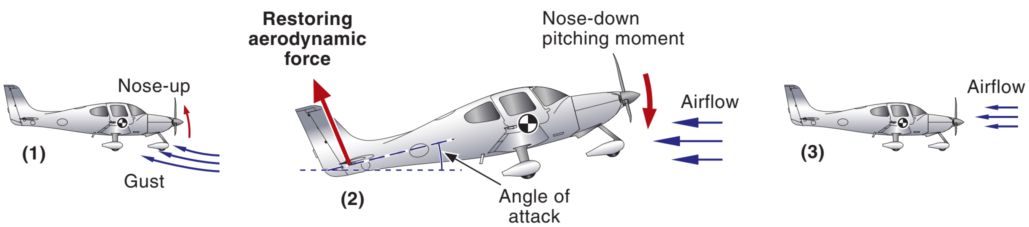


Figure 5-17 Longitudinal stability following an uninvited nose-up pitch.

As shown in figure 5-18, the horizontal stabilizer has a similar stabilizing effect following an uninvited nose-down pitch. In this way changes in the horizontal stabilizer's aerodynamic force lead to longitudinal stability.

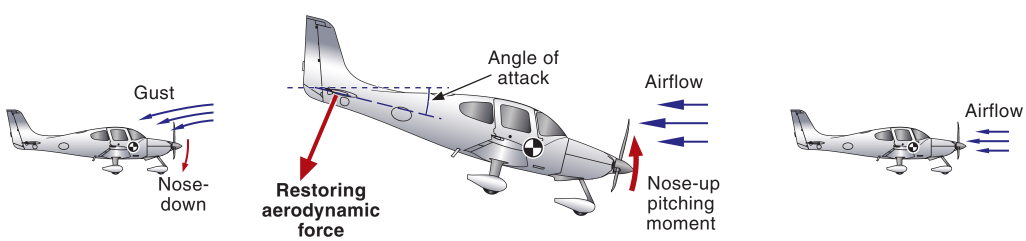


Figure 5-18 Longitudinal stability following an uninvited nose-down pitch.

A good example of the stabilizing effect of a horizontal stabilizer is the flight of a dart or an arrow through the air, where the tail feathers act as a horizontal stabilizer to maintain longitudinal stability.

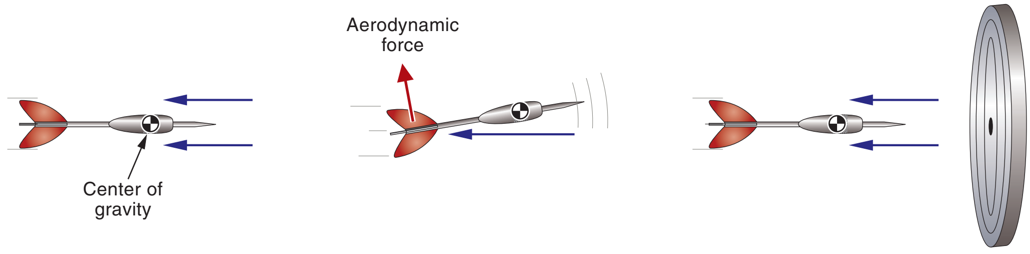


Figure 5-19 Longitudinal stability is provided by the tail feathers of a dart.

The CG and Longitudinal Stability

The longitudinal stability of an airplane is determined by the size of the horizontal stabilizer and its distance from the airplane's CG. The pilot has a lot of control over the CG position when the airplane is being loaded. The further forward the CG, the greater the moment arm of the horizontal stabilizer, and therefore the greater the leverage effect of the horizontal stabilizer aerodynamic force, and the greater the horizontal stability.

Limits are laid down for the range within which the CG must be located for safe flight. You must always load your airplane so that the actual CG position falls within the allowable CG range. If the CG is *behind* the legally allowable aft (rear) limit, the restoring moment of the horizontal stabilizer in pitch may be insufficient for satisfactory longitudinal stability, and the airplane may be difficult, or even impossible to control. The further *forward* the CG, the greater the longitudinal stability.

Also, the more stable the airplane, the greater the control force you must exert to maneuver it, which can become tiring. If the CG is even further forward, beyond the allowable limit, the elevator may not be sufficiently effective at low speeds to flare the nose-heavy airplane for landing.

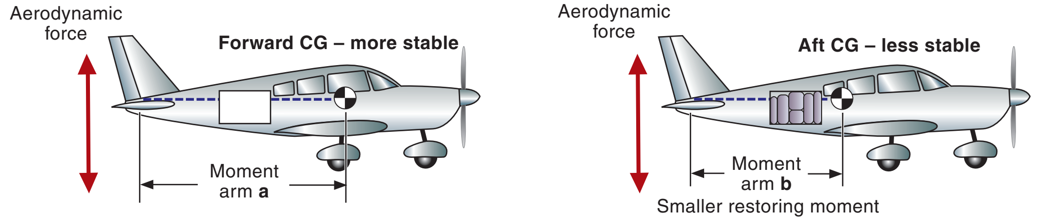


Figure 5-20 A forward CG—greater longitudinal stability.

Design Considerations

Tailplane design features are very important to longitudinal stability. Horizontal stabilizer area, distance from the center of gravity, aspect ratio, angle of incidence, and longitudinal dihedral are considered by the designer. The aim is to generate a restoring force that is effective because of a long moment arm, leading to an airplane that is longitudinally stable.

At high angles of attack the wing may shield the horizontal stabilizer or cause the airflow over it to be turbulent, decreasing longitudinal stability.

> **Note.** Longitudinal dihedral is the difference between the angle of incidence of the wing and the normally smaller angle of incidence of the horizontal stabilizer.

Directional Stability

Directional stability of an airplane is its natural tendency to recover from a disturbance in the yawing plane about the vertical axis. It refers to an airplane's ability to weathercock or weathervane its nose into any airflow from the side.

If the airplane is disturbed from its straight path by the nose or tail being pushed to one side (yawed) by turbulence or by the pilot, then, because of its inertia, the airplane will initially keep moving in the original direction.

The airplane will now be moving somewhat sideways through the air, with its side surfaces, or keel surfaces, exposed to the relative wind.

The vertical stabilizer is a symmetrical airfoil. As it is now positioned at an angle of attack to the relative airflow, it will generate a sideways aerodynamic force that acts about the CG and yaws the airplane back to its original position.

The position of the CG and size of the vertical stabilizer (fin) determine the directional stability. The greater the vertical stabilizer area and keel surface area behind the CG, and the greater the moment arm, the greater the directional stability of the airplane. Therefore, the further *forward* the CG, the greater the directional stability.

As well as being caused by turbulence, a yawing effect will also result from power changes, which cause changes in the slipstream over the vertical stabilizer and can lead to large changes in rudder requirements.

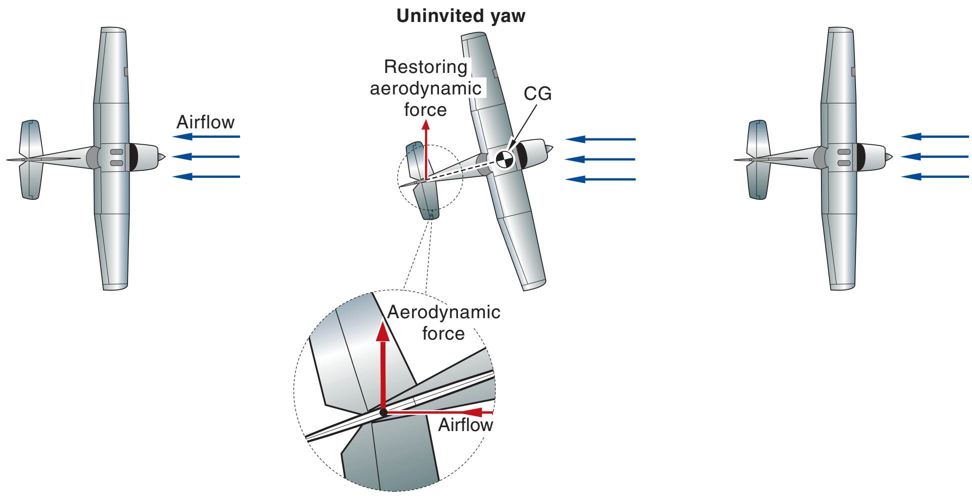


Figure 5-21 Directional stability following an uninvited yaw.

Lateral Stability

Lateral stability is the natural ability of the airplane to recover from a disturbance in the lateral plane (that is, rolling about the longitudinal axis) without any pilot input.

Wing Dihedral

The wings can add lateral stability to an airplane if they have *dihedral*—a design feature where each wing is inclined upward from the fuselage to the wingtips. When an airplane is disturbed in roll, the lift force is inclined and causes the airplane to *sideslip*. This sideslip combines a sideways and downward motion, which results in the relative airflow having a small upward and sideways component, as shown in figure 5-23.

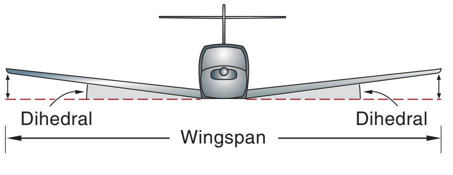


Figure 5-22 Wing dihedral.

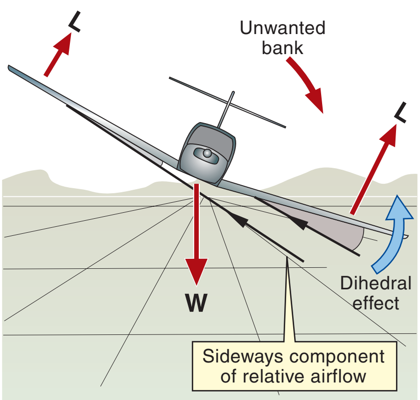


Figure 5-23
Dihedral corrects an uninvited roll.

As the airplane sideslips, the lower wing, because of its dihedral, will meet the upcoming relative airflow at a larger angle of attack and produce increased lift. The upper wing will meet the relative airflow at a smaller angle of attack and will produce less lift. The upper wing may also be shielded somewhat by the fuselage, causing even less lift to be generated. The rolling moment so produced will tend to return the airplane to its original wings-level position.

Negative dihedral, or *anhedral* (where the wing is inclined downward from the fuselage) has a destabilizing effect and is used when an airplane would otherwise be too stable (more difficult to maneuver).

Wing Sweepback and Lateral Stability

The wing can increase lateral stability if it has sweepback. As the airplane sideslips following a disturbance in roll, the lower sweptback wing generates more lift than the upper wing. This is because in the sideslip the lower wing presents more of its span to the airflow than the upper wing. Therefore the lower wing generates more lift and tends to restore the airplane to a wings-level position.

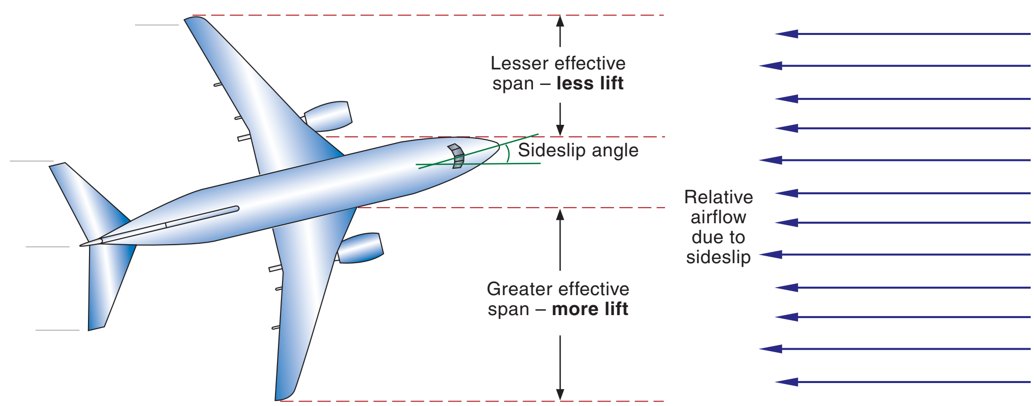


Figure 5-24 Sweepback corrects uninvited roll.

High Keel Surfaces and Low CG

In the sideslip that follows a disturbance in roll, a high sideways drag line caused by high keel surfaces (high vertical stabilizer, a T-tail high on the vertical stabilizer, or high wings) and a low CG will give a restoring moment tending to raise the lower wing and return the airplane to the original wings-level position. See figure 5-25.

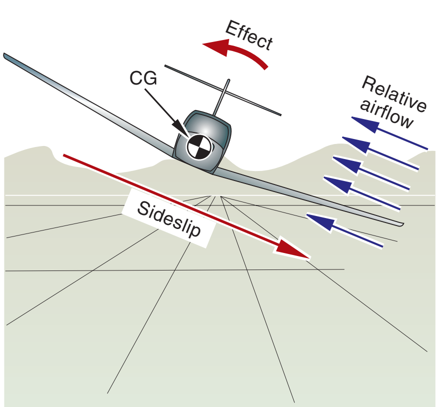


Figure 5-25
High keel surfaces and
a low CG correct uninvited roll.

High-Wing Airplanes

If a wind gust causes a wing to drop, the lift force is tilted, and the airplane will sideslip. The airflow striking the upper keel surfaces, including the high wings, will tend to return the airplane to the wings-level condition.

The increased stability of a high-wing airplane also comes from the pendulum effect when the airplane rolls. The CG is displaced from vertically beneath the CP and so a couple is established which tends to roll the airplane wings-level. Conversely, a low wing, below the airplane's CG, will be unstable. This is apparent when observing the difference in dihedrals of high- and low-wing airplanes.

High- wing airplanes have more lateral stability (by virtue of their wing position) than low-wing airplanes. If the high wing also has sweepback, it may require zero or even negative dihedral to achieve the required lateral stability. The McDonnell Douglas C-17, Lockheed C-141 Starlifter and British Aerospace 146 regional airliner are examples of high-wing airplanes with negative dihedral.

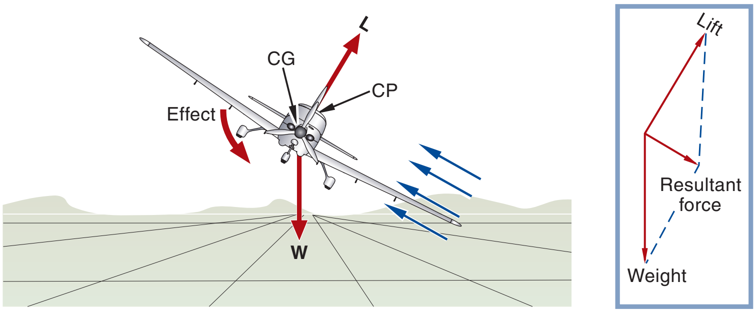


Figure 5-26 A high wing tends to level the wings.

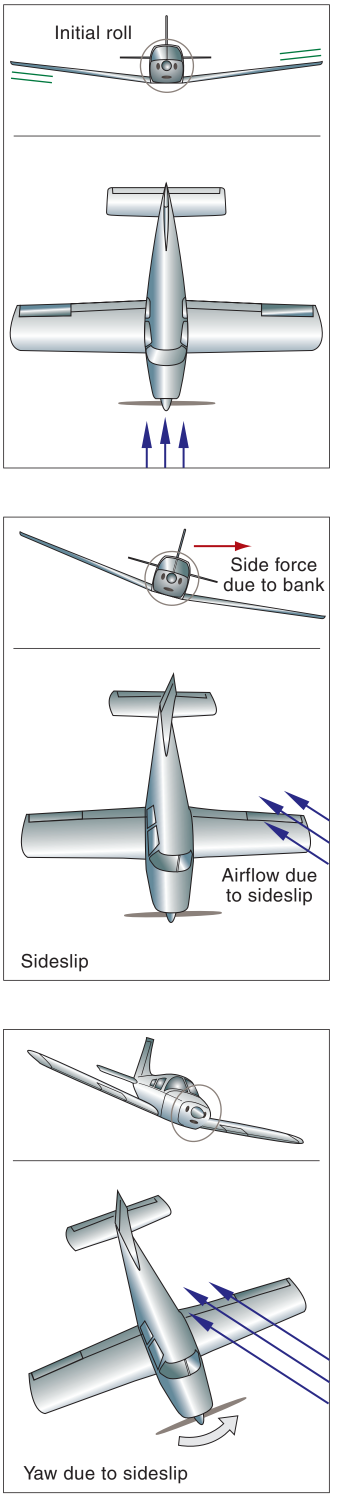


Figure 5-27 Roll causes yaw.

Lateral and Directional Stability Together

Roll Followed by Yaw

A roll is always followed by yaw. For lateral stability it is essential to have the sideslip that the disturbance in roll causes. This sideslip exerts a force on the side or keel surfaces of the airplane, which, if the airplane is directionally stable, will cause it to yaw its nose into the relative airflow. The roll causes a yaw in the direction of the sideslip and the airplane will turn further from its original heading in the direction of the lower wing.

Note this interesting consequence: the greater the directional stability of the airplane, the greater the tendency to turn away from the original heading in the direction of the lower wing when the airplane is banked.

The lateral stability characteristics of the airplane, such as those resulting from wing dihedral, cause the lower wing to produce increased lift and to return the airplane to the wings-level position. There are two effects in conflict here.

1. The directionally stable characteristics (large vertical stabilizer) want to steepen the turn and drop the nose farther.
2. The laterally stable characteristics (dihedral) want to level the wings.

If the first effect wins, with directional stability overriding lateral stability, (large vertical stabilizer and no dihedral), then the airplane will tend to bank farther into the sideslip, toward the lower wing, with the nose continuing to drop, until the airplane is in a spiral dive (and all this without any input from the pilot). This is called *spiral instability.*

Most airplanes are designed with only weak positive lateral stability and have a slight tendency toward spiral instability. This is preferable to Dutch roll (see figure 5-30).

If the lateral stability (dihedral) is stronger, the airplane will right itself to wings-level, and if the directional stability is weak (small vertical stabilizer) the airplane may have shown no tendency to turn in the direction of sideslip and may even turn away from the sideslip, causing a wallowing effect known as *Dutch roll,* which is best avoided.

Yaw Followed by Roll

If the airplane is displaced in yaw, it will initially continue in the original direction of flight because of its inertia, and therefore enter a sideslip. This sideslip will cause the lateral stability features of the airplane's wing such as dihedral, sweepback, or a high-wing, to increase lift on the forward wing and decrease lift on the trailing wing. This causes a rolling moment that will tend to raise the forward wing, resulting in the airplane rolling toward the trailing wing and away from the sideslip. Yaw causes roll.

Also, as the airplane is actually yawing, the outer wing will move faster and produce more lift than the inner wing, giving a tendency to roll toward the inner wing. The aircraft then sideslips due to bank. The airplane's inherent directional stability (from the vertical stabilizer) will tend to weathercock or yaw the airplane in the direction of the sideslip.

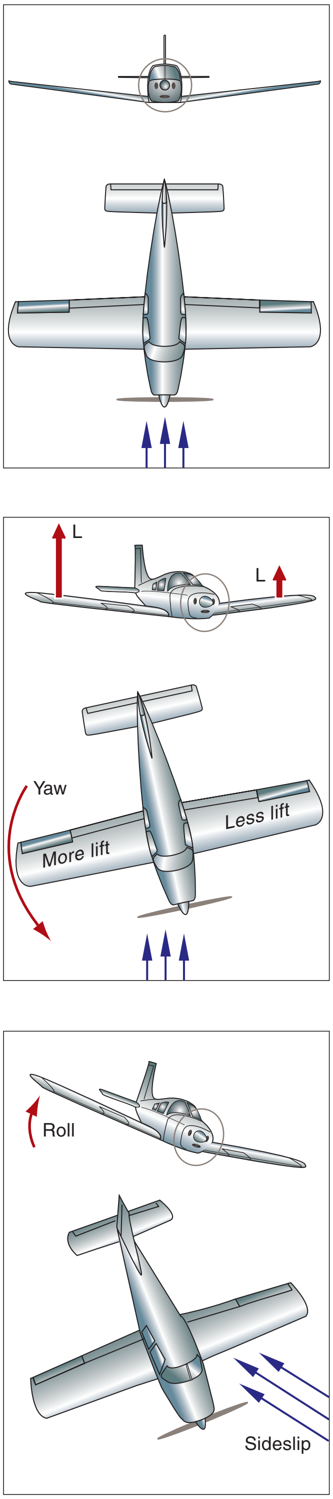


Figure 5-30 Yaw causes roll.

Note that a roll causes a yaw and a yaw causes a roll, and the two effects need to be studied together.

Stability on the Ground

On the ground, the center of gravity (CG) of an airplane must lie somewhere in the area between the three wheels at all times. The farther away the CG is from any one wheel, the less the tendency for the airplane to tip over that wheel.

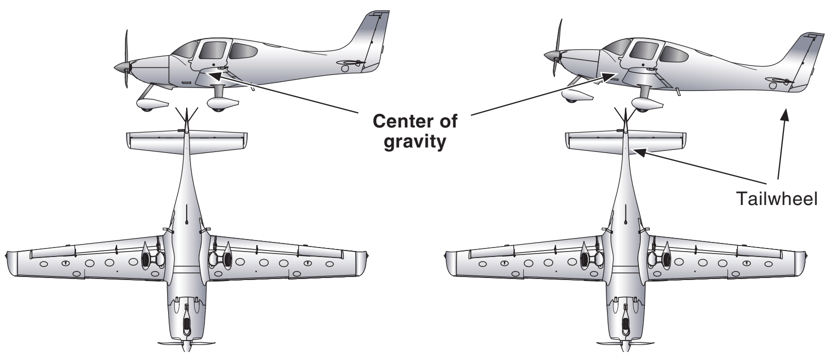


Figure 5-28 The CG must remain within the area bounded by the wheels.

A low CG and widely spaced wheels reduces the tendency for the airplane to tip over on the ground when turning, braking the airplane, or when applying high power on takeoff.

A low thrust-line reduces the tendency for an airplane to pitch over on its nose when high power is applied (especially with brakes on). High keel surfaces and dihedral allow crosswinds to have a greater destabilizing effect. You move in a straight line on the ground by using the rudder pedals to maintain directional control and using the control wheel to prevent any cross-wind from lifting the upwind wing. This is covered in Chapter 6.

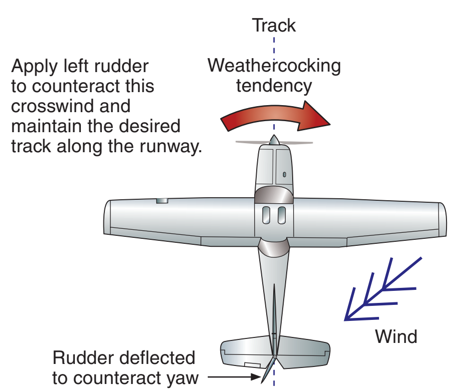


Figure 5-29 A destabilizing crosswind.

Control

All airplanes have a flight control system to allow the pilot to maneuver the airplane in flight about each of the three axes. Airplanes normally have three *primary control* circuits, each one is equipped with its own control surface(s):

- *elevators* for longitudinal (pitch) control, operated by forward and rearward movement of the control wheel or stick;
- *ailerons* for lateral (roll) control, operated by rotation of the control wheel or by sideways movement of the control stick; and
- *rudder* for directional (yaw) control, operated by movement of the two interconnected rudder pedals.

Ideally, each set of control surfaces should produce a moment about only one axis, but in practice *secondary* moments about other axes are often produced as well. For example, if an airplane yaws it will then start to roll.

The control surfaces work by deflecting airflow and changing the pressure distribution over the whole airfoil, not just over the control surface itself. The effect is to change the aerodynamic force produced by the total airfoil—control surface combination. The effectiveness of moving these control surfaces will partially determine the airplane's maneuverability. As mentioned earlier, an airplane with too much stability is very resistant to change and has poor maneuverability. Excessive stability opposes maneuverability.

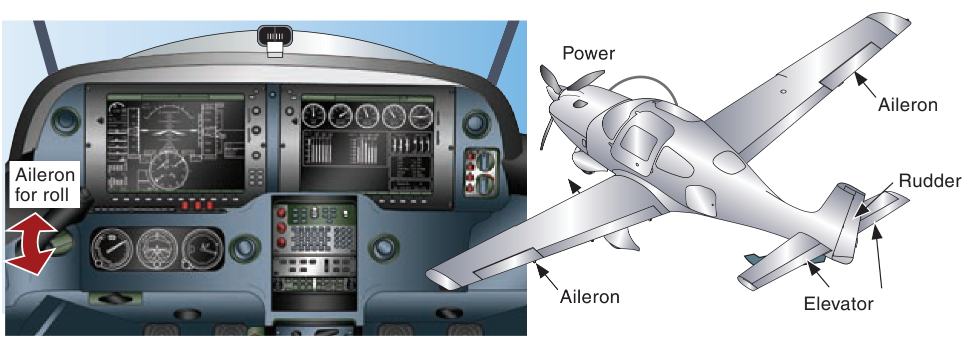


Figure 5-31 The primary flight controls: elevator, ailerons, and rudder.

The Elevator

The pilot controls the elevator by forward and rearward movement of the control column. A forward movement of the control column moves the elevator down which has the effect of pushing the nose of the airplane down. Rearward movement of the control column moves the elevator up, which has the effect of pulling the nose of the airplane up. These movements will become logical and instinctive to you.

When the control wheel is moved forward, the elevator moves down and the horizontal stabilizer section becomes cambered so that it provides an upward aerodynamic force. This creates an upward force on the tail section of the airplane and a moment about the airplane's CG that moves the nose down. A further effect of pitching the nose down with the elevator is a gradual increase in airspeed. When the control wheel is pulled back, the elevator moves up and an extra downward aerodynamic force is produced by the horizontal stabilizer airfoil, causing the nose of the airplane to move up. The strength of the tail moment depends on the force produced by it and the length of the moment arm between it and the CG.

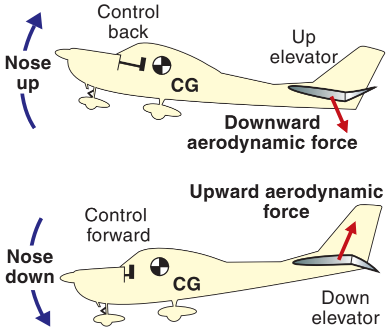


Figure 5-32
The elevator is the primary pitching control.

CG Position

To retain satisfactory handling characteristics and elevator effectiveness throughout the airplane's entire speed range, the position of the CG must be kept within the prescribed range. If the *CG is too far forward,* the airplane will be too longitudinally stable because of the long moment arm to the horizontal stabilizer. Even with the control column pulled fully back there will be insufficient up-elevator to reach the high angles of attack and low speeds sometimes required in maneuvers such as flying slowly, taking off and landing. Therefore, the *forward allowable CG limit* is determined by the amount of pitch control available from the elevator. The *aft (rear) limit of the CG* is determined by the requirement for longitudinal stability.

If the CG is too far forward, the airplane will be too longitudinally stable. If the CG is too far aft the airplane will be longitudinally unstable.

Usually, the most critical situation for a nose-up requirement is in the flare and landing. A forward CG makes the airplane nose-heavy and resistant to changes in pitch. This may make it difficult to raise the nose during a landing, especially since the elevator will be less effective because of the reduced airflow over it due both to the slow landing speed and weak propeller slipstream (low power).

The Stabilator

Some designers combine the horizontal stabilizer and elevator into one airfoil and have the whole tailplane movable. A combined horizontal stabilizer/elevator combination is called a *stabilator.* Other terms include all-moving tail, all-flying tail and slab tail. When the control column is moved the entire slab moves. Forward movement of the control column increases the angle of attack of the stabilator, thereby generating a force that causes the tail to rise). Some airplanes have a V-tail (butterfly tail), which combines the functions of the elevator and rudder.

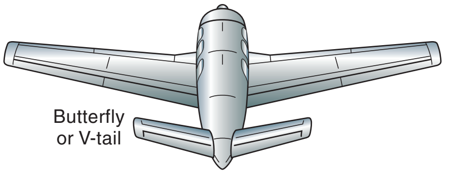


Figure 5-33 A butterfly tail (early Beech Bonanza model).

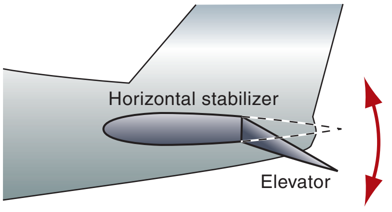


Figure 5-34
Separate horizontal stabilizer and elevator.

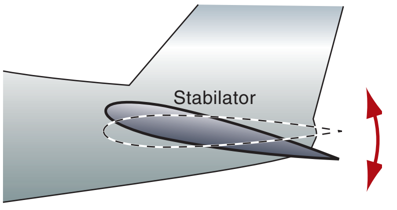


Figure 5-35
Stabilator.

The Ailerons

The primary control in roll is provided by the ailerons.

The ailerons are positioned on the outboard trailing edges of the wings. The ailerons act in opposing senses, one goes up as the other goes down, so that the lift generated by one wing increases and the lift generated by the other wing decreases. The pilot operates the ailerons with rotation of the control wheel or sideways movement of the control stick. A resultant rolling moment is exerted on the airplane. The magnitude of this rolling moment depends on the distance the ailerons are from the airplane's CG (fixed at construction), and the magnitude of the differing lift forces (determined by the degree of aileron deflection and airspeed). Note that the aileron on the up-going wing is deflected downward. Conversely, the aileron on the down-going wing is deflected upward.

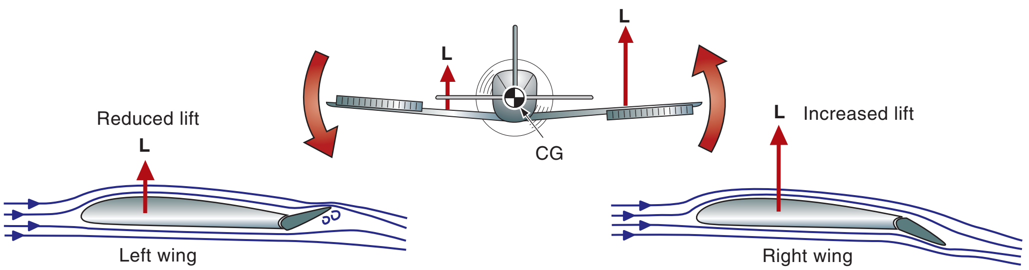


Figure 5-36 The ailerons—one up, one down—provide a rolling moment.

Adverse Yaw Effect

Adverse yaw effect is caused by differential aileron drag. Deflecting an aileron down causes an effective increase in the camber of that wing section and an increase in the effective angle of attack. The lift from that wing increases, but unfortunately so does the drag. As the other aileron rises, the effective camber of that wing section is decreased and its angle of attack is less, therefore lift and drag from that wing are decreased. The differing lift causes the airplane to bank one way, but the differential aileron drag causes it to yaw the other way. This is known as *aileron drag* or *adverse yaw effect* and is mainly a low airspeed problem that you would most notice during a turn entry at low speed shortly after takeoff or on final approach.

Adverse yaw effect can be reduced by differential ailerons, Frise-type ailerons, or interconnecting the rudder to the ailerons.

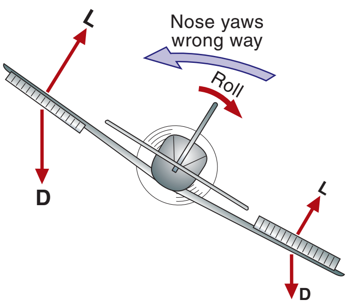


Figure 5-37 The rising wing has increased aileron drag, causing adverse yaw effect.

Differential ailerons overcome adverse yaw effect.

Differential Ailerons. Differential ailerons are designed to minimize adverse yaw effect by increasing the drag on the down-going wing. This is achieved by deflecting the upward aileron (on the descending wing) through a greater angle than the down-going aileron (on the up-going wing). The greater aileron deflection means that drag is increased on the down-going wing, reducing (but not eliminating) the adverse yaw. The remaining unwanted yaw can be removed with rudder.

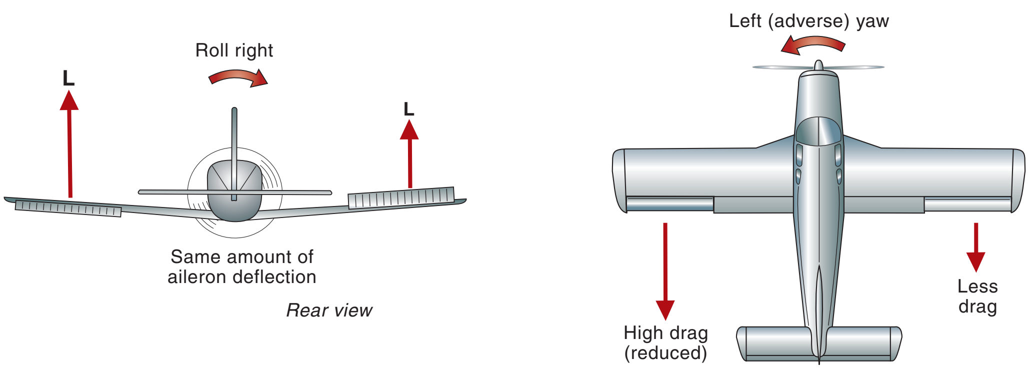


Figure 5-38 Differential ailerons reduce adverse yaw.

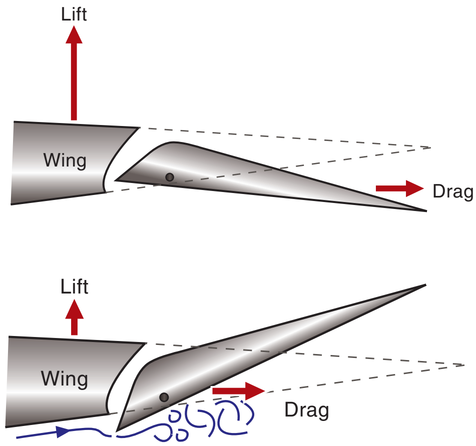


Figure 5-39 Frise-type ailerons equalize aileron drag nd reduce adverse yaw.

Frise-Type Ailerons. Frise-type ailerons are shaped so that the drag from the descending wing is increased. The leading edge of the Frise aileron on the down-going wing protrudes into the airstream beneath the wing causing increased drag on the down-going wing. The leading edge of the up-going aileron does not protrude into the airstream, causing no extra drag. Frise-type ailerons also can be designed to operate differentially, thereby combining both effects.

Interconnected Ailerons and Rudder. Interconnected ailerons and rudder cause the rudder to move automatically and yaw the airplane into the bank, opposing the adverse yaw from the ailerons. The primary effect of the ailerons is to roll the airplane, and the secondary effect is to yaw it. The primary effect of the rudder is to yaw the airplane, and the secondary effect is to roll it. Using the rudder to neutralize adverse yaw, with the ailerons deflected and the airplane rolling is one of the most important elements of airplane control by the pilot.

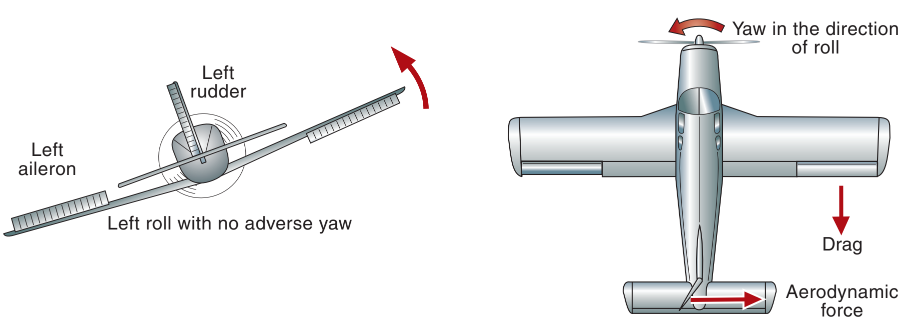


Figure 5-40 Aileron/rudder interconnect can reduce adverse yaw.

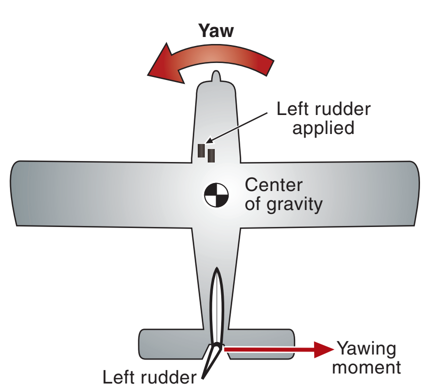


Figure 5-41
Left rudder pressure—the nose yaws left.

The Rudder

To control and eliminate unwanted yaw, the airplane has a rudder. The rudder does not turn the airplane, it yaws it, which by itself, does not cause any change in flight path direction. By pushing the left rudder pedal, the rudder will move left. This alters the vertical stabilizer-rudder airfoil section and a sideways aerodynamic force is created that moves the tail to the right and yaws the airplane to the left about the vertical axis. Left rudder—the airplane yaws left.

Rudder effectiveness increases with airspeed, so large rudder deflections at low airspeeds and small deflections at high airspeeds are required to gain the same effect. In propeller-driven airplanes, any propeller *slipstream* flowing over the rudder increases rudder effectiveness.

Yaw Is Followed by Roll

The primary effect of rudder is to yaw the airplane. This causes the outer wing to speed up, generate increased lift, and cause the airplane to roll.

When it has begun to yaw, the airplane will continue on its original flight path for a brief period because of inertia. Any dihedral on the forward wing will cause it to be presented to the airflow at a greater angle of attack and therefore generate more lift. Consequently, having first yawed the airplane, the secondary effect of the rudder is to cause a roll.

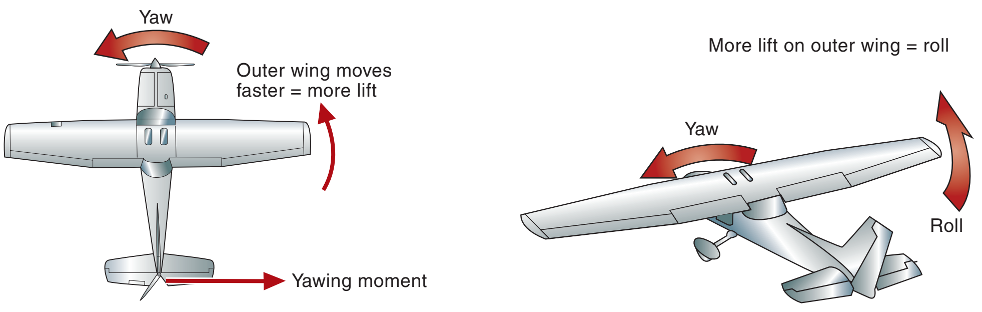


Figure 5-42 Yaw is follows by roll.

Control Effectiveness

The size and shape of a control surface and its moment about the center of gravity primarily determine its effectiveness. Since the size and shape are fixed by the designer, and the CG (with the airplane loaded within limits) only moves a small amount, they can all be considered constant.

The variables in control effectiveness are *airspeed* and *control deflection*. For a given amount of control deflection, if the airspeed is doubled, the effect is squared ($2 \times 2 = 4$), so it quadruples. If the airspeed is halved, the same control surface deflection is only one-fourth as effective. Therefore, at low airspeeds, achieving a nominal change in attitude requires a much greater control-surface deflection but the forces are lighter (often referred to as *sloppy controls* or *less powerful controls*).

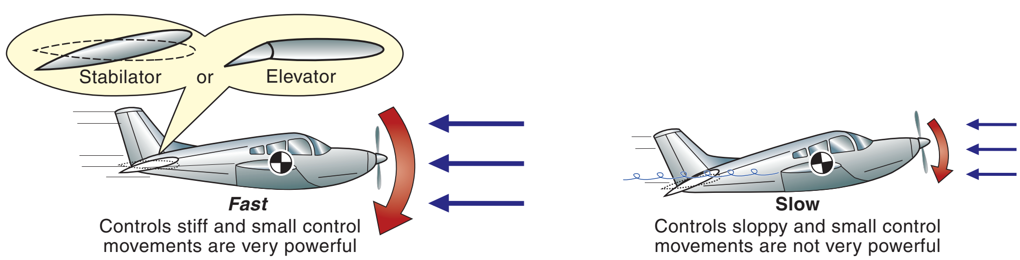


Figure 5-43 The controls are more powerful with increased airflow.

Slipstream Effect

Any factor that increases the speed of the airflow over a control surface will make it more effective. Such an increase in airflow does not necessarily have to be achieved by an increase in the airplane's forward speed. For instance, with high engine power set, the propeller slipstream (or *propwash)* of a single-engine airplane will flow strongly back over the empennage, making the elevators and rudder more effective, even at low airspeeds.

Approaching the stall with power on, the elevator and rudder will be more effective than the ailerons, because of the propeller slipstream flowing over them. The slipstream helps when taxiing single-engine tailwheel airplanes because power application increases rudder effectiveness.

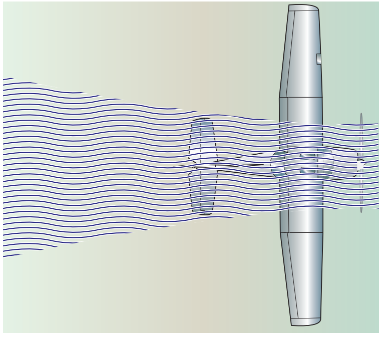


Figure 5-44 The slipstream only affects the elevator and rudder.

Control Forces Felt by the Pilot

When a control surface is deflected, the aerodynamic force produced by the control surface itself opposes its own deflection. This causes a moment to act on the control surface about its hinge line trying to return the control surface to its original faired (streamlined) position, and the pilot must overcome this to maintain the selected position. The pilot feels this as *stick force.*

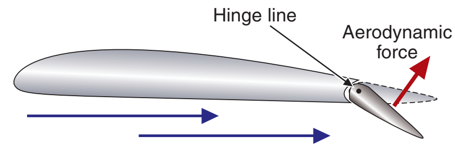


Figure 5-45
Hinge moment at the control surface.

Aerodynamic Balances

The *stick force* (the amount of control force a pilot feels) depends on the turning moment at the hinge line of the control surface and the means by which the control wheel is linked to the control surface. If the control surface is hinged at its leading edge and trails from this position in flight, the stick forces required will be high, especially in heavy or fast airplanes. These forces can be made smaller by the designer adding an *aerodynamic balance,* which reduces the stick load on the pilot.

An aerodynamic balance on a control reduces the stick load on the pilot.

The designer may use an *inset hinge*, a *horn balance*, or a *balance tab* to provide an aerodynamic force during control surface deflection that partially balances or reduces the hinge moment. The aerodynamic balance of a control surface is designed to reduce the control forces required from the pilot. The designer, however, must be careful not to over-balance the controls, otherwise the pilot will lose the important sense of feel.

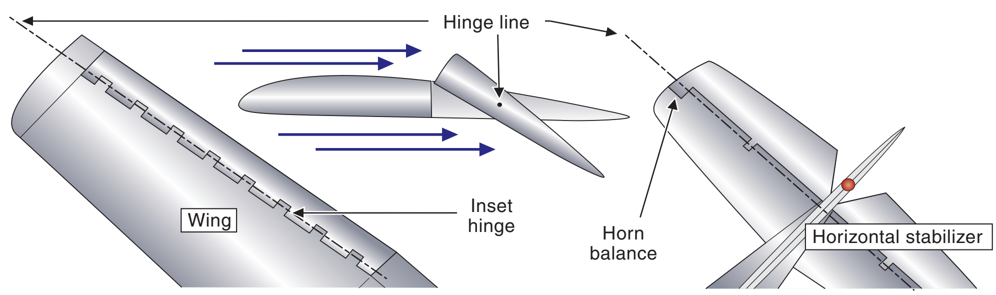


Figure 5-46 Inset hinge balance (at left) and horn balance (at right).

An *inset hinge* reduces the distance from the hinge line to the control's center of pressure, which reduces the moment that the pilot feels as stick load. In addition, the part of the control ahead of the hinge protrudes into the airflow causing a balancing moment which assists the pilot by reducing the stick load.

On conventional tailplanes, the elevator may have a *balance tab* incorporated. It is mechanically connected to the elevator by a linkage that causes it to move in the opposite direction.

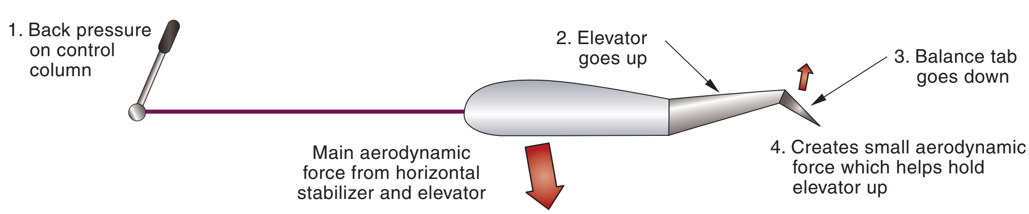


Figure 5-47 The balance tab.

If the pilot exerts back pressure on the control wheel, the elevator is raised and the balance tab goes down. The elevator balance tab unit now generates a small upward aerodynamic force that acts to hold the elevator up, thereby reducing the control effort required from the pilot.

Note. The balance tab acts automatically as the elevator moves. This movement should be checked during the preflight inspection by moving the elevator one way and noting that the tab moves the other way.

Anti-Balance Tab

An anti-balance tab increases the control force on the pilot to prevent overcontrolling.

Airplanes fitted with a stabilator often have an *anti-balance tab* (sometimes referred to as an *anti-servo tab*) to increase control forces at higher airspeeds to reduce possible overstress when maneuvering. Because of their combined function, stabilators have a much larger area than elevators and so produce a more powerful response to control input. Small movements can produce large aerodynamic forces. To prevent you from moving the stabilator too far and overcontrolling the airplane (especially at high airspeeds), stabilators are often designed with anti-balance tabs.

An anti-balance tab moves in the *same* direction as the stabilator's trailing edge and generates an aerodynamic force that makes it harder to move the stabilator further, as well as providing feel for the pilot.

Correct operation of the anti-balance tab can be checked during the preflight inspection by moving the trailing edge of the stabilator and noting that the anti-balance tab moves in the same direction.

Figure 5-48 Anti-balance tab on stabilator.

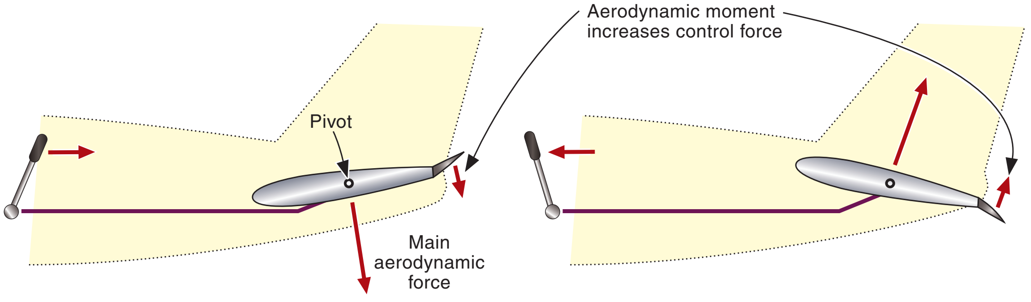


Figure 5-49 The anti-balance tab opposes further control deflection and provides feel.

Trim Tabs

Trim tabs are designed to remove the stick load on the pilot.

An airplane is "in trim" in pitch, roll, or yaw when it maintains a constant attitude without the pilot having to exert any steady pressure on the particular control surface. An airplane that you have trimmed properly is far more pleasant to fly than an untrimmed airplane. It requires control inputs only to maneuver and not to maintain an attitude or heading. The function of the *trim tab* is to reduce the moment at the hinge line of the control surface to approximately zero, so that the present condition of flight can be maintained hands-off.

Almost all airplanes have an elevator trim, many light single-engine and all multi-engine airplanes have a rudder trim, and more sophisticated airplanes also have an aileron trim. Trim tabs can differ in complexity. Some are metal strips that can only be altered on the ground, or springs that can apply a load to the control column. Other trim tabs can be operated from the cockpit by the pilot, usually by a trim wheel or trim handle (this may be mechanical or electrical). Airplanes with stabilators may have the elevator trim incorporated so that trimming moves the entire slab.

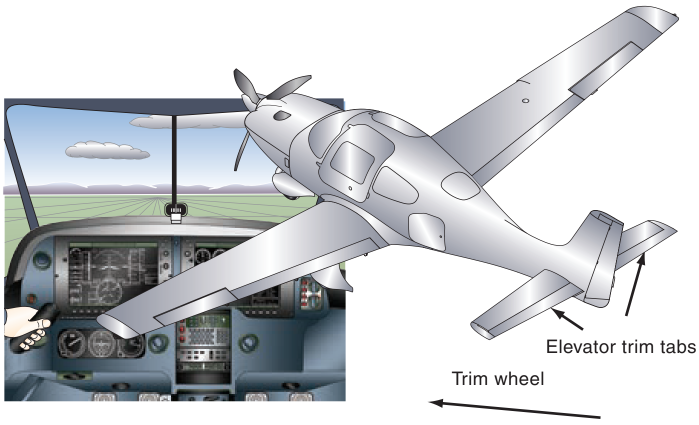


Figure 5-50 An elevator trim tab.

Mass Balancing

A mass balance prevents flutter.

At high speeds some control surfaces have a tendency to flutter. This is a vibration that results from the changes in pressure distribution over the surface as its angle of attack is altered. If part of the airframe structure starts to vibrate—control surfaces are particularly susceptible to this—then these oscillations can quickly reach structurally damaging proportions. To avoid this flutter, the designer may need to alter the mass distribution of the surface.

The *mass balance* is placed forward of the hinge line to bring the CG of the control surface up to the hinge line or even slightly ahead of it. On the inset hinge or horn balance this mass can easily be incorporated in that part ahead of the hinge line, but on others the mass must be placed on an arm that extends forward of the hinge line. The distribution of mass on control surfaces is an important design consideration. The aim of mass balancing is not for the control to be balanced in the sense of remaining level, but to alter the mass distribution of the control to avoid flutter or vibration.

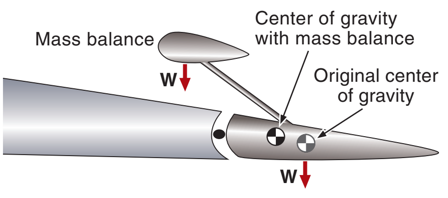


Figure 5-51
A mass balance moves the control's CG forward to prevent flutter.

Control on the Ground

Directional control on the ground is achieved by use of the rudder, nosewheel steering (which may be connected to the rudder pedals), power, and brakes. Airflow over the rudder increases its effectiveness.

Review 5
Stability and Control

Stability

1. Following a disturbance, an airplane that returns to its original position unassisted by the pilot is said to be inherently stable. Is this sort of airplane easier to fly?
2. If the center of pressure is behind the center of gravity, what sort of pitching moment will the lift–weight couple have?
3. If the thrust line is lower than the drag line, what sort of pitching moment will the thrust–drag couple have?
4. In questions 2 and 3, if there was a sudden loss of thrust, what would the nose do?
5. Where is the center of pressure in relation to the center of gravity in most training airplanes?
6. What sort of aerodynamic force does the horizontal stabilizer produce?
7. When power is reduced, what will the reduced propeller slipstream and reduced downwash over the horizontal stabilizer cause the nose to do?
8. Longitudinal stability refers to the motion of the airplane about its:
   a. longitudinal axis.
   b. lateral axis.
   c. vertical axis (sometimes called the normal axis).
9. What is rotation about the lateral axis known as?
10. What is rotation about the vertical axis known as?
11. What is the most important factor contributing to longitudinal stability?
12. Is longitudinal stability greater with a forward CG?
13. True or false? An airplane loaded with the CG too far aft will be stable at slow speeds, but if stalled will be difficult to recover.
14. Will a forward CG location cause an airplane to be more unstable at high speeds?
15. How can aircraft directional stability be improved?
16. If the airplane is loaded incorrectly so that the CG is forward of the allowable range, the elevator force required to flare the airplane for landing will be:
   a. the same as usual.
   b. greater than usual.
   c. less than usual.
17. If a wing has dihedral or sweepback, which sort of stability is increased?
18. If an airplane is yawed, it will sideslip. What will the dihedral cause it to do?

Control

19. What primary control provides pitch?
20. Nose movement up and down occurs in which plane?
21. Nose movement involves angular movement around its CG as well as which axis?
22. In order to raise the nose and lower the tail of the airplane, which direction does the trailing edge of the elevator move in?
23. What are the consequences of loading the airplane incorrectly with:
   a. the center of gravity forward of the forward limit?
   b. with the center of gravity behind the aft limit?
24. What primary control provides roll?
25. Rolling is angular motion about which axis running through the CG?
26. In which direction does the pilot move the control column to make the right wing rise?
27. True or false? At normal flight speeds, for the right wing to rise, the right aileron will go down and the left aileron will go up.
28. True or false? If differential ailerons are used to counteract the effect of adverse yaw effect, one aileron will rise by an amount the same as the other aileron is lowered.
29. Does the area below the wing have higher static pressure than the area above the wing?
30. Yawing occurs about which axis that passes through the CG?

31. An airplane is banking left for a left turn. What effect will the extra drag on the right aileron have?

32. How can adverse yaw effect be reduced?

33. What primary control provides yaw?

34. Yawing increases the speed of the outer wing. Does this cause its lift to increase? If so, what does this lead to?

35. Yaw also generates a sideslip. Will the dihedral on the more forward wing cause it to rise?

36. At high airspeeds, are the control surfaces more effective than at low airspeeds?

37. Does slipstream from the propeller over the rudder and elevators increase their effectiveness?

38. What is the purpose of aerodynamic balance?

39. Give three examples of aerodynamic balance.

40. If the stabilator is moved in the preflight external inspection, the anti-balance tab should:

a. move in the same direction.
b. move in the opposite direction.
c. not move.

41. If the elevator is moved in the preflight external inspection, the balance tab should:

a. move in the same direction.
b. move in the opposite direction.
c. not move.

42. What is mass balance used for?

Answers are given on page 767.

Aerodynamics of Flight 6

Straight-and-Level Flight

Relationship Between Attitude, Angle of Attack, and Airspeed

In straight-and-level flight, there is a fixed relationship between attitude, angle of attack, and indicated airspeed. At high speed, the dynamic pressure is high, and the required value of lift can be generated at a small angle of attack. In level flight, this is reflected by a lower nose attitude. At lower airspeeds, the dynamic pressure is reduced, and the loss of lift must be compensated by increasing the angle of attack. The pitch attitude is directly affected also. At low airspeed, the value of the dynamic pressure reduces significantly, and the angle of attack must increase disproportionately. At the minimum level flight speed, the pitch attitude is at its highest. With this increase in angle of attack, there is an associated increase in induced drag, and to sustain a very slow airspeed, the power also has to be increased. Extending the flaps allows a slower speed and a reduced pitch attitude.

In steady straight-and-level flight, lift equals weight and thrust equals drag.

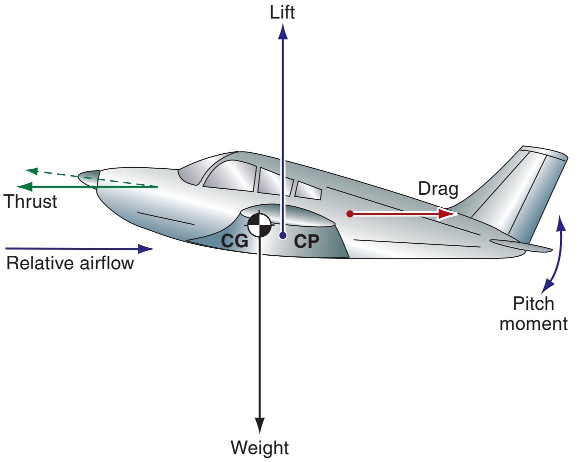


Figure 6-1 Balance of forces and moments.

For straight-and-level flight at constant weight, the lift required will be constant. For a given airfoil, each angle of attack has a particular lifting ability. At low speed a high angle of attack (high lifting ability) is needed to maintain altitude, while at high speed only a small angle of attack (low lifting ability) is required. Since we are considering level flight, the pilot *sees* the angle of attack as the pitch attitude of the airplane relative to the horizon—nose-up at low speeds and approximately nose-level at high speeds.

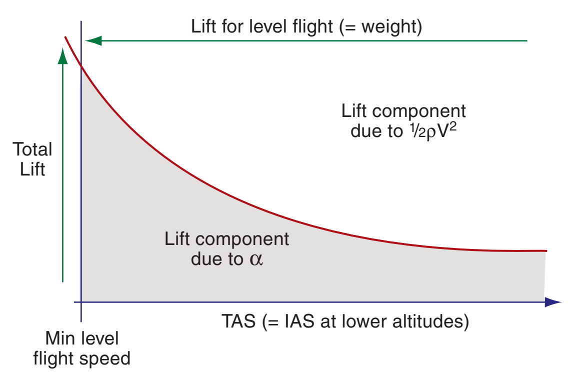


Figure 6-2
Indicated airspeed varies inversely with angle of attack.

The Effect of Weight

In flight the weight gradually decreases as fuel is burned off. If the airplane is to fly level, the lift produced must gradually decrease as the weight decreases. If there is a sudden decrease in weight, say by parachutists jumping out, then to maintain straight-and-level flight the lift must also decrease. In Chapter 1 we said that if the airplane wing shape and area are kept constant by not using the flaps, then lift depends only on angle of attack and airspeed. Therefore to reduce lift either angle of attack or airspeed must be reduced.

Suppose that an airplane is flying at a particular angle of attack, say at that for the best L/D ratio (about 4°). As weight gradually decreases, lift must also be reduced to remain equal to weight. If lift is to be reduced without altering the angle of attack, the airspeed must gradually be reduced. The power (thrust) will also need to be reduced because drag will decrease as lift decreases.

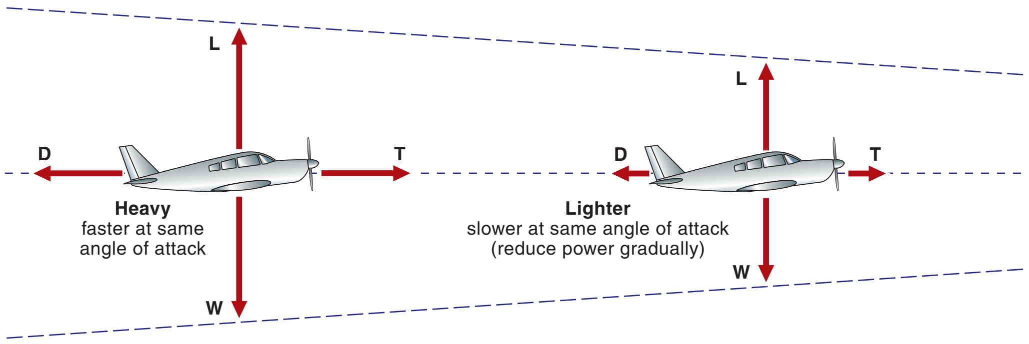


Figure 6-3 At a constant angle of attack, a lighter airplane must fly slower.

If the power (thrust) is kept constant and you want to maintain altitude as the weight decreases, the lift must be decreased by lowering the angle of attack. The speed will then increase until the thrust produced by the engine-propeller is equal to the drag (which increases as the speed increases). This is the normal technique for the cruise in small training airplanes.

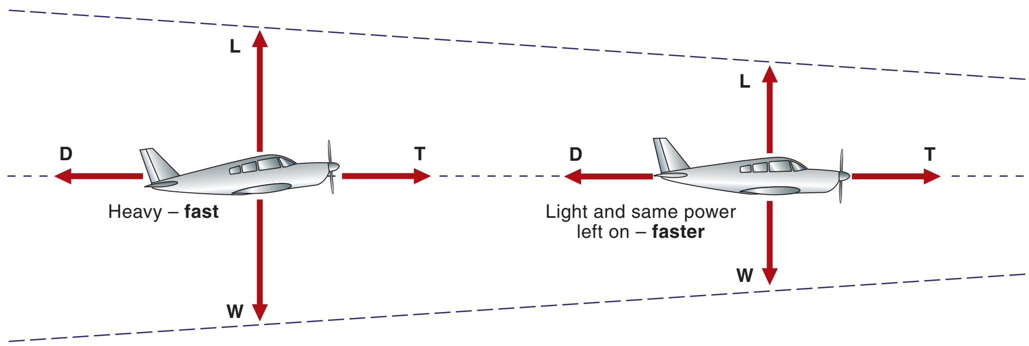


Figure 6-4 Same power—lighter airplane has a lower angle of attack and flies faster.

If you want to keep the speed constant and maintain altitude, then as the weight decreases you must reduce the lift produced, and you do this by decreasing the angle of attack. In cruise flight this will mean less drag, and therefore the power required from the engine-propeller is less. If the power is not reduced as the weight decreases, the airspeed will increase.

If your aim is to maintain a constant airspeed without reducing power, then you would need to slightly raise the nose to avoid the airspeed increasing. The airplane would then commence a climb and gradually a new set of equilibrium conditions (balance of forces) would establish themselves for a steady climb—no longer level flight. (This is covered in the next part of this chapter where we deal with *climbing and descending*.)

A very practical relationship to remember is that:

Power + attitude = performance (flight path + speed)

If you have excess power, you can adjust the pitch attitude so that altitude is maintained and airspeed increases; or you can maintain the pitch attitude and airspeed and accept a rate of climb.

Climbs

As an airplane climbs, it gains potential energy (the energy of position, in this case because of altitude). There are two ways an airplane can do this:

- by making a zoom climb; or
- by a steady, long-term climb.

Zoom Climb

A zoom climb exchanges the kinetic energy of motion for potential energy by exchanging high velocity for an increase in altitude. Therefore, kinetic energy *reduces* while potential energy *increases*, and (kinetic + potential) energy remains the same. It is only a transient (temporary) process, as the velocity cannot be decreased below flying speed. Of course, the greater the speed range of the airplane the greater the capability of the zoom. For example, a jet fighter being pursued at high speed can gain altitude rapidly with a zoom, or an aerobatic glider that converts the kinetic energy of a dive into potential energy at the top of a loop. An airplane can zoom as long as it is above its stall speed.

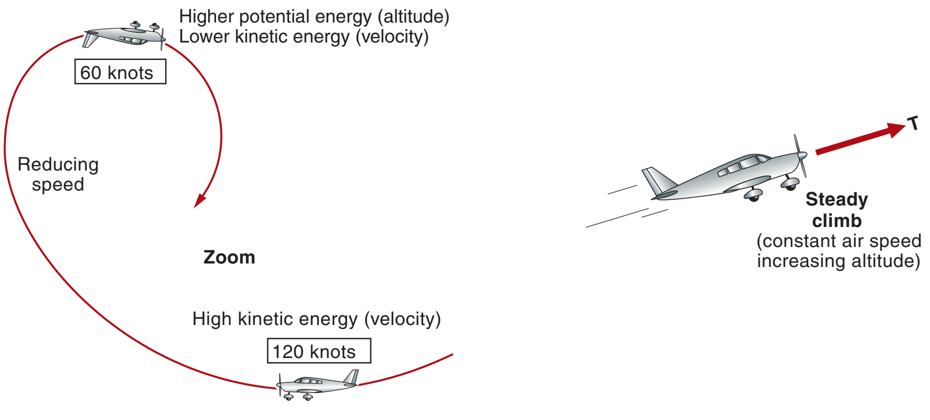


Figure 6-5 A zoom and a steady climb.

Steady Climb

In a steady climb, kinetic energy remains *constant* while potential energy increases. This increase in (kinetic + potential) energy is provided by the additional fuel which is burned in the engine during the climb. It is the steady climb that is of importance in day-to-day flying. To enter a steady climb, raise the nose (which temporarily increases the angle of attack) and add power. The airplane quickly settles into a steady climb.

Forces in the Climb

In a steady en route climb the thrust force acts in the direction of flight, directly opposite to the drag force. The lift force acts perpendicular to the relative wind and is no longer vertical. The weight force acts vertically, but note how, in the climb, it has a component that acts in the direction opposing flight.

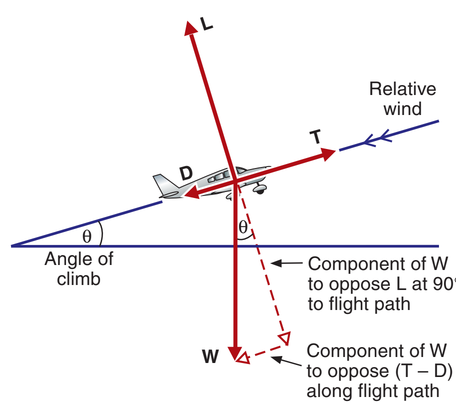


Figure 6-6
The four forces in equilibrium in a steady climb.

If you maintain a *steady climb* at a constant indicated airspeed, the engine-propeller must supply sufficient thrust to:

- overcome the drag force; and
- help lift the weight of the airplane at a vertical speed (known as rate of climb).

In a steady climb there is no acceleration. The forces are in equilibrium, with the up forces equaling the down forces, and the forward forces equaling the rearward forces. Consequently, the resultant force acting on the airplane is zero.

Types of Climb

There are three types of climb, each with a different purpose.

Maximum Angle Climb

A *maximum angle climb* is used to clear obstacles, as it gains the greatest altitude for a given *horizontal distance.* By definition it is the steepest climb (maximum gradient) and is flown at a relatively slow airspeed, referred to as V_X. Because the slow airspeed results in reduced cooling and higher engine temperatures, it should only be used for short periods while clearing obstacles.

Maximum Rate Climb

A *maximum rate climb* is used to reach cruise altitude as quickly as possible, as it gains the greatest altitude in a given *time.* Best rate of climb speed is known as V_Y. The airspeed is faster than V_X at sea level and is usually somewhere near the speed for the optimum lift/drag ratio. It is a shallower climb than the maximum angle climb. Rate of climb is a vertical velocity and is indicated on the vertical speed indicator (VSI) in feet per minute (FPM).

Cruise Climb

A *cruise climb* is a compromise climb that allows for a higher groundspeed (to expedite your arrival at the destination) as well as allowing the airplane to gain altitude and reach the cruise altitude without too much delay. It also allows for better engine cooling because of the faster speed, and better forward visibility because of the lower pitch attitude. The cruise climb is the shallowest climb at a higher airspeed compared with V_X and V_Y. For most airplanes it is the *normal climb*.

Climb Speed

Refer to your Pilot's Operating Handbook for the various climb speeds for your particular airplane. Typically, the best angle-of-climb speed V_X is about 10-15 knots less than the best rate-of-climb speed V_Y at sea level for single-engine airplanes.

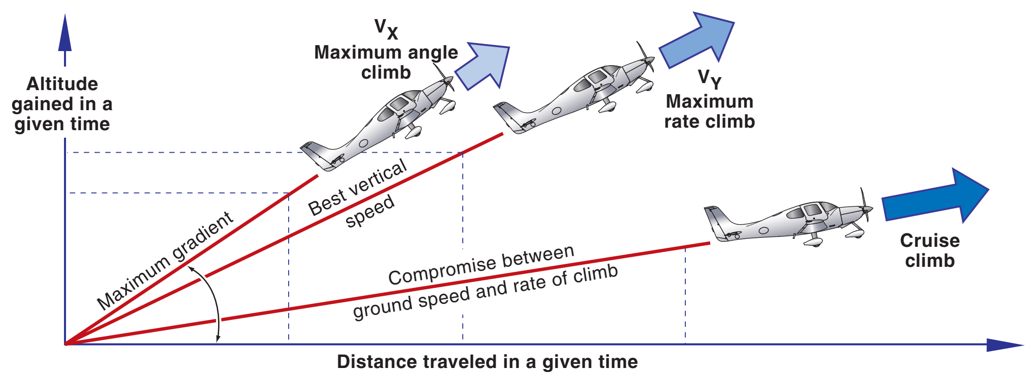


Figure 6-7 Maximum angle climb, maximum rate climb, cruise climb; use the one that suits the situation.

Climb Performance

Performance in the climb, be it angle or rate of climb, will:

- decrease when power is decreased;
- decrease when airplane weight is increased;
- decrease when temperature increases because of lower air density;
- decrease if you fly at the incorrect speed (either too fast or too slow); and
- decrease as altitude increases because of lower air density.

The power available from the engine and propeller decreases with altitude. The climb performance, rate of climb, and angle of climb capabilities all decrease with altitude.

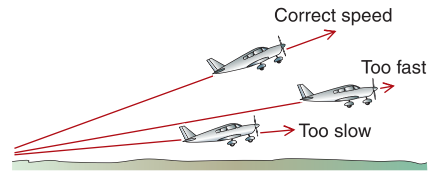


Figure 6-8
Fly at the correct climb speed for best performance.

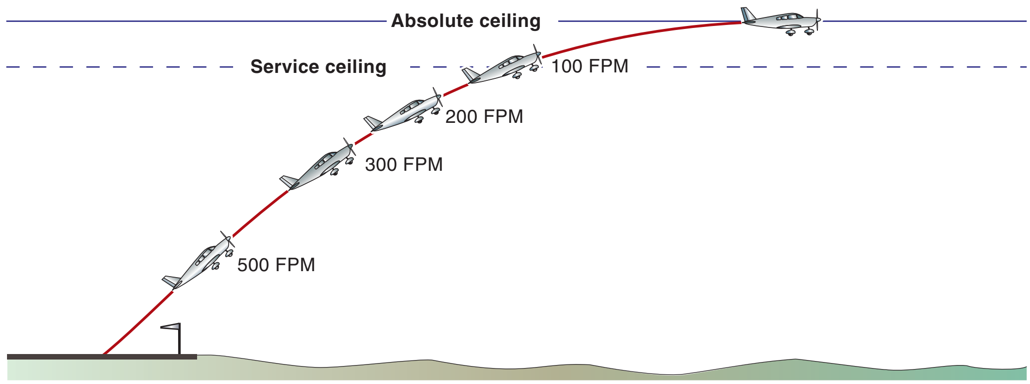


Figure 6-9 Climb performance decreases with altitude.

The altitude at which climb performance falls close to zero and a steady climb can no longer be maintained is called *ceiling*. The *service ceiling* is the altitude at which the steady rate of climb has fallen to just 100 feet per minute (FPM). The *absolute ceiling* is the slightly higher altitude at which the steady rate of climb achievable at climbing speed is zero. It is therefore almost impossible to climb to the absolute ceiling, and the speed you maintain at this altitude is at the point where V_X and V_Y meet, as V_X increases and V_Y decreases with altitude.

The airplane's Pilot's Operating Handbook normally contains a table or graph with climb performance information.

MAXIMUM RATE OF CLIMB

SAMPLE ONLY
Not to be used in conjunction with flight operations or flight planning.

CONDITIONS:
Flaps Up
Full Throttle

NOTE:
Mixture leaned above 3,000 feet for maximum rpm.

WEIGHT LBS	PRESS ALT FT	CLIMB SPEED KIAS	RATE OF CLIMB – FPM			
			–20°C	0°C	20°C	40°C
1,670	S.L.	67	835	765	700	630
	2,000	66	735	670	600	535
	4,000	65	635	570	505	445
	6,000	63	535	475	415	355
	8,000	62	440	380	320	265
	10,000	61	340	285	230	175
	12,000	60	245	190	135	85

Climbing IAS for best rate of climb decreases with altitude.

Rate of climb decreases with altitude increase.

Rate of climb decreases with temperature increase.

Figure 6-10 A typical climb performance table.

The Effect of a Steady Wind on Climbing

A headwind increases climb gradient a tailwind reduces it. Wind does not affect rate of climb, but does affect angle of climb over the ground.

Because rate of climb is a vertical velocity and wind normally acts horizontally, rate of climb is not affected by a steady wind. Angle of climb through the air also is not affected by a steady wind. However, if we consider the angle (or gradient) of climb over the ground—the airplane's flight path—a headwind increases the effective climb gradient over the ground and a tailwind decreases it. *Taking off into a headwind* has obvious advantages for obstacle clearance—it improves your clearance of obstacles on the ground.

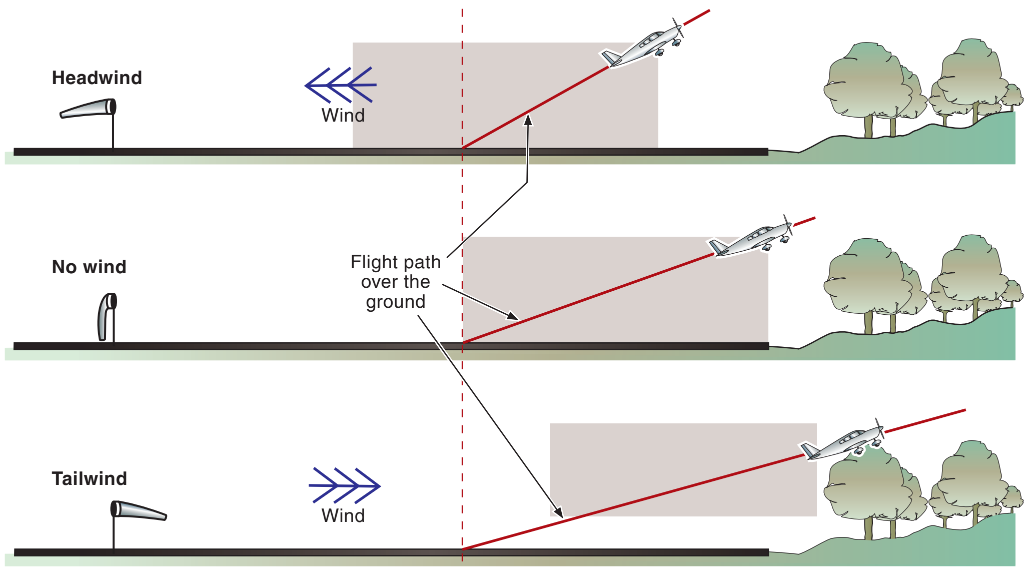


Figure 6-11 Wind affects the flight path achieved over the ground.

Descent

If an airplane is in a glide descent, with no thrust being produced by the engine and propeller, only *three* of the four main forces will be acting on the airplane: *weight*, *lift*, and *drag*. In a *steady* glide these three forces are in equilibrium as the resultant force acting on the airplane is zero. Suppose that the airplane is in steady straight-and-level flight and the thrust is reduced to zero. The drag force is no longer opposed with an equal and opposite force, and will therefore decelerate the airplane—unless a descent is commenced where the component of the weight force acting in the direction of the flight path is sufficient to counteract the drag. This effect allows the airplane to maintain airspeed by descending and converting potential energy because of its altitude into kinetic energy (motion).

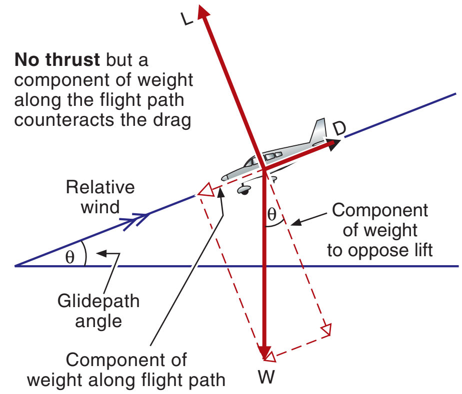


Figure 6-12
In a glide descent, a component of weight counteracts the drag.

Resolving the forces in the direction of the flight path shows that a component of the weight force acts along the flight path in a descent, counteracting drag and contributing to the airplane's speed. The airspeed in the descent remains constant when this component of weight is equal and opposite to the drag.

Resolving the forces vertically, you can see that, in a glide descent, the weight is counteracted by the total aerodynamic force, which is the resultant of the lift and drag. Notice that the greater the drag force, the steeper the glide. The shallowest glide is obtained at the maximum lift/drag ratio when, for the required lift, the drag is least:

- *if the L/D ratio is high*, the angle of descent is shallow—a flat glide angle—and the airplane will glide a long distance; and
- *if the L/D ratio is low* (a poor situation), with a lot of drag being produced for the required lift, then the airplane will have a large angle of descent—a steep glide angle—and the airplane will therefore not glide very far.

Two points can be made here:

1. an aerodynamically efficient airplane is one which can be flown at a high lift/drag ratio. It is capable of gliding further for the same loss of altitude compared with an airplane that is flown with a lower L/D ratio; and
2. the same airplane will glide furthest through still air when it is flown at the angle of attack (and airspeed) that gives its maximum L/D ratio. This angle of attack is usually about 4°.

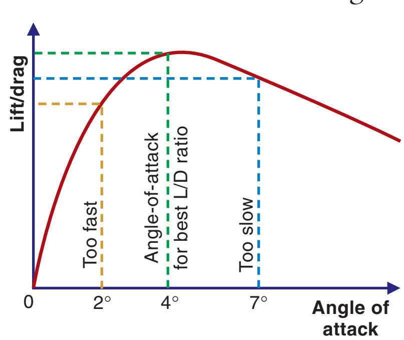


Figure 6-14
Angle of attack versus L/D ratio.

Because you cannot read angle of attack in the cockpit, flying at the recommended best glide or descent speed (listed in the Pilot's Operating Handbook) ensures that the airplane is somewhere near this most efficient angle of attack to achieve the best glide angle.

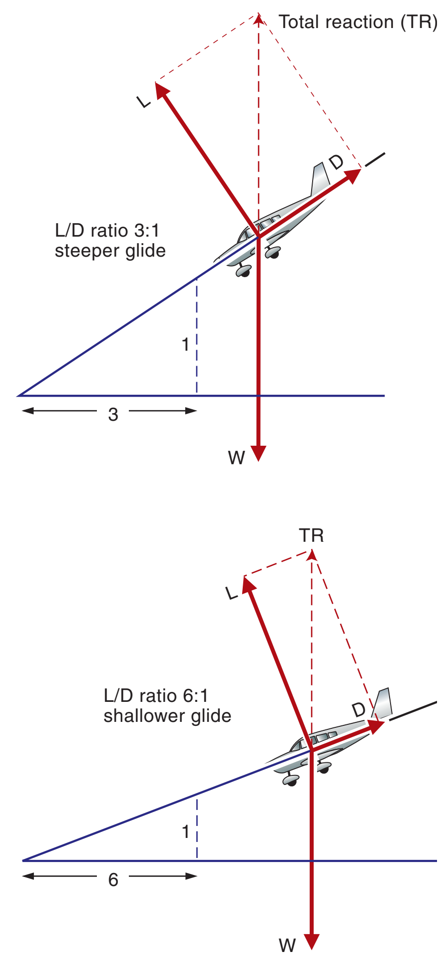


Figure 6-13
A smaller L/D ratio (increased drag) results in a steeper glide.

Factors Affecting Glide Angle

Airspeed

The wrong airspeed (too fast or too slow) steepens the glide angle.

To glide the furthest in still air, fly at the recommended airspeed (and therefore angle of attack) that gives the maximum lift/drag ratio. This may be deceptive for the pilot because the nose attitude may be quite high, but the airplane is descending steeply.

If you are gliding at the recommended airspeed and it looks like you will not reach the selected point, do not raise the nose to increase the glide distance. It will not work! The higher nose attitude may give the appearance of stretching the glide, but in fact it will decrease your glide distance.

The best glide speed reduces as weight decreases.

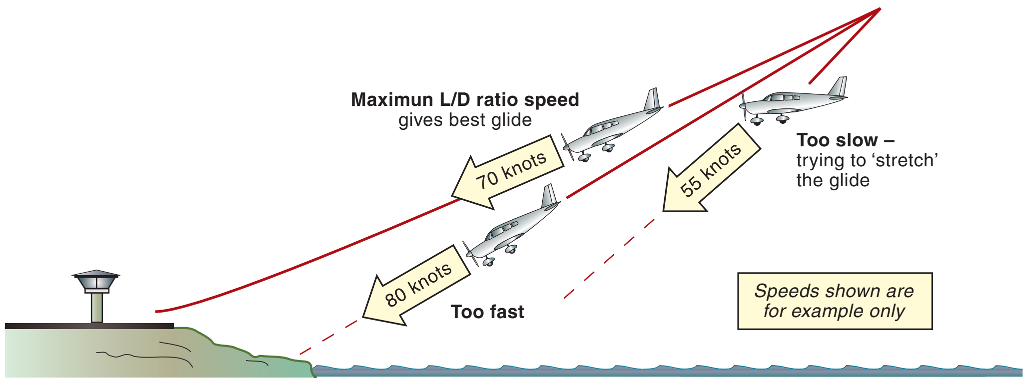


Figure 6-15 The flattest glide is achieved at the maximum L/D ratio.

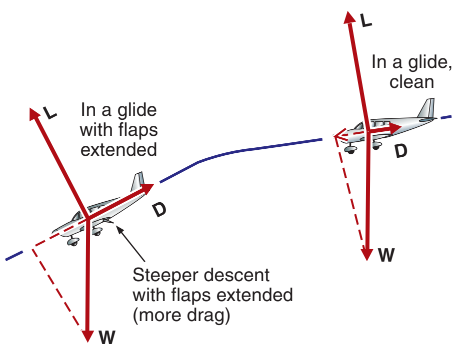


Figure 6-16
Steeper glide angle with flaps extended.

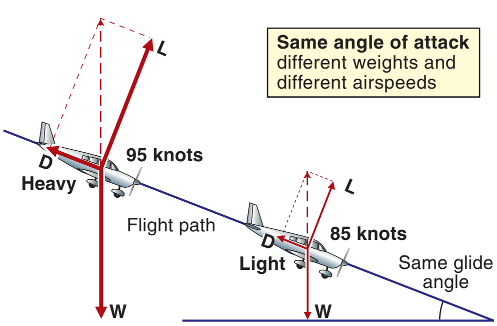


Figure 6-17 The best glide angle is the same at all weights (maximum L/D) but the airspeed must be lower at lower weights.

Flap Setting

Flaps increase the drag more than the lift and consequently the L/D ratio is lower. This gives a steeper glide.

Weight

If the airplane weight reduces, you can achieve the best glide angle by flying a slightly slower glide speed. By maintaining the angle of attack for the maximum L/D ratio (and therefore for the best glide), the airspeed will be lower but the glide angle the same. This also means that the rate of descent for the airplane when it is lighter will be less—it will glide the same distance through the air, but take longer to reach the ground because of the reduced airspeed.

The recommended glide speed (stated in the Pilot's Operating Handbook) is based on *maximum gross weight*. The variation in weight for most training airplanes is not large enough to significantly affect the glide if the recommended glide speed is used at all times—even though, theoretically, a slightly lower glide speed could be used when lightly loaded.

The recommended glide speed in your Pilot's Operating Handbook is suitable for all permissible weights of your light training airplane.

Glide Distance over the Ground

A headwind reduces the glide distance over the ground, even though it does not affect the glide distance through the air, nor does it affect the rate of descent:

- *glide angle* means relative to the *air mass* and is not affected by wind; and
- *flight path* means relative to the *ground* and is affected by wind.

A headwind reduces the glide distance over the ground a tailwind increases it.

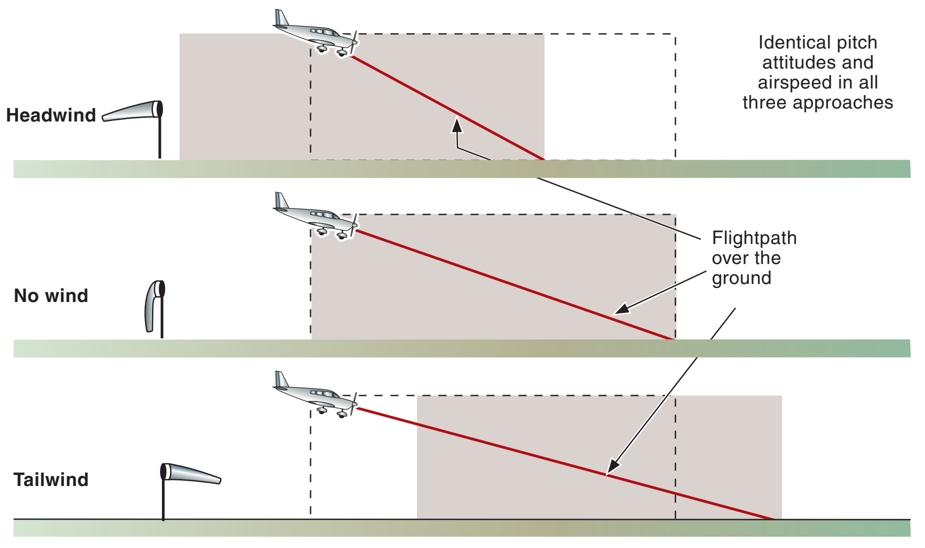


Figure 6-18 More ground is cvered gliding with a tailwind and less with a headwind.

The airplane "sees" only the air in which it is flying. In the case illustrated in figure 6-18, we can see three identical glides through an air mass—same airspeed, same nose attitude, same angle of attack, same rate of descent (therefore same time taken to reach the ground) in all three cases. The only difference is that the air mass is moving over the ground in three different ways and carrying the airplane with it. The ground distance covered differs. A tailwind increases the glide distance over the ground, even though it does not affect the glide distance relative to the air mass or the rate of descent.

Wind does not affect rate of descent.

Still Air Glide Distance

Figure 6-19 shows the forces acting in a glide. You will see that the glide distance is furthest when the L/D ratio is at its maximum value. If the L/D ratio is 5:1, the airplane will glide 5 times as far as it will descend. If you are 1 nautical mile (NM) high (about 6,000 feet), you will glide for about 5 NM. If you are at about 12,000 feet (2 NM), you will glide approximately 10 NM. An airplane with a L/D ratio of 12:1 will glide 12 times as far in still air as it will descend.

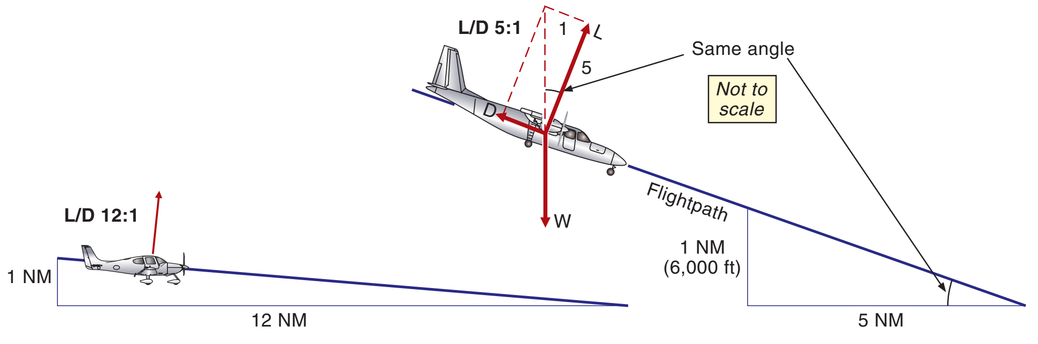


Figure 6-19 "Air distance/altitude" is the same ratio as "lift/drag."

Turning and Load Factor

Forces in a Turn

For an object such as an airplane to turn, a force is required that acts toward the center of the turn. This turning force is known as the *centripetal force*. Holding a string tied to a heavy object such as a stone, your hand supplies a lift force equal and opposite to the weight of the stone. If you swing the stone in a circle, however, your hand supplies not only a vertical force to counteract the weight but also a centripetal force to keep the stone turning. The total force exerted through the string is greater than the weight of the stone, and you will feel the increase in effective weight.

To turn an airplane, a centripetal force (toward the center of the turn) needs to be generated. This can be done by banking the airplane and tilting the lift force so that it has a sideways component.

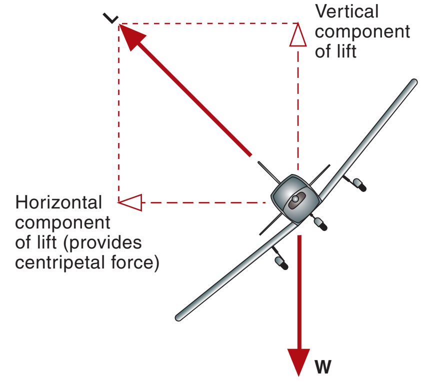


Figure 6-20 By banking, the tilted lift force has a horizontal component which provides the centripetal force.

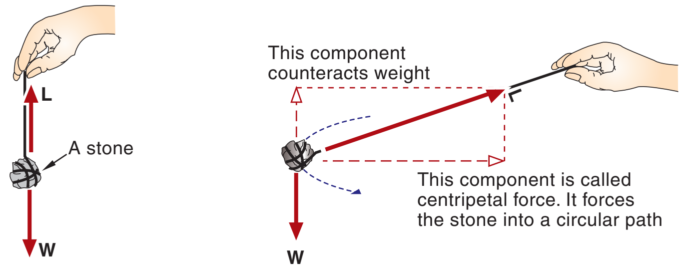
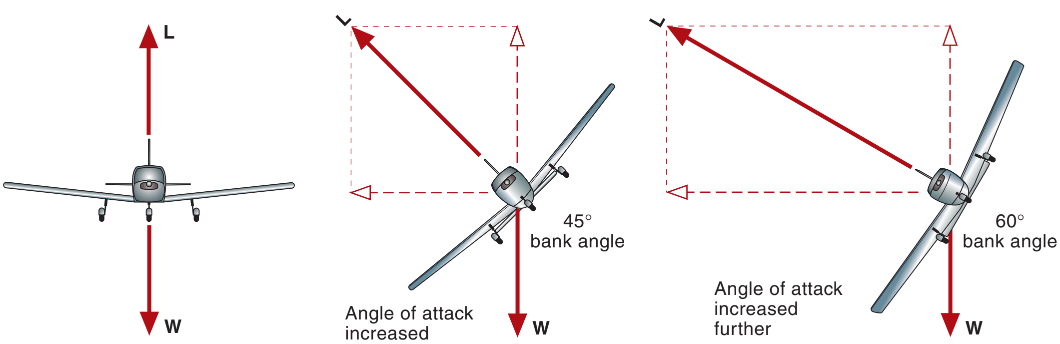


Figure 6-21 The centripetal force pulls a body into a turn.

Flying straight-and-level, the lift force from the wings counteracts the weight of the airplane. If you turn the airplane, the wings still need to supply a vertical force to counteract the weight (unless you want to descend) plus the centripetal force toward the center of the turn to keep the turn going. Consequently, the lift force in a level turn must be greater than the lift force when flying straight-and-level. To develop this increased lift force at the same airspeed, the angle of attack must be increased by applying back pressure on the control column.

The steeper the bank angle in a level turn, the greater the lift force required. Note that you select the bank angle using the *ailerons* (to roll the airplane) and *elevator* to increase the angle of attack (and increase lift) to produce the centripetal force required to turn the airplane and maintain the selected altitude.

Figure 6-22 The steeper the bank, the greater the lift force required from the wings.



The stability designed into the airplane, together with adverse yaw effect, may resist it turning, and the application of a little rudder (left rudder for a left turn and vice versa) helps bring the tail around and yaw the nose into the turn, aligning the fuselage with the turning flight path—therefore the rudder is used to *coordinate* the turn by controlling yaw. You, of course, are forced into the turn along with the airplane and feel this as an increase in the force exerted by the seat; it feels like an *apparent* increase in your weight—the centrifugal reaction.

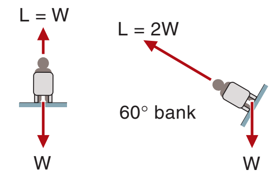


Figure 6-23
The steeper the bank angle, the greater the g-forces.

Load Factor

The load factor on the wings is increased in a turn. Flying straight-and-level, the wing produces a lift force *equal* to the weight and L = W. The load factor is said to be 1. You experience a force from the seat equal to normal weight, and feel it as "1g."

In a banked turn of 60°, the wings produce a lift force equal to *double* the weight and L = 2W. This means the loading on the wings is doubled when compared with straight-and-level flight, or each square foot of wing has to produce twice as much lift in a 60° banked turn as it does in straight-and-level flight. You experience a force from the seat equal to twice your weight. This is 2g and the load factor is 2. This is true for all 60° banked turns, irrespective of airspeed, rate of turn, or weight of the airplane.

The *load factor* is the ratio of the lift force produced by the wings compared with the weight force of the airplane.

$$\text{Load factor} = \frac{\text{lift}}{\text{weight}} = \frac{\text{wing loading in maneuver}}{\text{wing loading straight-and-level}}$$

At bank angles beyond 60°, the lift force generated by the wings must increase greatly so that its vertical component can counteract the weight, otherwise altitude will be lost. Increased lift from the wings means increased wing loading and an increased load factor. We can show this in a curve of load factor versus bank angle.

Note the following:

- in a 30° banked turn you will experience 1.15g load factor. The wings will produce 15% more lift than when straight-and-level, and you will feel 15% heavier;
- at 60° bank angle, the load factor is 2. The wings have to produce a lift force equal to double the weight to maintain altitude. The g-force is 2g, you will feel twice as heavy, and the wing will have to support double the weight;
- a 70° bank, the load factor is 3;
- a utility category airplane has a maximum allowable positive load factor of 4.4g, which is reached at approximately 77° bank angle (a normal category airplane is limited to 3.8g); and
- in a 90° banked turn, the lift force is horizontal, and, even if of infinite size, would have no vertical component to counteract the weight. Therefore altitude cannot be maintained in a coordinated turn at 90° bank angle (unless extreme excess thrust is used).

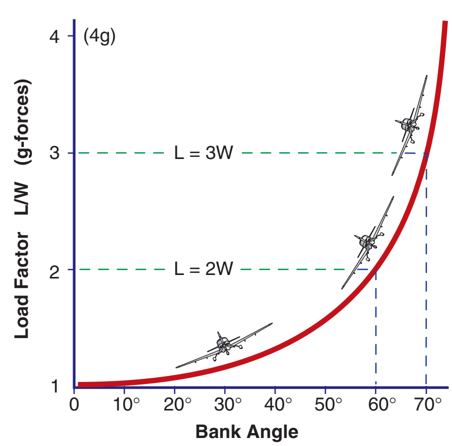


Figure 6-24
Load factor versus bank angle.

For those who are interested in a mathematical explanation, the load factor in a turn can be calculated from 1 divided by the cosine of the bank angle, or.

The maximum weights permitted to be carried in a particular airplane (or compartments within an airplane) take into account load factor. A normal category airplane is stressed to 3.8g. If the baggage compartment is approved for 220 lb, then it will not be overstressed provided 3.8g is not exceeded.

Load Factor in a Turn

Load factor increases as bank angle increases.

In straight-and-level flight, the wings support a load that is the weight of the airplane. In a banked turn of 60°, the load factor is 2, and now each wing has to support twice the load that it did in straight-and-level. Wing loading is the load supported by the wings divided by their area. For example, an airplane weighing 2,500 pounds (lb) with a wing area of 200 square feet has a wing loading of 12.5 lb/sq. feet in level flight. In a 60° banked turn the load factor is 2. Therefore the load that the wings are supporting is 2,500 × 2 = 5,000 lb:

$$\text{Wing Loading} = \frac{\text{load}}{\text{wing area}} = \frac{5{,}000}{200} = 25 \text{ lb/square foot}$$

Like load factor, wing loading in a turn depends only on the bank angle. But wing loading is not only of concern for structural strength, it also affects minimum landing speeds: the smaller the wing, the higher the wing loading and the faster the minimum landing speed.

Thrust in a Turn

In a turn, extra thrust is required to maintain airspeed.

In a turn, increased lift from the wings is required to provide the centripetal force and to maintain altitude. This is achieved by applying back pressure on the control column to increase the angle of attack.

The steeper the bank angle, the greater the angle of attack and back pressure required. As we saw in our discussion on drag, an increase in the angle of attack will lead to an increase in the induced drag. If a constant airspeed is to be maintained in a level turn, an increase in thrust to counteract the increased drag in a turn is required (typically 50 RPM for a fixed-pitch propeller or ½ in. Hg manifold pressure for an airplane with a constant-speed propeller). In practice, however, the power is usually kept constant in medium turns and you accept a reduction in airspeed of approximately 5 knots. If extra thrust is not added, the airspeed will decrease in a level turn. If required, airspeed could be maintained by allowing the airplane to lose altitude, trading potential energy for kinetic energy.

Steep Turns

A steep turn is one in which the bank angle exceeds 45° and airspeed is maintained by applying a significant increase in power. It is a high-performance maneuver that requires good coordination and positive control. A steep level turn requires a significant increase in lift so that:

- a strong horizontal component exists to pull the airplane into the turn; and
- the vertical component is sufficient to support the weight and allow altitude to be maintained.

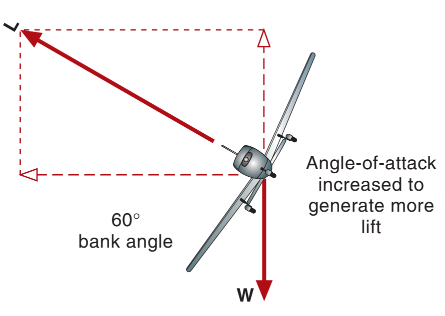


Figure 6-25
A steep level turn requires increased lift.

Firm *back pressure* is needed on the control column to increase the lift force, and *increased power* is required to overcome the tendency to lose airspeed because of the increased drag. Ailerons must be used to maintain the selected bank angle as accurately as possible.

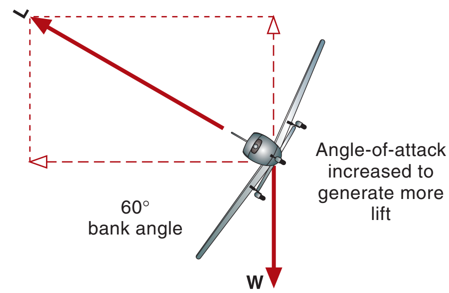


Figure 6-26
A steep level turn requires increased lift.

The Stall in a Turn

In a turn, the angle of attack has to be greater than at the same speed in straight-and-level flight, to create the additional lift needed to turn the airplane as well as support its weight. This means that the stall angle of attack will be reached at a higher speed in a turn — the steeper the bank angle, the higher the airspeed at which the stall angle of attack is reached:

- at 30° bank angle, the stall speed is increased by 7% over the straight-and-level stall speed;
- at 45° bank angle, the stall speed is increased by 19%;
- at 60° bank angle, the stall speed is increased by 41%; and
- at 75° bank angle, the stall speed is increased by 100%, or doubled.

For example, if your airplane stalls at 50 knots straight-and-level, then in a 60° banked turn it will stall at 71 knots (141% of 50 knots) which is a significant increase. In steep turns, you may feel the onset of the stall buffet because the margin between your speed and the stall speed has decreased.

Note. The stall speed increases by the square root of the load factor.

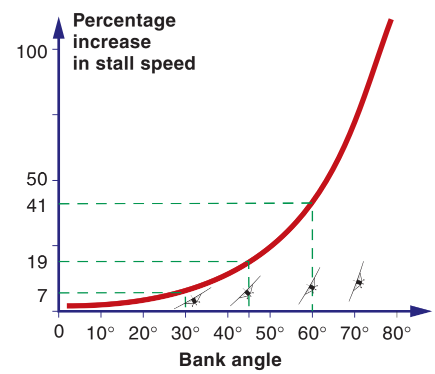


Figure 6-27 Percentage increase in stall speed versus bank angle.

Rate of Turn

The rate of turn of an airplane in degrees per second is important. Instrument flying usually requires *standard-rate* turns of *3°/second*. This means that the airplane turns through:

- 180° in 1 minute; and
- 360° in 2 minutes.

A standard-rate turn at a higher airspeed requires a steeper bank angle.

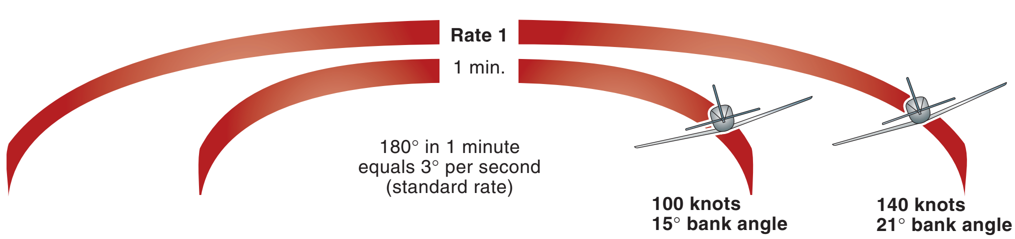


Figure 6-28 A standard-rate turn requires a steeper bank angle at a higher airspeed.

An easy way to estimate the bank angle (in degrees) required for a standard-rate turn is:

$\frac{1}{10}$ of the airspeed in knots, plus $\frac{1}{2}$ the answer

For example, at 140 knots, for a standard-rate turn, bank angle is $^{140}/_{10} + \frac{1}{2}\,(^{140}/_{10}) = 14 + 7 = 21°$.

Turn Performance

Constant-Angle Turn

An airplane in a 30° banked turn travels around different circular paths depending on its airspeed. At low speed the turn is tighter (the radius of turn is smaller) than at high speed, see figure 6-29.

At a constant bank angle, the slower airplane has an increased rate of turn. This is because the radius of turn decreases by the square of airspeed. Therefore although the airplane is flying through the air at a slower speed than the faster airplane, its radius of turn is much smaller, and the overall rate of turn is greater.

In summary, if the bank angle is kept constant and the speed reduced, the radius of the turn will decrease and rate of turn increase.

Constant-Radius Turn

To fly a turn of the same radius at a higher speed requires a greater bank angle.

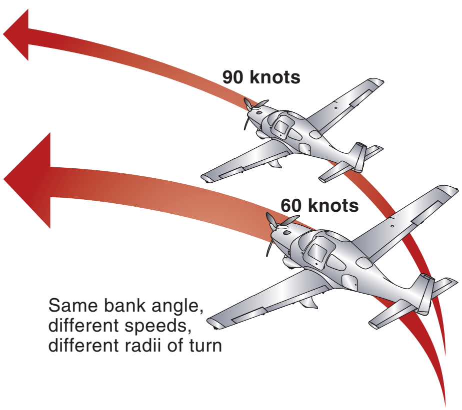


Figure 6-29 Turning performance is increased at low airspeeds.

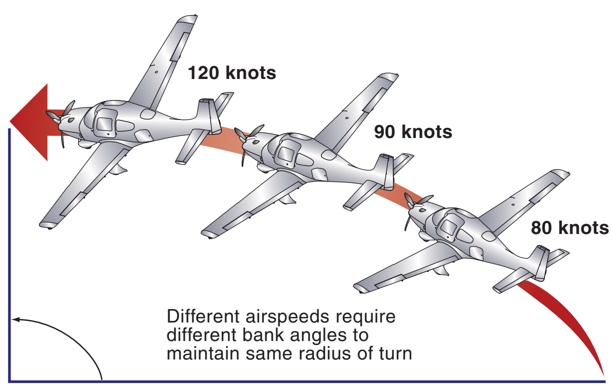


Figure 6-30 Constant-radius turn.

Stalling

A wing stalls when it reaches the *stall*, or *critical* angle of attack, which is the point where the smooth airflow breaks down and becomes turbulent, thereby considerably reducing the lift generated. You can induce a stall on purpose by increasing the angle of attack using back pressure on the control column.

A stall occurs at the critical angle of attack.

It is very easy both to prevent a stall, simply by ensuring that the critical angle of attack (about 16°) is not approached, and to recover from a stall, by easing the nose forward to decrease the angle of attack. Sometimes you want to approach the stall, for instance during the final stages of a landing.

Ideally the airflow around an airfoil would be streamlined. In flight however, the streamlined flow breaks away (or separates) at some point from the airfoil surface and becomes turbulent. At low angles of attack this separation point is toward the rear of the wing and the turbulence is not significant. At higher angles of attack the separation point moves forward. As the angle of attack is increased, a critical angle is reached beyond which the separation point suddenly moves well forward causing a large increase in the turbulence over the wing.

The separation of the airflow from the wing's upper surface and breakdown of the streamlined flow reduces the magnitude of the low static pressure above the wing, greatly reducing the lift developed by the wing. Conversely, as the angle of attack increases the small aerodynamic force produced by the airflow striking the wing's lower surface increases slightly. The overall effect however, is a marked decrease in lift and the airplane loses altitude. This reduction in the wing's lifting ability is shown in figure 6-31.

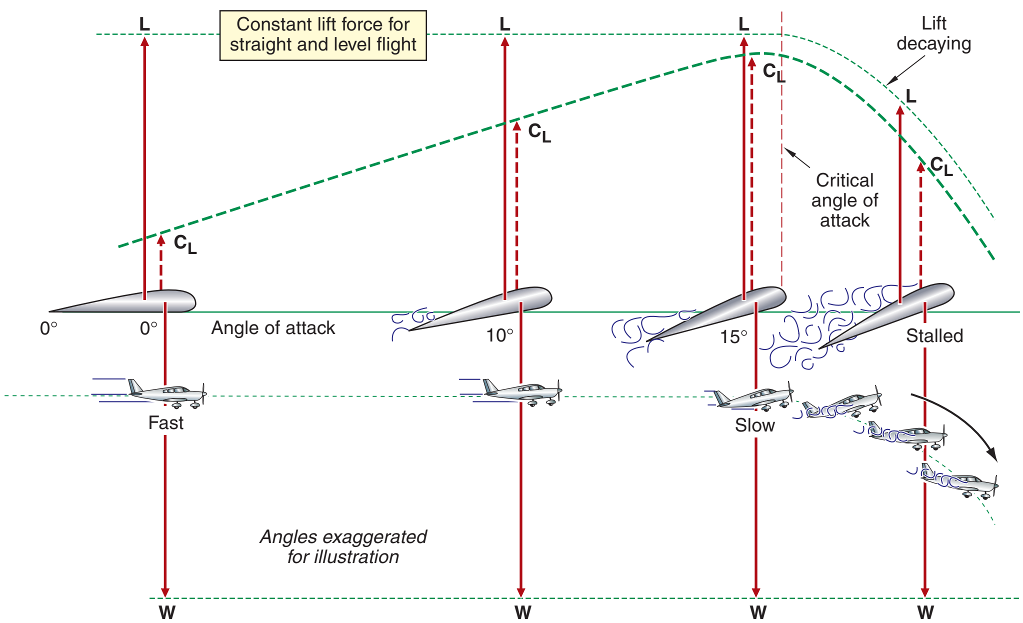


Figure 6-31 An airfoil reaches its maximum lifting ability at the critical angle of attack.

Recognition of the Stall

Approaching the stall angle of attack, the streamlined flow breaks down over parts of the wing and turbulent air flows back over the horizontal stabilizer. The airframe may shake or *buffet* as a result, known as *pre-stall buffet* or *control buffet*. Many airplanes have stall warning devices such as a buzzer or horn that sounds to warn the pilot that the wing is approaching the stall angle.

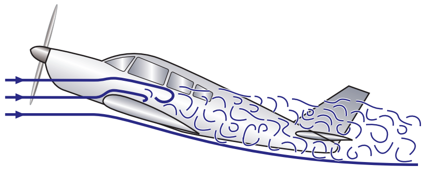


Figure 6-32 Turbulent flow over the horizontal stabilizer.

To recover from a stall reduce the angle of attack by lowering the nose.

At the stall, the decrease in lift causes the airplane to *sink*. The rearward movement of the center of pressure causes the *nose to drop.*

Recovery from the Stall

To recover from a stall, the angle of attack must be reduced. This is achieved by releasing the back pressure on the control column and allowing the nose to come down. If the airspeed is low, which is often the case, full power should also be applied to increase the airspeed as quickly as possible. Stall recovery should be initiated at the first indication of an impending stall.

Stall and Angle of Attack

For most training airplanes, the stall angle of attack is about 16°. This stalling or critical angle of attack is always the same regardless of airspeed, weight, loading, position of the center of gravity, load factor in maneuvers, altitude, and so on. The wing stalls at a particular angle of attack, and not at a particular airspeed.

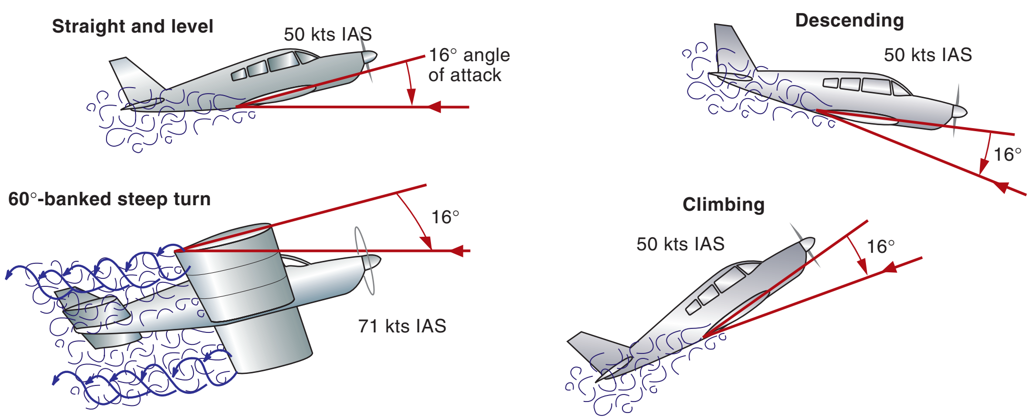


Figure 6-33 The stall occurs at the same stall angle in all phases of flight, but not necessarily at the same speed.

Factors Affecting Stall Speed

A specific airfoil stalls at a particular angle of attack; however, the stall may occur, for example, at:

- 50 knots straight-and-level for an airplane at maximum gross weight;
- 45 knots straight-and-level when it is light;
- 44 knots straight-and-level with flaps and gear down;
- 70 knots in a 60° banked turn; and
- 80 knots if you experience 3g pulling out of a dive.

Note. Do not bother learning these figures as they are only examples.

There is, however, some connection between *angle of attack* and *indicated airspeed*. Their relationship depends on:

- lift produced by the airfoil;
- load factor;
- bank angle;
- weight;
- power; and
- flap setting (which changes the airfoil's shape and lifting ability).

Load Factor

Stall speed increases with load factor.

If the wing has to produce increased lift to maneuver the airplane at a particular airspeed, for instance in a turn or pulling out of a dive, then you will apply back pressure on the control column to increase the angle of attack. Lift will be increased, causing an increased load factor, and you will feel an increase in your g-loading.

Stalling occurs at a critical angle of attack not at any particular airspeed.

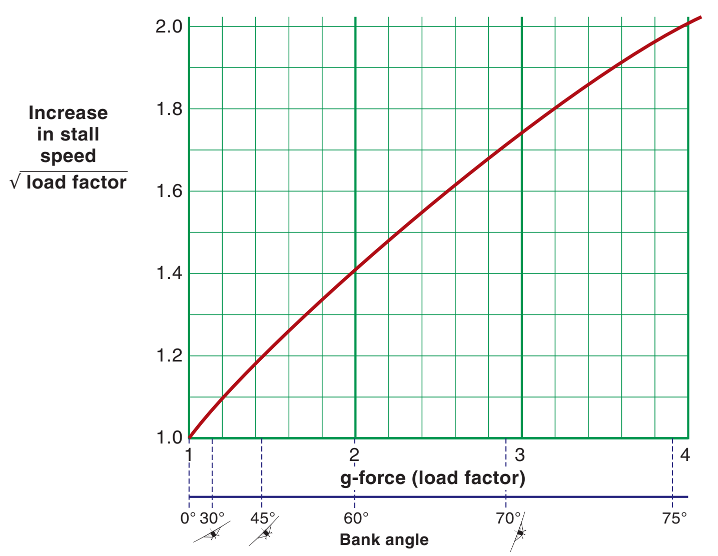
An increased angle of attack in maneuvers will bring the wing closer to the critical or stall angle, even though the airspeed has not changed, and, in the extreme case, if you increase the angle of attack to the critical angle, the wing will stall even though the airspeed is well above the 1g straight-and-level stall speed.

In *airfoil lift* (Chapter 4) we saw that lift depends on angle of attack and airspeed squared. If lift depends on airspeed-squared then, conversely, airspeed is related to the square root of lift. This means that the actual stall speed when the critical angle of attack is reached depends on the square root of the lift being produced.

If lift is increased by a factor of four in an aggressive maneuver, the stall speed will be doubled. If the straight-and-level 1g stall speed is 50 knots, then when pulling 4g the wing will stall at 100 knots. Note that 4g is outside the load limits for most training airplanes.

If the load factor is doubled, for instance in a 60° banked turn, you will feel 2g (double your normal weight), and the stall speed will be 1.4 times greater (the square root of 2 is approximately 1.41), which is approximately 71 knots (1.41 × 50). This is illustrated in figures 6-34 and 6-35.

Because the stall angle is reached in maneuvers at higher speeds than when flying under 1g conditions, these are known as *accelerated stalls.* Stall speed will be increased any time lift from the wings is increased, which will occur in turns, when pulling out of dives, in gusts, and in turbulence.



Examples

1. At 2g (load factor 2) the stall speed increases by 1.41, and at 3g by 1.73 times the level stall speed for the airplane.

2. In a 60° bank turn the load factor is 2 and the stall speed increase is by 1.41.

Figure 6-34 Stall speed increases with load factor.

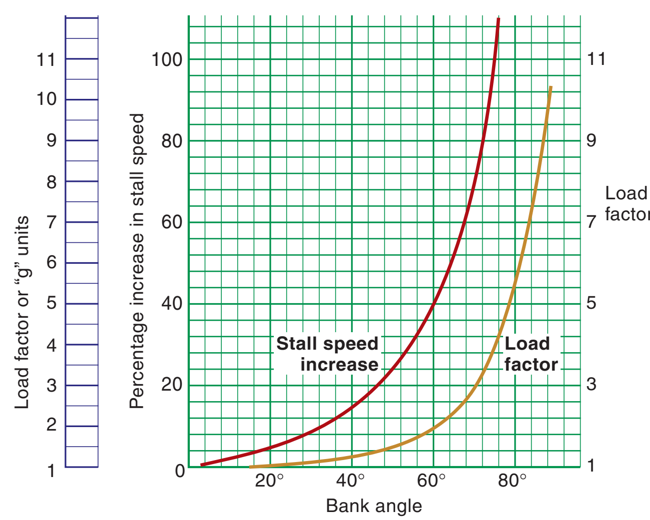


Figure 6-35
Relationship between stall speed, load factor and bank angle.

Weight

Stall speed increases with weight (stall angle of attack stays the same.)

In straight-and-level flight, sufficient lift must be generated to balance the weight. The heavier the airplane, the greater is the lift force required. Because the stall speed varies with the square root of lift, an increase in airplane weight increases the stall speed—but does not affect the stall angle of attack.

If the weight decreases 20% to only 0.8 of its original value, then the stall speed will decrease to 0.9 times its original value (0.9 is the square root of 0.8).

If the stall speed at maximum gross weight (say 2,000 pounds) was stated in the Pilot's Operating Handbook to be 50 knots, then at 1,600 pounds (only 80% of the maximum weight), the stall speed is only 90% of the original stall speed which is 45 knots. Conversely, an increase in weight increases the stall speed.

The Pilot's Operating Handbook states various stall speeds. V_S is the minimum steady-flight speed at which the airplane is controllable or stall speed, in straight-and-level flight, with the power off, at *maximum allowable gross weight.* Remember that whenever your airplane weighs less than its maximum weight it will stall at a speed slightly *below* that specified in the Pilot's Operating Handbook.

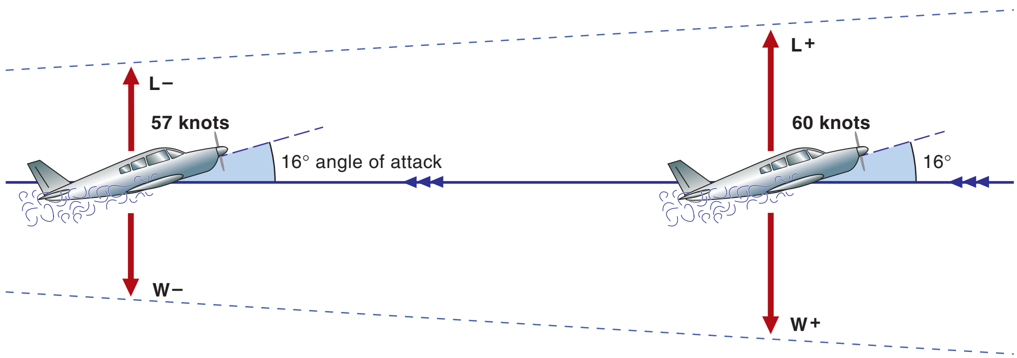


Figure 6-36 Stall speed is a function of weight.

Power

Stall speed is lower in a power-on stall.

With full power on, the strong slipstream passes over the inner section of each wing as well as the empennage. The separation of the airflow from the upper surface of the inner section of each wing is thereby delayed, so a more positive stall occurs at a *lower* indicated airspeed, compared with power off.

In addition, as the stall angle is approached with power on, the high nose attitude allows the thrust to have a vertical component that will partially support the weight. Therefore, the wings are off-loaded a little and less lift is required from them. Less lift means a lowered stall speed.

Because the slipstream encourages the generation of lift from the inner parts of the wing, the outer sections of the wing may stall first. Any uneven production of lift from the outer sections of the two wings will lead to a rapid roll called a *wing drop*. If a wing does drop close to the stall, do not correct by putting the aileron on the dropped wing down. In other words, do not try lifting the wing with aileron.

This will further increase the lower wing's effective angle of attack resulting in the wing becoming more stalled and dropping further. If a wing drops close to the stall, correct with rudder (the secondary effect of rudder is roll). Be aware rudder input yaws the airplane, increasing the angle of attack on the dropped wing.

A power-on stall may be more definite and accompanied by a wing drop.

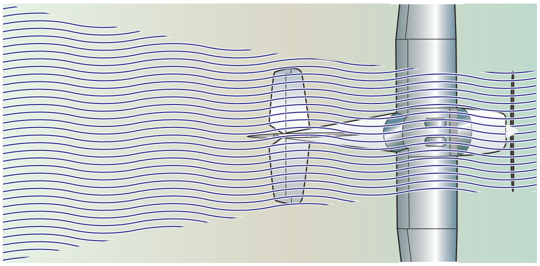


Figure 6-37 Slipstream can lower stall speed.

Altitude

The stall angle of attack will be reached (straight-and-level) at the same stall indicated airspeed irrespective of altitude. If the airplane has a 1g stall speed of 45 knots indicated airspeed (KIAS) at 1,000 feet MSL, its 1g stall speed at 5,000 feet MSL will also be 45 KIAS.

Stall indicated airspeed does not vary with altitude.

Ice, Frost, and Other Wing Contamination

Ice accretion has two effects:

- ice increases weight, so the stall speed is increased; and
- much more significantly, ice accretion, frost, or other contamination on the wings (particularly the front half of the upper surface where most of the lift is generated) disrupts the airflow over the wing, decreasing its lifting ability, and causes early separation of the airflow from the wing.

Ice, frost, or other wing contamination increases stall speed.

The early separation of the airflow results in the breakdown of streamlined flow at angles of attack well below the normal stall angle, and stalling occurs at higher speeds. In addition, the higher stall speeds result in the takeoff speed increasing above the normal takeoff speed, and the takeoff distance increasing at an unknown rate. Ice can prevent an airplane from becoming airborne.

> **Note.** Any ice or frost at all, even if only the texture of very fine sandpaper, should be removed from the wing prior to flight, as should insects and salt from the wing leading edges.

Flaps

Extending flaps gives us a new airfoil shape with increased camber and an *increased lifting ability.* This enables the wings to support the same load at a lower speed, and the airspeed can decrease to a lower value before the stall angle is reached.

Flaps reduce the stall speed.

The reduction of stall speeds is the main advantage of flaps. It makes for safe flight at lower speeds—very useful for takeoffs, landings (shorter fields) and low speed searches. Also, extending the flaps allows lower nose attitudes—not only is visibility increased, but also the stall angle will be reached at a lower nose attitude.

The stall with flaps extended may be accompanied by a wing drop, especially with power on. Use rudder to correct the wing drop, not aileron. Because of the increased drag with flaps extended, any speed loss, especially with power off, could be quite rapid, with little advance warning to the pilot of an impending stall.

In the stall with flaps down, turbulence over the horizontal stabilizer may cause very poor control from the elevator, known as *blanketing* of the elevator. Some training airplanes have a T-tail with the horizontal stabilizer high on the fin to avoid any such blanketing of the elevator in the stall.

Note. Some airplane manuals publish tables that show stall speed at various bank angles with power off and power on, with the airplane clean, and also with the airplane in the landing configuration (gear and flaps down).

For example from figure 6-38, the predicted stall speed:

- clean (flaps 0% full up), CG most forward at 30° bank angle is 70 knots; and
- gear/flaps 100% full down, CG most aft in level flight is 54 knots.

Weight	Bank Angle	STALL SPEEDS					
		Flaps 0% Full Up		Flaps 50%		Flaps 100% Full Down	
LB	Deg.	KIAS	KCAS	KIAS	KCAS	KIAS	KCAS
3000 Most FWD C. G.	0	65	67	61	63	56	59
	15	66	68	62	64	57	60
	30	70	72	65	68	61	63
	45	78	80	72	75	67	70
	60	92	95	86	89	80	83
3000 Most AFT C. G.	0	64	66	59	62	54	57
	15	65	67	60	63	55	58
	30	69	71	64	66	58	61
	45	76	178	71	73	64	68
	60	90	93	84	87	76	61

Figure 6-38 Examples of stall speeds in different situations.

Stall Warning Devices

Most airplanes are equipped with a device such as a horn, flashing red light, or whistle to warn of an impending stall. Such artificial devices are only secondary to the aerodynamic *stall warnings* that you must learn to recognize, such as stall buffet, decreasing speed, and less effective controls. If a stall recovery is initiated at the sound of the stall horn, it is known as an *imminent stall recovery*.

Wing Design and Stall Characteristics

Stalling first at the wing root is preferable to stalling first at the wingtip.

If there is an uneven loss of lift from the outer sections of the wings near the tips, caused by one of them stalling first, then a strong rolling moment is set up because of the long moment arm from the outer sections of the wing to the CG. Also, the ailerons become less effective because of the disturbed airflow around them.

Stalling at the wing roots is preferable because it allows the control buffet over the horizontal stabilizer (because of the turbulent air from the inner sections of the wing) to be felt, while the outer sections of the wings are still producing lift and the ailerons should still be effective. An uneven loss of lift on the inner sections, if one wing stalls before the other, does not have as great a rolling moment compared with when the outer sections of the wing stall first.

A *rectangular* wing, compared with other wing planforms, has a tendency to stall first at the wing root, and so provide adequate stall warning to the pilot while the ailerons are still effective. This is one reason why rectangular wings are common in basic training airplanes.

Stalling at the wing root first can also be achieved with a lower angle of incidence (and therefore a lower angle of attack) at the wingtip when compared with the wing root, which is known as *washout*. This means that the wing root reaches the stall angle prior to the wingtip. (Washout also helps to reduce the induced drag from wingtip vortices.) On other airplanes, small metal plates can be placed at the inboard leading edges to encourage the early onset of the stall at the wing root.

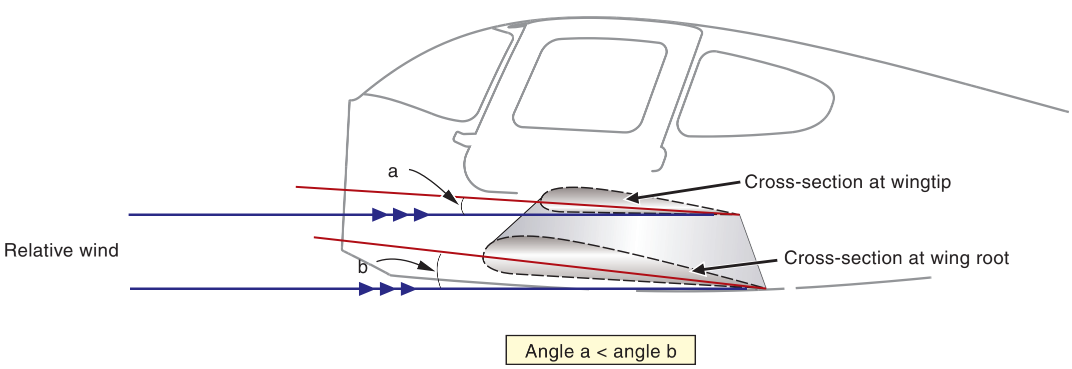


Figure 6-39 Built-in washout causes the wingtip to stall lataer than the root.

The Spin

To spin, an airplane must first be stalled.

A spin is a condition of stalled flight in which the airplane follows a spiral descent path. As well as the airplane being in a stalled condition, and yawing, one wing is producing more lift than the other, which results in a roll. The dropping wing is more deeply stalled than the other, and the greater drag from this wing results in further yaw, further roll, and autorotation develops. Upward pitching of the nose will also occur. You can induce a spin on purpose by yawing an airplane that is stalled, or just on the point of stalling.

In a spin, the airplane is in motion about all three axes. In other words, lots of things are happening in a spin! The airplane is:

- stalled;
- rolling;
- yawing;
- pitching;
- slipping; and
- rapidly losing altitude at a low airspeed (close to the stall speed).

In a spin the wings will not produce much lift, since they are stalled. The airplane will accelerate downward until it reaches a vertical rate of descent where the greatly increased drag, now acting upward, counteracts the weight. The altitude loss will be rapid as the airplane spins downward around the vertical spin axis but, because of the high angle of attack and the stalled condition, the airspeed in the spin will be quite low and fluctuating.

Characteristics of a developed spin include a *low airspeed* (which does not increase until recovery action is initiated), and a *high rate of descent*.

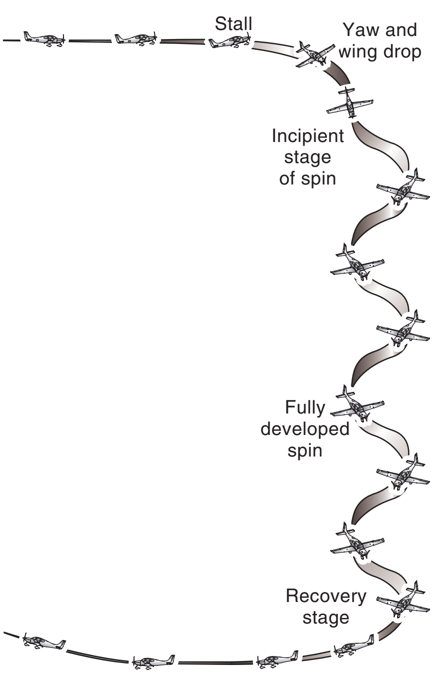


Figure 6-40 The flight path in a spin.

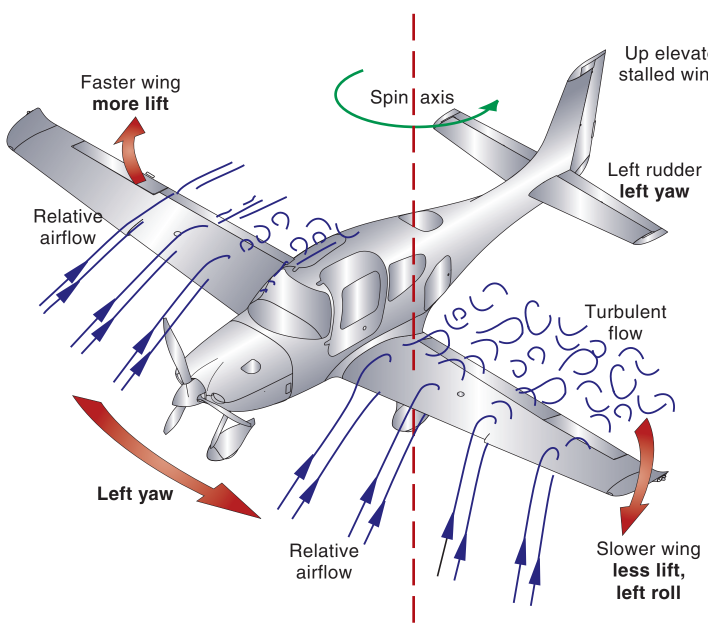


Figure 6-41 The airplane in a stable spin to the left.

Spin Recovery

To recover from a spin, you must ensure power is off, oppose the yaw, and unstall the wings. First note yaw direction and apply full opposite rudder, and then move the control column forward to unstall the wings by decreasing the angle of attack. Once the airplane has stopped spinning, ease the airplane out of the dive and resume normal flight.

Misuse of Ailerons

On some airplanes, misuse of the ailerons can cause a spin.

Trying to raise a dropped wing with opposite aileron may have the *reverse* effect when the airplane is near the stall. If, as the aileron goes down, the stall angle of attack is exceeded, the wing may drop quickly instead of rising, resulting in a spin.

The application of aileron after a spin has developed may aggravate the spin. Discuss the spin characteristics of your particular airplane with your flight instructor.

The Spiral Dive

Do not confuse a spin (low airspeed and stalled) with a spiral dive (high airspeed and not stalled).

A maneuver that must not be confused with a spin is the spiral dive, which can be thought of as a steep turn that has gone wrong. In a spiral dive the nose attitude is low, and the rate of descent is high, but neither wing is stalled and the airspeed is high and rapidly increasing. A spiral dive is really just a steep descending turn. However, because the pilot may be disoriented it is often mistaken for a spin. The high and increasing airspeed indicates that the airplane is in a spiral dive rather than a spin (when the airspeed would fluctuate at a low value).

Recovery from a spiral dive is simple. Roll wings level and pull gently out of the dive. Beware of overstressing the airplane by pulling too quickly out of the dive—remember the controls will be very effective because of the high airspeed.

Takeoff Performance

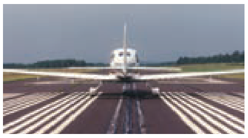


Figure 6-42
Takeoff is a critical phase.

Take off and landing are perhaps two of the most labor intensive tasks involved in piloting an airplane, and they start long before the wheels leave the ground.

Takeoffs involve much more than smooth piloting skills; they involve careful planning and preparation. A very smooth takeoff is of little value if the airplane, once airborne, is faced with obstacles impossible to avoid. The takeoff performance of the airplane needs to be matched to the runway and the surrounding obstacles prior to actually taking off.

Definitions

The *ground roll* is the distance an airplane will travel on the takeoff run, from a standing start until it leaves the ground. The *takeoff distance* is the distance established on a paved, level, dry runway for the airplane to clear a 50-foot obstacle from a standing start, at maximum takeoff power. The *takeoff safety speed* (TOSS), which provides a 20% margin over the stall speed, should be achieved by the 50-foot point.

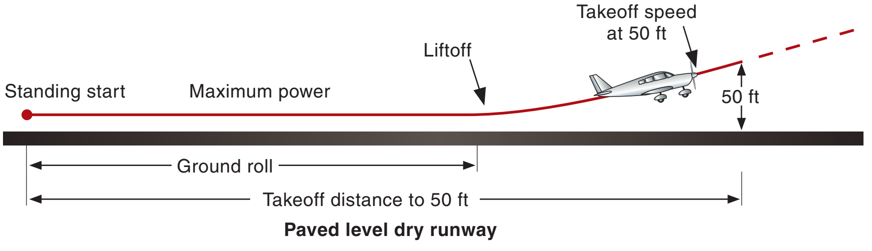


Figure 6-43 Takeoff distance.

Factors Affecting Takeoff Performance

Weight

A heavier airplane results in a greater takeoff distance.

A heavier airplane will require an increased ground run and takeoff distance to clear a 50-foot obstacle because of the slower airplane acceleration and increased takeoff speed. In addition, the greater weight on the wheels during the ground run increases the friction, further reducing acceleration and increasing the distance to reach a set takeoff speed.

Increased Takeoff Speed

A heavier airplane will have a higher stall speed. Because the liftoff speed is related to the stall speed, any increase in stall speed also means an increase in liftoff speed. After liftoff, the greater weight will also reduce the airplane's climb performance (rate of climb and angle of climb) and so the distance required for the initial climb to 50 feet above the runway will be greater. This climb is still part of the takeoff distance, hence there is a corresponding increase in the takeoff distance extracted from the performance chart.

The overall effect of a 10% increase in weight may be to increase the takeoff distance by 25%.

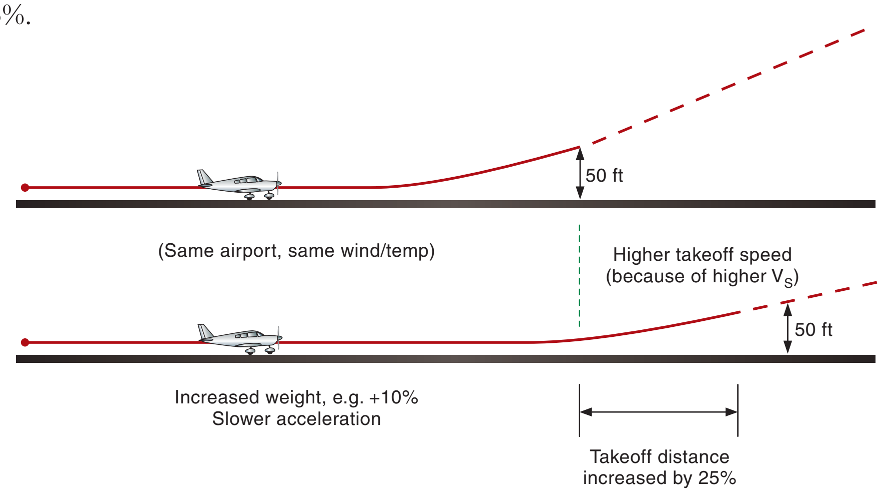


Figure 6-44 Increased weight decreases takeoff performance.

Air Density

One cause of an increase in density altitude is a decrease in air density. This results in a longer ground run and takeoff distance to clear a 50-foot obstacle. A decrease in air density can be caused by a number of factors.

A high airport elevation results in decreased airplane and engine performance.

A *lower air pressure* will decrease the density and this can occur as a result of a different ground-level ambient pressure or as a result of a higher airport elevation. This effect is covered by pressure altitude, which relates the actual pressure experienced by the airplane to a level in the standard atmosphere that has an identical pressure. High-elevation airports lead to longer takeoff distances.

High temperatures decrease airplane and engine performance.

A *higher air temperature* will also decrease the air density, reducing airplane and engine performance.

If the air density decreases, the engine-propeller combination will not produce as much power and so the takeoff distance will increase. In addition to the power-producing performance of the engine-propeller decreasing, the aerodynamic performance of the airplane will also decrease as air density becomes less.

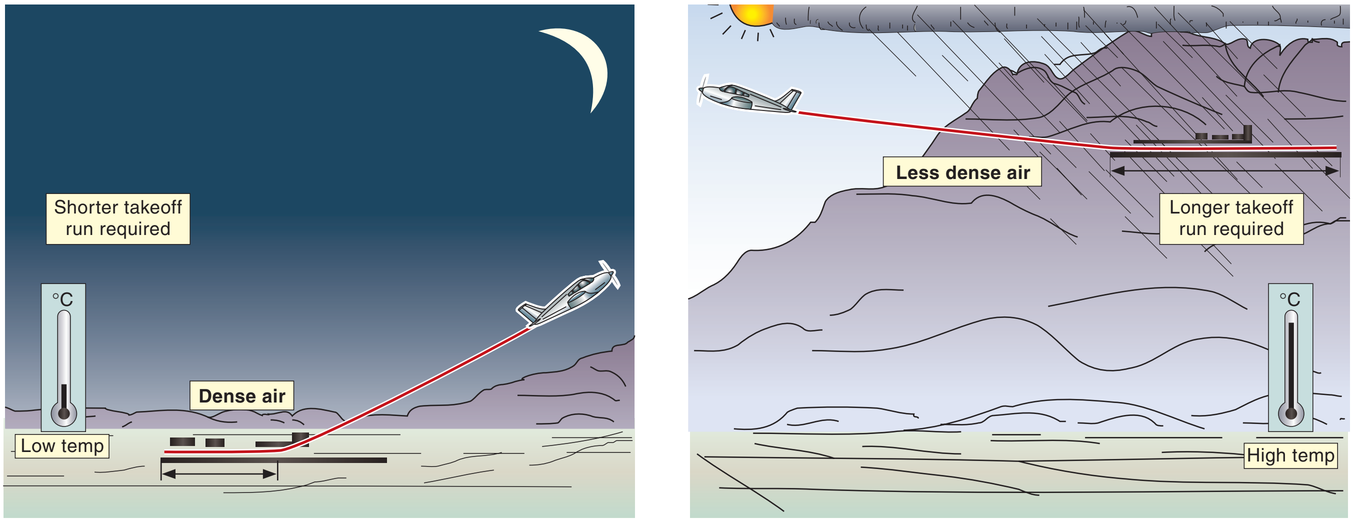


Figure 6-45 Hot, high and humid means decreased performance.

To produce the required lift force (L = Lifting ability $\frac{1}{2}\rho V^2 \times S$), a decrease in air density (ρ) means that for the same required indicated airspeed, an increase in the velocity (true airspeed, V) is required and a longer takeoff distance will result. Not only does a lower air density affect the aerodynamic performance of the airframe (controlled by $\frac{1}{2}\rho V^2$), it also decreases the weight of the fuel/air mixture in the engine cylinders, causing a decrease in engine power.

Headwinds and Tailwinds

A headwind reduces the takeoff distance.

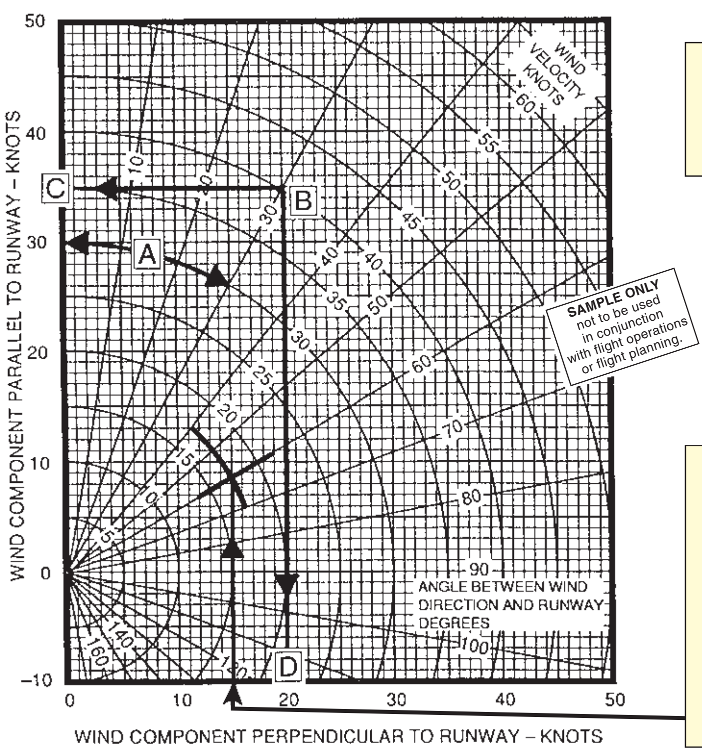
A headwind reduces the ground roll and takeoff distance to clear a 50-foot obstacle. For flight, the airplane requires a certain speed relative to the air in which it is flying. An airplane stopped at the end of the runway and facing into a 20-knot headwind is already 20 knots closer to the liftoff indicated airspeed, compared with the no-wind situation.

In a *headwind* takeoff the airplane therefore reaches liftoff indicated airspeed at a lower groundspeed, and so less ground run is required. Once in the air, the angle or gradient relative to the ground is increased by a headwind, making for better obstacle clearance.

In a *tailwind*, the effect is to lengthen the ground run and to flatten the climb-out. Tailwinds in excess of 5 knots are normally not considered suitable for takeoff. Obviously, a takeoff into the wind shows better airmanship.

Crosswinds

The airplane must not be taken off in a *crosswind* that exceeds the maximum crosswind limit for the airplane. Directional control is a problem. The aerodynamic force from the rudder is potentially not sufficient to overcome the effect of the keel surfaces wanting to weathercock the airplane into the wind. Lateral control is an additional problem, because the crosswind will generally try to lift the into the upwind wing, which then has to be held down with aileron.



Example 1. 40 kt wind at 30° angle.
A. 30° angle between wind and runway.
B. 40 knots total wind velocity.
C. 35-knot headwind component.
D. 20-knot crosswind component.

Example 2.
Calculate max. safe wind strength from 340°M given:
Airplane crosswind limit 15 kt
Rwy 28

Method:
1. Enter at 15 kt crosswind component.
2. Proceed up to 60° radial (60° being the difference between wind direction and runway bearing).
3. Read off wind speed 15 kt.

Answer: Max. safe wind strength from 340°M is 15 knots.

Figure 6-46 A typical crosswind corrections graph.

In calculating the strength of a crosswind component we will consider a 10-knot wind blowing from various directions. The approximate values of headwind and crosswind are:

- if the wind is 30° off the runway heading, then the crosswind component is ½ the wind strength;
- if the wind is 45° off the runway heading, then the crosswind component is ⅔ the wind strength;
- if the wind is 60° off the runway heading, then the crosswind component is 9⁄10 the wind strength; and
- if the wind is 90° off the runway heading, then it is all crosswind.

Note. Flight computers have the facility for calculating crosswind (and head/tail wind components). Sometimes a *crosswind corrections graph* is provided in the Pilot's Operating Handbook.

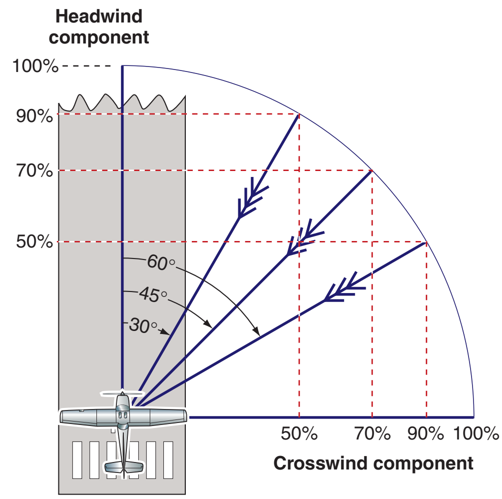


Figure 6-47 Estimating crosswind and headwind components.

Runway Surface

The length of the ground roll, at any given weight, will vary in response to the friction caused by the runway surface during the takeoff roll. A dry hard-paved runway causes the least amount of friction, and so this type of surface may serve as a datum, or reference surface, on takeoff performance charts. A runway with a short dry-grass surface, based on firm subsoil, has only a marginally higher retarding effect.

Poor runway surfaces increase takeoff ground run.

Soft ground or long grass (especially if wet) will reduce the acceleration, and this will result in a greater takeoff distance by as much as 25%. Gravel is considered to have the same effect as a short dry-grass surface. Pools of water on any type of runway surface can significantly retard the acceleration, and takeoff under such conditions requires very careful consideration. Soft, wet ground or a soft, sandy surface might make acceleration to the liftoff speed impossible, no matter what runway length is available.

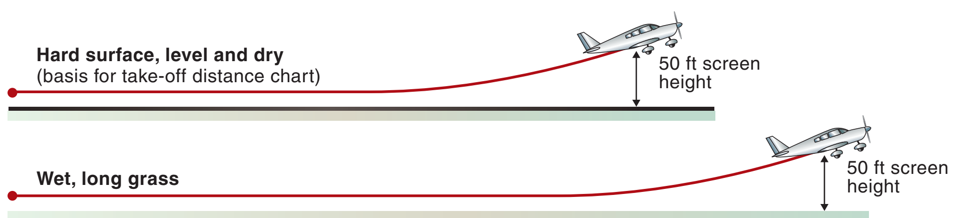


Figure 6-48 Poor surfaces may increase the ground run.

Flaps

The use of small flap settings decreases the ground run.

The use of small flap settings decreases the length of the ground run. Flaps have the effect of lowering the stall speed, which reduces the liftoff speed. Provided that the flap setting used for takeoff is small (so that the drag is not greatly increased), the slower liftoff speed after a shorter ground run may enable a shorter runway to be used.

If the ground surface is rough, using a small flap setting for takeoff will allow you to get off the ground sooner.

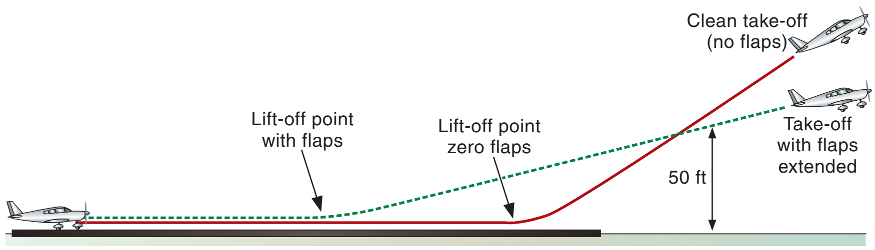


Figure 6-49 Use of takeoff flaps reduces the ground run.

Notice we have used the words "ground run" rather than "takeoff distance to clear a 50-foot obstacle." While the ground run will be less when small flap settings are used, the takeoff distance to clear a 50-foot obstacle may not be reduced significantly. This is because flaps, as well as increasing lift, increase drag, thus reducing the excess thrust and thereby the angle of climb. This is the main reason for only using small flap settings for takeoff. A larger flap setting, even though it might reduce the stall speed, would greatly increase the aerodynamic drag during the ground run, causing a slower acceleration and then, once airborne, would significantly degrade the climb-performance.

We cannot generalize too much in our statements here, as the precise effect of the use of flaps on the takeoff of a particular airplane depends on many things, including the flap setting, the engine-propeller combination and the airspeed flown. You must become familiar with your own airplane type.

Runway Slope

Takeoff distance is calculated for a level runway, and some takeoff charts allow for the effect of runway slope. A downslope of 2-in-100 or 2% down will allow the airplane to accelerate faster and so will decrease the ground roll. An upslope of 2-in-100 or 2% up will make it more difficult for the airplane to accelerate and so the ground roll will be greater. A 2% upslope may increase the takeoff distance to 50 feet by approximately 20%.

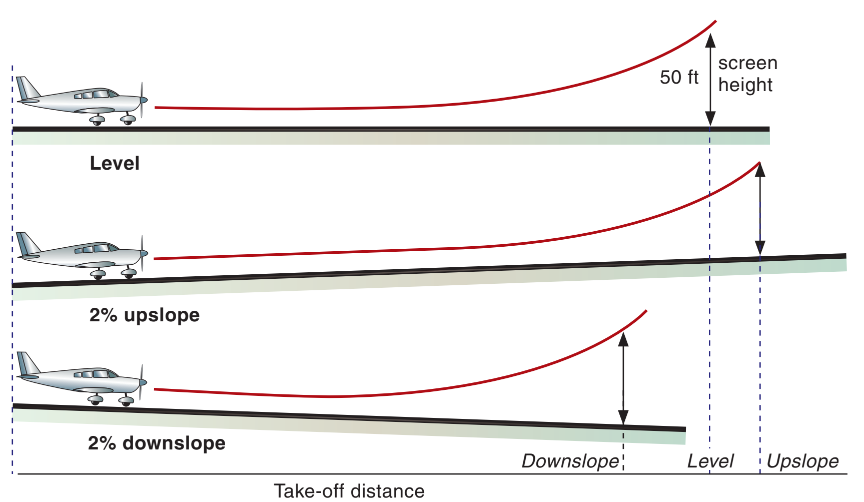


Figure 6-50 An upward-sloping runway will increase the ground roll and takeoff distance to 50 feet.

Note. Runway slope is calculated using the elevations at either end. Therefore a runway with downslope may have a hump (involving upslope) somewhere along its length.

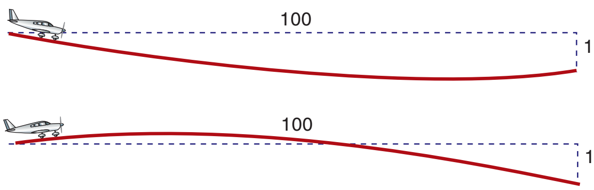


Figure 6-51
Each of these runways has a downslope of 1%.

The Takeoff Distance Table

Many manufacturers present performance data in the form of graphs and tables. When using performance tables, it is important to be certain to comply with the associated conditions stated in the table or make the recommended adjustments to the performance based on not complying with the associated conditions (if applicable). A common takeoff table is shown as an example in figure 6-52. Using the table you can apply corrections for:

- air density (using temperature, and pressure altitude);
- runway slope
- dry and wet grass runways
- airplane takeoff weight; and
- headwind or tailwind component (note that the tailwind must not exceed 10 knots).

A takeoff performance table allows you to determine:

- the takeoff distance from the starting point to a point 50 feet above the runway;
- the length of the ground roll prior to liftoff; and
- the liftoff speed and the speed over a 50 foot obstacle.

Weight: 3400 lb. Speed at Liftoff: 73 KIAS Speed over 50 ft. Obstacle: 78 KIAS Flaps: 50% Power: Takeoff Runway: Dry, Paved, Level	Headwind: Subtract 10% for each 12 knots headwind. Tailwind: Add 10% for each 2 knots tailwind upto 10 knots. Runway Slope: Reference Notes. Dry Grass: Add 20% to Ground Roll. Wet Grass: Add 80% to Ground Roll.

PRESS ALT FT	DISTANCE FT	TEMPERATURE~°C					ISA
		0	10	20	30	40	
SL	Grnd Roll	917	990	1067	1148	1229	1028
	50 ft	1432	1539	1650	1764	1883	1594
1000	Grnd Roll	1011	1092	1176	1264	1355	1117
	50 ft	1574	1691	1813	1939	2069	1728
2000	Grnd Roll	1116	1206	1299	1395	1496	1215
	Total50 ft	1732	1861	1995	2133	2276	1874
3000	Grnd Roll	1234	1332	1436	1542	1653	1382
	Total50 ft	1907	2049	2196	2349	2607	2035
4000	Grnd Roll	1355	1474	1588	1706	1829	1441
	50 ft	2102	2259	2422	2590	2764	2212
5000	Grnd Roll	1512	1633	1758	1889	2025	1572
	50 ft	2320	2493	2673	2858	3051	2407
6000	Grnd Roll	1676	1810	1950	2095	2245	1717
	50 ft	2564	2755	2953	3159	3371	26225
7000	Grnd Roll	1861	2009	2164	2325	2492	1877
	50 ft	2837	3048	3267	3494	3729	2859
8000	Grnd Roll	2068	2233	2405	2584	2770	2054
	50 ft	3142	3376	3619	3871	4131	3122
9000	Grnd Roll	2302	2495	2677	2975	3092	2250
	50 ft	23485	3744	4014	4293	4581	3412
10000	Grnd Roll	2564	2769	2982	3204	3434	2468
	50 ft	3870	4168	4457	4767	5088	3733

Figure 6-52 Takeoff distance table.

Landing Performance

The total *landing distance* is the distance established from a point where the airplane is 50 feet over the runway threshold (assumed to be a paved, level dry runway) to the point where the airplane reaches a full stop, assuming a steady, full flaps approach, with power off at 50 feet and maximum braking once the wheels are on the ground.

Note. This is the certification technique—you are not required to carry out all landings and stops exactly like this in practice.

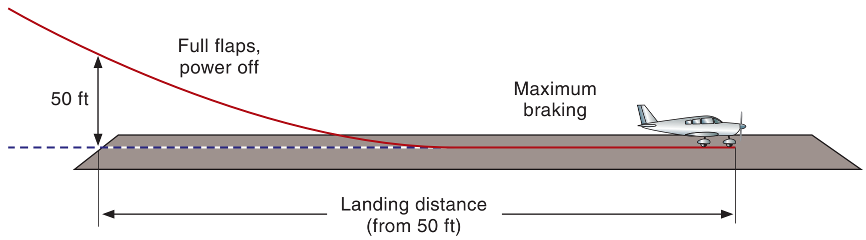


Figure 6-53 Landing distance.

Factors Affecting Landing Performance

Weight

A heavier airplane will need a greater ground roll and total landing distance. A heavier weight has a number of effects:

A heavier airplane will need a greater landing distance.

- the stall speed is increased, so the approach speed must be greater; and
- the higher approach speed results in the airplane possessing greater kinetic energy ($\frac{1}{2}mV^2$) which has to be absorbed by the brakes, increasing the length of the landing run. (There will, however, be a slight increase in the retarding friction force because of the extra weight on the wheels.)

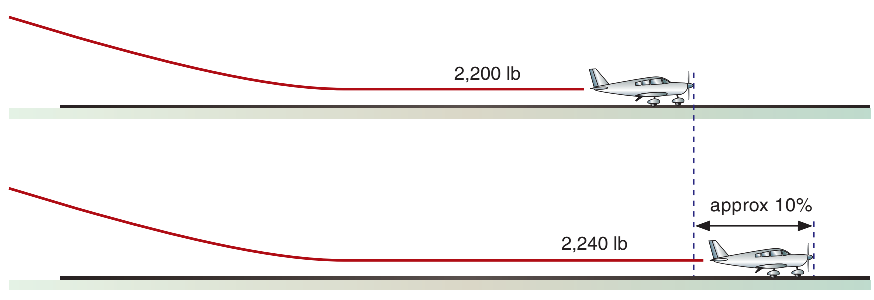


Figure 6-54 A 10% increase in weight requires a 10% increase in landing distance (approximately).

Air Density

An increased density altitude results in a longer landing distance. Low ambient pressure, high elevation and high ambient temperatures decrease the air density (ρ), giving a higher density altitude.

An increased density altitude results in a longer landing distance.

A decreased air density (ρ) means an increased V (TAS) is needed to provide the same lift force. Even though you see the same indicated airspeed ($\frac{1}{2}\rho V^2$) in the cockpit, the true airspeed is higher in air of lower density.

At high density altitudes the true airspeed will be greater than for lower density altitudes, and the touchdown groundspeed will be higher. Therefore the amount of kinetic energy to be dissipated in the ground roll is greater—hence a longer ground run and total landing distance is required.

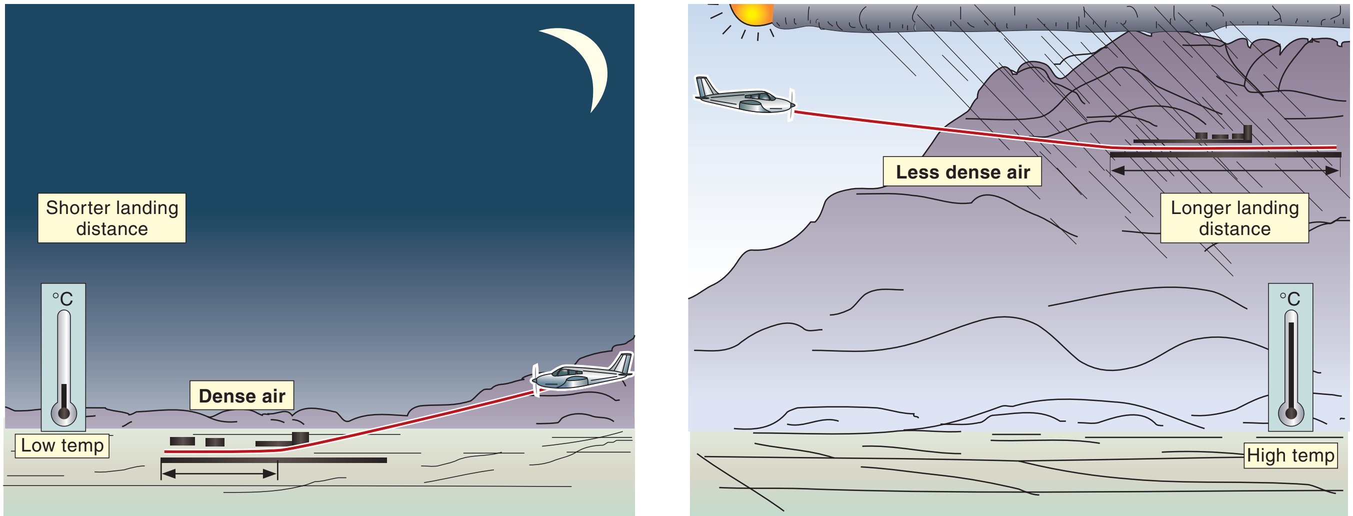


Figure 6-55 High temperature and high altitudes result in a longer landing distance.

The Effect of Wind

A headwind reduces the takeoff distance.

A headwind reduces the landing distance because the groundspeed is reduced by the headwind for the same true airspeed (V). A tailwind means that the groundspeed will exceed the true airspeed, and so the touchdown speed relative to the ground is higher and a longer landing distance will be required.

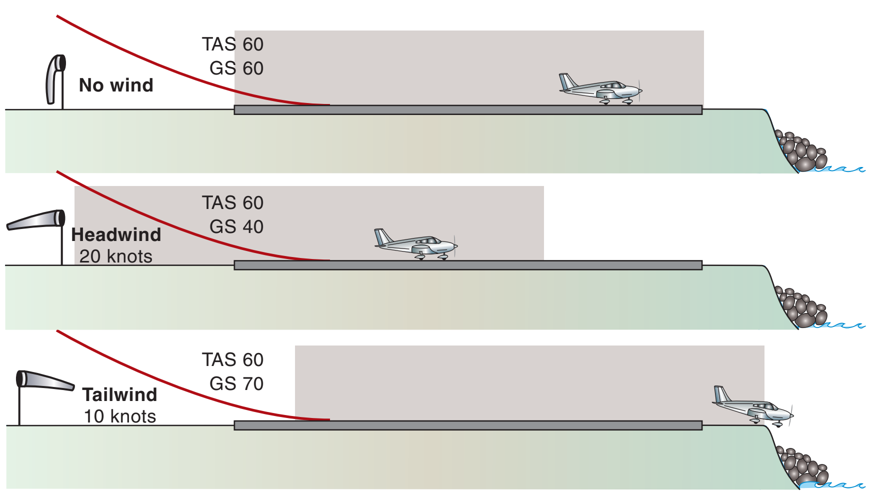


Figure 6-56 Headwind reduces landing distance.

Figure 6-57 Consider runway surface.

Runway Surface

Smooth, wet, or loose runway surfaces will not allow good braking to occur and so the landing distance required will be longer. On a wet surface, hydroplaning may occur, which will greatly increase the stopping distance. Conversely a runway with long grass has increased friction and will reduce the landing distance.

Hydroplaning is the phenomenon of a tire skating along on a thin film of water and not rotating, even though it is free to do so. Wheel braking therefore has no effect. Friction forces are practically zero.

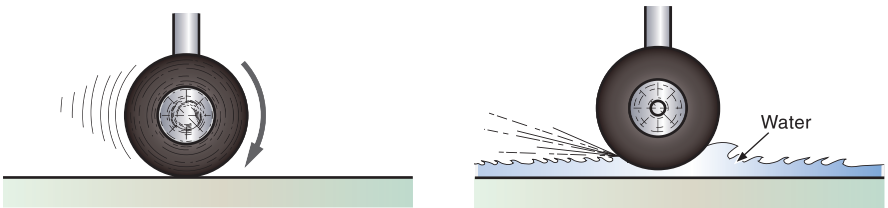


Figure 6-58 Hydroplaning.

Runway Slope

A downslope will result in a longer total landing distance. It will take longer for the airplane to touch down from 50 feet above the runway threshold, because the runway is falling away beneath the airplane, and airplane braking while going downhill will not be as effective as on a level or upward sloping runway.

A downslope will result in a longer landing distance.

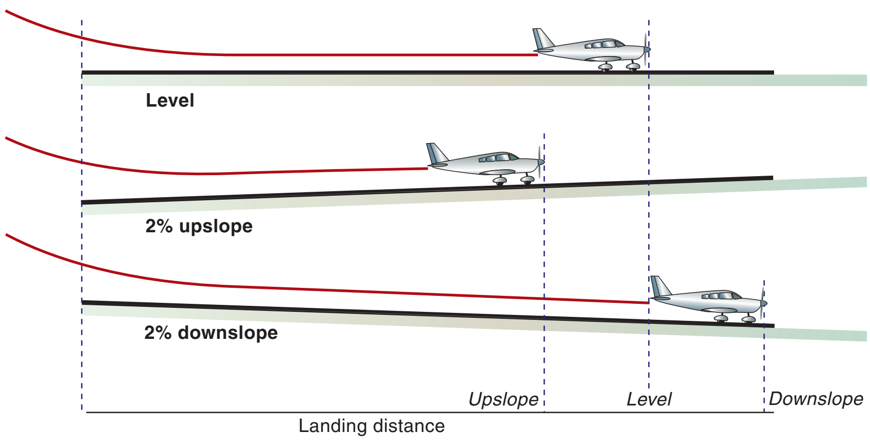


Figure 6-59 Downslope increases landing distance.

Flaps

Higher flap settings reduce the stall speed and therefore the approach speed, which provides a 30% buffer over the stall speed, is lower. High flap settings also give additional aerodynamic drag that helps to slow the airplane down, but only in the initial stages of the landing roll, after which they lose their effect.

Increased flap settings decrease the landing distance.

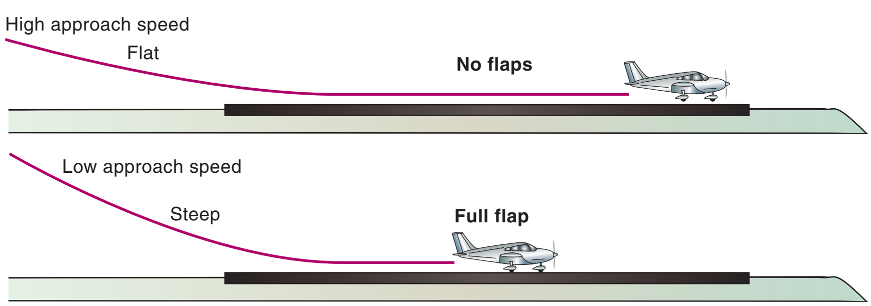


Figure 6-60 Increased flaps-slower and steeper.

Fast Approach Speeds

The landing performance charts are based on *specified approach speeds.* If you approach for a landing at a speed higher than that specified, the landing distance will exceed that predicted by the chart. This is because of the greater kinetic energy of the airplane and the tendency of the airplane to float at the round-out because of ground effect (see page 190).

The Landing Distance Table

Some manufacturers present performance data in the form of a table. The landing performance table in figure 6-61 is an example. This table has been prepared will full or 100% flaps, power at idle, on a dry, level and paved runway with zero wind, at

Weight: 2900 lb.
Speed over Total Obstacle: 75 KIAS
Flaps: 100% Idle
Runway: Dry, Paved, Level

Headwind: Subtract 10% for each 13 knots headwind.
Tailwind: Add 10% for each 2 knots tailwind upto 10 knots.
Runway Slope: Reference Notes.
Dry Grass: Add 20% to Ground Roll.
Wet Grass: Add 60% to Ground Roll.

PRESS ALT FT	DISTANCE FT	TEMPERATURE~ºC					ISA
		0	10	20	30	40	
SL	Grnd Roll	962	997	1032	1067	1102	1014
	Total	1972	2017	2063	2109	2156	2040
1000	Grnd Roll	997	1034	1070	1067	1143	1045
	Total	2018	2065	2113	2161	2210	2079
2000	Grnd Roll	1034	1072	1110	1148	1188	1076
	Total	2066	2116	2166	2217	2268	2121
3000	Grnd Roll	1073	1112	1151	1191	1230	1108
	Total	2117	2169	2222	2275	2329	2164
4000	Grnd Roll	1113	1154	1195	1236		1142
	Total	2170	2225	2281	2337		2209
5000	Grnd Roll	1156	1198	1240	1283		1177
	Total	2227	2285	2343	2402		2258
6000	Grnd Roll	1200	1244	1288	1332		1214
	Total	2287	2348	2409	2471		2306
7000	Grnd Roll	1246	1292	1337			1251
	Total	2351	2415	2479			2358
8000	Grnd Roll	1295	1342	1389			1291
	Total	2418	2485	2553			2412
9000	Grnd Roll	1345	1394	1444			1331
	Total	2490	2560	2631			2470
10000	Grnd Roll	1399	1499				1373
	Total	2565	2639				2529

Figure 6-61 Landing distance table.

specific pressure altitudes at standard temperatures. Both the total distance to land from 50 feet over the runway threshold, and the ground roll, are published. For instance, at pressure altitude 2,000 feet and with a temperature of 30°C, the landing distance from over a 50 foot obstacle is 2,217 feet and the ground roll is 1,148 feet.

When the pressure altitude is between the values given in the table, you will need to interpolate to find the landing distance and ground roll.

For example, If you plan to land on a runway when the temperature is 20°C and at the pressure altitude 3,500 feet, you will have to interpolate the table. 3,500 feet is halfway between the published pressure altitudes 3,000 feet and 4,000 feet, so the distances will also be halfway between the published figures. To find the "landing distance over a 50 foot obstacle", take the 3,000 feet pressure altitude at 20°C figure of 2,222 feet, and to this add one-half of the *difference* between it and the figure for 4,000 feet pressure altitude at the same temperature (2,281 – 2,222 = 59 feet, half of 59 = 30 rounded up). The correct answer for 3,500 at 20°C would be *2,252 feet* (2,222 + 30). Ground roll is 1,151 + half of (1,195 – 1,151) = 1,151 + 22 = *1,173 feet*.

Once the ground roll and landing distance to clear a 50-foot obstacle have been found for a given pressure altitude, apply the following corrections, if applicable:

- headwind or tailwind component;
- runway slope; and
- a dry or wet grass runway (instead of a hard surface).

Headwind Component Correction

For each 13 knots of headwind, you must reduce the distances by 10%. You can calculate this 10% and then subtract, but a faster method is simply to take 90% of the distance, by multiplying it by 0.9. If an airport is at sea level and the temperature is 10°C and if the landing runway had a 13 knot headwind then the corrected total distance would be 2,017 × 0.9 = 1,815.3, say *1,816 feet*.

Dry or Wet Grass Runway Correction

Grass runways will decrease the airplane's braking effectiveness and therefore lengthen the ground roll. Wet grass is even worse. When making this calculation you must add the extra distance to both the ground roll and 50-foot landing distance. The logic for this is that the effect of the grass does not occur before touchdown, hence the same increase for both distances.

At 1,000 feet and 40°C for example, the ground roll distance would be 1,143 feet if the landing were on pavement. But if the landing is made on grass we must estimate additional distance for landing. If the grass is dry the table requires us to estimate a 20% addition to the ground roll. Twenty percent of 1,143 is 228.6 feet, therefore the dry grass ground roll would be 1,372 feet (1,143 + 228.6 rounded up). The total landing distance from over a 50-foot obstacle—which is more likely at a grass strip—would be 2,439 feet (2,210 + 228.6 rounded up). If the grass were wet, the braking would be even worse and the estimated landing distances would become: Ground roll of 1,143 plus an additional 60% would become 1,829 feet (60% of 1,143 is 685.8. 1,143 + 685.8 = 1,829 rounded up). Total distance over the 50-foot obstacle would become 2,896 feet (2210 + 685.8 rounded up).

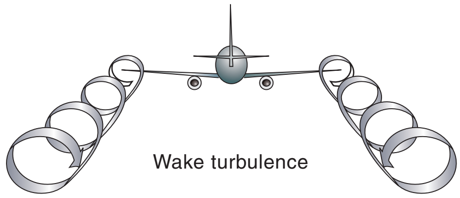


Figure 6-62
Wake turbulence from a large, slow-flying airliner.

Wake Turbulence

As a wing produces lift, the higher static pressure area beneath the wing causes an airflow around the wingtip to the lower pressure area above. The greater the difference in pressure, the greater the flow around the wingtips. (We suggest that you reread the section on induced drag (page 113) to refresh your memory.) At the high angles of attack necessary to produce the required lift force at low speeds, very large and strong trailing vortices are formed. High angles of attack are required when an airplane is heavy and flying slowly (particularly if flaps are not extended). As a large and heavy airplane is rotated for takeoff or flared for landing, the angle of attack is also large. The trailing wingtip vortices formed at these high angles of attack can be strong enough to rapidly roll a following airplane if it flies into them. This hazardous trail of wingtip vortices behind an airplane is known as *wake turbulence.*

The main danger from wake turbulence is loss of control because of induced roll.

The wake turbulence behind a Boeing 747 can significantly affect a 737 and cause a lighter airplane to become uncontrollable. The induced rolling motion may exceed the rolling capability of the airplane affected, making it impossible for the pilot to hold the wings level. The rolling effect will be greatest when the affected airplane is aligned with the flight path of the airplane generating the vortices.

To avoid wake turbulence accidents and incidents, Air Traffic Control may delay the operation of light airplanes on runways behind heavy jets for up to five minutes to allow the vortices to drift away and dissipate.

Every pilot should have an awareness of wake turbulence because the Air Traffic Control procedures may occasionally provide insufficient separation from the wingtip vortices behind another airplane. Remember that pilots have the ultimate responsibility for the safety of their airplanes—so learn to visualize the formation and movement of invisible wingtip vortices. Recent research also suggests wake turbulence (from about 500 feet down) has the ability to descend, strike the ground, and then "bounce" back up to about 250 feet (or more) above the surface. This is important because it is also drifting and can drift across the landing approach path of another unrelated runway, causing problems for pilots who think they are being safe by going to another runway.

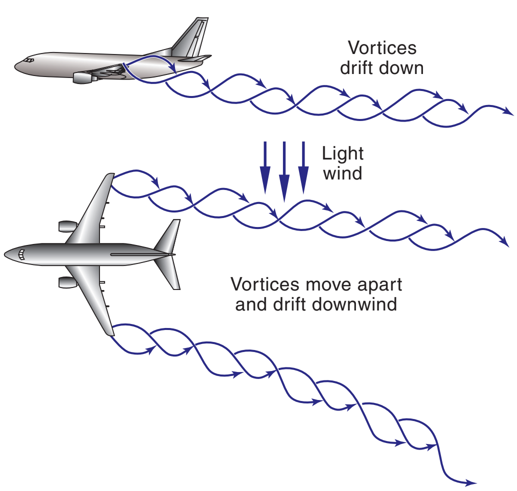


Figure 6-63
Wingtip vortices slowly lose height, move apart and drift downwind.

Wingtip vortices tend to *lose height* slowly (typically at approximately 500 fpm), slowly *move apart* and drift *downwind*. To be able to avoid these invisible danger areas, you must visualize the movement of the vortices and take steps to avoid them.

Helicopters also produce wake turbulence. The helicopter blades act as a wing to produce lift and, as the helicopter proceeds, a trail of wingtip vortices will be left behind, just the same as for a fixed-wing aircraft. The heavier and slower the helicopter, the stronger the wake turbulence behind it.

Avoiding Wake Turbulence

The main aim of wake-turbulence avoidance is to avoid passing through it at all. This is accomplished by flying *above* and *upwind* of the flight path of the aircraft producing wake turbulence.

Avoid wake turbulence by flying above and upwind of the path of other aircraft.

Takeoff

When taking off behind a large airplane which has itself just taken off, commence your takeoff at the end of the runway so that you will become airborne in an area well before where the heavy airplane rotated, or to where its vortices may have drifted with the wind. If in doubt, delay your takeoff. Once airborne, maneuver to avoid the vortices in flight by turning away from where you think the wake turbulence is.

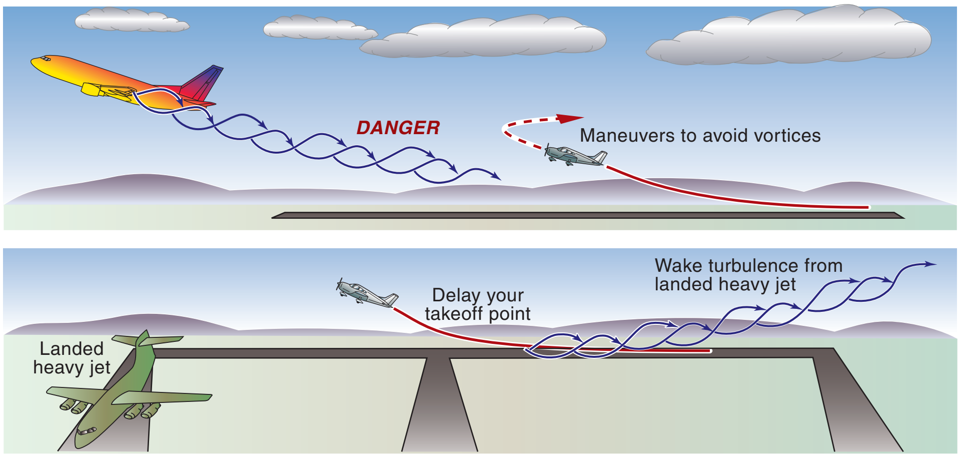


Figure 6-64 Avoid wake turbulence on your takeoff.

When taking off after a heavy airplane has landed, plan to become airborne well past the point where it flared and landed.

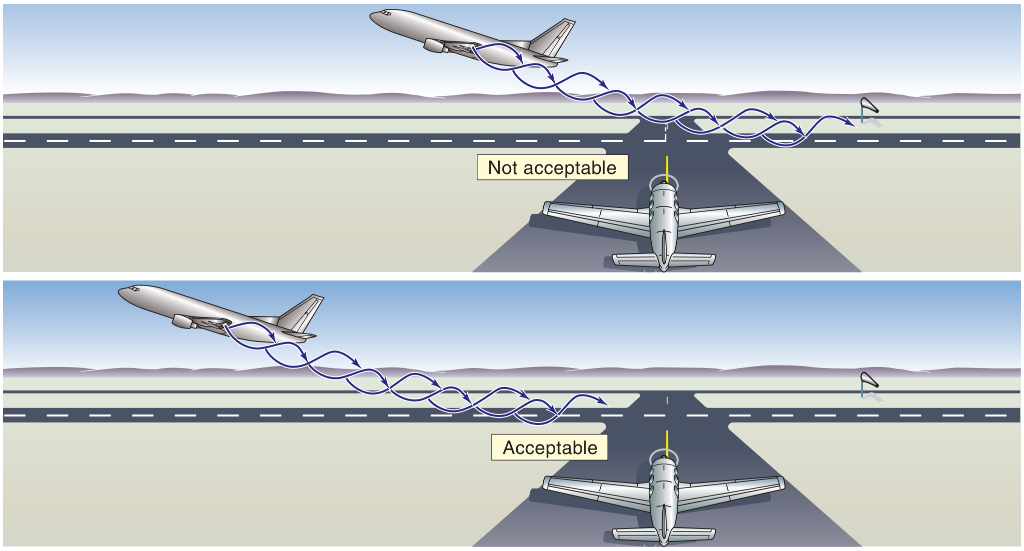


Figure 6-65 Awareness of wake turbulence for your takeoff.

If a heavy airplane has taken off on a different runway and you expect to be airborne prior to the intersection of the runways, check to ensure that the heavy airplane was still on the ground and hasn't rotated until well past the intersection, before you commence your takeoff. This is because unless an airplane is flying (or rotated for takeoff) and therefore producing lift, it will not be producing wake turbulence.

In the Traffic Pattern

Avoid flying below and behind large airplanes. Fly a few hundred feet above them, a thousand feet below them or upwind of them. Calm days, where there is no turbulence to break up the vortices, are potentially the most dangerous.

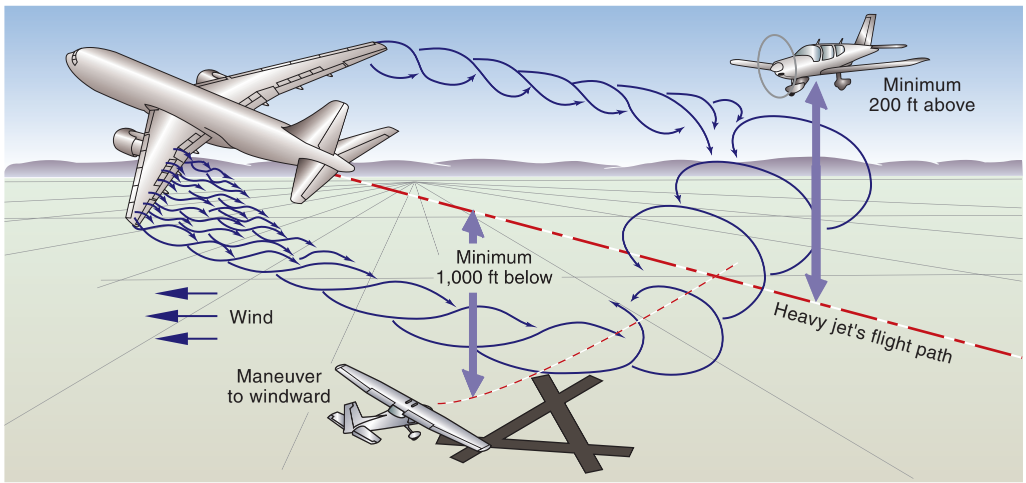


Figure 6-66 Avoidance of wake turbulence in the traffic pattern area.

Figure 6-67
Beware wake turbulence.

Approach to Land

When following a preceding landing airplane, fly above the approach path of the heavy airplane and land well beyond his touchdown point. This is usually possible in a light airplane landing on a long runway where heavy airplanes are landing. Be very cautious in light, quartering tailwinds, which may drift the vortices of the preceding airplane forward into your touchdown zone.

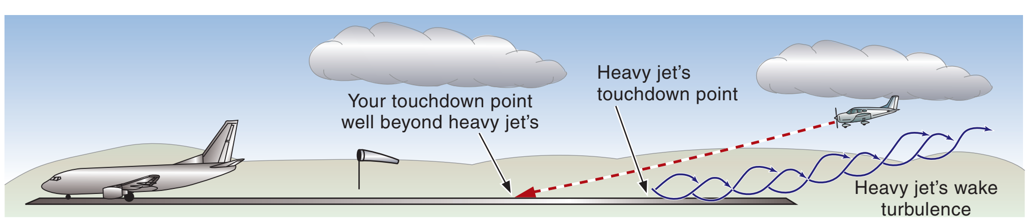


Figure 6-68 Avoidance of wake turbulence on approach.

If a preceding heavy airplane has discontinued its approach and gone around, its turbulent wake will be a hazard to a following airplane. You must consider changing your flight path in these circumstances.

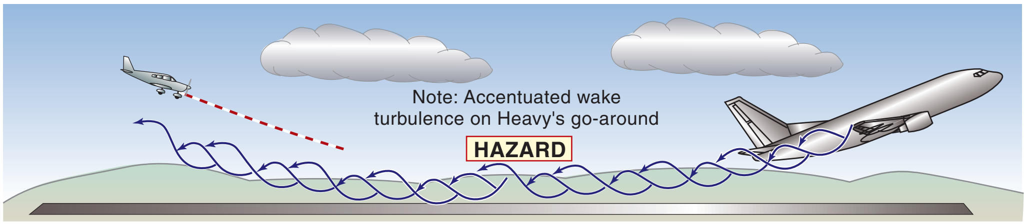


Figure 6-69 Making an approach behind a heavy airplane that has gone around.

Jet Blast

Do not confuse wake turbulence (wingtip vortices, see figure 6-62) with jet blast, which is the high velocity air exhausted from a jet engine. Jet blast can be dangerous to a light airplane taxiing on the ground behind a jet, so always position your airplane when taxiing or when stopped to avoid any potential jet blast.

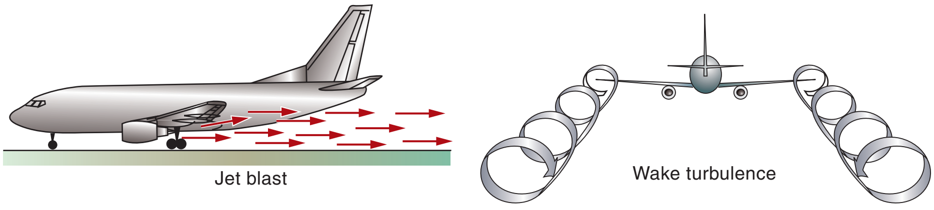


Figure 6-70 Jet blast.

Helicopter Rotor Downwash

Helicopters produce wake turbulence. The helicopter blades act as a wing to produce lift, and as the helicopter proceeds, a trail of wingtip vortices will be left behind, just the same as for a fixed-wing aircraft. The heavier and slower the helicopter, the stronger the wake turbulence behind it. A helicopter hovering near the runway is a hazard to small aircraft.

Rotor downwash from a hovering or taxiing helicopter can be hazardous up to a radius of approximately three times the rotor diameter.

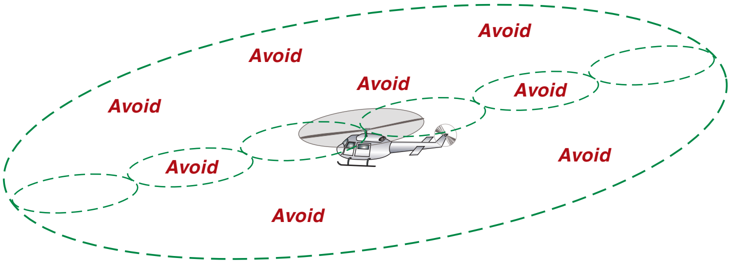


Figure 6-71 Beware rotorwash.

Small aircraft need to exercise care when behind helicopters that are departing, landing, or are in forward flight.

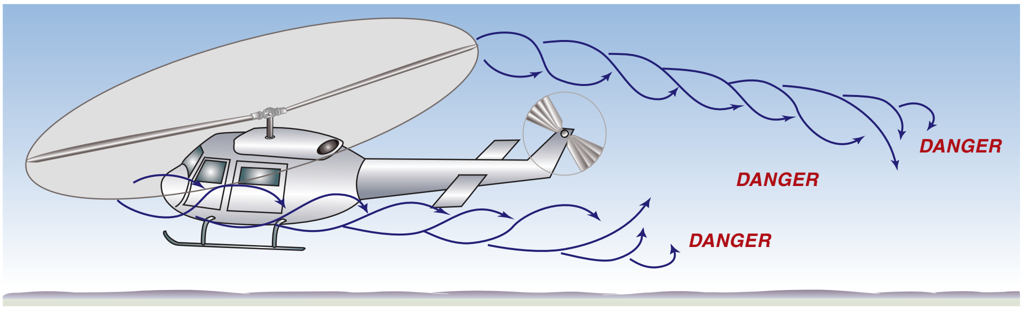


Figure 6-72 Rotorwash.

Ground Effect

Figure 6-73
Ground effect.

An airplane's flight characteristics change when it is very close to the ground or any other surface, because:

- it can fly at a slower speed than when it is at altitude; and
- it can fly at the same speed using less thrust than when it is at altitude.

This increased performance of an airplane flying just above a surface is known as *ground effect*. Ground effect is greatest when the aircraft is just airborne and least when the aircraft is at an altitude above the ground approximately one wingspan's distance. In part one, we considered the airplane to be flying well away from the ground. There was no restriction to the downwash of the airflow behind the wings, nor to the upwash ahead of the wings. There was also no restriction to the formation of wingtip vortices.

When the wing is just above the ground, the ground modifies the downwash and the angle is reduced, thus reducing the effect on the local average relative wind. In other words, the relative wind angle about the wing will be closer to the remote free stream. This keeps drag at a minimum and the wingtip vortices at a minimum.

As the aircraft gradually climbs and increases its altitude above the ground, the downwash angle steepens and increases the induced drag, all without an aircraft attitude change. When at one wingspan's height above the ground, ground effect ceases to affect the downwash or wingtip vortices and induced drag is at its maximum.

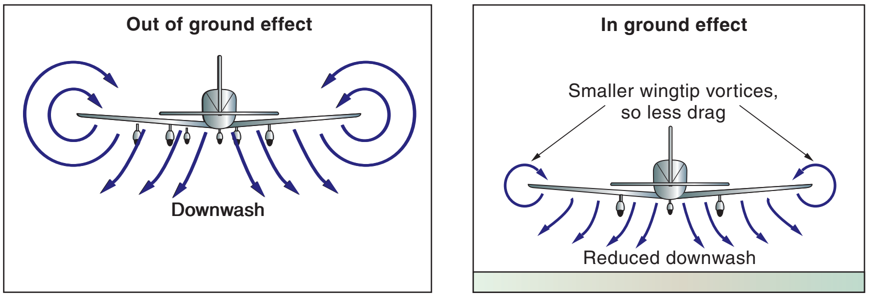


Figure 6-74
Near the ground, the upwash and downwash are restricted and the formation of wingtip vortices is restricted.

Reduced Drag

In Chapter 4 we divided the total drag on an airplane into two main types: *induced drag*, which is a by-product of the production of lift, and *parasite drag*, which is not directly associated with the production of lift. Wingtip vortices, and trailing vortices behind the trailing edge, are the major cause of induced drag. So when a nearby surface, such as the ground, restricts their formation, the induced drag will be less, and therefore the total drag on the airplane will be less.

Ground effect limits the size of wingtip vortices which reduces induced drag.

You are aware that, in level flight, drag is counteracted by thrust. The reduction in drag when near the ground or water means that the same airspeed can be maintained using less thrust. Therefore, under-powered airplanes may be able to maintain flying speed while in ground effect, even if they cannot maintain that speed in free air, well away from the ground.

Ground effect becomes noticeable when the airplane is at a height above the surface of less than one wingspan. The effect is greater the closer the wing is to the surface.

Ground Effect During Landing

On an approach to land, as the airplane enters ground effect at about one wingspan's height, the pilot will experience a floating sensation—a result of the extra lift (from the increased lifting ability of the wing) and the slower deceleration (because of less drag).

In most landings there is no desire to maintain speed—indeed the aim is to lose speed. It is therefore usually important at flare height and in ground effect to ensure that the power is throttled back, especially considering the reduction in drag because of ground effect.

Excess speed at the beginning of the landing flare and the better flyability of an airplane in ground effect may incur a considerable *float* distance prior to touchdown. This is not desirable, especially on short landing strips.

Ground Effect on Takeoff

As the airplane climbs out of ground effect on takeoff the lifting ability of the wing will decrease for the same airplane pitch attitude. In addition the induced drag will increase because of the greater wingtip vortices and line vortices. Thus the airplane will not perform as well in free air as it will in ground effect. You will feel a sagging in climb-out performance as the airplane flies out of ground effect. You will need to increase the angle of attack to generate the same lift as you fly out of ground effect, and either increase thrust to overcome the additional induced drag or accept a reduced climb performance.

It pays to bear this in mind if you are ever operating on very short runways, or runways which finish on the edge of a cliff (or aircraft carrier). Ground effect may allow the airplane to become airborne before reaching the recommended takeoff speed. Once away from the takeoff surface the climb performance will be less—a good reason for not forcing the airplane to become airborne at too low a speed. It might manage to fly in ground effect, but it will be unable to climb out of it.

Windshear

The study of windshear and its effect on airplanes, and what protective measures can be taken to avoid potentially dangerous results, is still in its infancy and much still remains to be learned. What is certain is that every airplane and every pilot will be affected by windshear—usually the light windshears that occur in everyday flying, but occasionally a moderate windshear that requires positive recovery action from the pilot. On rare occasions, severe windshears can occur from which a recovery may even be impossible. A little knowledge can help you understand how to avoid significant windshear, and how best to recover from a windshear encounter.

Windshear Terminology

Windshear is a change in wind speed and/or wind direction.

A *windshear* is defined as a change in wind direction and/or wind speed in space. This includes updrafts and downdrafts. Any change in the wind velocity (be it a change in speed or in direction) as you move from one point to another is a windshear. The stronger the change and the shorter the distance within which it occurs, the stronger the windshear.

Updrafts and *downdrafts* are the vertical components of wind. The most hazardous updrafts and downdrafts are usually those associated with a thunderstorm.

The term *low-level windshear* is used to specify any windshear occurring along the final approach path prior to landing, along the runway and along the takeoff/initial climb-out flight path. Windshear near the ground (below 3,000 feet) is often the most critical in terms of safety for the airplane.

Turbulence is eddy motions in the atmosphere which vary both with time and from place to place.

The Effects of Windshear on an Airplane

So far our studies have considered an airplane flying in still air or a steady wind. However, an actual air mass does not move in a totally steady manner—there will be gusts and updrafts and changes of wind speed and direction, which the airplane will encounter as it flies through the air mass. These windshears will have a *transient effect* on the flight path of an airplane. Even when the wind is relatively calm on the ground, it is not unusual for the light and variable surface wind to suddenly change into a strong and steady wind at a level only a few hundred feet above the ground. If we consider an airplane making an approach to land in these conditions, we can see the effect the windshear has as the airplane passes through the shear.

An airplane flying through the air will have a certain *inertia* depending on its mass and its velocity relative to the ground. Its inertia makes it resistant to change. If the airplane has an airspeed of 80 knots and the headwind component is 30 knots, then the inertial speed of the airplane over the ground is (80 – 30) 50 knots.

When the airplane flies down into the calm air, the headwind component reduces reasonably quickly to, say, 5 knots. The inertial speed of the airplane is still 50 knots, but the new headwind of only 5 knots will mean that its airspeed has suddenly dropped back to 55 knots. The normal reaction is to add power and/or to lower the nose to regain airspeed, and to avoid undershooting the desired flight path. The stronger the windshear, the greater the changes in power and attitude that will be required. Any fluctuations in wind will require adjustments by the pilot, and this is why you have to work so hard sometimes, especially when approaching to land.

In gusty wind conditions, a power-on approach and landing should be used so that the engine can respond more quickly when required. In addition, if turbulence is encountered during the approach to land you should increase the airspeed to slightly above the normal approach speed to allow for sudden changes in indicated airspeed.

In gusty conditions, use a power-on approach and landing and consider adding a few knots to the approach speed.

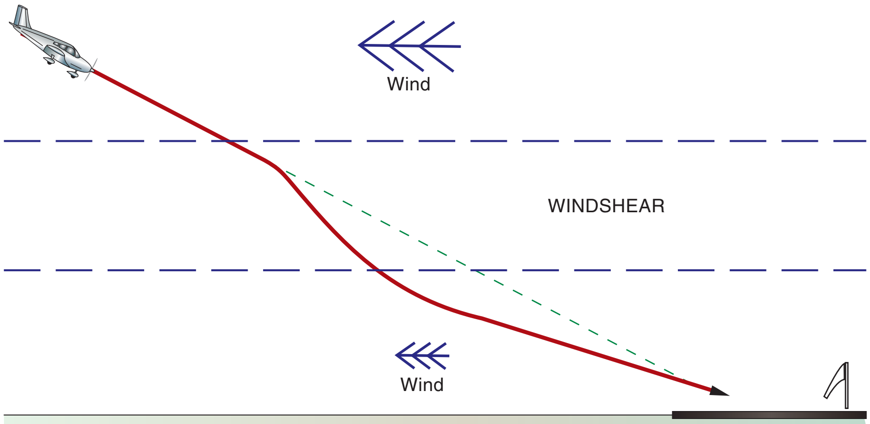


Figure 6-75
A typical windshear situation—calm on the ground with a wind at altitude.

Overshoot and Undershoot Effect

The effects of windshear on an airplane's flight path depend on the nature and location of the shear, as follows.

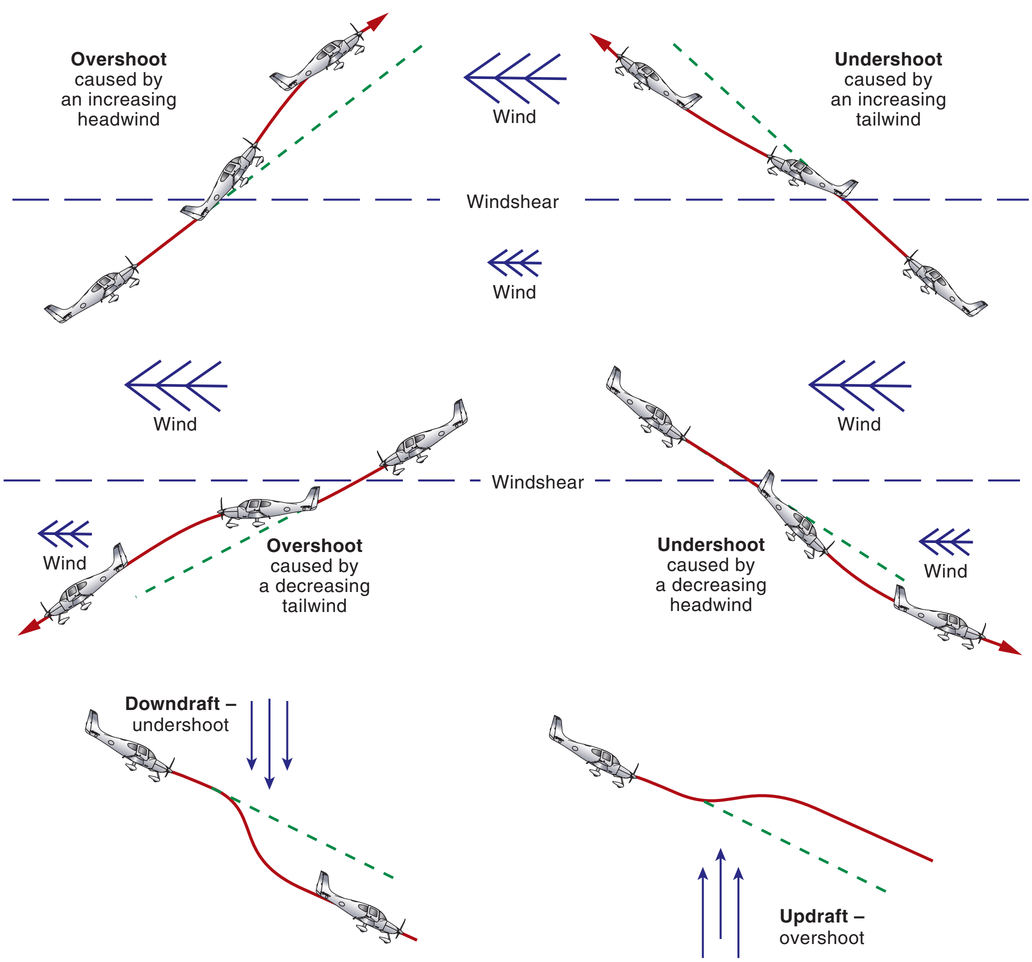


Figure 6-76
Six common windshear situations.

Overshoot Effect

Overshoot effect is caused by a windshear that results in the airplane flying above the desired flight path and/or an increase in indicated airspeed. The nose of the airplane may also tend to rise. Overshoot effect may result from flying into an increasing headwind, a decreasing tailwind, from a tailwind into a headwind, or an updraft.

Undershoot Effect

Undershoot effect is caused by a windshear that results in an airplane flying below the desired flight path and/or a decrease in indicated airspeed. The nose of the airplane may also tend to drop. Undershoot effect may result from flying into a decreasing headwind, an increasing tailwind, from a headwind into a tailwind, or into a downdraft.

The actual effect of a windshear depends on:
- the nature of the windshear;
- whether the airplane is climbing or descending through that particular windshear; and
- the direction in which the airplane is proceeding.

Windshear Reversal Effect

Windshear reversal effect is caused by a windshear which results in the initial effect on the airplane being reversed as the airplane proceeds further along the flight path. It is an overshoot effect followed by undershoot, or undershoot followed by overshoot effect, as appropriate.

Windshear reversal effect is a very common phenomenon that pilots often experience on approach to land, when things are usually happening too fast to analyze exactly what is taking place in terms of wind. The pilot can, of course, observe undershoot and overshoot effect and react accordingly with changes in pitch attitude and/or power to maintain the desired flight path and airspeed.

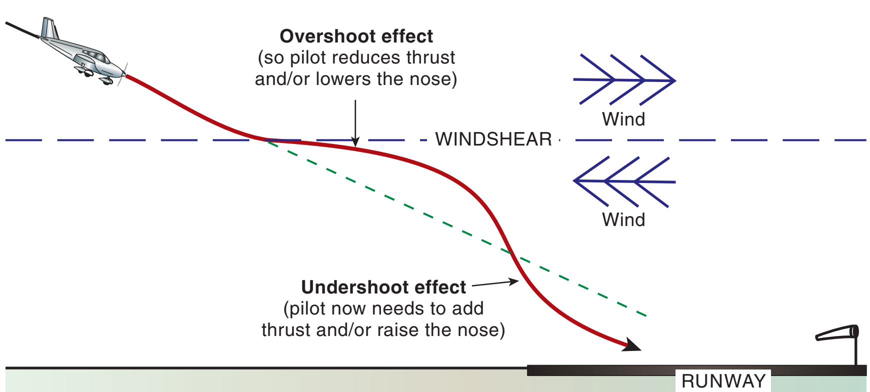


Figure 6-77 Windshear reversal effect.

Crosswind Effect

Crosswind effect is caused by a windshear that requires a rapid change of airplane heading to maintain a desired track (not uncommon in a crosswind approach and landing because the crosswind component changes as the ground is neared). On crosswind landings, at the moment of touchdown the direction of the airplane's motion and its longitudinal axis must be parallel to the runway. If this is not the case the airplane will skip sideways on landing imposing large side loads on the landing gear.

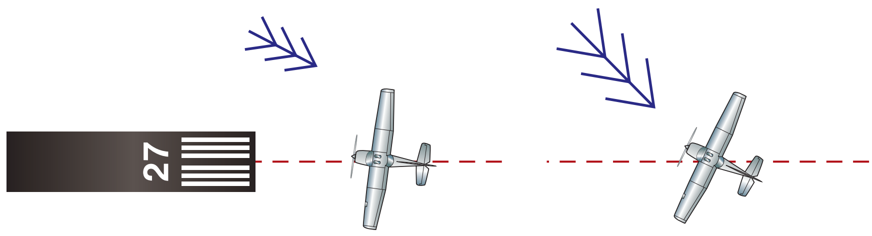


Figure 6-78 Crosswind effect.

The Causes of Windshear

There are many causes of windshear. They include: obstructions and terrain features which disrupt the normal smooth wind flow; localized vertical air movements associated with thunderstorms, cumulonimbus and large cumulus clouds; low-level temperature inversions; and sea breezes. These will be discussed in the Weather section.

Review 6

Aerodynamics of Flight

Straight-and-Level Flight

1. In steady straight-and-level flight:
   a. lift is greater than drag and thrust equals weight.
   b. weight equals lift and drag equals thrust.
   c. lift equals weight and thrust is greater than drag.
2. In steady-state flight, what is the sum of the opposing forces acting on an airplane?
3. If indicated airspeed is decreased, what needs to happen to the angle of attack for the airplane to remain in straight-and-level flight?
4. What are low indicated airspeeds associated with?
5. There is a decrease in aircraft weight. You want straight-and-level flight to continue, so lift is decreased. How is this achieved?
6. Why is ice or frost on the wings hazardous?

Climb and Descent

7. Are the four main forces in equilibrium in a steady climb when the airplane is not accelerating or decelerating?
8. An airplane will clear obstacles by a greater margin at the:
   a. best angle-of-climb speed.
   b. best rate-of-climb speed.
   c. cruise-climb speed.
9. What is the rate of climb (FPM) for an airplane that climbs 700 feet in 2 minutes?
10. During the transition from straight-and-level flight to a climb, the angle of attack is:
    a. increased but lift is decreased.
    b. increased but lift remains the same.
    c. increased and lift is momentarily increased.
11. What rate of climb is needed to climb 1,200 feet in 2 minutes?
12. An airplane will reach a given altitude in the minimum time if it climbs at the:
    a. best angle-of-climb speed.
    b. best rate-of-climb speed.
    c. cruise-climb speed.
13. What instrument depicts rate of climb?
14. True or false? The angle of climb of the same airplane carrying the pilot and three passengers will be less than the angle of climb when only the pilot is on board.
15. What is absolute ceiling?
16. If the airplane is climbing into a headwind after takeoff, the climb angle relative to the ground obstacles on the ground will be:
    a. the same.
    b. steeper.
    c. shallower.
17. Climb performance reduces if:
    a. weight, altitude, and temperature decrease.
    b. weight, temperature, and altitude increase.
    c. power and weight increase.
18. What is weight counteracted by for an airplane to be in equilibrium in a steady glide?
19. What effect will adding power while maintaining the same airspeed have on the rate and angle of descent?
20. True or false? If flaps are lowered, the drag increases and the descent becomes shallower.
21. True or false? Flying faster than the correct descent speed flattens the descent angle through the air.
22. If the same angle of attack is maintained, will a heavily loaded airplane glide further compared with when it carries a light load?
23. What adjustment to airspeed must be made for an airplane with a light load to glide the same distance as when it is heavy?
24. If you have a rate of descent of 500 FPM, how long will it take you to descend 3,000 feet in a 20-knot headwind?
25. An airplane is flown in a glide at an airspeed where the L/D ratio is 8:1. How many feet air distance will this airplane glide for each 1,000 feet of altitude lost?
26. How much altitude would an airplane lose in gliding 1 statute mile in still air at an airspeed that provides an L/D ratio of 10:1 (1 statute mile is 5,280 feet)?

Turning and Load Factor

27. What is load factor?

28. What sort of force is required for an airplane to turn?

29. What is the force in question 28 provided by?

30. True or false? To maintain airspeed in a turn, the pilot must apply power to overcome the increased parasite drag.

31. The load factor in a turn depends on:
- **a.** bank angle.
- **b.** airspeed.
- **c.** bank angle and airspeed.

Refer to figure 6-24 (page 161) for questions 32 to 34.

32. In a 60° banked turn at a constant altitude:
- **a.** what is the load factor?
- **b.** the wings must generate a force equal to how many times the weight of the airplane?

33. If an airplane weighs 3,300 pounds, what is the approximate "load" (in pounds) that the airplane structure is required to support in a 30° banked turn while maintaining altitude?

34. If an airplane weighs 5,400 pounds, what is the approximate "load" (in pounds) that the airplane structure is required to support in a 55° banked turn while maintaining altitude?

Stalling and Spinning

35. What can the turbulent airflow over the horizontal stabilizer cause if the wings stall?

36. What is the stall angle on a typical light training airplane (degrees angle of attack)?

37. An airplane wing can be stalled:
- **a.** only when the nose is high and the airspeed is low.
- **b.** at any airspeed and in any flight attitude, provided that the critical angle of attack is reached.

38. Indicated stall speed is affected by changes in:
- **a.** temperature.
- **b.** density.
- **c.** altitude.
- **d.** load factor.

39. True or false? At higher weights, the airplane will stall at a higher angle of attack.

40. Washout designed into a wing causes which section of the wing to stall first?

41. If the airplane approaches the stall angle with a lot of power on, the slipstream adds a lot of kinetic energy to the airflow so separation and stalling is delayed. Is the stall speed with power on the same as the power-off stall speed?

42. In what flight condition must an aircraft be placed in order to spin?

43. During an approach to a stall, an increased load factor caused by turning or turbulence will make the airplane:
- **a.** stall at a higher airspeed.
- **b.** have a tendency to spin.
- **c.** more difficult to control.

44. How does frost and ice affect the lifting surfaces of an airplane on takeoff?

Takeoff Performance

Refer to figure 6-46 (page 176) for questions 45 to 48.

45. In crosswind conditions, should the headwind or tailwind component be applied when calculating the takeoff or landing distances?

46. There is a 20-knot wind at 30° off the runway heading. What is the crosswind component?

47. What is the crosswind component for a landing on Runway 18 if the tower reports the wind as 220° at 30 knots?
- **a.** 19 knots.
- **b.** 23 knots.
- **c.** 30 knots.

48. The airplane has a crosswind limit of 12 kt.
- **a.** What is the maximum wind strength you can tolerate from 30° off the runway direction (such as runway 18 with the wind from 150°)?
- **b.** What headwind component would this wind give you?

Refer to figure 6-52 (page 180) for questions 49 to 58.

49. What effect does each of the following have on takeoff distance?
- **a.** An increase in pressure altitude.
- **b.** An uphill runway slope.
- **c.** An increase in headwind component.

50. How is takeoff distance measured?
51. What flap setting is indicated in the graph?
52. What is the maximum pressure altitude allowed for in the graph?
53. What is the maximum takeoff weight for the airplane in the graph?
54. What would be the ground roll distance for a takeoff at sea level pressure altitude and a temperature of 20ºC?
55. What would be the total distance to clear a 50 foot obstruction when taking off from an airport with a pressure altitude of 5,000 feet and a temperature of 10ºC?
56. What would be the predicted ground roll when taking off from a dry grass runway that has a pressure altitude of 2,000 feet and a temperature of 30ºC?
57. What would be the predicted ground roll when taking off from a wet grass runway that has a pressure altitude of 4,000 feet and a temperature of 40ºC?
58. What would be the predicted total distance to take off over a 50 foot obstacle from a runway with a pressure altitude of 8,000 feet, temperature 10ºC and into a 12 knot headwind?

Landing Performance

Refer to figure 6-61 (page 184) for questions 59 to 68.

59. The landing distances predicted by the Landing Performance chart (figure 6-61) are for a specific aircraft weight. What is that weight?
60. At what speed should the pilot fly the plane over a presumed 50 foot obstacle in order to expect the predictions of this table to be correct?
61. The predicted landing distances of this table only will be correct when using a specific flap and power setting. What are those settings?
62. What is the predicted ground roll distance when landing this airplane at an airport with a pressure altitude if 1,000 feet and a temperature of 20ºC?
63. What is the predicted total distance from over a 50 foot obstacle when landing this airplane at an airport with a pressure altitude if 3,000 feet and a temperature of 30ºC?
64. What is the predicted total distance from over a 50 foot obstacle when landing this airplane at an airport with a pressure altitude if 9,000 feet and a temperature of 0ºC?
65. What is the predicted ground roll of this airplane when landing at an airport with a pressure altitude of 4,000 feet, a temperature of 20ºC, and into a 26 knot headwind?
66. What is the predicted total landing distance from over a 50 foot obstacle of this airplane when landing at an airport with a pressure altitude of 6,000 feet, a temperature of 10ºC, and a 6 knot tailwind?
67. What is the predicted ground roll of this airplane when landing at an airport with a pressure altitude of 2,000 feet, a temperature of 40ºC, on a dry grass runway?
68. What is the predicted ground roll of this airplane when landing at an airport with a pressure altitude of 5,000 feet, a temperature of 20ºC, on a wet grass runway?

Wake Turbulence

69. The air beneath a wing of an airplane in flight tends to leak around the wingtip and into the lower static pressure area above the wing.
a. What does this leave a trail of?
b. What kind of turbulence does this trail cause?
70. Wingtip vortices tend to drift in which direction(s)?
71. The greatest vortex strength occurs when the generating aircraft is:
a. light, dirty (flaps down), and fast.
b. heavy, dirty, and fast.
c. heavy, clean (flaps up), and slow.
72. A large airplane generating turbulence. Where in relation to its flight path is wake turbulence most likely to be encountered?
73. You are departing behind a heavy airplane. How do you avoid its wake turbulence?

74. How can a pilot minimize the hazard of wingtip vortices during a takeoff made behind a departing large jet airplane?

75. A heavy jet airplane has landed on the runway you intend to use for takeoff and there is a light headwind blowing. When should you become airborne in relation to its touchdown point?

76. What procedure should you follow to avoid wake turbulence if a large jet crosses your course from left to right approximately 1 mile ahead and at your altitude?

77. Vortices created by a helicopter:
- **a.** only descend downward in the propwash.
- **b.** do not exist.
- **c.** trail behind it and descend gradually, like from fixed-wing aircraft.

Ground Effect

78. What is ground effect?

79. An airplane leaving the ground will:
- **a.** experience a reduction in ground friction and require a slight power reduction.
- **b.** experience an increase in induced drag.
- **c.** require a lower angle of attack to maintain the same lift coefficient.

80. If the same angle of attack is maintained in ground effect as when out of ground effect, lift will:
- **a.** increase, and induced drag will decrease.
- **b.** decrease, and parasite drag will increase.
- **c.** increase, and induced drag will increase.

81. When can ground effect cause floating during a landing?

82. After climbing out of ground effect immediately after takeoff, the induced drag will:
- **a.** increase, leading to decreased performance capability.
- **b.** decrease, leading to increased performance capability.
- **c.** stay the same, leading to the same performance capability.

83. Ground effect is most likely to result in:
- **a.** settling to the surface abruptly during landing.
- **b.** becoming airborne before reaching recommended takeoff speed.
- **c.** an inability to become airborne even though airspeed is sufficient for normal takeoff needs.

Windshear

84. What is windshear?

85. What is the "overshoot effect?"

86. What is "windshear reversal effect?"

87. A sudden decrease in headwind will cause the airplane to briefly show a loss of airspeed equal to the decrease in wind velocity. On approach to land, could this be more dangerous than an increase in headwind?Which type of approach and landing is recommended during gusty wind conditions?
- **a.** A power-on approach and landing.
- **b.** A power-off approach and a power-on landing.
- **c.** A power-on approach and a power-off landing.

89. When turbulence is encountered during the approach to a landing, what action is recommended and for what primary reason?
- **a.** Increase the airspeed slightly above normal approach speed to attain more positive control.
- **b.** Decrease the airspeed slightly below normal approach speed to avoid overstressing the airplane.
- **c.** Increase the airspeed slightly above normal approach speed to penetrate the turbulence as quickly as possible.

Answers are given on page 768.

The Airplane

Airframe 7

Airplane Components

The major components of an airplane are:
- the fuselage;
- the wings;
- the empennage (tail section);
- the flight controls;
- the landing gear (or undercarriage); and
- the engine and propeller.

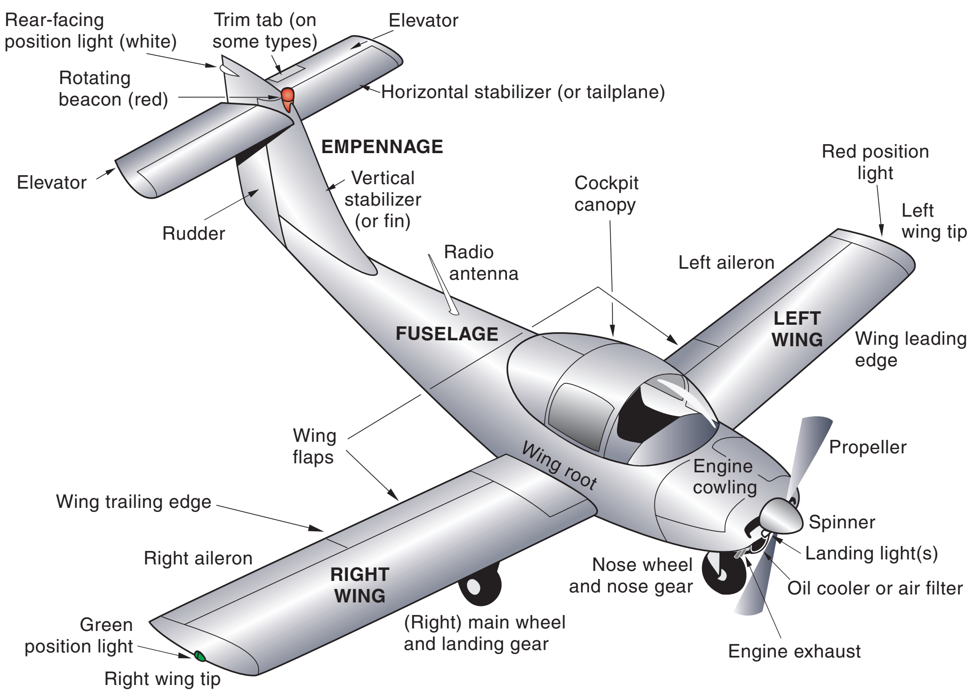


Figure 7-1 Features of a modern training airplane.

Fuselage

The fuselage is the body of the airplane to which the wings, empennage, engine and landing gear are attached. It contains a cabin with seats for the pilot and passengers plus cockpit controls and instruments. It may also contain a baggage compartment.

The fuselage of many modern training airplanes is of *semi-monocoque* construction, a light framework covered by a skin (usually aluminum) that absorbs much of the stress. It is a combination of the best features of a *strut-type* structure, in which the internal framework absorbs almost all of the stress, and a *monocoque* structure which, like an eggshell, has no internal structure and the stress is carried entirely by the skin.

Figure 7-2 Fuselage.

Figure 7-3 Composite construction.

Wings

The wings are designed to cope with the flight loads of lift and drag. They also may support other external devices such as engines (on multi-engine airplanes) and flaps.

Wings generally have one or more internal *spars* which are attached to the fuselage and extend to the wingtips. The spars carry the major loads, which are upward bending because of the lift, and downward bending because of wing-mounted engines and fuel.

Figure 7-4 Wing with fuel tank located inside.

The wings in most airplanes also contain *fuel tanks* installed between the curved upper and lower surfaces. This is an efficient use of the space available, and the weight of the fuel in the tanks also provides a downward force on the wing structure that reduces the upward bending effect of the lift forces.

In addition to the spar(s), some wings also have external *struts* connecting them to the fuselage to provide extra strength by transmitting some of the wing loads to the fuselage.

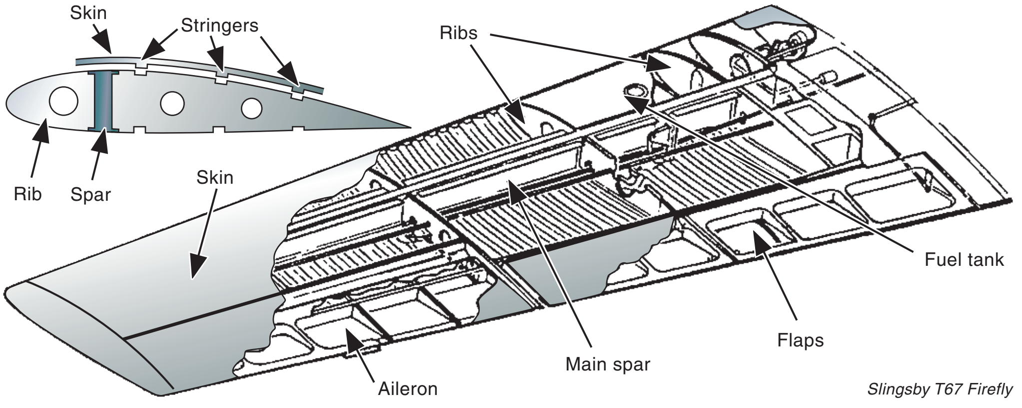


Figure 7-5 Components of a wing.

Ribs, roughly perpendicular to the wing spar(s), assisted by stringers running parallel to the spars, provide the airfoil shape and stiffen the skin which is attached to them. The ribs transmit loads between the skin and the spar(s).

Monoplanes are designed with a single set of wings placed so that the airplane is known as a high-wing, low-wing, or mid-wing monoplane. Biplanes, such as the Pitts Special, are designed with a double set of wings. The Cessna 172 is a high-wing monoplane; the Piper Warrior is a low-wing monoplane.

Figure 7-7 Biplane.

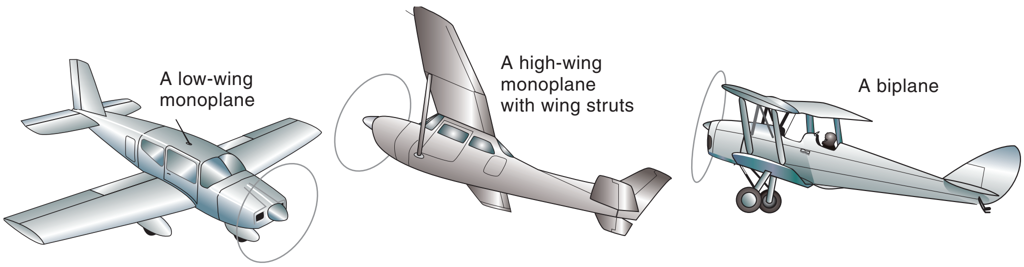


Figure 7-6 Low-wing monoplane, high-wing monoplane, and biplane.

Figure 7-8 Empennage.

Empennage

The empennage is the tail section of the airplane. It is generally constructed like the wings and consists of a fixed *vertical stabilizer* (or fin) to which is attached a movable *rudder*, and a fixed *horizontal stabilizer* with a movable *elevator* hinged to its trailing edge.

There are variations in design, some airplanes have a stabilator (all-moving tailplane), others have a *ruddervator* (combined rudder and elevator) in the form of a butterfly tail, and yet others have a high T-tail, with the horizontal stabilizer mounted on top of the vertical stabilizer.

Figure 7-9 V-tail.

Flight Controls

The main flight control surfaces are the *elevator, ailerons* and *rudder.* They are operated from the cockpit by moving the control wheel and rudder pedals. In a typical airplane, movement of the control wheel or rudder pedals operates an internal system of cables and pulleys that then moves the relevant control surface. Turnbuckles may be inserted in the cables to allow the cable tension to be adjusted by qualified personnel.

There are usually stops to protect the control surfaces from excessive movement in flight and on the ground. Stops in the flight control system may be installed to limit control wheel movement.

Figure 7-10 Aileron.

Landing Gear

The landing gear (or undercarriage) supports the weight of the airplane when it is on the ground, and may be of either the tricycle type (with a nosewheel) or the tailwheel type. Most tricycle landing gear airplanes are equipped with *nosewheel steering* through the rudder pedals, and almost all airplanes have *mainwheel brakes.*

Figure 7-11 Conventional landing gear.

Mainwheels

Figure 7-12
Spring-steel strut.

The mainwheels carry most of the load when the airplane is on the ground, especially during the takeoff and landing, and so are more robust than the nosewheel (or tailwheel). They are usually attached to the main airplane structure with legs in the form of:

- a very strong spring leaf of steel or fiberglass;
- struts and braces; or
- an oleo strut.

Figure 7-13
Retractable gear.

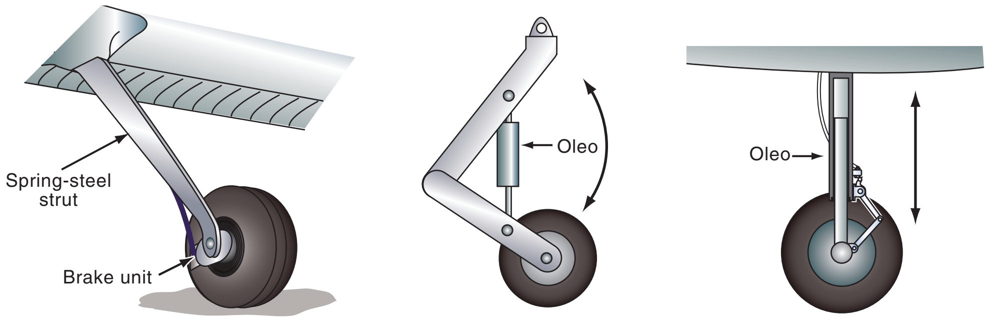


Figure 7-14 Various types of landing gear.

A squat switch is used on airplanes with retractable landing gear to prevent the wheels from being inadvertently raised when the airplane is on the ground. With the weight of the airplane pressing down on the wheel struts, the squat switch opens the gear circuit so electricity will not flow to the hydraulic gear pump, even if the gear handle is placed in the up position.

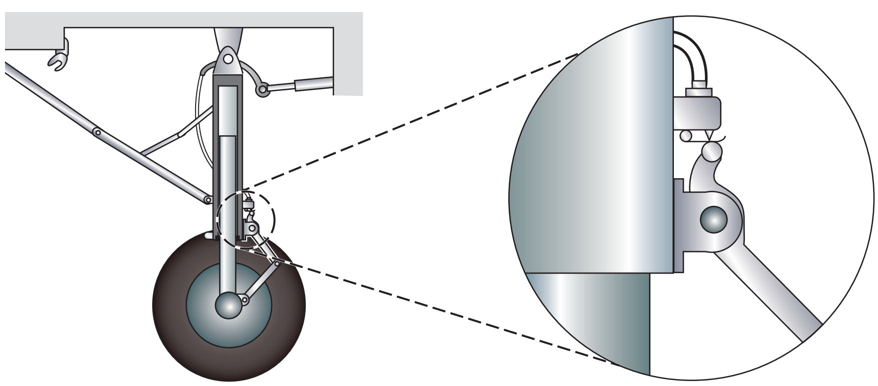


Figure 7-15 Micro-switch (squat switch).

The *oleo strut* acts as a shock absorber, and is of telescopic construction, with a piston that can move within a cylinder against an opposing pressure of compressed air. The piston is attached to the wheel by an oleo strut and the cylinder is attached to the airframe.

The greater the load on the strut, the more the air is compressed by the piston. While the airplane is moving along the ground, the load will vary, and so the strut will move up and down as the compressed air absorbs the loads and shocks, preventing jarring of the main airplane structure.

Special oil is used as a *damping agent* to prevent excessive in-and-out telescoping movements of the oleo strut and to damp its rebound action.

When the airplane is stationary, a certain length of polished oleo strut should be visible (depending to some extent on how the airplane is loaded), and this should be checked in the preflight external inspection. Items to check are:

- correct extension when supporting its share of the airplane's weight;
- the polished section of the oleo strut is clean of mud or dirt (to avoid rapid wearing of the seals during the telescoping motion of the strut); and
- there are no fluid leaks.

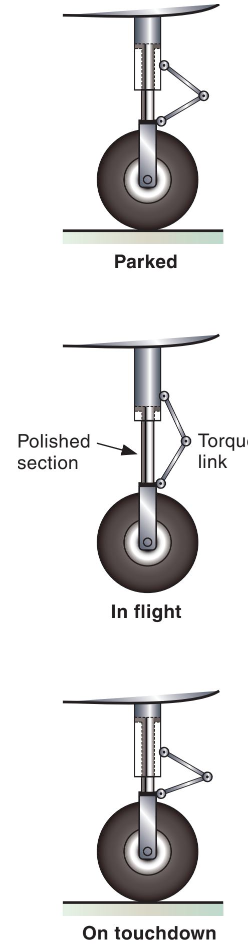


Figure 7-16 The oleo strut.

Nosewheel

The nosewheel is usually of lighter construction than the mainwheels and is usually attached to the main structure of the airplane near the engine firewall. A *torque-link* is used on nosewheel assemblies to correctly align the nosewheel with the airframe. It links the cylinder assembly attached to the airplane structure with the nosewheel assembly, and is hinged to allow for the telescopic extension and compression of the oleo.

Most airplanes have *nosewheel steering*, achieved by moving the rudder pedals which are attached by control rods or cables to the nosewheel assembly, thereby allowing the pilot greater directional control when taxiing.

Some airplanes have *castoring nosewheels* which are free to turn, but are *not* connected by controls to the cockpit. The pilot can turn the airplane by using the rudder when it has sufficient airflow over it (from either slipstream or airspeed) or with differential braking of the mainwheel brakes.

Nosewheel oleo struts are prone to *nosewheel shimmy*, an unpleasant and possibly damaging vibration set up when the nosewheel oscillates a few degrees either side of center as the airplane moves along the ground. To prevent this, most nosewheel assemblies are equipped with a *shimmy damper*, a small piston-cylinder unit that dampens out the oscillations and prevents the vibration. If nosewheel shimmy does occur, it could be because the shimmy damper is insufficiently pressurized or the torque link has failed.

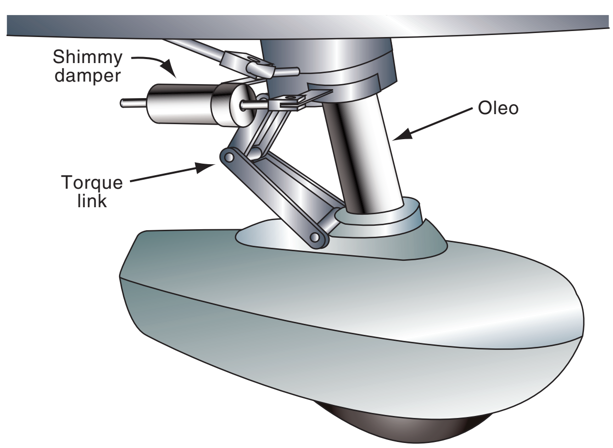


Figure 7-17 Shimmy damper.

Tires

Airplane tires must be inflated to the correct pressure for them to function as designed. Vibration during taxiing, uneven wear and burst tires may result from a pressure that is too high; damage to the tire structure and a tendency for the tire to creep with respect to the rim can occur if pressure is too low. Correct *inflation* is important in achieving a good service life from a tire. Aircraft tires are unique in that they have to withstand ballooning pressures on each landing.

Creep can occur in normal operations because of the stresses during landing, when a stationary tire is forced to rotate on touching the ground and has to "drag" the wheel around with it, and will also occur when the airplane is braking or turning.

To monitor creep, there are usually paint marks on the wheel flange and on the tire which should remain aligned. If any part of the two creep marks is still in contact, that amount of creep is acceptable, but if the marks are separated, then the inner tube may suffer damage and the tire should be inspected and serviced. This may require removal and reinstallation, or replacement.

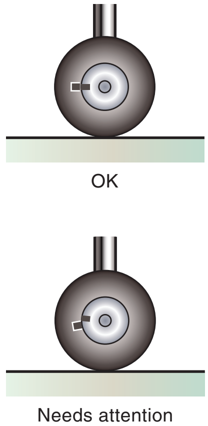


Figure 7-18
Creep marks on the tire and wheel flange enable visual checks for creep.

Tire *strength* comes from its carcass which is built up from casing cords and then covered with rubber. The ply rating is a measure of its supposed strength. Neither the rubber sidewalls nor the tread provide the main strength of the tire; the sidewalls protect the sides of the tire carcass, and the rubber tread provides a wearing surface at the contact points between the tire and the runway.

Shallow cuts or scores in the sidewalls or on the tread, or small stones embedded in the tread, will not be detrimental to tire strength. However, any large cuts (especially if they expose the casing cords) or bulges (that may be external indications of an internal casing failure) should cause you to reject the tire prior to flight. The condition of the tires should be noted during the preflight external inspection, especially with respect to:

- inflation;
- creep;
- wear, especially flat spots caused by skidding;
- cuts, bulges (especially deep cuts that expose the casing cords); and
- damage to the structure of the sidewall.

Wheel Brakes

Most training airplanes are equipped with *disc brakes* on the mainwheels. These are hydraulically operated by the *toe brakes* which are situated on top of the rudder pedals. Pressing the left toe brake will slow the left mainwheel down and pressing the right toe brake will slow the right mainwheel down. Used separately, they provide differential braking, which is useful for maneuvering on the ground. Used together, they provide normal straight-line braking.

A typical system consists of a separate master cylinder containing hydraulic fluid for each brake. As an individual toe brake is pressed, this toe pressure is hydraulically transmitted via the master cylinder to a *slave cylinder* which closes the brake friction pads

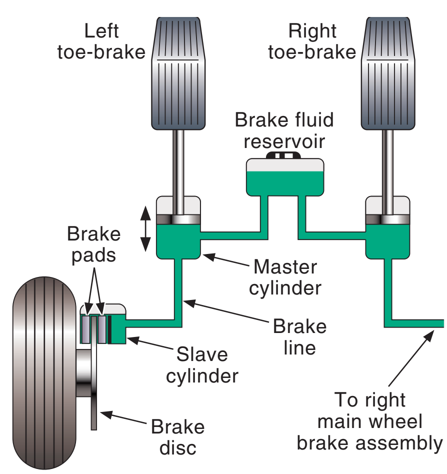


Figure 7-19
Typical simple hydraulic braking system.

(like calipers) onto the brake disc. The brake disc, which is part of the wheel assembly, then has its rotation slowed down.

Most airplanes have a *parking brake* (usually hand-operated, sometimes in conjunction with the toe-brakes) that will hold the pressure on the wheel brakes and can be used when the airplane is parked.

During the preflight external inspection, you should check the brakes to ensure that they will function when you need them, ensuring that:
- there are no leaks of hydraulic brake fluid from the brake lines;
- the brake discs are not corroded or pitted;
- the brake pads are not worn-out; and
- the brake assembly is firmly attached.

A severely corroded or pitted disc will cause rapid wear of the brake pads, as well as reducing their effectiveness, and, in an extreme case, the disc may even fail structurally. Fluid leaks from the brake lines or cylinders indicate a faulty system that may provide no braking at all when it is needed. Any brake problems should be rectified prior to flight.

Following a satisfactory external inspection, you should still test the brakes immediately after the airplane first moves, by closing the throttle and gently applying toe brake pressure. *Brake wear* can be minimized by judicious use of the brakes during ground operations.

Engine and Propeller

The engine is usually mounted on the front of the airplane, and separated from the cockpit by a *firewall.* In most training airplanes, the engine drives a *fixed-pitch propeller*, although more advanced airplanes will have a *constant-speed propeller* with blades whose pitch can vary. The engine and its attachments are considered in detail in the next few chapters.

Figure 7-20 Variable pitch propeller.

Review 7
Airframe

1. What is the main structural component of the wing?
2. Name the four major components of the empennage.
3. What is the airfoil shape of the wing surface formed by?
4. What sort of airplanes are designed with only one pair of wings?
5. What is the most usual form of fuselage construction in training airplanes, in which the skin covers a light structure and carries much of the stress?
6. Does a cracked or severely corroded landing gear strut found during your preflight inspection need to be inspected by a qualified maintenance technician before the airplane flies?
7. What is the agent used to dampen the rebound action in the oleo strut following a shock?
8. True or false? The oleo strut will only extend the same in flight as on the ground.
9. Why should mud or dirt noticed in a preflight inspection be cleaned off the polished section of an oleo strut prior to taxiing?
10. What is the nosewheel held in alignment by?
11. What are nosewheel oscillations either side of center damped by?
12. What is the relative movement between a tire and a wheel flange called?
13. What type of nosewheel is free to turn but is not connected to the cockpit by any control rods or cables for turning?
14. Nosewheel steering in light airplanes is usually operated by:
    a. control rods or cables operated by the rudder pedals.
    b. a steering wheel.
    c. the brakes.
15. A castoring nosewheel can be made to turn:
    a. by a steering wheel.
    b. with differential braking.
16. If a tire has moved so that the creep marks are out of alignment, then:
    a. the tire is serviceable.
    b. the tire should be inspected and possibly reinstalled or replaced.
    c. tire pressure should be checked.
17. Does a tire that has some shallow cuts in the sidewalls and a number of small stones embedded in its tread need to be rejected for further flight?
18. Does a tire that has a deep cut that exposes the casing cords or a large bulge in the sidewall need to be rejected for further flight?
19. Most light airplane braking systems are:
    a. operated by cables.
    b. operated pneumatically.
    c. operated hydraulically.

Answers are given on page 769.

Engine 8

Airplanes can be powered by a variety of engines, and the two fundamental types are *reciprocating* or *piston engines* and *gas turbines* (jets). The jet engine will not be considered in this manual. The piston engine can be designed in various ways, many of which are suitable for airplanes. Older engine types often had the cylinders arranged *radially* around the crankshaft, for example the radial powerplants in the Stearman, Douglas DC-3, North American T-6, de Havilland Canada Beaver and Cessna 195.

The de Havilland Canada Beaver and the Grumman Ag-Cat are two types with radial engines that are still in use today. These engines have an excellent power/weight ratio in the high power range required for operations such as agricultural spraying.

Some airplanes have *in-line engines,* where the cylinders are arranged in one line—the same basic design as in many automobiles. Some of the earliest airplanes had upright, in-line engines, with the cylinder head at the top of the engine and the crankshaft/propeller shaft at the bottom, but this caused some design problems. Raising the thrust line to a suitable position, put the cylinders and the main body of the engine in a very high position. This obscured the pilot's vision and prevented effective streamlining.

Another problem was the ground clearance of the propeller, requiring long struts for the mainwheels. The easiest way to solve this problem was to invert the engine and have the crankshaft/propeller shaft at the top of the engine. Many airplanes have these *inverted* in-line engines. There are other possibilities, such as V-engines and H-engines (V and H describes the layout of the cylinders).

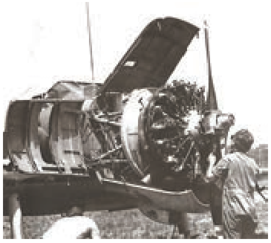


Figure 8-1 Radial engine.

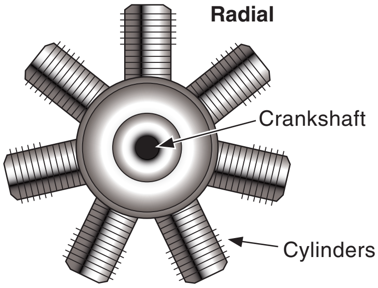


Figure 8-2 Radial engine.

Figure 8-3 Inverted in-line engine.

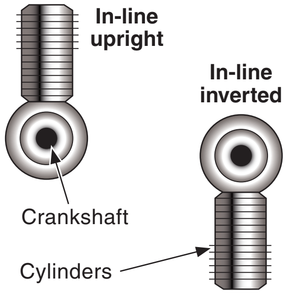


Figure 8-4 In-line engine and inverted in-line engine.

Figure 8-5 Horizontally opposed engine.

The usual powerplant found in the modern light airplane is the *reciprocating engine*, with the cylinders (4, 6 or 8 of them) laid out in a *horizontally opposed* manner.

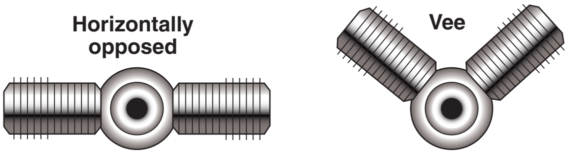


Figure 8-6 Horizontally opposed engine and vee configuration.

Basic Principles

The reciprocating engine has a number of cylinders within which pistons move back and forth (hence the name reciprocating engine). In each cylinder a fuel/air mixture is burned, and the heat energy causes gases to expand and push the piston down the cylinder. A two-stage energy-conversion process is therefore involved, whereby chemical energy (in the fuel) is initially converted to heat energy in the cylinder, and then finally converted to mechanical energy by the action of the piston.

The piston is connected by a rod to a crankshaft, which it turns. This connecting rod, or conrod, converts the back-forth motion of the piston into a rotary motion of the crankshaft, which transmits the power generated by the engine to the propeller. Light airplanes with fixed-pitch propellers (and most with constant-speed propellers) have the propeller directly attached to the crankshaft, in which case the crankshaft is also the propeller shaft. The propeller produces the thrust force necessary for powered flight.

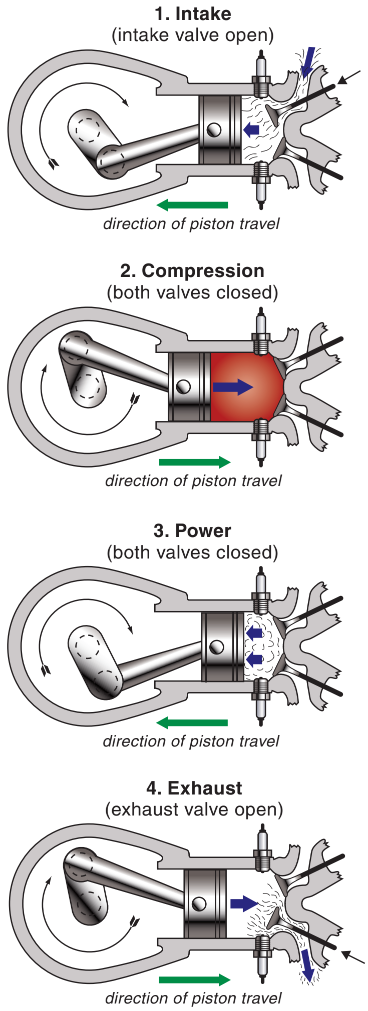


Figure 8-8 The four strokes of a reciprocating engine.

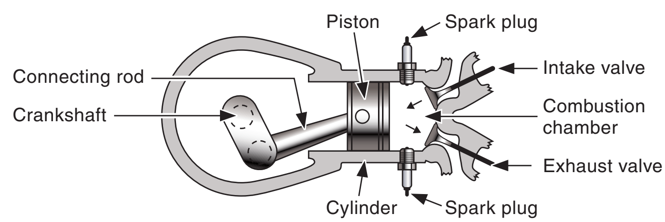


Figure 8-7 Parts of a typical reciprocating engine.

Four-Stroke Engine Cycle

A complete cycle of this type of piston engine comprises four strokes of the piston traveling within the cylinder, hence the name *four-stroke engine.* The German engineer, Nikolaus Otto, developed this engine, so the four-stroke cycle is also known as the *Otto cycle.* The four strokes are:

1. *intake* (or induction);
2. *compression*;
3. *power* (or expansion); and
4. *exhaust*.

In the *intake* (or *induction*) stroke, the fuel/air mixture is "sucked" or induced to flow into the top of the cylinder. The piston, moving from the top to the bottom of the cylinder, decreases the pressure in the cylinder by increasing the volume of the space between the piston and the top of the cylinder. The decreased pressure draws air in through the induction system and, as the air passes through the carburetor prior to reaching the cylinder, fuel is metered into the airflow to provide a fuel/air mixture. A charge of this fuel/air mixture of gases is drawn into the cylinder during each induction stroke via the intake manifold and the temporarily open intake valve. The *intake manifold* is a pipe system distributing from a single input (the carburetor) to multiple outlets which are fed to the cylinder inlet ports.

Early in the *compression stroke*, the intake valve is closed and the piston moves back toward the top (or the head) of the cylinder. This increases the pressure of the fuel/air mixture, and because of the compression, the temperature of the fuel/air mixture rises.

As the piston is completing the compression stroke well before it reaches top center, the fuel/air mixture is ignited by an electrical discharge between the electrodes of a spark plug and a controlled burning commences. This causes the gases to expand rapidly and exert a strong pressure on the piston. The piston, which has now passed the top of its stroke, is pushed back down the cylinder in the *power stroke.*

Just prior to the completion of the power stroke, the exhaust valve opens and then, as the piston returns to the top of the cylinder in the *exhaust stroke*, the burnt gases are forced out of the cylinder to the atmosphere via the exhaust manifold, a pipe system that collects gases from the cylinder outlets and feeds them through an exhaust pipe to the atmosphere. As the piston is approaching the cylinder head again, while the last of the burnt gases is being exhausted, the intake valve opens in preparation for the next induction stroke. And so the cycle continues.

In a single-cylinder Otto-cycle engine involving four strokes of the piston (down—*induction,* up—*compression*, down—*power*, up—*exhaust*), only one stroke provides power for each two rotations of the crankshaft (which carries the power to the propeller).

The four-stroke cycle comprises intake, compression, power and exhaust.

To increase the power developed by the engine and to allow smoother operation, the engine has a number of cylinders whose power strokes occur at different positions during the revolution of the crankshaft. The spacing of these power strokes is equal, so that evenly spaced impulses are imparted to the crankshaft. So, in a full Otto cycle of a six-cylinder engine, the crankshaft would, in two revolutions, receive the power from six different power stokes—one per cylinder.

An engine with four cylinders (common in light airplanes) would receive four impulses of power in two revolutions of the crankshaft. The more evenly these impulses of power from each of the cylinders are spread, the more efficient the transfer of power, the smoother the running of the engine and the less the vibration.

Valves and Valve Timing

The intake valve, through which the fuel/air mixture is taken into the cylinder, and the exhaust valve, through which the burned gases are exhausted, must open and close at the correct times during the four-stroke cycle of each piston. To achieve this, there is a *camshaft*, which is usually gear-driven by the crankshaft of the engine. The camshaft operates rocker arms and push rods which push the appropriate valve open (against spring pressure) at what has been determined by the design engineers to be the most suitable moment in the cycle.

A typical engine speed while cruising is *2,400 revolutions per minute* (RPM). Since the intake valve and exhaust valve of each cylinder must each open and close once during the four piston strokes of each complete cycle, the camshaft must rotate at half-crankshaft speed. At an engine speed of 2,400 RPM, each valve will have to open and close 1,200 times—1,200 times in 60 seconds means 20 times a second—quite amazing!

The power that the engine can develop depends on how much fuel/air mixture can be induced through the intake valve during the intake stroke, which, as we have seen, is extremely short. Opening the intake valve just prior to the piston reaching the top of its stroke, or *top dead center* (TDC), and not closing it until the piston has gone just past *bottom dead center* (BDC) following the induction stroke, allows maximum time for the intake of the fuel/air mixture to occur. This is called *valve lead* and *valve lag.*

Power is increased by increasing the amount of fuel/air mixture entering the cylinder by extending the time of the intake stroke using valve lead and valve lag.

Similarly, the exhaust valve opens just prior to the piston reaching bottom-dead-center on the power stroke and remains open until a little after the piston passes top-dead-center for the exhaust stroke and commences the induction stroke.

Notice that, for a brief period at the start of the induction stroke, the burned gases are still being exhausted through the still-open exhaust valve while a fresh charge of fuel/air is commencing induction through the just-opened intake valve. This brief period when both the intake and the exhaust valves are open together is called *valve overlap*.

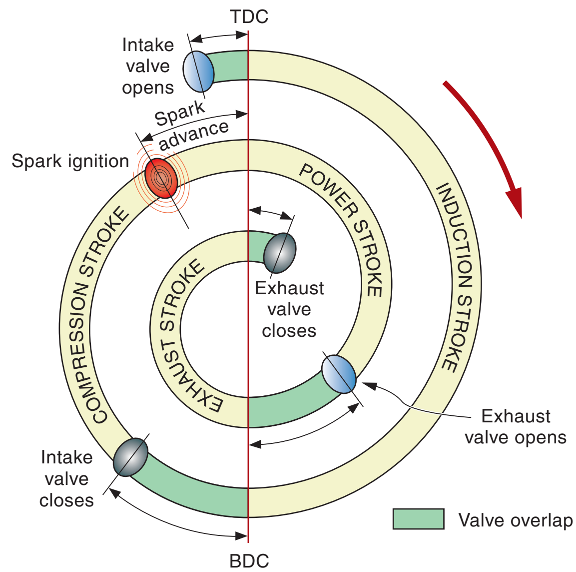


Figure 8-9 Typical valve timing in the four-stroke cycle.

Ignition

A high voltage (or high tension) spark occurs in the cylinder just prior to the piston reaching top-dead-center, shortly before commencing the power stroke. This slightly advanced spark is to enable a controlled flame front to start moving through the fuel/air mixture that has been compressed in the cylinder. The purpose of the ignition system is to provide this correctly timed spark.

Dual ignition is safer and results in improved fuel combustion.

Most airplane engines have *dual* (and independent) *ignition* systems running in parallel with one another, with the magneto of each ignition system supplying one of the two *spark plugs* per cylinder.

A dual ignition system:

- improves engine performance;
- is safer, in the event of failure of one ignition system; and
- results in more even and more efficient fuel combustion.

The necessary high-tension electrical current for the spark plugs comes from self-contained generation and distribution units called the *magnetos.* Each of the dual ignition systems has its own magneto which is mechanically driven by the engine.

The magneto consists of a magnet that is rotated (within the magneto housing) near a conductor which has a coil of wire wound around it. The rotation of the magnet induces an electrical current to flow in the coil. Around this primary coil is wound a secondary coil of many more turns of wire, which transforms the primary voltage into a much higher voltage. This arrangement of primary and secondary coils is known as a transformer. The higher voltage is fed to each spark plug at the appropriate time, causing a spark to jump between the two electrodes. This spark ignites the fuel/air mixture.

The timing of the spark is critical. The magneto has a set of *breaker points* which are forced open and closed by a small cam that is part of the rotating magnet-shaft connected indirectly to the crankshaft. The points are in the circuit of the primary coil and, when they open, the electrical current in the primary coil stops flowing. This sudden collapse of the primary current (aided by a condenser or capacitor placed across the points) induces a high voltage in the secondary coil. The spark plug is in the circuit of the secondary coil and the large voltage (up to approximately 20,000 volts) across its electrodes causes a spark to jump between them.

As each cylinder is operating out of phase with the others, the current must be distributed by the distributor to each spark plug at the correct moment (generally 20°–25° before top center).

Each cylinder fires once in every two revolutions of the crankshaft and the distributor has a *finger* (distributor rotor) which is geared to the crankshaft in such a way that it turns only once for every two turns of the crankshaft. Therefore the distributor finger turns once in every complete four-stroke cycle. Once during each turn of the distributor finger it transfers the high-tension secondary current to each cylinder, in the correct firing order of the cylinders.

Separate leads to each of the spark plugs belonging to each ignition system (one per cylinder) emanate from different electrodes of the distributor case. These leads are often bound together, forming an *ignition harness.* Leakage of current from the ignition harness will lead to rough running. One item of the preflight inspection is a visual check for chafing and heat cracking of those parts of the ignition harness easily seen. While the engine is running, the magneto is a completely self-sufficient source of electrical energy and it operates independently of all the other electrical power sources. All it needs is mechanical energy from the engine to rotate the magnet.

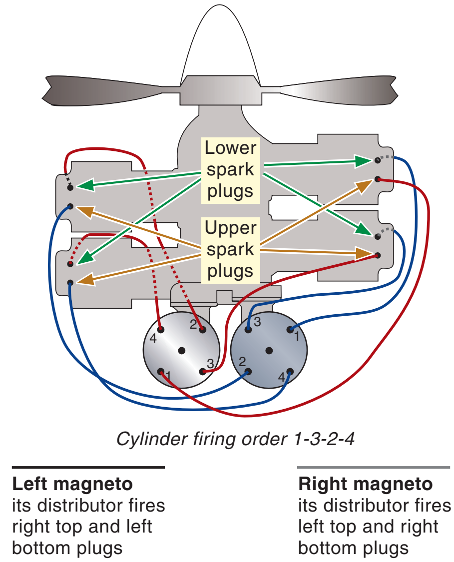


Figure 8-10 A typical ignition system.

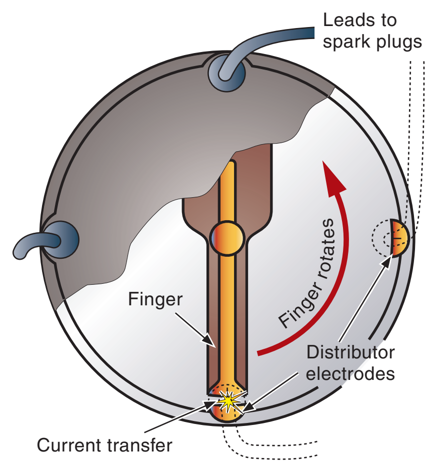


Figure 8-11 Distributor finger.

Starter

Most modern training airplanes have an *electric starter motor* that is powered by the battery and activated by turning the ignition key to the *start* position.

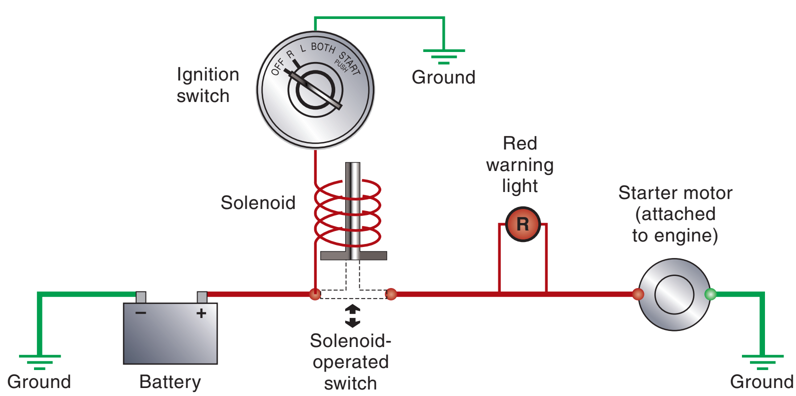


Figure 8-12 The electric starter system.

Starting the engine causes a very high current to flow between the battery and the starter motor, and this requires heavy-duty wiring. If the ignition switch in the cockpit was directly connected to the starter circuit, heavy-duty wiring to the cockpit switch would be required.

Such an arrangement would have a number of disadvantages, including the additional weight of the heavy cable, a significant loss of electrical energy over the additional length, and high electrical currents through the cockpit environment (which would introduce an unnecessary fire risk). To avoid these disadvantages, the starter circuit connecting the battery to the starter motor is remotely controlled from the cockpit using a solenoid-activated switch.

Moving the ignition key to *start* causes a small current to flow through the starter key circuit point A to B and energize a *solenoid* (an electromagnet with a movable core). The energized solenoid operates a heavy-duty switch that closes the heavy-duty circuit between the battery and starter motor. High current flows through this circuit, activating the starter motor which turns the engine over (point C to D).

Electric starters often have an associated *starter warning light* in the cockpit that glows while the starter is engaged. It should extinguish immediately when the starter is released. If by any chance the starter relay sticks (so that electrical power is still supplied to the starter motor even though the starter switch has been released from the *start* position) the warning light will remain on. The engine should be stopped (mixture control to *idle cut-off)* to avoid damage to the engine and/or starter motor.

Only one spark per cylinder is necessary for start-up, so when the ignition key is in the *start* position, the right magneto system is automatically de-energized and only the left magneto system provides a high-tension supply to the spark plugs. (For this reason, only the left magneto is equipped with an impulse coupling, a device which aids the starting process—see below.) After start-up, switching the ignition key to *both* activates the right magneto system as well, and the engine now runs with dual ignition in each cylinder.

Older airplanes with the starter switch separate to the magneto switches should have only the left magneto switch *on* for start-up. Once the engine is started, you should switch the other magneto on as well.

There are two design limitations of magnetos that significantly affect starting an engine.

1. When the starter motor turns the engine over, the engine rotates comparatively slowly (approximately 120 RPM as against 800 RPM at idle speed). Because the magneto rotates at half crankshaft speed (to supply one spark per cylinder every two revolutions of the crankshaft), magneto speed at start-up is very slow, up to about 60 RPM. To generate a spark of sufficiently high voltage to ignite the fuel/air mixture requires a magneto speed of about 100-200 RPM, so some device must be incorporated in the system to overcome this slow magneto speed when starting the engine.
2. When the engine is running (800-2,700 RPM is a typical operating range) the spark occurs at a fixed number of degrees *prior* to the piston reaching top-dead-center at the commencement of the power stroke. This is known as *spark advance.* On start-up, with only very low revs occurring, unless the spark is *retarded* (delayed) until the piston is at or past top-dead-center, ignition of the gases could push the piston down the cylinder prematurely, causing the crankshaft to turn in the wrong direction. This is called *kick-back.*

To overcome these two difficulties special devices have been developed for installation in the magneto; the most common in small airplane engines is the *impulse coupling.*

Impulse Coupling

The impulse coupling initially delays the magnet from rotating as the engine is turned over. Energy from the initial part of the engine rotation is stored by winding up a coiled spring. When a certain amount of energy is stored, the coupling releases, and the spring accelerates the magnet rapidly. This generates a current of sufficient strength to create a spark across the electrodes of the spark plug. It also retards the spark sufficiently to allow the burning fuel/air mixture to drive the crankshaft in the correct direction. Once the engine is started and is running at its usual RPM, the magneto's driveshaft accelerates away from the coiled spring, which has no further effect. The spark is then produced normally (by the engine rotating the magnet), and the timing is no longer retarded but operates normally, with the spark occurring just prior to commencement of the power stroke.

Impulse coupling generates a high voltage and retards the ignition timing to start the engine.

Notice that, as the impulse coupling does not depend on any electrical power source, the engine can be started by swinging the propeller. (This should only be done by trained and qualified personnel.) If you use an electric starter powered by the airplane battery to start the engine then, once the engine is running, disconnecting the battery will not stop the engine. It will, however, prevent the battery from being recharged.

Ignition Switch

There are two separate ignition systems for safety in the event of failure of one of them, as well as for more efficient burning of the fuel/air mixture with two sparks in the cylinder instead of one. Older airplanes often have separate switches for each magneto, while most modern airplanes have rotary switches operated by the ignition key. With these, you can select either the left system *L,* the right system R, or *BOTH.* BOTH is selected for normal engine operation. Airplanes with a separate starter button are usually started on the left magneto.

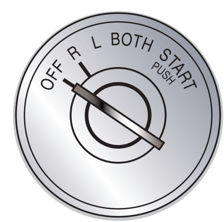


Figure 8-13
The ignition switch in the cockpit.

The engine will run on just one magneto, but not as smoothly as on two, and with a slight drop in RPM. With one spark instead of two, there will be only one flame-front advancing through the fuel/air mixture in the cylinder instead of two. This increases the time for full combustion to occur and decreases the efficiency of the burning.

If *L* is selected, only the left magneto system supplies a spark. The *R* magneto is grounded to the airframe, which means its primary current runs to ground and no spark is generated. Switching from *BOTH* to *L* should cause a drop in RPM and possibly slightly rougher running. If a slight drop in RPM does not occur, then either the *R* system is still supplying a spark or else the *R* magneto was not working previously when *BOTH* was selected. The pilot will normally check both left and right magneto systems in this way as part of the pre-takeoff power check, switching from *BOTH* to *L,* noting the RPM drop and returning to *BOTH,* when the RPM originally set should be regained. Then the pilot will switch from *BOTH* to *R,* noting the RPM drop, and back to *BOTH.*

Comparisons are made between the two RPM drops, which should be within certain limits (see the Pilot's Operating Handbook for your particular airplane). Some typical figures are: check at 1,600 RPM on *BOTH,* magneto drop 125 RPM maximum on either *L* or *R,* with a difference between these two drops not to exceed 50 RPM.

Remember that placing the ignition switch to *OFF* grounds the primary winding of the magneto system so that it no longer supplies electrical power. This means that with a particular magneto's ignition switch *OFF,* the system is supposed to be grounded and unable to supply a spark. The magneto ground wire is called a *p-lead.* With a loose or broken wire, or some other fault, switching the ignition to *OFF* may not ground both of the magnetos. Therefore, a person moving the propeller could inadvertently start the engine, even though the ignition is switched off. It *has* happened, often with fatal results, and is still happening.

Always treat a propeller as live.

If the ignition switch is momentarily switched off and the engine continues to run, this indicates that the system is not grounded, which is a dangerous situation.

The pilot has no visual method of checking that the magneto systems, although switched off, are actually de-activated. Just before shutting an engine down, some pilots do a system function test at idle RPM, checking *BOTH, L, R*. This is followed by a dead-cut, where the ignition is switched to *OFF* (a sudden loss of power should be apparent) and rapidly back to *BOTH* to allow the engine to run normally. The engine is then shut down normally using the idle cut-off function of the mixture control. Some manufacturers/instructors advise against a dead-cut check as it may damage the engine. Refer to your Pilot's Operating Handbook. During a preflight power check, if there is no drop in speed while checking the magnetos, the magneto may be hot. A hot magneto is one that cannot be turned off by the ignition switch.

Exhaust System

The burnt gases leave the engine cylinders and are carried out to the atmosphere via the exhaust system. It is important that there is no leakage of exhaust gas into the cabin because it contains carbon monoxide, a colorless and odorless gas that is difficult to detect, but can cause loss of consciousness and death.

The Oil System

Oil lubricates, clears, and cools and seals.

The purpose of the oil system is to circulate oil around the engine, to:

- lubricate the moving parts so that they can move smoothly;
- prevent high temperatures by reducing friction between the moving parts;
- provide a seal between the cylinder walls and the pistons, increasing the effectiveness of the expanding gases in the combustion process;
- assist in cooling the engine by carrying some of the heat generated by combustion away from the pistons; and
- carry away contaminants which are then removed in an oil filter.

Sufficient quantity of oil of the correct grade is absolutely essential. An oil dipstick to check oil quantity is generally found under a small cowl above the engine, along with an oil filling point if more oil is required. Always check that the oil filler cap has been firmly replaced prior to flight. Indication of correct operation of the oil system is provided in the cockpit by an *oil pressure gauge*, an *oil temperature gauge*, and, in some aircraft, a *cylinder-head temperature gauge*.

Figure 8-14
Oil check.

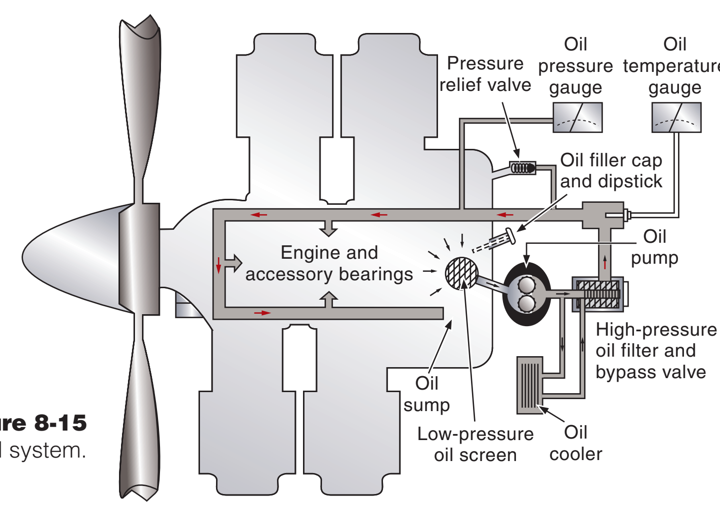


Figure 8-15
A typical oil system.

The Functions of Engine Oil

Friction

If a small film of oil separates two metal surfaces, it will allow them to slide over each other without actually touching. There will be only low friction forces and consequently, high temperatures will not be generated in the metal. The metallic friction will be replaced by internal friction in the lubricating oil, which will heat up to some extent. Engine components subjected to high loads, such as the bearings at either end of the connecting rods and the crankshaft (or *big end)* bearings, need to be cushioned by a layer of oil so that the mechanical shock on them is reduced. Without oil there would be high friction forces, causing very high temperatures to develop quickly in the metal, with extreme wearing of the metal surfaces and, very likely, subsequent mechanical failure.

Oil reduces friction.

Cooling

The pistons absorb a lot of heat from the combustion chamber and are cooled by oil splashed or sprayed onto them from below. Lubrication and cooling of the bearings and pistons is the main function of the oil system.

Oil cools the hot sections of the engine.

Heat generated by internal friction in the oil and the heat absorbed from the hot sections of the engine is removed by the oil continually being circulated. The hot oil is carried away and cooled in a component known as the *oil cooler*, which is exposed to the airflow.

Removal of Contaminants

Oil circulating through an engine can carry away dirt and other foreign material, thereby reducing abrasive wear on the moving parts of the engine. This contamination is removed from the oil as it passes through the *oil filter.* If the filter is not kept clean (by correct maintenance or replacement at the recommended service intervals) it may become blocked, causing dirty oil to bypass the filter and circulate within the engine's lubrication system. Dirty oil has poorer cooling and lubricating qualities, which can cause excessive wear. This increased wear rate will shorten the life of the engine.

Oil carries away contaminants.

Sealing Qualities

Oil also provides a seal between the cylinder walls and the pistons as they move up and down within the cylinders, preventing the compressed gases (burning fuel/air) escaping past the piston rings into the crankcase, and so increasing the effectiveness of the compressed gases in forcing the piston down the cylinder.

Oil provides a seal.

Oil Properties

Oil must have appropriate *viscosity* over the operating temperature range of the engine — it must flow freely, but not be too thin. An oil of high viscosity (thickness) flows slowly; an oil of low viscosity flows more easily. High temperatures make oil less viscous and cause it to flow more freely. The oil must remain sufficiently viscous under the wide range of operating temperatures and bearing pressures found in aviation engines.

Excessively high temperatures affect the lubricating qualities of oil, impairing its effectiveness, so keep an eye on the oil temperature gauge.

The owner or operator of the airplane may decide to use an oil of lower viscosity than normal in a severely cold climate. Likewise, an oil of higher viscosity could be used if the airplane is to be operated in a continually hot climate. Be aware of the oil grade being used and *do not mix oil grades.* The oil must also have a sufficiently *high flash point* and fire point to ensure that it will not vaporize excessively or catch fire easily. It must also be chemically stable and not change its state or characteristics.

Use only recommended type and grade of oils. Do not mix grades.

Maintenance

Since the same oil in an engine is continually circulated, over a period of time it will become contaminated because the filters cannot clean it perfectly. Chemical changes will also occur in the oil in the form of:

- oxidation caused by contamination from some of the byproducts of the fuel combustion in the engine; and
- absorption of water that condenses in the engine when it cools after shutdown.

Consequently the *oil must be changed at regular intervals,* as required by the maintenance schedule.

The airplane's Pilot's Operating Handbook will usually show the oil grade as an SAE rating (Society of Automotive Engineers), but commercial aviation oil has a *commercial aviation number* which is *double* the SAE rating:

- 80 grade oil—SAE 40; and
- 100 grade oil—SAE 50.

There are different types of oils designed for different operating conditions. Use only the correct type of oil as directed in the Pilot's Operating Handbook and *do not use turbine (jet) oil in piston engines.*

A Typical Oil System

After doing its work in the engine, the oil gathers in the *sump*, which is a reservoir attached to the lower part of the engine casing:

- a *wet sump* engine has a sump attached to it in which the oil is stored. Most light aircraft engines are wet sump engines; and
- a *dry sump* engine has scavenge pumps that scavenge the oil from the sump attached to the lower part of the engine casing and pump it back into the oil tank, which is separate from the engine. It is usual to have a dry sump on aerobatic airplanes for continuous lubrication in extreme attitudes. Radial engines have dry sump oil systems.

There is usually an *engine-driven oil supply pump* that supplies oil from the sump or the tank through oil lines, passages and galleries to the moving parts of the engine. Within the oil pump is a spring-loaded *oil pressure relief valve.* If the pressure set on the pressure relief valve is exceeded, it will open and relieve the pressure by allowing oil to be returned to the pump inlet.

An *oil pressure gauge* in the cockpit indicates the oil pressure provided by the oil pump. The oil pressure sensor is situated after the oil pump and before the oil does its work in the engine.

Oil filters and screens are placed in the system to remove any foreign matter such as dirt or carbon particles in the circulating oil. The oil filters should be inspected and replaced at regular intervals, as required in the maintenance schedule. The foreign matter collected may give an indication of the condition of the engine—for instance, small metal particles might indicate an impending engine failure. Within the oil filter housing is the *oil filter bypass valve.* This permits the oil to bypass the filter in the event of the filter becoming clogged. Dirty and contaminated oil is preferable to no oil at all.

Because the oil absorbs engine heat, the cooling that occurs in the sump is often insufficient, so most engines have an *oil cooler.* The oil is pumped from the sump through the oil filter to the oil cooler. If the oil is already cool, a thermally operated valve allows it to bypass the oil cooler, as further cooling is unnecessary. If the oil is hot (as it is when the engine has warmed-up), the thermally operated valve directs the oil through the cooler. Should the cooler become blocked, a *pressure bypass valve* allows the oil to bypass the cooler. The oil cooler is usually positioned in the system so that the oil cools a little in the sump and then passes through the oil cooler for further cooling just prior to entering the main parts of the engine.

As part of your *daily/preflight inspection* you should check the condition of the oil cooler for freedom from insects, birds' nests and other contamination, to ensure free air passages and any oil leakage or fatigue cracks.

There is an *oil temperature gauge* in the cockpit. It is connected to a temperature probe that senses the temperature of the oil after the oil has passed through the oil cooler and before its use within the hot sections of the engine. Also, some airplanes have a *cylinder-head temperature* (CHT) *gauge* to provide another indication of engine temperature, this time in the cylinder head.

Malfunctions in the Oil/Lubrication System

Incorrect Oil Type

The *incorrect type of oil* will possibly cause poor lubrication, poor cooling, and engine damage. Oil temperature and oil pressure indications may be abnormal. For instance, mixing detergent and mineral oils can lead to engine damage.

Incorrect Oil Quantity

The *oil level* should be checked and corrected if necessary prior to flight. There will be an *oil dipstick* in the tank for this purpose. The dipstick is calibrated to show maximum and minimum oil quantities. If the oil quantity is below the minimum, then you will find that the oil overheats and/or the oil pressure is too low or fluctuates. If the oil quantity is too great, then the excess oil may be forced out through various parts of the engine, such as the front shaft seal. The oil quantity needs to be checked before each flight, as it gradually decreases because of:

- being burned with the fuel/air mixture in the cylinders;
- loss as a mist or spray through the oil breather; and
- leaks.

Low Oil Pressure

At normal power a low oil pressure may indicate an impending engine failure caused by:

- insufficient oil;
- lack of oil because of a failure in the oil system;
- a leak in the oil tank or oil lines;
- failure of the oil pump;
- a problem in the engine, such as failing bearings; or
- the oil pressure relief valve (PRV) stuck open.

Where an indication of low or fluctuating oil pressure occurs and is associated with a rise in oil temperature while in flight—play it safe and land as soon as possible, as it could indicate a serious problem in the lubrication system.

High Oil Temperature

Too little oil being circulated will also be indicated by a high oil temperature, therefore a rising oil temperature may indicate a decreasing oil quantity. Prolonged operation at excessive cylinder head temperatures will also give rise to a high oil temperature indication. This would be most likely to occur in situations of high power, low airspeed (climbing), especially in high ambient air temperatures.

Gradual Loss of Oil

Lack of oil will cause an engine seizure and an immediate loss of power.

If the engine is gradually losing oil, the oil temperature will gradually rise as less oil is available for cooling and lubricating the engine. If oil is lost, the oil pressure will probably be maintained, until the oil quantity reaches a critically low level. This may be indicated by rapidly rising oil temperature with a sudden drop in oil pressure occurring just before engine seizure.

If you suspect a problem concerning oil, then you should plan a landing before the time you estimate the oil problem will become serious. This is a matter of judgment, especially if the choice of nearby landing areas is not great.

Faulty Oil Pressure Gauge

Sometimes of course, the oil pressure gauge may be faulty. A low oil pressure indication may be recognized as a faulty indication—and not a genuine low pressure—by noting that the oil temperature remains normal over a period of time. Keep your eye on both gauges.

High Oil Pressure

A pressure relief valve in the system should ensure that the oil does not reach an unacceptably high oil pressure. A high oil pressure may cause some part of the system to fail, rendering the whole oil system inoperative.

The Cooling System

The engine cooling system is designed to keep the engine temperatures within those limits designed by the manufacturer. The burning of the fuel/air mixture in the engine's cylinders, and the friction of its moving parts, results in the engine heating up. Engine temperatures are kept within acceptable limits by:

- the oil that circulates within the engine;
- expulsion of much heat energy in the exhaust gases; and
- the air cooling system that circulates fresh air around the engine compartment.

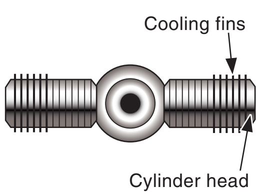


Figure 8-16
Cooling fins.

Most modern light airplane engines are *air-cooled* by exposing the cylinders and their cooling fins to an airflow. The fins increase the exposed surface area to allow better cooling.

As the airflow passes around a cylinder it may become turbulent and break away in such a manner that uneven cooling occurs, forming local poorly cooled hot-spots. To avoid this uneven cooling, cowling ducts at the front of the engine capture air from the high-pressure area behind the propeller, and then baffles distribute it as evenly as possible around the cylinders. After cooling the engine, the air flows out holes at the bottom rear of the engine compartment.

Air cooling is least effective at high power and low airspeed, for instance on takeoff or go-around. The high power produces a lot of heat, and the low airspeed provides a reduced cooling airflow. At high airspeed and low power, for instance on descent, the cooling might be too effective.

Some airplanes have movable cooling *cowl flaps* that can be operated (electrically or manually) from the cockpit, giving the pilot more control over the cooling of the engine. Open cowl flaps permit more air to escape from the engine compartment. This causes increased airflow over and around the engine. The open cowl flaps cause parasite drag to increase.

Cowl flaps are normally open for takeoff, partially open or closed on climb and cruise, and closed during a power-off descent. They will be open on final in readiness for a go-around, when high power at a low airspeed will be required. Cowl flaps should be open when taxiing to help dissipate the engine heat.

The deciding factor for the pilot in where to position the cowl flaps is the cylinder head temperature, or the anticipated cylinder head temperature, and this may be indicated in the cockpit by a *cylinder-head temperature* (CHT) *gauge.*

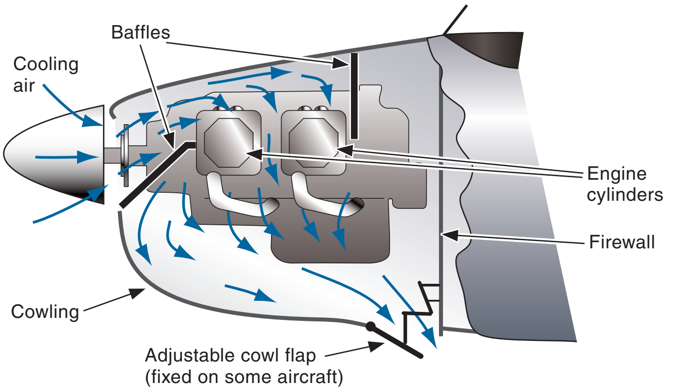


Figure 8-17 Cowl flaps and engine cooling.

Excessive engine temperatures may be caused by:
- high power (greater heat generation);
- low airspeed (less air cooling);
- incorrect fuel (lower-than-specified grade);
- a too-lean mixture (no excess fuel to evaporate and cool the cylinders); or
- a low oil level.

You should monitor the cylinder-head temperature gauge throughout the flight, and also on the ground when air-cooling will be poor.

Monitor CHT and adjust engine cooling if necessary.

Note. The Pilot's Operating Handbook will give advice on satisfactory temperatures.

If excessive cylinder-head temperatures are noted in flight, the cooling of the engine can be improved by:
- opening the cowl flaps fully (to allow greater airflow around the engine);
- making the mixture richer (extra fuel has a cooling effect in the cylinders because more fuel is evaporated, so a rich mixture cools better than a lean mixture);
- reducing the engine power (so that less heat is produced); or
- increasing the airspeed (for greater air cooling).

Just how you achieve the latter two is a matter of judgment. In a climb, you could increase speed by reducing the rate of climb. In a cruise (straight-and-level) at normal cruise speeds, you could maintain the power and increase the airspeed by commencing a descent, unless terrain prevents this.

Other factors influencing engine cooling and over which the pilot has little control during flight include:
- the condition of the oil cooler; and
- the outside air temperature.

A dirty and inefficient oil cooler will not allow the best cooling of the circulating oil. The oil, if warmer than optimum, will be unable to carry as much heat away from the engine, and its viscosity and lubricating qualities will be reduced, which will lead to higher engine temperatures.

Obviously, warm air will not cool the engine as well as cool air.

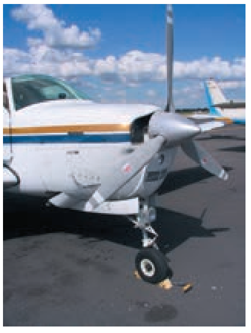


Figure 8-18 The cowls direct cooling air.

Note. On some airplanes the propeller *spinner* is part of the airflow director for the cooling air, so these airplanes should *not* be operated without the spinner installed. If you find yourself in such a situation, refer to the Flight Manual or a technician to establish what is allowable for your airplane.

The Carburetor

The carburetor mixes fuel with air.

Gasoline needs to be mixed with oxygen in the correct ratio to burn properly. The correct *fuel/air* ratio is about 1 part of fuel to 12 parts of air by *weight*. The device commonly used to mix fuel with air in an engine is called the *carburetor.*

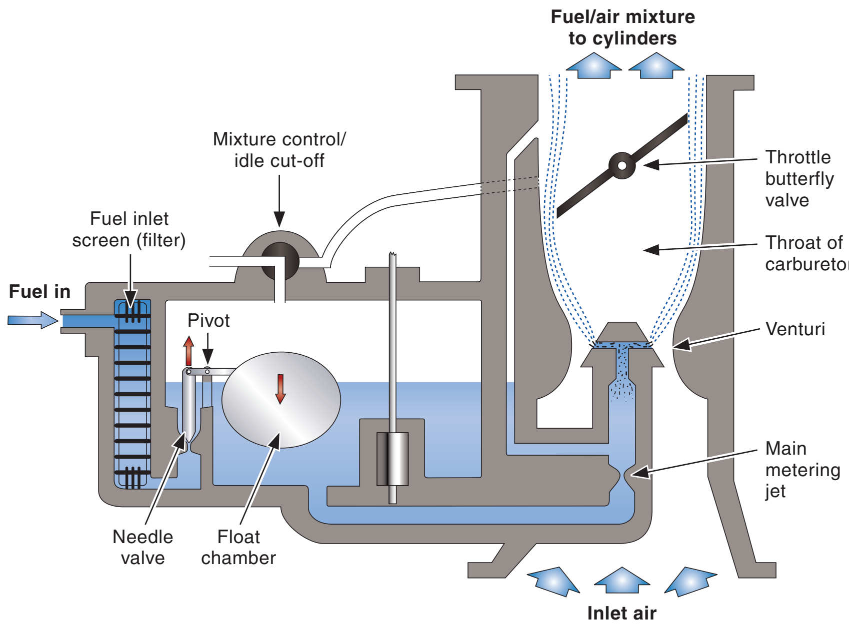


Figure 8-19 Cross-section of a simple float-type carburetor.

The carburetor works on the principle that the airflow through the throat of the carburetor will have its pressure reduced by the venturi effect. This causes the fuel to flow through the main metering jet and into the airstream, because of the atmospheric pressure in the float chamber being greater. The fuel vaporizes and mixes with the air. The fuel/air mixture then flows through to the cylinders in preparation for burning. The pilot can vary the airflow using the *throttle lever* in the cockpit. The fuel/air mixture can be varied, if necessary, using the *mixture control*.

Vary the fuel/air mixture with the mixture control.

Combustion can occur in the cylinders when the fuel/air ratio is between approximately 1:8 (*rich mixture*) and 1:20 (*lean mixture*). The ideal or chemically correct mixture of fuel/air is one in which the fuel and the oxygen are perfectly matched so that, after burning, all of the fuel and all of the oxygen have been used. The chemically correct mixture may be referred to as the *ccm* or the *stoichiometric* mixture.

If the mixture is rich, there is *excess* fuel and, after burning, some unburned fuel will remain. If the mixture is lean, there is a *shortage* of fuel in the sense that, after all of the fuel has burned, there will still be some oxygen remaining.

A simple carburetor, like that in figure 8-19, has a venturi through which the amount of airflow is controlled by a *throttle valve* (or *butterfly*). The venturi has fuel jets positioned in it so that the correct amount of fuel by weight is metered into the airflow. The butterfly valve is controlled with the throttle lever in the cockpit.

It is important that you move the throttle smoothly so that unnecessary stress is not placed on the many moving parts in the engine. To open or close the throttle fully should take about the same time as a "1-2-3" count.

A simple float-type carburetor has a small chamber that requires a certain level of fuel. If the level is too low, the float-valve opens and allows more fuel from the fuel tanks to enter. This is happening continually as fuel is drawn from the float chamber into the venturi of the carburetor. The air pressure in the float chamber is atmospheric, while the air pressure near the metering jet is reduced by the venturi effect.

The acceleration of the airflow through the carburetor venturi causes a decreased static pressure (Bernoulli's principle—increased velocity, decreased static pressure). The higher atmospheric pressure in the float chamber forces fuel through the main metering jet into the venturi airflow. The faster the airflow, the greater the differential pressure and the greater the quantity of fuel discharged to the airflow. Therefore the *weight* of fuel that flows through the carburetor is controlled by the airflow through the carburetor venturi.

Accelerator Pump

When you fully open the throttle, the butterfly valve is fully opened and does not restrict the airflow through the venturi. The airflow therefore increases. If the throttle is opened quickly, the airflow initially increases at a rate greater than the fuel flow, producing an insufficient lean mixture. This would cause a lag in the production of power if it were not for the *accelerator pump.* The accelerator pump is therefore used to prevent a weak-cut when the throttle is rapidly opened. The accelerator pump is a small plunger within the float chamber, connected to the throttle linkage so that it gives an extra spurt of fuel as the throttle is opened.

Idling System

When the engine is idling with the butterfly valve almost closed, the pressure differential between the venturi and the float chamber is not great enough to force fuel through the main jet. To allow for this, there is a small *idling jet* with an inlet near the butterfly valve, where a small venturi effect is caused when the valve is almost closed. This provides sufficient fuel to mix with the air to keep the engine idling at low RPM.

Fuel/Air Mixture Control

The *fuel/air ratio* is the ratio between the weight of fuel and the weight of air mixed together and entering the cylinders where the combustion process is to occur. The carburetor is the device used to mix the fuel and the air, and it is designed in its most basic form to function best under mean sea level conditions at standard temperature +15°C (59°F).

Under other conditions when the air density is significantly less, such as at high altitudes or with high temperatures, the basic operation of the carburetor must be modified by the pilot to maintain a suitable fuel/air ratio.

Using the Mixture Control for Climbs and Descents

As altitude is gained in a climb, the volume of air flowing through the carburetor remains the same, but the weight of air is less because of its lower density (fewer molecules in the same volume). The same weight of fuel is drawn into the airstream, however, which means that the fuel/air mixture is now richer with fuel. This may lead to rough running, fouling of the spark plugs, increased fuel consumption, and a loss of power (loss of RPM for a fixed-pitch propeller and loss of manifold pressure for a constant-speed propeller).

A *mixture control* is provided to keep the fuel/air ratio roughly constant. To return to a correct mixture, you can reduce the amount of fuel entering the carburetor venturi by moving the mixture control back out slightly toward lean. This moves a small needle in the carburetor which restricts the fuel flow through the main metering jet, thereby *leaning* the mixture, or making it less rich. The mixture control in the cockpit is usually a red knob. It should be moved smoothly and gradually, to avoid leaning the mixture too far and perhaps even stopping the engine by starving it of fuel. When climbing above approximately 5,000 feet MSL, if rough running is present, the mixture should only be leaned sufficiently to return the engine to smooth running. Normally, an engine is leaned if less than 75 percent power is being used.

Conversely, as an airplane descends the air becomes more dense, and so the weight of air in each charge increases while the weight of fuel remains the same. This causes the fuel/air mixture to become leaner. The correct procedure on descent is to move the mixture control in toward the *RICH* position, which (for a given throttle position) will provide additional fuel to match the increased weight of air. Since most descents are made with low power set from cruise altitude until reaching pattern altitude at the destination airport, it is common practice to move the mixture control to the rich position at the top of descent, or to progressively richen the mixture (if descending from high altitude), so that the mixture control is correctly positioned for the approach and landing phase, when full power should be available in case of a go-around.

The mixture control is usually in *FULL RICH* for takeoff, unless you are operating at a high-elevation airport, possibly with high temperatures, where the air density as a consequence is very low (see below). Usually, the mixture remains in *FULL RICH* for the climb, unless it is an extended climb to altitudes in excess of 5,000 feet MSL.

As you climb with the mixture in *FULL RICH* the resulting excess fuel as the fuel/air mixture gradually becomes richer acts as a cooling agent for the cylinder walls and piston tops to help prevent abnormal combustion. Some of the more sophisticated engines require leaning during the climb, but for training airplanes this is not generally the case.

Using the Mixture Control at Cruise Altitude

On the cruise, and with cruise power set, you should consider leaning the mixture to regain a more chemically correct fuel/air ratio. This ensures more efficient burning of the gases in the cylinders, more efficient operation of the engine (slightly higher RPM for a fixed-pitch propeller) and better fuel economy. In some light airplanes correct leaning on the cruise can reduce the fuel consumption by over 25 percent compared with full rich, allowing greatly improved range and endurance performance.

The mixture should be slightly on the rich side of the chemically correct mixture, provided the cruise power setting is less than 75 percent of maximum continuous power (MCP).

Normal cruise for most airplanes is about 55–65 percent MCP, and so leaning the mixture is advisable.

At high power settings (in excess of 75 percent) a full-rich mixture is necessary to provide excess fuel as a coolant. The Pilot's Operating Handbook contains information on how to achieve the best power mixture and how to achieve the best economy mixture.

To lean the mixture, slowly move the mixture control toward the lean position. As a chemically correct fuel/air ratio is regained, the RPM for a fixed-pitch propeller will increase. Eventually, with further leaning, the RPM will decrease slightly and the engine will show signs of rough running. The mixture control should then be gently pushed back in a small amount to regain the best RPM (indicating a chemically correct mixture) and smoother running. The mixture control is then moved further in to a slightly richer position to ensure that the engine is operating on the rich side of the chemically correct mixture. This must be repeated when either cruise altitude or power-setting is changed.

Some airplanes are equipped with an *exhaust gas temperature* (EGT) *gauge* which indicates peak EGT when there is a chemically correct mixture, and this can assist you in leaning the mixture correctly.

For a constant-speed propeller, the leaning is normally done with reference to a *fuel flow gauge* (to obtain minimum fuel flow for smooth running) or the exhaust gas temperature gauge. Refer to your Pilot's Operating Handbook.

The principles of leaning the mixture apply to both carburetor-equipped and fuel-injected engines (to be discussed shortly).

> **Note.** Above 5,000 feet density altitude, a normally aspirated (not turbocharged) engine *cannot* achieve more than 75 percent maximum continuous power (even at full throttle).

Using the Mixture Control for Takeoff and Landing

During takeoff (and landing, when high power may be required in case of a go-around), the mixture control should normally be in *FULL RICH*.

In conditions where the air density is very low, however, such as at a very high elevation airport with high outside air temperatures (say 6,000 feet MSL and 100°F), you should consider if there is a need to lean the mixture. The reduced air density, sometimes referred to as a *high density altitude*, may result in too little air for the normal fuel flow, and an excessively fuel-rich mixture. When the engine runs too rich it is unable to provide its best power for takeoff.

An excessively rich mixture may be indicated on the ground by slightly rough running that is made worse during the carburetor heat check, when hot and even less-dense air enters the carburetor, starving the engine of air and further richening the fuel/air mixture.

You should discuss leaning the mixture for high density altitude takeoffs with your flight instructor, and refer to the Pilot's Operating Handbook.

Rich and Lean Mixtures

The mixture is usually slightly rich to protect against abnormal combustion and overheating in the cylinders. These damaging events are more likely to occur at power settings above 75 percent maximum continuous power than at the normal cruise power settings (55-65 percent), when leaning is advisable.

An over-rich mixture will cause a loss of power, rough running, high fuel consumption, fouling of the spark plugs and formation of lead deposits (from unburned fuel) on the piston heads and valves. The extra fuel in a rich mixture causes cooling within the cylinders by its evaporation which absorbs some of the heat produced in the combustion chamber. A lean mixture will therefore have higher cylinder head temperatures.

An excessively lean mixture will cause excessively high cylinder head temperatures, leading to abnormal combustion (detonation). The pilot is then faced with a loss of power and quite possibly complete engine failure. If you suspect that conditions are conducive to detonation, richen the mixture and check engine temperatures. A high cylinder head temperature could be an indication of detonation. Too rich is preferable to too lean.

Too rich a mixture is preferable to too lean a mixture.

Idle Cut-Off (or Idle Cut-Out)

The *idle cut-off* position of the mixture control is the normal means of shutting the engine down. In a typical system, when the mixture control is moved fully out to the idle cut-off position by the pilot, a small needle moves to cut off the fuel flow between the float chamber and the venturi. The supply of fuel to the fuel jets is then cut off.

The engine will continue running until all of the fuel/air mixture in the inlet manifold and the cylinders is burned. This leaves no combustible fuel/air mixture anywhere in the system, which would not be the case if the engine was stopped simply by turning the ignition *OFF*.

Abnormal Combustion

There are two kinds of abnormal combustion and both should be avoided:

- detonation — explosive combustion; and
- preignition — early ignition ahead of the spark.

Detonation

Correct progressive burning of the fuel/air mixture should occur as the flame-front advances through the combustion chamber. This causes an increase in pressure which smoothly forces the piston down the cylinder in the power stroke.

Detonation is the instantaneous, explosive combustion of the unburned charge in the cylinder.

When a gas is compressed, it experiences a rise in temperature. You can feel this if you hold your hand over a bicycle pump outlet during the compression stroke. If the pressure and the temperature rise is too great for the fuel/air mixture in the cylinders, the burning will not be progressive, but explosive, spontaneous combustion of the unburned charge after normal spark ignition.

This explosive increase in pressure is called *detonation* and can cause severe damage to the pistons, valves and spark plugs, as well as causing a decrease in power and quite possibly complete engine failure. Detonation cannot normally be detected by a pilot, although an indication of excessively high cylinder head temperature is a warning that conditions conducive to detonation may exist.

Detonation can be caused by:

- a lower fuel grade than recommended;
- a time-expired fuel;
- an over-lean mixture;
- excessive manifold pressure;
- an over-heated engine; or
- excessive temperature of the air which is passing through the carburetor.

If detonation conditions are expected, for instance by an excessively high cylinder head temperature:

- richen the mixture;
- reduce pressures in the cylinders (throttle back); or
- increase airspeed to assist in reducing cylinder head temperatures.

Preignition

Preignition, while involving a progressive combustion of the fuel/air mixture, is an ignition that commences before the spark from the plug. This early ignition (or preignition) can be caused by a hot-spot in the cylinder (from a carbon or lead deposit) becoming red-hot and igniting the mixture before the spark plug fires, causing peak pressures in the cylinder at the wrong point in the cycle. The results of preignition are:

Preignition is the uncontrolled firing of the fuel/air charge before the spark ignition.

- rough running;
- possibly back-firing;
- a sudden rise in the cylinder head temperature;
- possible engine damage such as a burnt piston, broken cylinder head, scuffed cylinder wall, and damage to valves and spark plugs; and
- cross-firing ignition leads or bad magneto distribution.

Preignition can be caused by:

- carbon or lead deposits in the cylinder;
- using high power when the mixture is too lean (no extra fuel for cooling); or
- overheated or wrong heat range spark plugs (possibly as a result of detonation).

Preignition may occur in one cylinder only, where a hot-spot exists, whereas detonation will normally occur in all cylinders. Preignition is a function of the condition of a particular cylinder or cylinders (such as a hot spot) whereas detonation is a function of the fuel/air mixture that is being supplied to all cylinders (too lean and/or too hot).

Both detonation and preignition can be prevented, provided the correct fuel is used, good magneto maintenance and inspection, and the operating limitations of the engine are observed. This information is available to you in the Pilot's Operating Handbook.

Carburetor Ice

The expansion of the air as it accelerates through the carburetor venturi causes it to drop in temperature. Even quite warm air can cool to below zero and, if it contains moisture, ice can form. This will seriously degrade the functioning of the carburetor, even to the point of stopping the engine! The first sign of carburetor ice in an airplane equipped with a fixed-pitch propeller is a loss of RPM.

Fuel-injected engines do not have a carburetor and are less susceptible to ice.

Impact Ice

Impact ice will occur when water droplets, which are below freezing point (in the intake air), contact the metal surfaces of the inlet air scoop and duct to the carburetor, immediately forming ice. (This can happen even in a fuel-injected system as well as in a normal carburetor system.)

Impact ice can occur when the outside air temperature is near or below zero, or if the inlet surfaces themselves are below zero and the airplane is in visible moisture such as cloud, rain or sleet. This may be the case if the airplane is on descent from high altitudes, where the temperature is below the freezing level, into areas of visible moisture.

Fuel Ice

When fuel is introduced into the carburetor airstream, the temperature of the resulting fuel/air mixture is lowered substantially because of the latent heat absorption that occurs during fuel vaporization. You can feel this effect when water or perspiration evaporates off your skin on a hot day.

Fuel ice will form downstream of the metering jet in the throat of the carburetor if the temperature of the fuel/air mixture drops to between 0°C to -8°C (32°F to 16°F). The water will precipitate from the incoming air (if it is moist) and freeze onto any surface it encounters, such as the inlet manifold walls and the throttle butterfly valve. This ice will seriously restrict the airflow and thus reduce the engine's power output.

Fuel ice can occur in ambient air temperatures well above freezing, even as high as 30°C (85°F) when the relative humidity exceeds about 50 percent.

Note. Fuel ice is sometimes called refrigeration ice since it is caused by the vaporizing of a liquid—the same process that is used in most refrigerators.

Throttle Ice

As the fuel/air mixture accelerates past the throttle valve, there is a decrease in static pressure and a consequent drop in temperature. This process can cause ice to form on the throttle valve. The acceleration and resulting temperature drop is greatest at small throttle openings because the throttle butterfly restricts the airflow at these low power settings, creating a substantial pressure drop. Therefore, there is a greater likelihood of carburetor ice at low throttle settings.

Formation of Carburetor Ice

Carburetor ice is most likely when the temperature is between 10°C to +20°C (20°F to 70°F) and the relative humidity is high.

Both fuel ice and throttle ice can occur even when the *outside* air temperature is high. Any time the outside air temperature is within the approximate range (20°F to 70°F) and especially if the relative humidity is high, you should remain alert for signs of carburetor ice, caused by cooling in the carburetor venturi.

Note. Visible moisture is not necessary for the formation of throttle ice.

All of this carburetor ice can have a very serious effect on the running of the engine. The size and shape of the carburetor passages are altered by the ice, the airflow is disturbed, and the fuel/air mixture ratio is affected. These factors all lead to rough running, a loss of power and possibly a total stoppage of the engine unless prompt corrective action is taken.

Typical symptoms of carburetor ice formation are:

- a power loss (a drop in RPM for a fixed-pitch propeller, and a drop in manifold pressure for a constant-speed propeller), resulting in poorer performance (a loss of airspeed or a poorer rate of climb); and
- rough running.

Carburetor Heat

Most modern airplanes have a carburetor heat system to prevent and remove carburetor ice. This usually involves heating the induction air prior to intake into the carburetor by passing the air close to the (hot) exhaust system of the engine. The density of this *heated air* passing through the carburetor will be less, therefore making the fuel/air mixture too rich. The initial effect of applying carburetor heat will be to decrease the power from the engine (seen as an initial drop in RPM for a fixed-pitch propeller or an initial drop in manifold pressure for a constant-speed propeller), possibly by as much as 10–20 percent.

The *carburetor heat control* is usually located near the throttle in the cockpit. By pulling it fully out, heated air is passed into the carburetor. It is usual, if carburetor ice is suspected, to apply full carburetor heat. As the hot air passes through the carburetor venturi, it will melt the ice. If there has been a large ice build-up in the carburetor, the engine may run extremely roughly, especially as the melted ice (now water) passes through the cylinders along with the fuel/air mixture, but this roughness will quickly disappear.

When the ice clears from the carburetor, the engine will begin running smoother and there will be an increase in power. The RPM of a fixed-pitch propeller will rise as the ice clears, as will the manifold pressure of a constant-speed propeller. Following this, carburetor heat may be removed and cold air again used, at which time there will be a further slight increase in power.

If carburetor ice re-forms, then this operation will have to be repeated. Full carburetor heat must be re-applied until the carburetor ice melts. You may find that, under some conditions, full carburetor heat is required not only to remove carburetor ice, but also to prevent it from re-forming.

Some engines have a *carburetor air temperature gauge*, which may be used to keep the carburetor air temperature out of the icing range. It may allow you to use only partial carburetor heat to prevent further formation of ice once the initial ice has been removed with full carburetor heat. If carburetor ice still forms, immediately re-apply full carburetor heat to remove it, and then try a higher setting of partial heat to prevent its formation.

Caution. Partial use of carburetor heat may raise the temperature of the induction air into the temperature range which is most conducive to the formation of carburetor ice, thereby increasing the risk of ice build-up rather than decreasing it. Monitor the engine power gauges and be alert for any rough running.

On descent with low power, particularly in high humidity, it is usual to apply carburetor heat to ensure that no carburetor ice forms or is present. The small throttle butterfly openings needed for low power increase the chance of carburetor ice forming.

On short final approach to land, the carburetor heat is usually returned to *COLD,* just in case full power is required in the event of a go-around.

Avoid using carburetor heat on the ground because the hot air is taken from around the engine exhaust manifold (in most airplanes) and, unlike the normal inlet air, is unfiltered. This will avoid introducing dust and grit into the carburetor and the engine itself, which could lead to unnecessary wear and damage.

Fuel Injection Systems

Many sophisticated engines have fuel directly metered into the induction manifold and then into the cylinders without using a carburetor. This is known as *fuel injection.*

A venturi system is still used to create the pressure differential. This is coupled to a *fuel control unit* (FCU), from which metered fuel is piped to the *fuel manifold unit* (fuel distributor). From here, a separate fuel line carries fuel to the *discharge nozzle* in each cylinder head, or into the inlet port prior to the inlet valve. The mixture control in the fuel injection system controls the idle cut-off.

With fuel injection, each individual cylinder is provided with a correct mixture by its own separate fuel line. (This is unlike the carburetor system, which supplies the same fuel/air mixture to all cylinders. This requires a slightly richer-than-ideal mixture to ensure that the leanest-running cylinder does not run too lean.)

The advantages of fuel injection include:

- freedom from fuel ice (no suitable place for it to form);
- more uniform delivery of the fuel/air mixture to each cylinder;
- improved control of fuel/air ratio;
- fewer maintenance problems;
- instant acceleration of the engine after idling with no tendency for it to stall; and
- increased engine efficiency.

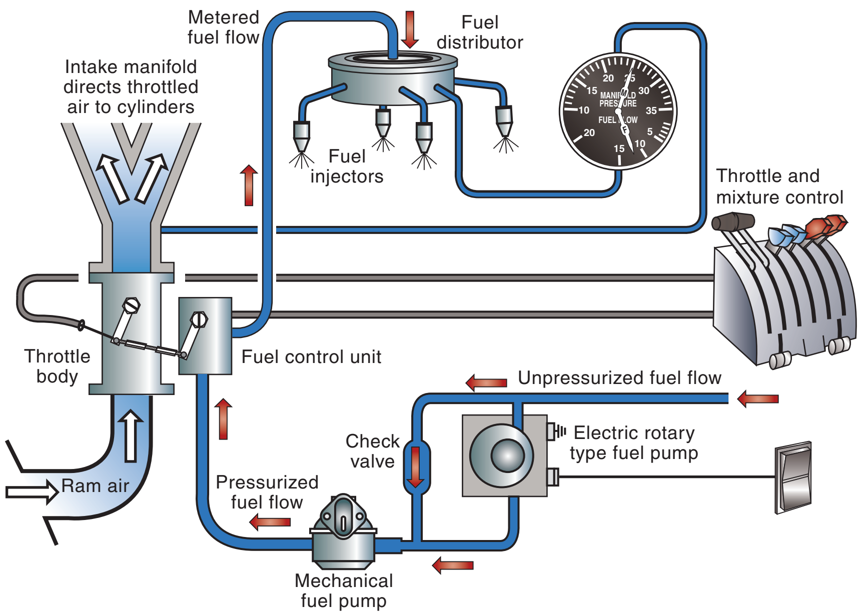


Figure 8-20 Typical fuel injection system

Correct fuel management is imperative! Know the fuel system of your airplane!

Starting an already hot engine that has a fuel injection system may be difficult because of vapor locking in the fuel lines. Electric boost pumps that pressurize the fuel lines can help alleviate this problem. Having very fine fuel lines, fuel injection engines are more susceptible to any contamination in the fuel such as dirt or water. Correct fuel management is imperative! Know the fuel system of your particular airplane. Surplus fuel provided by a fuel injection system will pass through a *return line* which may be routed to only one of the fuel tanks. If the pilot does not remain aware of where the surplus fuel is being returned to, it may result in uneven fuel loading in the tanks or fuel being vented overboard (thus reducing flight fuel available).

Engine Operation

Starting the Engine

Ensure that adequate *safety precautions* are always taken prior to engine start:

- prior to start, position the aircraft so that it is clear of obstructions, other aircraft, open hangar/workshop doors, and fueling installations;
- set the parking brakes on, or chock the mainwheels, to avoid the embarrassing and dangerous situation of the airplane commencing its own taxiing. Chocking the nosewheel is *not* advisable because of its proximity to the propeller and the consequent risk to a person walking into the rotating propeller when removing a nosewheel chock;
- be aware of the location of firefighting equipment—just in case of fire. Ensure no open flames, cigarettes or fuel spillages in the vicinity; and
- most importantly *check* the immediate area is clear of people and then *warn* any nearby persons (especially those you may not be able to see) of the impending danger of a spinning propeller by making a loud warning call of *"clear!"* or *"clear prop!"* The aircraft red rotating beacon should be turned on just prior to starting the engine. Be prepared to discontinue the start immediately if a problem develops or if someone approaches the danger area near the propeller.

Figure 8-21
Check propeller is clean.

Your first action after starting the engine should be to adjust for proper RPM and check for the desired indications on the engine gauges, especially the oil pressure gauge which should show an increase within 30 seconds.

If it is necessary to handprop an airplane engine (an extremely hazardous procedure) it is important that a competent pilot be at the airplane controls and that the person turning the propeller has sufficient training.

Figure 8-22
RPM and MAP gauges.

Starting a Cold Engine

Starting in cold conditions usually requires some *priming* (providing an initial charge of fuel to the cylinders). Many aircraft have a priming pump (electrical or manual) in the cockpit for this purpose—it is used only prior to startup, and should be locked at all other times.

Know the procedures recommended in your Pilot's Operating Handbook. These differ from airplane-to-airplane, engine-to-engine and situation-to-situation. You should understand the reasons why a certain procedure is recommended and when it is appropriate to vary it slightly. An over-primed (flooded) engine or restarting a hot engine, for example, will require different techniques to starting a cold engine in a cold climate.

Figure 8-23
Starting.

> **Note.** On start-up of a cold engine, the oil pressure should normally rise within 30 seconds, to ensure adequate lubrication of the engine and its moving parts. If the oil pressure rise is not indicated within this time, shut down the engine to avoid possible damage. If the engine is warm, the oil pressure should rise more quickly. In cold climates, it is normal for the oil pressure rise to take up to 60 seconds—*see* your Pilot's Operating Handbook.

Starting an Engine That Has Been Over-Primed

Most over-primed engines will start more easily with the mixture control in *idle cut-off* so that no more fuel enters the cylinders until the engine has actually started. When the mixture in the cylinders reaches the right balance as air-only is drawn in, the engine should fire, at which stage the mixture control should be moved quickly to *full rich* to provide a continuing fuel supply.

If the engine does *not* fire, the rotations may have cleared the cylinders of fuel. Therefore move the mixture control to rich to allow fresh fuel to be drawn into the cylinders. This technique applies to both carbureted and fuel-injected engines. Refer to your Pilot's Operating Handbook.

Starting a Hot Engine

Usually a hot carbureted engine will start satisfactorily using the normal procedure for a cold engine if you do not prime it or pump the throttle.

When starting a hot fuel-injected engine, the hot air and vapor in the very narrow fuel lines may cause a vapor lock and prevent the flow of any fuel. To prevent this, switch on the fuel boost pumps. This will pressurize the fuel lines up to the fuel control unit, removing any vapor in that part of the system. Leave the mixture control in *idle cut-off* so that fuel does not reach the cylinders but is recycled back into the tank.

Some engines require the throttle to be opened for the boost pumps to work in *high*. After 15 to 20 seconds, the narrow fuel lines to the fuel injectors should have been purged of vapor and be full of fuel. Because a small amount of fuel will probably have found its way into the fuel nozzles near the cylinders, a start can be made without priming (with throttle at idle or open about ½ inch).

Stopping the Engine

A brief *cooling period* at 1,000 RPM is usually recommended to allow gradual cooling. During this time check for any abnormal indications and perform a systems check of the ignition system for *off.*

Most engines are shut down from a low power position (usually 1,000 RPM) by moving the mixture control to *idle cut-off,* thus allowing the cylinders to be purged of fuel. All switches are usually moved to *off.*

It is a good practice to:

- leave the mixture control in the idle cut-off position; and
- leave the throttle in the closed position in case someone turns the propeller and firing occurs because the magneto system is still *live.*

Changing Power Settings with a Constant-Speed Propeller

Change RPM with the propeller control. Change MP with the throttle. Never exceed the recommended manifold pressure.

While almost all training airplanes have a *fixed-pitch propeller* whose RPM is controlled with the throttle, more advanced airplanes which you may soon fly are equipped with a *constant-speed propeller* with blades that can vary their pitch angle.

The controls in the cockpit for a constant-speed propeller are:

- the *propeller control* (or pitch knob) to control *RPM*; and
- the *throttle* to control fuel flow and *manifold pressure (MP).*

The pilot selects the desired RPM of the engine and propeller using the *propeller control* (also known as the *pitch control* or *RPM control*). The propeller blades will then automatically change their pitch angle or blade angle to absorb the power available and maintain the selected RPM. For instance, if you have selected a cruise RPM of

2,400 with the propeller control and then move the throttle to increase manifold pressure from 22 to 23 in. Hg, the propeller pitch will increase to absorb the extra power by increasing the blade angle and providing increased thrust.

Conversely, if power is reduced, the propeller blade angle will reduce to maintain RPM. The constant-speed unit in the propeller operates automatically—usually the blade movement to a new pitch angle is hydraulically operated by a governor sensitive to RPM.

There is a mechanical limit to how far the propeller pitch or blade angle can reduce, known as the *low-pitch stop*. With the blades back on the low-pitch stop, the propeller will behave like a fixed-pitch propeller.

The pilot selects the desired power with various combinations of RPM and manifold pressure. *Manifold pressure* is the pressure in the intake manifold of the engine, and is normally measured in inches of mercury (in. Hg). Manifold pressures higher than those recommended by the manufacturer can lead to high cylinder pressures and possibly detonation, and must be avoided. This can occur if high manifold pressures are set at low RPM.

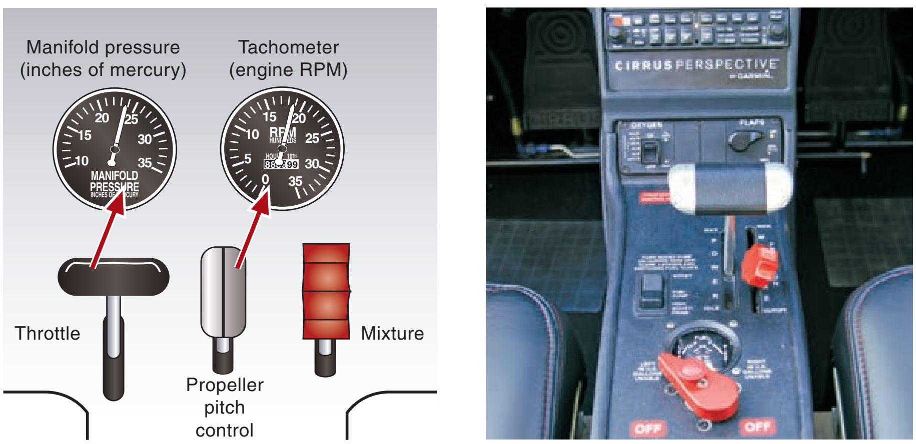


Figure 8-24
With a constant-speed propeller, the propeller control controls RPM and the throttle determines the manifold pressure. Some newer constant speed propeller systems employ a single power lever that combines the function of a prop and throttle control.

Increasing Power

To avoid high MP and low RPM:

- *first increase RPM* with the propeller control. The MP will drop automatically as a result of less time per cycle being available for the fuel/air mixture to be induced into the cylinder, hence a smaller charge in the cylinder for combustion; and
- *then increase MP* to desired value with the throttle.

When increasing power increase RPM before MP.

Decreasing Power

To avoid high MP and low RPM:

- *first reduce MP* with the throttle; and
- *then reduce RPM* with the propeller control. The MP will rise a little automatically—as a result of more time for cycle for the fuel/air mixture to be induced into the cylinder, hence a larger charge in the cylinder for combustion. After the reduction of RPM, some minor readjustment of MP will be necessary.

When decreasing power reduce MP before RPM.

Air pressure falls by about 1 in. Hg per 1,000 feet as altitude is gained, and so will the manifold pressure in an unsupercharged engine if you do not adjust it with the throttle. In this situation the RPM would remain the same, but the power would reduce gradually. Superchargers and turbochargers are used in more sophisticated engines to boost the air pressure to the engine, thereby increasing the power available at altitude.

Note. The propeller governor that controls RPM is operated by engine oil, which is another very good reason for regular oil changes. Dirty oil could have an adverse effect on propeller operation.

Engine Handling

At all times, follow recommended procedures found in the manufacturer's handbook. This will ensure correct operation of the engine, avoid spark plug fouling and overstressing the engine components, and achieve best fuel economy. Know the manufacturer's engine limitations and do not exceed them.

When the engine is operating, you should monitor the *oil temperature gauge* (and the *cylinder-head temperature gauge* if installed). An abnormally high engine oil temperature could indicate insufficient oil in the engine. High engine temperatures, either in the air or on the ground, will cause:

- loss of power;
- excessive oil consumption; and
- possible permanent internal engine damage.

In flight, you could consider cooling the engine by opening the air-cooling cowl flaps (if installed), richening the mixture, reducing power, or lowering the nose and increasing airspeed.

Avoid running the engine *on the ground* for prolonged periods if possible but, if unavoidable, face the aircraft into wind for better cooling and, if they are installed, open the cowl flaps. If the limiting red-line temperatures are approached during ground operations, consider taxiing clear of the runway and shutting the engine down to allow cooling.

Prevent *spark-plug fouling* by avoiding operating the engine at very low RPM for long periods. At low idling RPM, deposits can form on the spark plugs which will increase their electrical conductivity and may lead to misfiring.

Advance and retard the throttle smoothly.

Misuse of controls can lead to de-tuning of engine crankshaft counterweights and engine damage. Opening the throttle by ramming it forward can produce an incorrect fuel/air mixture in the carburetor and cause the engine to cut-out, or encourage detonation. Rough handling of the throttle can also cause de-tuning of the crankshaft counterweights, which will permanently reduce the efficiency of the engine as a power-producer. As a guide you should take about three seconds to open the throttle from idle to full. Similarly when reducing power, do so slowly.

On a prolonged descent at low power, it is good airmanship to smoothly open the throttle for brief periods to avoid the engine becoming too cool. Closing cowl flaps, if installed, also helps. This will avoid a sudden temperature shock to the engine when it is returned to high power at the end of the descent.

Use the mixture control correctly. A too-lean mixture at high power and low altitudes can cause detonation. It is usual to lean the mixture when cruising at altitude, depending on the manufacturer's recommendations. On a very hot day, even at only 1,000 feet MSL the atmosphere may have a density altitude of several thousand feet, and leaning may be required for efficient operation.

Rough Running

The Engine

Figure 8-25
Engine checks.

Engine rough running can be continuous or intermittent. If the engine starts running roughly, immediately refer to the engine instruments to see if they indicate the cause. In all cases, follow the procedures laid down in the Pilot's Operating Handbook. A thorough knowledge of these is essential.

Rough running can be caused by:

- *an inadequate fuel supply*—check the fuel quantity gauge and if it indicates empty immediately select another tank. If the gauges show sufficient fuel suspect low fuel pressure caused by a blocked filter and switch on the fuel boost pumps to ensure a steady fuel pressure;
- *carburetor ice*—the formation of ice in the carburetor causes a loss of power and possibly rough running. Remember that carburetor ice can form when the outside air temperature is as high as 70°F if the humidity is high enough;
- *an incorrect mixture*—if the mixture is not leaned correctly, a prolonged climb will gradually lead to a richening of the mixture as the air density falls, with consequent rough running. A prolonged descent will require the pilot to move the mixture control towards the rich position;
- *a faulty magneto*—if you suspect a faulty magneto is causing the engine to run roughly, select a low cruise power, and then check each magneto individually by switching the other one off. If the engine runs smoothly on one particular magneto, but roughly on both or on the other magneto, then select the single magneto system that gives smoother running. Consideration should be given to landing at the nearest suitable airport, the airplane engine will still operate satisfactorily on only one ignition system, but a failure of the second magneto would leave you with none; or
- *a faulty ignition system*—fouling of the spark plugs can cause faulty ignition. Sometimes this can be cured by leaning the mixture to raise the temperature and perhaps burn the residue off the plug, or by changing the power setting. Leakage of the *ignition current,* which can sometimes occur around the ignition leads could be the cause, however this cannot be remedied in flight. This leakage may be worse at high altitude/high power settings and in wet weather.

The Propeller

An out-of-balance propeller can cause vibration.

Vibration or rough running usually indicates a problem or impending problem. An out-of-balance propeller can cause vibration.

If the vibration is caused by a damaged propeller, possibly an out-of-balance propeller due to nicks, then a change of RPM or a change of airspeed should reduce the vibration. This, of course, is only a temporary remedy and the nicks should be repaired on landing. Nicks in the propeller blade degrade its performance considerably and are liable to cause cracks which can ultimately lead to blade failure in flight, with disastrous results. Propeller nicks and other damage should be brought immediately to the attention of a maintenance technician.

If the vibration does not diminish, but worsens, it could indicate that the bolts attaching the propeller to the shaft are loosening. In this case, shutting down the engine is advisable. If you suspect this defect in a single-engine airplane, a landing as soon as possible (a forced landing, if necessary) should be contemplated. Ice on the propeller blades may also cause vibration.

Cross-Checking Engine Instruments

If one engine instrument indicates a problem, verify this, if possible, by checking against another instrument. For instance, an oil pressure gauge that suddenly shows zero could indicate that all the oil has been lost out of the system, or it could be just a faulty gauge. Cross-reference to the oil temperature gauge should establish the fault. A normal oil temperature would indicate sufficient oil is still circulating, whereas a rapidly increasing oil temperature would indicate that loss of oil has occurred.

If you are in flight, a serious loss of oil will mean an engine shutdown, so in a single-engine airplane you should prepare to land as soon as possible. With a faulty gauge, the engine will continue to operate normally.

Taxiing

Do not taxi over rough ground because the propeller could hit long grass, obstructions or the ground, damaging the propeller and possibly bending the engine crankshaft, a very costly lack of common sense.

Avoid engine runups or taxiing on stony or gravel surfaces where possible. The strong airflow and vortices around a propeller pick up stones, damaging the propeller and airframe and hitting other aircraft and people. Good airmanship involves looking after your airplane and thinking of others.

Emergencies

Engine Failure in Flight

Due to improved manufacturing and operating procedures, mechanical engine failure is becoming a rare event, but *fuel starvation* as a cause of engine stoppage is not as uncommon as it should be. Fuel starvation will of course stop an engine and can be caused by:

- insufficient fuel;
- mishandling of the fuel tank selection;
- incorrect use of the mixture control;
- ice forming in the carburetor; or
- contaminated fuel (such as water in the fuel).

If the *mixture control* is left in *lean* for descent (instead of being moved to *rich*), the fuel/air mixture will gradually become more and more lean as the airplane descends into denser air, possibly resulting in the engine stopping. *Carburetor ice* can also be a problem, especially on descent when the engine is idling and not producing much heat. *Electrical failure* in both magneto systems will also cause the engine to stop.

In all these cases, the airflow past the airplane may cause the propeller to windmill and turn the engine over, even though it is not producing power.

Mechanical failure, such as the break-up of pistons or valves, will probably be accompanied by mechanical noise and the engine and propeller may be unable to rotate. In such cases any attempt to restart the engine is not advisable.

Irrespective of whether you decide to glide down for a landing or attempt to restart the engine, you must ensure that flying speed is maintained.

Some obvious items to be considered in an attempted engine restart are:

- a fuel problem:
  - change fuel tanks;
  - fuel pump on (if installed);
  - mixture *rich*;
  - primer locked;
- an ignition problem:
  - check magneto switches individually *(both-left-right).* If the engine operates on one magneto as a result of a fault in the other magneto system, then operate using the one good ignition system, otherwise return to *both*; or
- an icing problem:
  - carburetor heat *full hot.*

Engine Fire In Flight

Engine fire is also a rare event, but you should always be prepared to cope with it. The firewall at the back of the engine is designed to protect the structural parts of the airframe from damage and the cockpit occupants from injury if a fire breaks out in the engine bay, provided the fire is extinguished without delay.

To check for the presence of fire, the pilot should yaw the nose left and look rearward and to the left for any trailing smoke.

The initial reaction to an engine fire in flight should be as per the Pilot's Operating Handbook. This usually involves turning off the fuel (fuel selector *off* or mixture control to *idle cut-off)* and allowing the engine to run itself dry of fuel and stop. The engine and induction system will then be purged of fuel and the fire should extinguish. At this point, the ignition should be switched off and a forced landing carried out.

Throughout any emergency procedure in flight, remember that your main task is to *fly the airplane* (maintain flying speed and avoid collisions)—and the secondary task is to resolve the emergency.

Engine Fire on Startup

If a fire starts in the engine air intake during startup, a generally accepted procedure to minimize the problem is:

- *continue cranking* the engine with the starter (to keep air moving through);
- move the mixture control to *idle cut-off* (to remove the source of fuel); and
- *open the throttle* (to maximize the airflow through the carburetor and induction system, and purge the system of fuel).

The fire will probably go out, but if it does not, then further action would be taken:

- fuel—*off*;
- switches—*off*;
- brakes—*off*; and
- evacuate the airplane, taking the fire extinguisher.

You should refer to the Pilot's Operating Handbook for the correct procedure for your particular airplane.

Review 8

Engine

The Engine

1. Name the four strokes of a piston engine commencing with the stroke intake.
2. Is the intake valve open during most of the compression stroke?
3. Is the exhaust valve open during most of the compression stroke?
4. Is the intake valve open during most of the exhaust stroke?
5. Is the exhaust valve open during most of the exhaust stroke?
6. What is the period when both intake and exhaust valves are open simultaneously known as?
7. How is the fuel/air mixture ignited in the cylinder?
8. If one of the magneto switches is turned to OFF, should there be an engine RPM drop?
9. True or false? Switching the ignition OFF connects the magneto systems to ground.
10. If a magneto ground wire comes loose in flight, will the engine stop?
11. The spark plugs in a piston engine are provided with a high energy (or high tension) electrical supply from:
    a. the battery at all times.
    b. the magnetos.
    c. the battery at start-up, then the magnetos.
12. What is the most probable reason an engine continues to run after the ignition switch has been turned off?
13. If the ground wire between the magneto and the ignition switch becomes disconnected, the engine:
    a. will not operate on one magneto.
    b. cannot be started with the switch in the BOTH position.
    c. could accidentally start if the propeller is moved with fuel in the cylinder.
14. Because of the very low revs as you start the engine, the spark needs to be delayed. How is this done automatically in some magnetos?

Carburetor and Fuel Injection

15. Describe the principle of a simple carburetor.
16. What is the fuel/air ratio?
17. How does the pilot control the fuel/air ratio?
18. What remains following combustion of a rich mixture?
19. What remains following combustion of a lean mixture?
20. What carburetor device ensures that sufficient fuel is fed to the cylinders when idling at low RPM?
21. What is meant by the term best-power mixture?
22. As air density decreases, the weight of fuel introduced into the cylinder needs to be reduced to match the decreased weight of air. How is this done?
23. What can an over-rich mixture cause?
24. For takeoff at a sea level airport on a cool day, the mixture control should normally be:
    a. full rich.
    b. lean.
    c. in idle cut-off.
25. True or false? The extra fuel in a rich mixture causes extra heating in the cylinders by its evaporation.
26. If no leaning is made with the mixture control as the flight altitude increases:
    a. the volume of air entering the carburetor decreases and the amount of fuel decreases.
    b. the density of air entering the carburetor decreases and the amount of fuel increases.
    c. the density of air entering the carburetor decreases and the amount of fuel remains constant.
27. The correct procedure to achieve the best fuel/air mixture when cruising at altitude is to move the mixture control toward LEAN until the engine RPM:
    a. drops to a minimum value.
    b. reaches a peak value.
    c. passes through a peak value at which point the mixture control is returned to a slightly richer position.

28. If a pilot suspects that the engine (with a fixed-pitch propeller) is detonating during climb-out after takeoff, the initial corrective action to take would be to:
    a. lean the mixture.
    b. lower the nose slightly to increase airspeed.
    c. apply carburetor heat.
29. What are hot-spots in a combustion chamber likely to cause?
30. How is carburetor ice formed?
31. What is the remedy for suspected carburetor ice?
32. What is one of the first indications of carburetor ice forming in an airplane equipped with a fixed-pitch propeller?
33. Hotter air entering the engine after carburetor heat is applied will be less dense, which means that less air by weight for the same weight of fuel enters the cylinders. Will applying carburetor heat therefore result in a richer mixture?
34. What is the effect of leaving the carburetor heat on while taking off?
35. Does the principle of leaning the mixture by reducing the fuel flow to match the lower density air as altitude is gained apply to fuel-injected engines?
36. True or false? The the pressure drop (and consequent temperature drop) near the throttle butterfly is greatest at small throttle openings, causing a greater likelihood of carburetor ice forming.
37. The presence of carburetor ice in an aircraft equipped with a fixed-pitch propeller can be verified by applying carburetor heat and:
    a. noting an increase in RPM, then a gradual decrease in RPM.
    b. noting a decrease in RPM, then a constant RPM indication.
    c. noting a decrease in RPM, then a gradual increase in RPM.
38. While cruising at 9,500 feet MSL, the fuel/air mixture is properly adjusted. What will occur if a descent to 4,500 feet MSL is made without readjusting the mixture?
39. What is detonation?
40. How is detonation caused?
41. What is the uncontrolled firing of the fuel/air charge in advance of normal spark ignition known as?
42. Which condition is most favorable to the development of carburetor icing?
    a. Any temperature below freezing and a relative humidity of less than 50 percent.
    b. Between 32°F and 50°F and low humidity.
    c. Between 20°F and 70°F and high humidity.
43. Why would you normally avoid using carburetor heat during ground operations?
44. With regard to carburetor ice, float-type carburetor systems in comparison to fuel injection systems are generally considered to be:
    a. more susceptible to icing.
    b. equally susceptible to icing.
    c. susceptible to icing only when visible moisture is present.

The Oil System

45. What is the function of oil?
46. True or false? Oil grades may be mixed.
47. How are impurities in the oil removed?
48. What might you observe with too little oil?
49. If the oil filter becomes blocked, what happens to the unfiltered oil?
50. True or false? Dirty and contaminated oil is better than no oil at all.

The Cooling System

51. What is the function of cooling fins?
52. For internal cooling, reciprocating aircraft engines are especially dependent on:
    a. a properly functioning thermostat.
    b. air flowing over the exhaust manifold.
    c. the circulation of lubricating oil.
53. What action can a pilot take to aid in cooling an engine that is overheating during a climb?
54. Excessively high engine temperatures will:
    a. cause damage to heat-conducting hoses and warping of the cylinder cooling fins.
    b. cause loss of power, excessive oil consumption, and possible permanent internal engine damage.
    c. not appreciably affect an aircraft engine.

Engine Operation

55. When is the engine fuel primer used?

56. What should the pilot monitor when an engine is started up?

57. If the engine is cold prior to start-up, it should be shut down if the oil pressure does not rise within how many seconds after start-up?

58. Prior to takeoff, should you check each of the two ignition systems with a magneto check?

59. How is power indicated:
- **a.** for a fixed-pitch propeller?
- **b.** for an engine equipped with a constant-speed propeller?

60. True or false? A fixed-pitch propeller achieve its best efficiency at only one airspeed and RPM.

61. True or false? A constant-speed propeller, with cruise RPM selected, automatically adjusts its blade angle to absorb the power available.

62. How should you increase power with a constant-speed propeller?

63. How should you decrease power with a constant-speed propeller?

64. For an engine equipped with a constant-speed propeller:
- **a.** what is fuel flow and consequently power output controlled by?
- **b.** what is the power output registered on?

65. In an airplane with a constant-speed propeller, which of the following procedures should be used?
- **a.** When power is decreased, reduce RPM before manifold pressure.
- **b.** When power is increased, increase RPM before manifold pressure.
- **c.** When power is increased or decreased adjust manifold pressure before RPM.

66. As altitude is gained when climbing in an airplane equipped with a constant-speed propeller:
- **a.** what will happen to the RPM?
- **b.** what will happen to the manifold pressure unless you adjust the throttle?

67. True or false? If you are cruising at 8,000 feet MSL, you will achieve better fuel efficiency by leaning the mixture.

68. When operating a constant-speed propeller:
- **a.** avoid high RPM setting with high manifold pressures.
- **b.** avoid low RPM settings with high manifold pressures.
- **c.** always use a rich mixture with high RPM settings.

69. A de-tuning of engine crankshaft counterweights is a source of overstress that may be caused by:
- **a.** rapid opening and closing of the throttle.
- **b.** carburetor ice forming on the throttle valve.
- **c.** operating with an excessively rich fuel/air mixture.

70. What does "leaning the mixture" mean?

71. The usual method of shutting an engine down is to:
- **a.** switch the magnetos off.
- **b.** move the mixture to idle cut-off.
- **c.** switch the master switch off.

72. Explain your answer to question 71 and state why the other alternatives are incorrect.

73. If the oil quantity gauge suddenly drops to zero in flight, which gauge should you check immediately?

74. The oil temperature gauge shows a rapid increase in temperature.
- **a.** What should you suspect?
- **b.** What actions should you consider?

75. If the oil temperature gauge and the cylinder head temperature gauge are both reading higher than their normal operating range, a possible cause is:
- **a.** an over-rich mixture and too much power.
- **b.** a too-lean mixture and too much power.
- **c.** fuel with a higher-than-specified fuel rating.

Answers are given on page 769.

Systems 9

The Fuel System

The function of a fuel system is to store fuel and deliver it to the carburetor (or fuel injection system) in adequate quantities at the proper pressures. It should provide a continuous flow of fuel under positive pressure for all normal flight conditions, including:

- changes of altitude;
- changes of attitude; and/or
- sudden throttle movements and power changes.

Fuel is stored in *fuel tanks*, which are usually installed in the wing. A sump and a drain point at the lowest point of the tank allows heavy impurities (such as water or sediment) to gather, be inspected and drained off. The tanks often contain *baffles* to prevent the fuel surging about in flight—especially during large attitude changes or uncoordinated maneuvers, or in turbulence.

The fuel supply line (tube) inlet is higher than the sump to prevent impurities (water or sludge) from entering the fuel lines to the carburetor, even though there is a *fuel filter* in the line to remove any small impurities from the fuel as it passes down the supply line. Because the fuel enters the supply line through a standpipe at the bottom of the tank, there will always be some *unusable fuel* in the tanks.

The top of the fuel tank is vented to the atmosphere so that the air pressure above the fuel in the tank remains the same as outside as altitude is changed. Reduced pressure in the tank caused by ineffective venting could reduce the rate of fuel flow to the engine and also cause the fuel tanks to collapse inward. *Fuel vents* should be checked in the preflight external inspection to ensure that they are not blocked or damaged.

An *overflow drain* prevents excessive pressure building up if fuel volume increases because the full tanks have been warmed in the sun.

A high-wing airplane with the tanks in the wings will generally allow the fuel to be *gravity-fed* to the carburetor without the need for a *fuel pump*. If there is no carburetor as with a fuel injection system, then electric *boost pumps* are necessary.

All engines have an engine-driven fuel pump.

In a low-wing airplane, the tanks, being lower than the engine, need a fuel pump to lift the fuel to the carburetor. Prior to start-up, an electric auxiliary (boost) pump is used to prime the fuel lines and to purge any vapor from them. Once the engine is started, the engine-driven mechanical fuel pump takes over. Pump function can be monitored on the fuel pressure gauge.

Some engines (such as those in low-wing airplanes) also have an electric auxiliary fuel boost pump.

For many airplanes, the Pilot's Operating Handbook recommends that the electric fuel pump be switched on for critical maneuvers such as the takeoff, landing and low flying. This prevents fuel starvation in the event the engine-driven mechanical fuel pump fails.

It is important that the fuel strainer drain valve in a low part of the fuel system is checked closed during the preflight external inspection. If it is not closed, the engine-driven fuel pump may not be able to draw sufficient fuel into the engine (sucking air instead), and the engine may be starved of fuel unless the electric fuel pump is used.

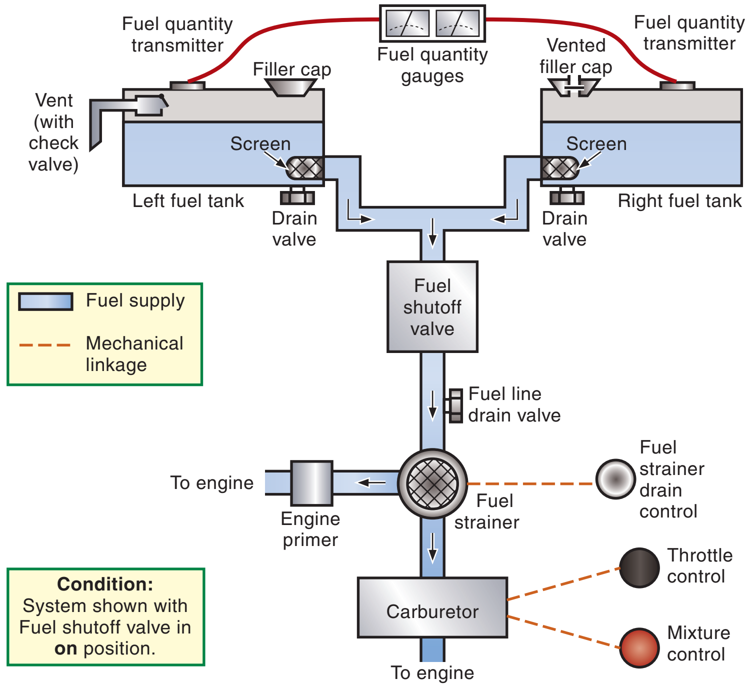


Figure 9-1 Simple carburetor fuel system.

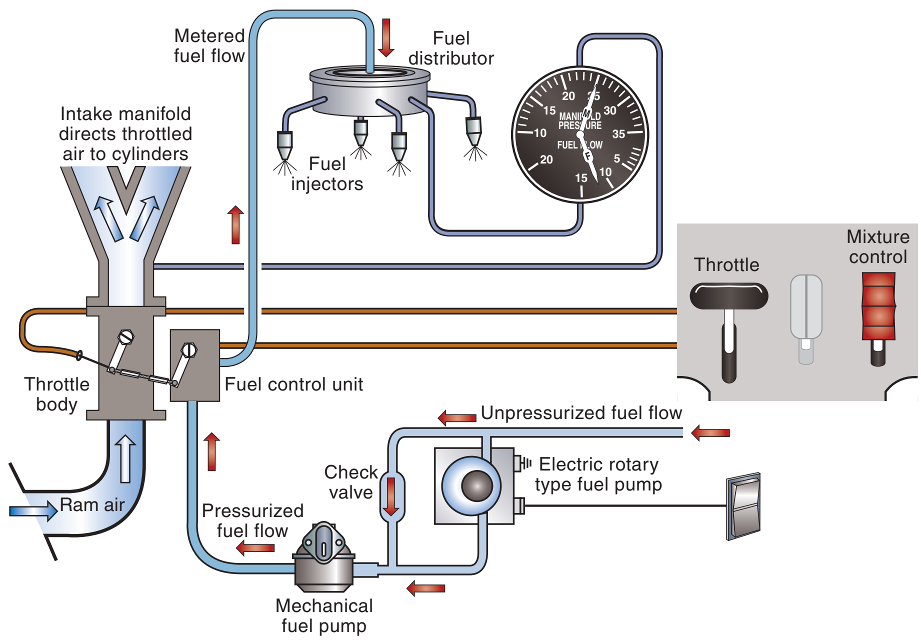


Figure 9-2 Typical fuel injection system.

The Priming Pump

A priming pump sends fuel directly into the engine prior to start-up.

The fuel primer is a hand-operated pump in the cockpit which the pilot uses to pump fuel into the induction system of the engine in preparation for engine start-up. This fuel does not pass through the carburetor, but is hand-pumped directly into the inlet manifold just before the cylinders.

Priming the engine is especially useful when starting a cold engine on a cold day, when the fuel in the carburetor is reluctant to vaporize.

The primer must be locked when the engine is running to avoid excessive fuel being drawn through the priming line into the cylinders, especially at low power settings, which could stop the engine if the fuel/air mixture is too rich.

Fuel Selection

A fuel line runs from each tank to a selector valve in the cockpit, which the pilot uses to select the tank from which fuel will be taken or to shut the fuel off. Incorrect fuel tank selection can result in fuel starvation, and has been the cause of many accidents—so study your Pilot's Operating Handbook very closely on this matter. The sounds of silence while you still have fuel in one tank, but not the tank that you have incorrectly selected, can be very loud indeed! You should not run a tank dry in flight before switching tanks, because the fuel pump may draw air into the fuel lines, causing a vapor lock which may stop the fuel flow, even from another tank, into the engine. Once a vapor lock has formed, it may be very difficult to restart the engine.

Know your fuel system and always select a tank that contains fuel.

It is advisable when changing tanks to switch on the electric auxiliary or booster fuel pump (if installed) to guarantee fuel pressure to the carburetor, and then to positively monitor the fuel pressure as the tanks are changed. Any sudden and unexpected loss of power should bring two possible causes immediately to mind:
- lack of fuel to the engine; or
- carburetor icing.

If the cause is incorrect fuel selection, your actions should include:
- close the throttle (to avoid a sudden surge of power as the engine restarts);
- set the mixture control to full-rich;
- turn the electric fuel pump on; and
- check fuel tank selection and tank quantity—change tanks if necessary.

If the cause of the engine problem is carburetor ice, then apply full carburetor heat. Refer to your Pilot's Operating Handbook for the correct actions to be taken in the event of any power loss.

Fuel Boost Pumps (or Auxiliary Pumps)

The reasons for installing *electric fuel boost pumps* are to:
- provide fuel at the required pressure to the carburetor or to the fuel metering unit of a fuel injection system;
- purge the fuel lines of any vapor to eliminate the possibility of a vapor lock;
- prime the cylinders of fuel-injected engines for start-up; and
- supply fuel if the engine-driven pump fails.

If an electric fuel pump is installed, it is usual to also have a *fuel pressure gauge* to monitor its operation.

Fuel Gauges

Most light airplanes have fuel gauges in the cockpit, which may be electrical, so the master switch will have to be *on* for them to register. Some older airplanes have direct-reading fuel gauges which do not require electrical power.

It is good airmanship not to rely on the fuel gauges, since they can read quite inaccurately, especially when the airplane is not straight-and-level. Always carry out a visual check of the contents in the fuel tanks during the preflight external inspection by removing the fuel caps, visually checking the contents of the tanks, and then replacing the caps securely.

Do not rely on the fuel gauges they can be inaccurate. Always check the contents of the fuel tanks visually before takeoff.

The fuel consumption rate specified in the Pilot's Operating Handbook assumes *correct leaning of the mixture* which, if not done, could lead to a fuel burn around 20% in excess of the 'book-figures,' and the fuel gauges consequently reading much less than expected because of excessive fuel burn.

Fueling

For safety during fueling, the airplane should be positioned well away from other airplanes and from buildings, the engine should not be running, and the ignition switches should be in the *off* position and the parking brake should be on. The location of any firefighting equipment should be noted in case it is needed. A *no-smoking* rule should be enforced and passengers should be kept well clear.

Before fueling, the airplane must be electrically grounded to minimize the risk of fire.

To prevent the possibility of a spark of static electricity igniting the fuel vapor that is present in any fueling operations, you should connect ground wires between the airplane, the fueling equipment and the ground to ensure that they are all at the same electrical potential. This should be done before you start fueling—even before you remove the fuel caps, when fuel vapor could be released into the atmosphere.

Figure 9-3 Fueling from a tanker.

Fuel Grades

AVGAS (AViation GASoline) comes in various grades to cater for different types of piston engines. These different grades of AVGAS are *color-coded* to aid you in checking that the correct fuel is on board. Normal fuel for light airplanes is blue-colored 100LL (low lead) or green-colored 100/130 octane.

Fuel Grade	Color
100LL	BLUE (low lead)
100/130	GREEN
80/87	RED

Table 9-1 Fuel grades.

Do not use jet fuel (kerosene) in piston engines. AVGAS decals on fueling equipment have a red background with white letters.

The most important thing is to ensure that you are loading the correct fuel type into the airplane tanks. Jet fuel (kerosene) is required for gas turbine engines (jets) and AVGAS for piston engines. Jet fuel is straw-colored or clear, has a distinctive smell, and must not be used in piston engines.

The *fueling equipment* has color-coded labeling:

- jet-fuel decals have a black background with Jet-A written in white letters; and
- AVGAS decals have a red background with white letters, (100/130 or AVGAS).

There are additional small labels on the fuel hoses or nozzles colored the same as the fuel grade, for both AVGAS and jet fuel.

Fuel should possess *anti-detonation* (or anti-knock) qualities, which are described by their *grade* (octane rating or performance number). The higher the grade, the greater the compression that the fuel/air mixture can take without detonating. High grade fuels have a higher lead content, which improves their anti-detonation qualities.

The higher grade indicates the power possible (compared with the standard reference fuel) before a rich mixture would detonate, and the lower grade indicates the power possible before the same fuel leaned-out would detonate. Certain engines require certain fuel — make sure you know which one your engine requires and use it, and make sure that the fuel already in the tanks is the same as that being loaded.

If you use fuel of a *lower* grade than specified, or fuel that is date-expired, excessive engine temperatures and detonation may occur, especially at high power settings, with a consequent loss of power and possible engine damage. If you use fuel of a *higher* grade than specified, the spark plugs can be fouled by lead deposits, and also the exhaust valves and their sealing faces can be eroded during the exhaust cycle.

> **Note.** A *higher* grade of fuel than specified is usually less dangerous than using a lower grade. If the recommended grade of fuel is not available, you could consider using the next higher grade of fuel on a short term basis, but not a lower grade. Refer to the manufacturer's handbook and your flight instructor.

Auto Gasoline

AVGAS comes in batches with tight quality control. Ordinary auto gasoline from the gas station does *not* have such tight quality control and has different burning characteristics to AVGAS. In an airplane engine, auto gasoline would cause a lower power output, lead fouling of the spark plugs and a strong possibility of detonation. Auto fuel is more volatile and vaporizes more readily than AVGAS, which might cause vapor locks in the fuel system and starve the engine of fuel.

Do not use auto gasoline in an airplane engine unless it is specifically authorized by the manufacturer and in accordance with an FAA Supplemental Type Certificate (STC).

Fuel Checks

Fuel must be checked for water and other contaminants.

Fuel which is about to be loaded should be checked first for contamination. The most common contamination is water. It can leak into ground fuel tanks, and from there be loaded into the fuel truck and into the tanks of an airplane.

Fuel naturally contains a small amount of water and this can condense with a drop in temperature, contaminate the fuel system, block the fuel passages in the carburetor, and possibly cause a loss of engine power. There are certain *fuel test pastes* and *fuel test papers* available which react when water is present, and the fueling agent will use these on a regular basis to guarantee the purity of the fuel in his storage tanks.

Other impurities besides water can also cause problems in the fuel. Rust, sand, dust and micro-organisms can cause problems just like water. Filtering or straining the fuel should indicate the presence of these and hopefully remove them prior to fueling.

Be especially careful when fueling from drums because they may have been standing for some time. Always check drum fuel with water-detection paste, for date of expiration, and for correct grade of fuel. Additionally, it is a good idea to check the release note for the fuel. Filter the fuel through a chamois cloth prior to loading into the airplane tanks if the drum pump has no filter.

Water, because it is more dense than fuel, will tend to gather at the low points in the airplane fuel system. After fueling has been completed, a small quantity of fuel should be drained from the bottom of each tank and from the *fuel strainer drain valve* to check for impurities, especially water, which will sink to the bottom of the glass. Fuel drains are usually spring-loaded valves at the bottom of each fuel tank, and the fuel strainer drain is usually found at the lowest point in the whole fuel system.

There is usually a drop in air temperature overnight and, if the space above the fuel in the airplane's fuel tanks is large, the fuel tank walls will become cold and there will be a lot more condensation than if the tanks were full of fuel. The water, as it condenses, will accumulate at the bottom of the fuel tanks.

Full fuel tanks minimize condensation in low temperatures.

If the tanks are kept full when the airplane is not being used for some days, or overnight if low temperatures are expected, condensation will be minimized. However, the disadvantages of fueling overnight include:

- if the airplane has a takeoff weight restriction the following day, it may have to be partially defueled to reduce the weight or adjust the balance; and
- if the tanks are full and the temperature rises, the fuel will expand and some could overflow from the tank, creating a possible fire hazard on the tarmac. This is an operational choice—check with your flight instructor.

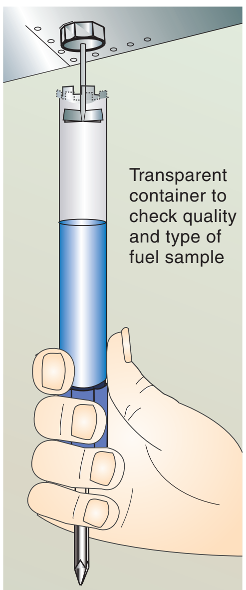


Figure 9-4
Fuel drains are located at the lowest point of the fuel tanks.

It is good practice to carry out a check for water in the airplane fuel system:

- prior to the first flight of the day;
- following each fueling; and
- any time you suspect fuel contamination.

In general terms, if you find a large quantity of water in the tanks, the following procedures should be included in your actions:

- the maintenance technician should be informed;
- drain the tanks until all the water has been removed;
- rock the wing to allow any other water to gravitate to the fuel strainer drain valve; and
- drain off more fuel and check for water at *all* drain points.

Fuel Management

Ensure that the airplane has the correct grade of fuel on board and that it is free of impurities. Ensure that sufficient fuel for the flight plus an adequate reserve is on board. Do not rely only on the fuel gauges as they are often inaccurate. Calculate the fuel required and be sure to check the tanks visually prior to flight for sufficient fuel. Remember that some of the fuel in the tanks will be unusable fuel. Carry out a fuel drain if required or if you think it is advisable.

Ensure that there are no leaks, that fuel caps are replaced, and that tank vents are clear and unobstructed. Fuel tank caps are usually on the upper surface of the wing, which is a low pressure area in normal flight. *Fuel can be siphoned out very quickly in flight if the tank caps are not secured*. With high-wing airplanes especially, where the tank caps are not visible easily from the ground or when in flight, extra care should be taken.

Fuel planning and good management are vital tasks.

Be familiar with, and follow, the procedures recommended in the Pilot's Operating Handbook for your airplane. Understand the fuel system, especially the functioning of the fuel selector valves. When selecting a new tank, ensure that the selector valve is moved firmly and positively into the correct detent.

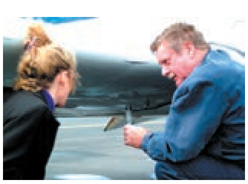


Figure 9-5
Fuel check.

Do not change tanks unnecessarily immediately prior to takeoff or landing, or at low altitude. If possible, verify prior to takeoff that fuel is being drawn from the appropriate tank(s). If operation is possible from more than one tank at the one time, this is usually preferred for operations near the ground. If boost pumps are installed, their use for takeoff is generally advised.

When changing tanks, check that there is fuel in the tank about to be selected; if an electric fuel pump is installed, switch it on and if a fuel pressure gauge is installed, monitor fuel pressure during and after the transfer, and when you switch off the electric boost pump.

The Electrical System

A typical modern light airplane has a *direct current* (DC) electrical system. The electric current is produced by an *alternator* when the engine is running, or from a *battery* or *external power source* when the engine is not running.

The current runs through wires and the *bus bar* to the electrical unit requiring power, does its work there and then runs to ground through a *ground wire* attached to the airplane structure (which is the return path of the electrical current).

Typical Electrical Systems

The Pilot's Operating Handbook for each airplane will contain a diagram of its electrical system and the services to which electrical power is supplied. It is good airmanship to be aware of what powers the vital services and instruments in your particular airplane. Electrical systems vary greatly between airplanes, but certain important services that may be powered electrically include:

- some, or all, gyroscopic flight instruments (turn coordinator, attitude indicator, and heading indicator)—a common arrangement is electrically powered turn coordinator with vacuum-driven attitude indicator and heading indicator to reduce the possibility of all gyroscopic instruments failing simultaneously (note that the pitot-static instruments—airspeed indicator, altimeter, vertical speed indicator—are not electrically powered);
- the fuel quantity indicators, and perhaps an oil temperature gauge, or carburetor air temperature gauge;
- the starting system;
- landing lights, beacon, strobe, cabin lights, instrument lights; and
- radios.

Check the electrical system diagram for your particular airplane. A schematic diagram of a typical light airplane electrical system follows.

The Bus Bar

The *bus bar* is the main conductor and the distribution center in the electrical system. Electrical power is supplied to the bus bar by the alternator (or generator) and a battery, from where it is distributed to the circuits and electrical components that require power.

The Battery

The battery provides emergency electrical power and electrical power for engine start.

The *battery* provides the initial electrical power to turn the engine over and start it with an *electric starter motor*, and also provides back-up or emergency electrical power at all times. Once the engine is running, it is self-sustaining and no longer needs electrical power from the battery. In fact the alternator (or generator), which is driven by the engine, provides current to recharge the battery after the engine has been started.

Most light airplanes have a *lead-acid battery* that creates an electrical current (measured in amps) by a chemical reaction between lead plates immersed in weak *sulfuric acid* that acts as an electrolyte. To prevent corrosion from any spillage of the acid, the battery is usually housed in its own compartment. The battery needs to be vented to exhaust the hydrogen and oxygen formed when it is being charged.

The battery is classified according to the voltage across its terminals (usually 12 or 24 volts) and its capacity to provide a current for a certain time (amp-hours). For instance, a 30 amp-hour battery is capable of steadily supplying a current of 1 amp for 30 hours (or 6 amps for 5 hours; 3 amps for 10 hours).

The battery should recharge after engine start.

If its electrical energy is depleted, as it is in an engine start, the battery needs to be recharged. This normally occurs after the engine is running, when the battery absorbs power produced by the alternator. The largest current draw on the battery is during start-up, when it supplies electrical power to the starter motor to turn the engine over, so the greatest rate of battery recharging will normally occur immediately after the engine is started.

The electrolytic level in the battery should be checked periodically, to ensure that the plates are covered. If the level is well below the top of the plates, the battery will not retain its full charge for very long, and the ammeter will indicate a high charging rate in flight. Leaks, connections and security of the battery should also be checked. This is carried out in the regular maintenance schedule by the maintenance technician.

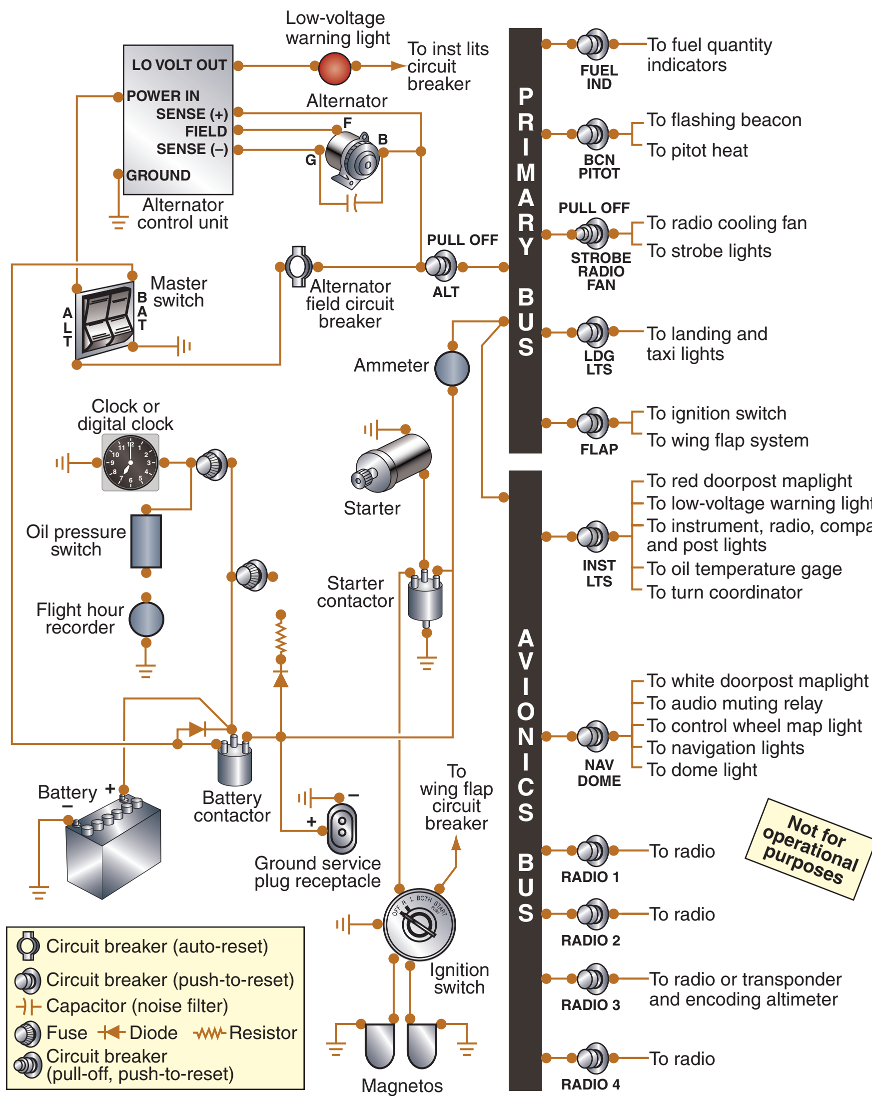


Figure 9-6 Typical light airplane electrical system.

Do not start a flight with an uncharged (flat) battery—it could result in you having no electrical power in flight if the engine-driven alternator fails. If the battery is flat, replace it or have it recharged before flight. Do not start the engine with radios and other unnecessary electrical equipment switched on. Large voltage fluctuations when the starter is engaged may severely damage sensitive electronic circuits. Turn on this ancillary electrical equipment after the engine is started, and after you have checked that the alternator is charging the battery. For the same reasons, turn off ancillary electrical equipment before shutting down the engine.

The Alternator

The electrical power in most modern light airplanes is usually supplied by an *alternator.* On older airplanes, the electrical power may be produced by a *generator.*

Both alternators and generators initially produce *alternating current* (AC)—an electric current that flows in alternate directions. Since most airplanes require *direct current* (DC)—electric current that flows in only one direction—the AC has to be rectified to DC. The AC within the alternator is rectified into DC electronically with diodes, whereas within the generator an electromechanical device known as the commutator performs this function. Also, the diodes in the alternator prevent any reverse current flow out of the battery, whereas a generator requires a reverse current relay.

As well as providing the power for lights, radios, and other services, a very important function of the generator/alternator is to recharge the battery so that it is ready for further use. Most airplane electrical systems are direct current of 14 or 28 volts. Note that these voltages are marginally higher than the battery voltages to allow the battery to be fully recharged by the electrical system.

The Advantages of an Alternator

Alternators:

- are lighter than generators because alternators do not contain as heavy electromagnets and casings, and have a simpler and lighter brush assembly;
- have a relatively constant electrical voltage output, even at low RPM; and
- are easier to maintain (because of their simpler brush assembly and the absence of a commutator).

The Disadvantage of an Alternator

An aircraft with an alternator must have a serviceable battery.

Unlike a generator, an alternator requires an initial current from the battery to set up a magnetic field, which is necessary before the alternator can produce an electrical current. Therefore an airplane with an alternator must have a serviceable battery. A flat battery must be replaced or recharged. If the propeller is hand propped to start the engine, the alternator will *not* come on-line unless the battery has at least some residual voltage. The advantages of an alternator outweigh this disadvantage.

Voltage Regulator

The correct output voltage from the generator/alternator is maintained by a *voltage regulator*, over which the pilot has no direct control.

Overvoltage Protector

Some airplanes have *overvoltage protectors* (or overvoltage relays). Refer to your Pilot's Operating Handbook for information.

The Ammeter

The *ammeter* measures the electrical current (amps) flowing into or out of the battery. (In some airplanes a *voltmeter* is provided to measure the electromotive force available to deliver the current.) There are two quite distinct types of ammeter presentation and you should understand exactly what this important instrument is telling you.

Left-Zero Ammeter

A *left-zero* ammeter measures only the output of the alternator or generator. It is graduated from zero amperes on the left end of the scale and increases in amperes to the right end of the scale, or it may be shown as a percentage of the alternator's rated load.

As the left-zero ammeter indicates the electrical load on the alternator, this type of ammeter can be referred to as a *loadmeter*:

- with the battery switch *on* and the engine not running, or, with the engine running and the alternator switch *off,* the ammeter will show zero; and
- if the engine is started and the alternator is turned *on,* the ammeter will then show the *alternator output*.

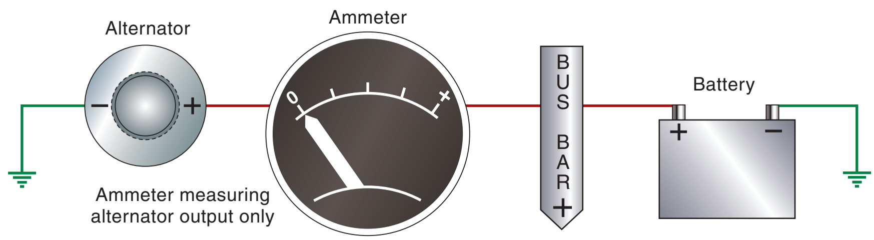


Figure 9-7 The left-zero ammeter.

During start-up, the battery discharges electrical power, so immediately after start-up the ammeter indication will be quite high during the initial battery recharging.

When the battery is fully charged, and the alternator is operating, the ammeter should show a reading slightly above the zero graduation if all the other electrical circuits are switched off. As these extra circuits are switched on (lights, radios), the ammeter reading will increase. *If the ammeter reading drops to zero* in flight, it probably means an alternator failure. Some electrical systems have a red warning light that illuminates when the alternator fails to supply electrical power. You should be familiar with the procedures for electrical failure in your Pilot's Operating Handbook, which may allow you to restore electrical power.

Generally, it is advisable to reduce electrical load to a minimum if the alternator fails, since only the battery will be supplying electrical power. Land as soon as practicable to have the problem corrected.

Center-Zero Ammeter

The *center-zero* ammeter measures the flow of current (amperage) into and out-of the battery:

- current into the battery is *charge*, with the ammeter needle deflected right of center;
- current out of the battery is *discharge*, with the ammeter needle deflected left of center;
- no current flow either into or out of the battery is shown by the needle being in the center-zero position;
- with the battery switch *on* and no alternator output, the ammeter will indicate a *discharge* from the battery, because the battery is providing current for the electrical circuits that are switched on. The ammeter needle is to the left (discharge) side of center-zero;

- with the alternator *on* and supplying electrical power, if the electrical load required to power the circuits switched on is less than the capability of the alternator, the ammeter will show a *charge,* because there will be a flow of current to the battery; and
- if the alternator is *on,* but incapable of supplying sufficient power to the electrical circuits, the battery must make up the balance and there will be some flow of current from the battery. The ammeter will show a discharge. If this continues, the battery could be drained or "flattened." In this case, reduce the load on the electrical system by switching off unnecessary electrical equipment until the ammeter indicates a charge, (a flow of current from the alternator into the battery).

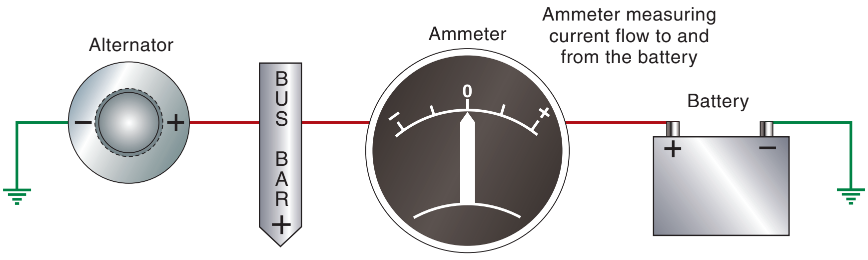


Figure 9-8 The center-zero ammeter.

The Master Switch

The *master switch* (or battery switch/alternator switch) controls all of the airplane's electrical system, with one very important exception—it does not control the ignition system which gets electrical power directly from the engine-driven magneto. This statement is not completely true if the airplane has an electric clock, which will draw a very small amount of electrical power at all times whether the master switch is on or not.

The master switch needs to be *on* for any other electrical system to receive power or for the battery to be recharged when the engine is running. It should be turned *off* after stopping the engine, to avoid the battery discharging by powering electrical equipment connected to it.

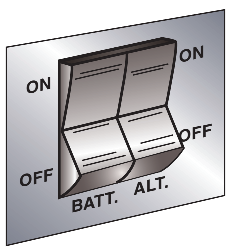


Figure 9-9 The master switch (battery switch/ alternator switch).

In airplanes with an alternator installed, the master switch is a *split switch* (with two halves that can be switched on and off separately):

- one half for operating the *battery switch* (or master relay for the electrical systems), which connects battery power to the bus bar (electrical load distribution point or bar); and
- the other half, the *alternator switch,* for energizing the alternator. It connects the alternator field to the bus bar, thus providing the alternator with battery power.

Both switches must be *on* for normal operation of the electrical system. If either switch has to be turned *off* due to malfunction in flight then you should consider terminating the flight as soon as possible. They can be switched on separately, but only the alternator can be switched off separately—switching the battery *off* will automatically switch the alternator off as well.

Fuses, Circuit Breakers and Overload Switches

Fuses, circuit breakers and *overload switches* are provided to protect electrical equipment from current overload. If there is an electrical overload or short-circuit, a fuse-wire will melt or a *circuit breaker* (CB) will pop out and break the circuit so that no current can flow through it. It may prevent the circuit from overheating, smoking or catching fire.

Only reset a circuit breaker once.

It is normal procedure (provided there is no smell or other sign of burning or overheating) to reset a circuit breaker once only, by pushing it back in or resetting it.

A fuse wire should not be replaced more than once.

Do not replace a blown fuse with one of a higher rating.

If a circuit breaker pops again, you can be fairly sure there is an electrical problem, and so it should not be reset a second time.

Similarly, a fuse-wire should not be replaced more than once (with the correct amperage first checked on the replacement fuse-wire). Spare fuses of the correct type and rating should be available in the cockpit.

Do not replace a blown fuse with one of a higher rating (15 amp is a higher rating than 5 amp), as this may allow excessive current to flow through the electrical circuit that it is supposed to protect. An electrical fire could result.

Overload switches are combined *on-off* switches and *overload protectors*. Overload switches will switch themselves off if they experience an electrical overload. The pilot can switch them back on like a resettable circuit breaker.

Some airplane handbooks recommend a delay of a minute or two prior to resetting, to allow for cooling of the possibly overloaded circuit. If you detect fire, smoke, or a burning smell, then caution is advised. Resetting the circuit breaker or replacing the fuse in such cases is not advisable.

Relays

A *relay* is a device in an electrical circuit that can be activated by a current or voltage to cause a change in the electrical condition of another electrical circuit.

Instead of having high currents and heavy wiring running to where the switches are in the cockpit (with consequent current losses and fire danger from arcing), a low amperage current operated by a switch in the cockpit can be used to close a remote relay and complete the circuit for a much higher amperage circuit in the engine compartment, the starter motor for example.

A relay is usually operated on the *solenoid* principle. A solenoid is a metal bar or rod with a coil of wire wound around it. If a current passes through the coil, it establishes a magnetic field that can move the metal rod, which can then perform some mechanical task, such as making or breaking a contact in another electrical circuit.

A typical relay consists of a contact held open by a spring, thereby interrupting an electrical circuit. Around the stem of the relay is wound a coil of wire. If a current is made to pass through this coil, a magnetic field is set up that will move the relay to the closed position, thereby completing the circuit and allowing current to flow in it.

The current that activates the relay is in a completely different circuit to the relay. Occasionally a relay will stick even though its activating current has been removed, and an unwanted current will flow through the circuit. Many electric starters have an associated red warning light that will stay illuminated to warn the pilot of the starter relay sticking and the starter motor still operating even though the starter has been selected to *off*. (In this situation, the engine could be stopped by starving it of fuel—mixture control to *idle cut-off*.)

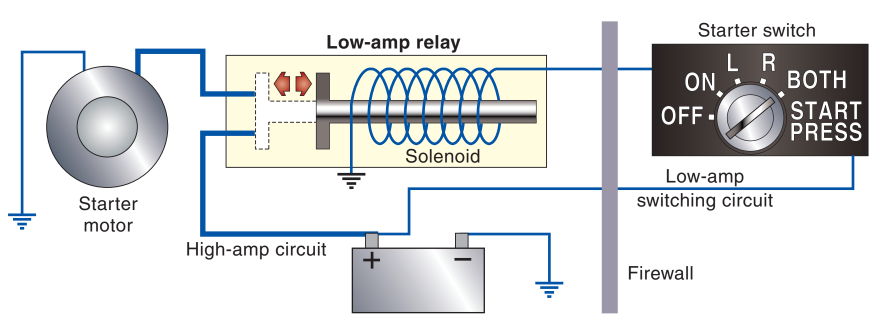


Figure 9-10 Low-amp relay circuit activates high-amp starter circuit.

External Power Sockets or Ground Servicing Receptacle

The more sophisticated light airplanes and most large airplanes have provision for a suitable external power source to be plugged into the airplane's electrical system. The external power source provides ground power over an extended period when the engine or engines are not running or conserves the airplane battery during an engine start.

On some airplane types external power can be plugged in but will not connect in to the airplane electrical system. A small current from the battery is needed to operate the relay that connects the plugged-in external power to the airplane circuit, hence a serviceable battery is required to use external power. There are other systems that operate differently to this, so refer to your Pilot's Operating Handbook. Ensure a ground power unit (GPU) of the correct voltage is used. (Connecting a 28V GPU on a 12 volt airplane will severely damage the radios and other electrical equipment.)

Electrical Malfunctions

An electrical overload will normally cause a fuse-wire to melt or a circuit breaker to pop. This protects the affected circuit. Allow two minutes to cool and, if no indication of smoke, fire, or a burning smell, replace the fuse or reset the circuit breaker—*but reset once only.* If the circuit breaker pops or the fuse melts again—do not reset or replace a second time.

The ammeter should be checked when the engine is running to ensure that the alternator is supplying sufficient current (amps) for the electrical services and to recharge the battery. The ammeter usually indicates the rate at which current is flowing into the battery and recharging it.

With the engine running, the ammeter can indicate two faults.

1. Insufficient current to charge the battery.
2. Too much current.

With insufficient current from the alternator, or none at all, nonessential electrical equipment should be switched off to conserve the battery, and thought should be given to making an early landing. Most airplane batteries cannot, on their own, supply all electrical equipment for a long period.

With too much current and an excessive charge rate, the battery could overheat and the electrolyte (which may be sulfuric acid) begin to evaporate, possibly damaging the battery. If the cause of the excessive current is a faulty voltage regulator, equipment such as the radio could be adversely affected. Many airplanes have an overvoltage sensor that would, in these circumstances, automatically shut-down the alternator and illuminate a red warning light in the cockpit to alert the pilot.

> **Note.** Operations of an alternator-powered electrical system with a partially charged battery that is unable to turn the engine over are not recommended for the above reasons.

If the alternator fails (indicated in most airplanes by either the ammeter indication dropping to zero and/or a red warning light), the battery will act as an emergency source of electrical power. To extend the period for which the battery can supply power following failure of the alternator, the electrical load should be reduced. This can be done by switching off nonessential services such as unnecessary lights and radios. Consideration should be given to terminating the flight at a nearby suitable airport while electrical power is still available.

The Vacuum System

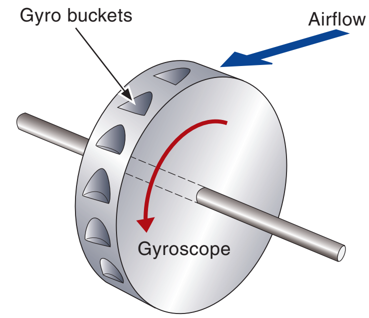


Figure 9-11
Gyroscope buckets.

The gyroscopes in the flight instruments may be spun electrically or by a stream of high-speed air directed onto buckets cut into the perimeter of the rotor. The vacuum system (which sucks this high-speed air into the gyro instrument cases and onto the gyro rotors, causing them to spin very fast) needs a little explaining.

The Engine-Driven Vacuum Pump

Most modern vacuum systems use an engine-driven vacuum suction pump. Some airplanes are equipped with an electrically driven system. The vacuum suction pump evacuates the cases of the gyroscopic-driven instruments creating a partial vacuum (low pressure). The required suction is typically 4.5 to 5.4 inches of mercury, which creates a pressure 4.5–5.4 in. Hg *less* than atmospheric, indicated in the cockpit on a suction gauge.

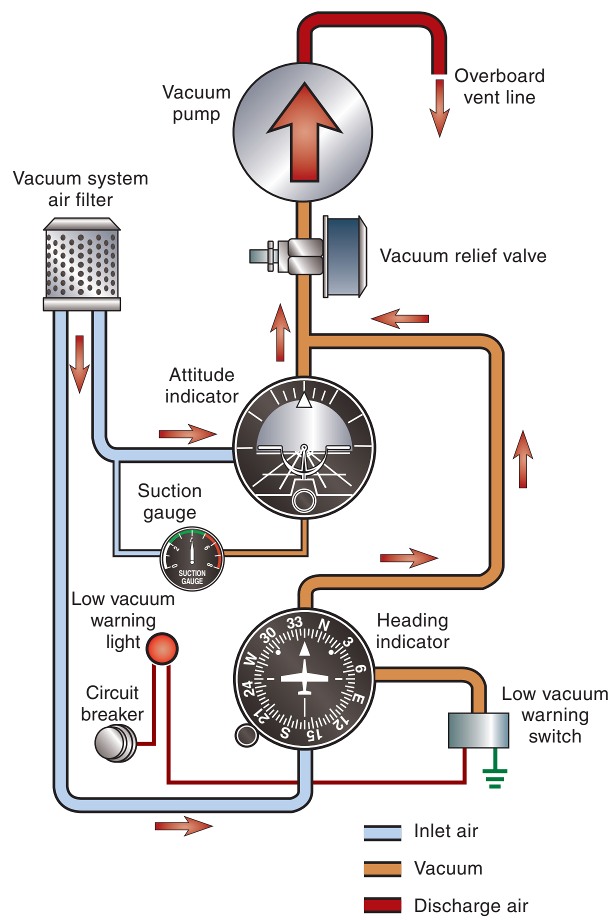


Figure 9-12 A typical vacuum system.

Filtered air is continuously drawn in at high speed through a nozzle directed at the gyro buckets, causing the gyro to spin at high speed, often in excess of 20,000 RPM. This air is continuously being sucked out by the suction pump and exhausted into the atmosphere.

The effects of various malfunctions in the vacuum system are summarized below:

- if the air filter blocks, or the vacuum system fails, the reduced airflow may allow the gyroscopes to gradually run down and the vacuum-operated instruments will eventually indicate erratically or incorrectly, or respond slowly. A lower suction will be indicated on the gauge;
- failure of the vacuum pump will be indicated by a zero reading on the suction gauge. It may be that the gyroscopes have sufficient speed to allow the instruments to read correctly for a minute or two before the gyros run down following failure of the vacuum pump;
- a zero reading on the suction gauge could also mean a failure of the gauge (rather than a failure of the vacuum pump), in which case the instruments should continue to operate normally; and
- if the vacuum pressure is too high, the gyro rotors may spin too fast and suffer mechanical damage. To prevent this, a vacuum relief valve (or vacuum regulator) in the system will admit air from the atmosphere to reduce the excessive suction.

When the gyros are not being used, they should normally be *caged* (if provision is made to do this). Caging a gyro locks it in a fixed position. Caging the gyros is also recommended in the Pilot's Operating Handbook of some airplanes when performing aerobatic maneuvers.

Figure 9-13 A typical venturi tube.

Vacuum Provided by a Venturi Tube

Some airplanes (especially older ones) have their vacuum system operated by a *venturi tube*. This is a shaped tube on the outside of the airframe, which replaces the engine-driven vacuum pump. When air flows through the venturi tube, and speeds up because of the shape of the venturi, the static pressure decreases (Bernoulli's principle). This low pressure area, if connected to the gyro instrument cases, will draw air through each instrument via an internal filter and spin the gyroscopes, as in the engine-driven system.

Before the venturi-powered vacuum system can work there must be an appreciable airflow through the venturi tube. This is normally created by the forward motion of the airplane through the air with sufficient airflow being provided at flying speeds. It may be several minutes after takeoff before the gyroscopes are spinning fast enough for the instrument indications to be reliable. This is a significant disadvantage compared with the engine-driven system. Other disadvantages are the increased drag caused by the externally mounted venturi-tube, and the possibility of ice affecting it (like in a carburetor, where the reduced pressure causes a reduced temperature).

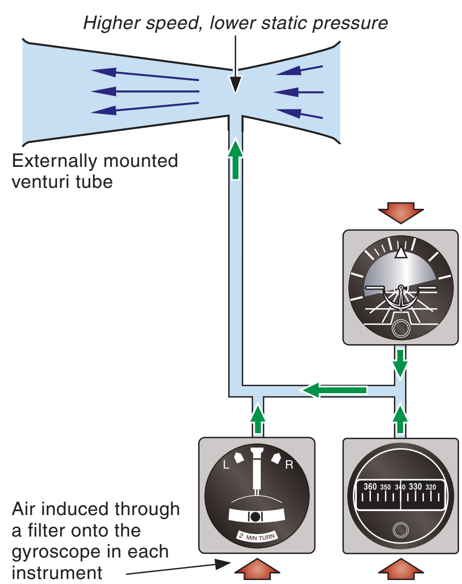


Figure 9-14
Air flowing through a venturi tube can create a "suction" and power a vacuum system.

Review 9

Systems

The Fuel System

1. What are the functions of an auxiliary fuel boost pump?
2. What type of fuel can be substituted in an aircraft if the recommended octane is not available?
3. Why should you not use fuel of a lower grade than specified?
4. Should auto gasoline be used in an airplane engine?
5. When should fuel be checked for contamination, especially water?
6. True or false? Water tends to collect at the highest points in the fuel system.
7. How is aviation gasoline distinguished from aviation turbine fuel (kerosene)?
8. What color is 100/130 fuel?
9. What color is 100 LL (low lead) fuel?
10. Filling the fuel tanks after the last flight of the day is considered a good operating procedure because this will:
    - **a.** force any existing water to the top of the tank away from the fuel lines to the engine.
    - **b.** prevent expansion of the fuel by eliminating airspace in the tanks.
    - **c.** prevent moisture condensation by eliminating airspace in the tanks.
11. What color are AVGAS fueling equipment decals?
12. What color are jet fuel equipment decals?
13. If you allow a fuel tank to run dry in flight before changing tanks, what do you run the risk of?

The Electrical System

14. What is the source for normal in-flight electrical power?
15. Where does the initial current required to activate the alternator come from?
16. A distribution point for electrical power to various services is called a:
    - **a.** circuit breaker.
    - **b.** distributor.
    - **c.** bus bar.
17. What is the function of the battery?
18. What does a center-zero ammeter do?
19. What does a left-zero ammeter do?
20. True or false? Immediately after start-up, the ammeter indication will be high while the battery is recharging.
21. What do fuses and circuit breakers protect against?
22. A fully charged battery rated at 15 amp-hours is capable of providing 5 amps for how many hours without recharging?
23. Which of the following would normally be electrically powered?
    - **a.** ASI.
    - **b.** Altimeter.
    - **c.** VSI.
    - **d.** AI.
    - **e.** Turn coordinator.
    - **f.** HI.
    - **g.** Fuel quantity gauges.
    - **h.** Engine RPM gauge.
    - **i.** Oil temperature gauge.

The Vacuum System

24. The vacuum pump, if installed on a modern airplane, is most likely to be:
    - **a.** electrically driven.
    - **b.** engine-driven.
    - **c.** hydraulically driven.
25. How are air-driven gyro rotors prevented from spinning too fast?
26. True or false? Insufficient suction may cause gyroscopic instruments (such as the artificial horizon or the heading indicator) to indicate incorrectly, erratically, or respond slowly.

Answers are given on page 770.

Flight Instruments 10

The first impression most people have of an airplane cockpit is of the number of instruments. However when you analyze the instrument panels of even the largest jet transport airplanes, you will find that the instrumentation is not all that complicated. In fact, the basic instruments will be very similar to those found in the smallest training airplane.

Airplane flight instruments fall into three basic categories:

- pressure instruments—which use variations in air pressure;
- gyroscopic instruments—which use the properties of gyroscopic inertia; and
- magnetic instruments—which use the earth's magnetic field.

It is also important to realize that even if you fly with a glass cockpit, it is extremely important to know the fundamentals of how traditional instruments work.

Figure 10-1 The flight instruments.

Pressure Instruments

The basic flight instruments that inform the pilot of airspeed (airspeed indicator), altitude (altimeter) and rate of change of altitude (vertical speed indicator) are *pressure instruments*.

Static Pressure

At any point in the atmosphere static pressure is exerted equally in all directions. It is the result of the weight of all the air molecules above that point pressing down. As its name implies, static pressure does not involve relative movement of the air. Static pressure is measured on the surface of an airplane through a *static vent* or *static port* (see figure 10-4, page 261).

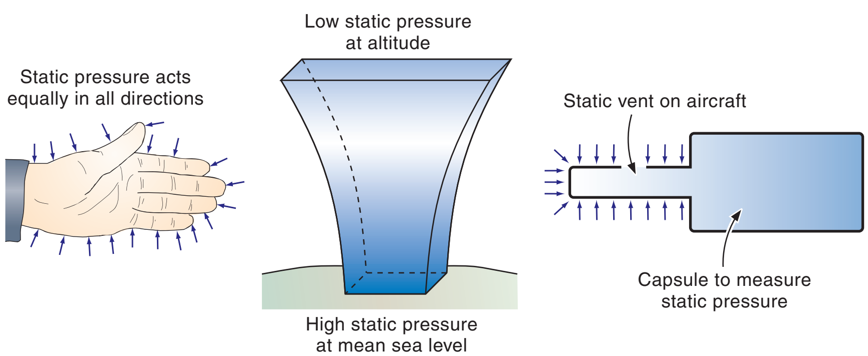


Figure 10-2 Static pressure.

Dynamic Pressure

If you hold your hand up in a strong wind or out of the window of a moving automobile, you feel extra pressure (over static pressure) because of the air impacting your hand. This extra pressure, over and above the static pressure is called dynamic pressure, the pressure that results from relative movement.

Dynamic pressure is expressed as $\frac{1}{2}\rho V^2$ and therefore depends on the air's density (ρ) and relative speed (V). The faster the airflow or the denser the air, the stronger the dynamic pressure, because of the greater number of air molecules that impact per second. Dynamic pressure is also known as *impact pressure*.

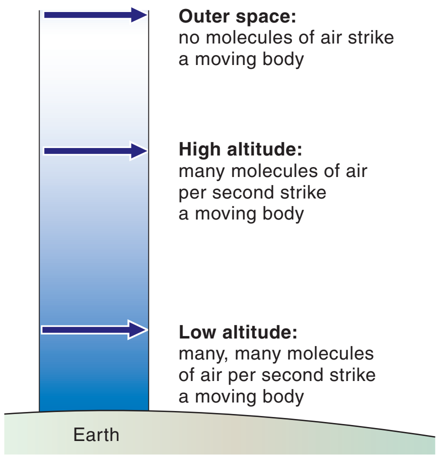


Figure 10-3
Dynamic pressure depends on air density.

Total Pressure

In Chapter 4 we looked at Bernoulli's principle and noted that the total air pressure equals static pressure plus dynamic pressure:

Static pressure measured by static vent	+	dynamic pressure $\frac{1}{2}\rho V^2$	=	total pressure measured by the pitot tube

From this equation dynamic pressure can be found by subtracting the static pressure (measured by the static vent) from the total pressure (measured by the pitot tube). Although the airspeed indicator (ASI) indicates dynamic pressure, it is calibrated to read in units of speed (usually knots) rather than in units of pressure.

The Pitot-Static System

Three flight instruments make use of pressure readings:
- the *altimeter* which converts static pressure to altitude;
- the *vertical speed indicator* which relates the rate of change of static pressure to a rate of climb or descent; and
- the *airspeed indicator* which relates the difference between total pressure and static pressure to the indicated airspeed.

The *pitot tube* mounted on the airplane is the source of total pressure and the airplane's static vent is the source of static pressure. There are two common arrangements of the pitot-static sensing system:
- a combined pitot-static head; or
- a pitot tube (possibly on the wing) and a static vent (or two) on the side of the fuselage.

The pitot tube must be positioned where the free airflow is not greatly disturbed by changes in static pressure, often forward of, or beneath the outer section of one wing. Otherwise the airspeed indicator system will suffer from significant errors. In addition, pitot heaters are sometimes provided as a precaution against ice blocking the pitot tube. They usually consist of electrical elements built into the pitot tube, and are operated by a switch from the cockpit.

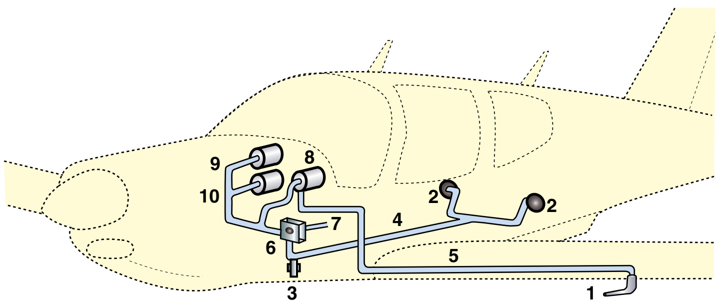
Some airplanes have two *static vents,* one on each side of the fuselage, so that the reading for static pressure, when averaged, is more accurate, especially if the airplane is slipping or skidding.

There is often an *alternative static source* that can measure pressure inside the cabin, in case of ice or other matter obstructing the external vents. Cabin pressure is usually slightly less than the external atmospheric pressure and will cause the instrument readings to be slightly in error when the alternate static source is being used.

It is vital that the pitot tube and static vent(s) are not damaged or obstructed, otherwise false readings from the relevant flight instruments could degrade the safety of the flight. They should be carefully checked in the preflight external inspection. The pitot cover, used to prevent water or insects accumulating in the tube, should be removed. They should not be tested by blowing in them, since very sensitive instruments are involved.

Figure 10-4
Static vent.

Figure 10-5
Pitot head.



1. Pitot tube
2. Static vents
3. Static drain
4. Static line
5. Pitot line
6. Alternate static selector
7. Alternate static pressure
8. Airspeed indicator
9. Altimeter
10. Vertical speed indicator

Figure 10-6 Typical pitot-static installation.

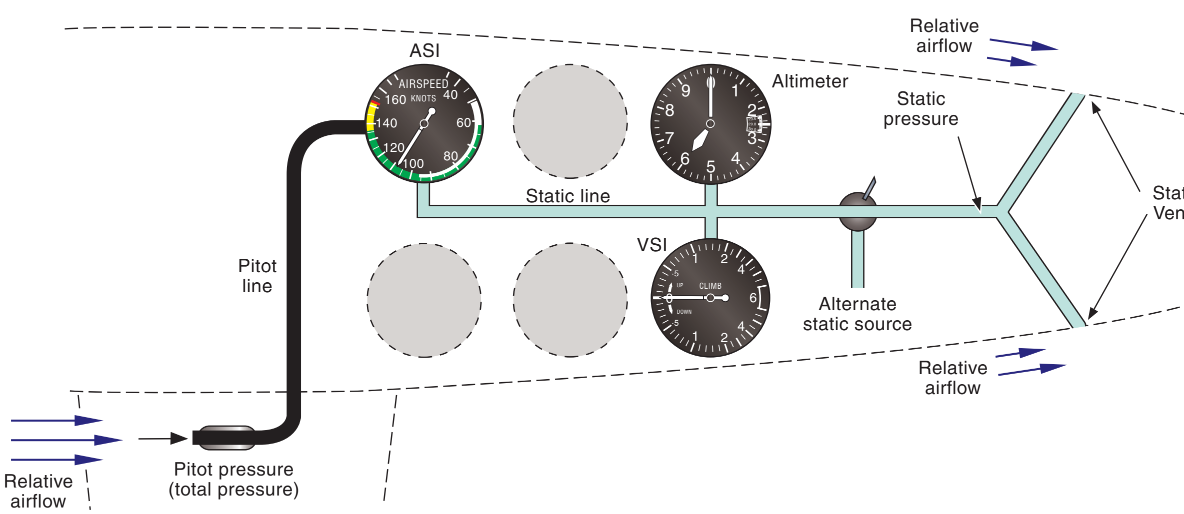


Figure 10-7 The pitot-static system.

Airspeed Indicator (ASI)

The airspeed indicator displays indicated airspeed (IAS), which is related to dynamic pressure. We can find dynamic pressure by subtracting the static vent measurement from the pitot tube measurement. This is easily done by having a diaphragm with total pressure from the pitot tube being fed onto one side of it and static pressure from the static line being fed onto the other side of it. The diaphragm and pointer connected to it will move according to the difference between the total pressure and the static pressure.

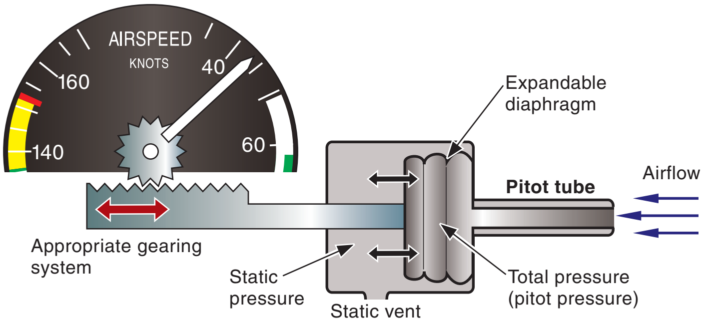


Figure 10-8 The airspeed indicator measures dynamic pressure.

As airspeed increases, the dynamic pressure increases, but the static pressure remains the same. The difference between the total pressure (measured by the pitot tube) and the static pressure (measured by the static vent or static port) gives us a measure of the dynamic pressure (which is related to indicated airspeed). This difference between total and static pressures causes the diaphragm to reposition itself, and the pointer to indicate a higher airspeed.

Color Coding on the Airspeed Indicator

To assist the pilot, ASIs in modern airplanes have certain speed ranges and certain specific speeds marked according to a conventional color code:

Figure 10-9
ASI coding.

- the *green arc* denotes the *normal-operating speed range*, from stall speed V_{S1} at maximum gross weight (flaps up, wings level) up to V_{NO} (normal-operating limit speed or maximum structural cruise speed) which should not be exceeded except in smooth air. Operations at indicated airspeeds in the green arc should be safe in normal flying conditions. The maximum airspeed to use in turbulence is V_A or V_B (specified in the Pilot's Operating Handbook);
- the *yellow arc* denotes the *caution range*, which extends from V_{NO} (normal-operating limit speed) up to V_{NE} (the never-exceed speed). The airplane may be operated at indicated airspeeds in the caution range *only in smooth air*, and then only with small control inputs;
- the *white arc* denotes the *flaps operating range*, from stall speed at maximum gross weight in the landing configuration V_{S0} (full flaps, landing gear down, wings level, power-off) up to V_{FE} (maximum flaps-extended speed); and
- the *red radial line* denotes V_{NE}, the *never-exceed speed*. It is the maximum speed at which the airplane may be operated.

One important speed not marked on the airspeed indicator is the maneuvering speed (V_A)—the maximum speed at which the limit load factor can be imposed (either by gusts or by full control deflection) without overstressing or causing structural damage.

Note. ASI markings refer to indicated airspeed (IAS) and not true airspeed (TAS). Where weight is a factor in determining limit speeds, such as stall speeds, the value marked is for the maximum gross weight situation.

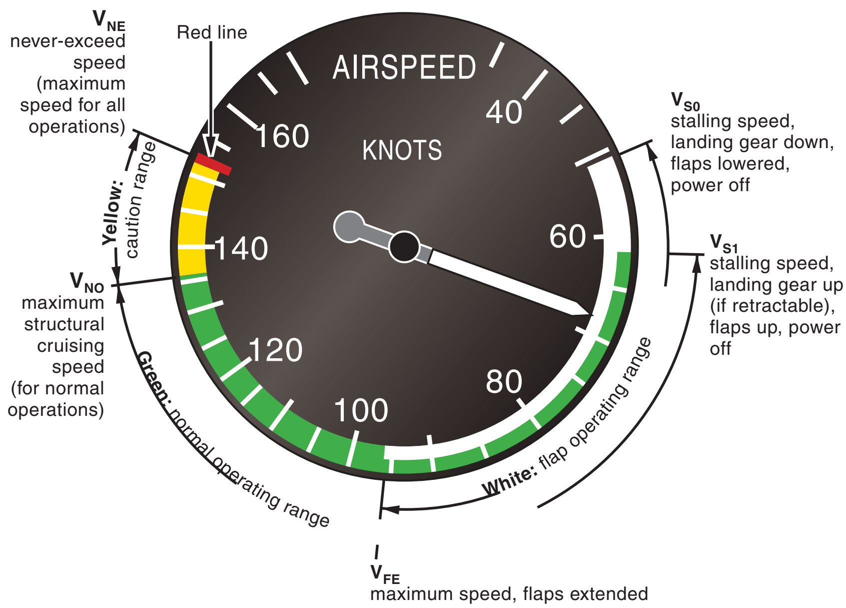


Figure 10-10 The airspeed indicator.

Indicated Airspeed (IAS) and True Airspeed (TAS)

The fact that indicated airspeed (IAS) and true airspeed (TAS) are usually different seems to worry many student pilots, but it need not. IAS is closely related to dynamic pressure ($\frac{1}{2}\rho V^2$), and is of aerodynamic importance.

Indicated airspeed (IAS) is important aero-dynamically.

When we discuss the flight performance of the airplane—lift, drag, stall speed, take-off speed, maximum speeds and climb speeds—we talk in terms of *indicated airspeed* (IAS). The indicated airspeed is vital performance information for the pilot, as the aerodynamic qualities of the airplane depend on it.

True airspeed (TAS) is important for navigation.

The *true airspeed* (TAS) is the actual speed of the airplane relative to the air. TAS (or V) is important for navigational purposes, to describe speed through the air (TAS). By incorporating wind, we can calculate speed over the ground.

True Airspeed Usually Exceeds Indicated Airspeed

In a climb it is usual for the pilot to maintain the same indicated airspeed. As the airplane gains altitude it climbs into less dense air because air density (ρ) decreases with increasing altitude.

For IAS to remain the same, the value of dynamic pressure ($\frac{1}{2}\rho V^2$) must remain constant. Because air density (ρ) decreases with increasing altitude, a constant IAS ($\frac{1}{2}\rho V^2$) can only be maintained by increasing the value of V (TAS). Therefore, climbing to a higher altitude with the airspeed indicator showing a constant IAS, will mean TAS is gradually increasing. You can calculate true airspeed from indicated airspeed, pressure altitude and temperature using a flight computer.

On hot days and at high airports, to generate sufficient lift for takeoff the airplane must be accelerated to a higher V (TAS) to compensate for the decreased air density. (IAS shown on the ASI will remain the same.) This, coupled with possible reduced performance from the engine-propeller, will mean a longer takeoff distance—this is discussed in detail in Chapter 6.

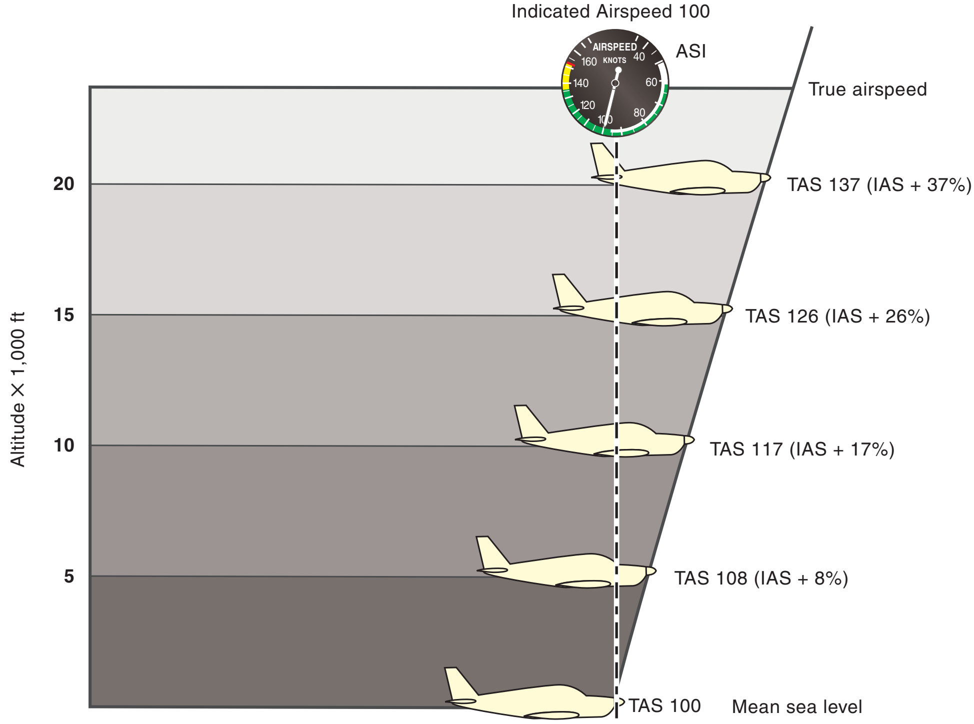


Figure 10-11 With IAS constant, TAS increases with increase in altitude.

ASI Errors Caused by a Blocked Static Vent

If the static vent(s) become blocked the ASI will read low in a climb, and high in a descent.

A blockage or ice buildup in either the static vent(s) or pitot tube will cause the pressure to be trapped in that particular line to the pressure instruments. If you are climbing and the static vent ices over, then the static pressure trapped in the line will be higher than the actual static pressure at the altitude the airplane has climbed to. The measured difference between pitot (total) pressure and static pressure will be less than actual and the ASI will read low, (show a lower indicated airspeed than actual).

On a descent, the reverse would be the case, a blocked static vent would cause the ASI to read high, (show an indicated airspeed higher than actual). This is a dangerous situation if the pilot does not recognize it and reduces speed, because the airplane will actually be flying at a lower speed than indicated.

ASI Errors Caused by a Blocked Pitot Tube

A blocked pitot tube will cause the ASI to read high in a climb, and low in a descent.

If the pitot tube becomes blocked, say by ice, the total pressure trapped in the pitot tube (which remains constant) will be fed to the ASI, to be compared to the varying static pressure from the static vent. Therefore in a climb, the outside static pressure reduces, hence the airspeed indicator will read higher than it should. Conversely, on descent below the altitude where icing occurred, it will read a lower airspeed than it should.

Altimeter

Unlike an automobile, an airplane must be navigated and its position known in three dimensions, not only left and right (or west and east), but also up and down. The altimeter is the most important instrument for *vertical navigation* and *vertical separation* between yourself and the ground or other aircraft. You must use it correctly and understand exactly what it is telling you.

Figure 10-12
Altimeter.

A very important reference point for vertical navigation and for charts is *mean sea level* (MSL), the average height of the sea surface calculated from hourly tide readings taken over many years. The altimeter relates the static pressure at the level of the airplane to a height in the *International Standard Atmosphere* (ISA), a theoretical "average" atmosphere which acts as a convenient hypothetical yardstick. The main purpose of the International Standard Atmosphere is to calibrate altimeters. Standard pressure at mean sea level (MSL) is 29.92 inches of mercury. (Its metric (SI) equivalent is 1,013.2 hectopascals, usually written 1,013 hPa.)

Atmospheric pressure reduces by approximately 1 in. Hg (one inch of mercury) for each 1,000 feet gain in altitude in the lower levels of the atmosphere (up to about 5,000 feet).

Atmospheric pressure reduces by approximately 1 in. Hg for each 1,000 feet gain in altitude.

The altimeter converts this reduction in atmospheric pressure to a gain in altitude. For instance, if the pressure falls by 0.45 in. Hg, the altimeter will indicate a gain in altitude of 450 feet.

How the Altimeter Works

The altimeter contains sealed, but expandable, aneroid capsules that are exposed within the instrument case to the current static pressure that enters through the static port. As the airplane climbs and static pressure decreases, the sealed capsules expand and drive pointers, via a mechanical linkage, around the altimeter scale. These indicate the increased height above the selected pressure level. There may be a short time lag before changes in altitude are actually indicated on the altimeter.

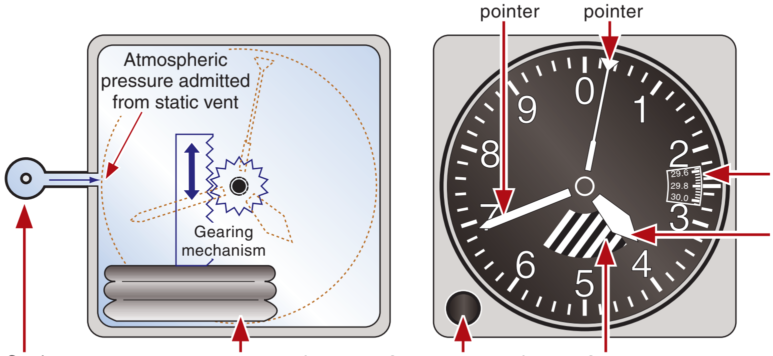


Figure 10-13 The altimeter is a pressure-sensitive instrument.

Unfortunately for altimeters, the real atmosphere existing at a particular place and time can differ significantly from the standard atmosphere. Atmospheric pressure at MSL will vary from place-to-place and from time-to-time as weather pressure patterns move across the country. If an altimeter is to measure altitude from any particular level, such as mean sea level (MSL), then it must be designed so that the appropriate MSL pressure setting can be selected.

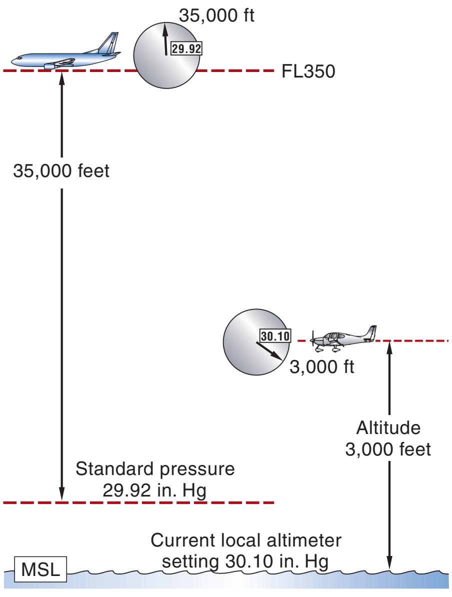


Figure 10-14
The altimeter measures height above the pressure level set in the pressure window.

The Pressure Window

The altimeter incorporates a small adjustable pressure subscale that allows the pilot to select the pressure level from which altitude will be measured. This subscale is known as the *pressure window* or *Kollsman window*. If you want to measure the altitude of the airplane above the 29.92 in. Hg standard pressure level, then you set 29.92 in the pressure window.

If you want to measure the height of the airplane above the 30.10 in. Hg pressure level, then you set 30.10 in the pressure window. If 30.10 in. Hg happens to be the current MSL barometric pressure, then the altimeter will be indicating the altitude of the airplane above sea level.

For flight operations in the United States below 18,000 feet MSL, the level from which height is measured is mean sea level (MSL). Although 29.92 inches of mercury is standard MSL pressure, the existing MSL pressure will usually differ, often significantly, from this value.

The MSL pressure at a particular place and time is called the *local altimeter setting* and, when this is set in the pressure window, the altimeter will display what is known as the *indicated altitude*.

When the setting in the pressure window is changed by winding the pressure setting knob, the altimeter needle will also move around the dial. This is because it measures height above the selected pressure level and the selected level is being changed. A one inch decrease in pressure in the lower levels of the atmosphere indicates approximately 1,000 feet gain in altitude. Therefore, increasing the setting in the pressure window will increase the altimeter reading. This can be remembered as "Wind on inches, wind on altitude."

Pressure Settings Above 18,000 feet MSL

When flying in the United States at or above 18,000 feet MSL, standard pressure (29.92 in. Hg) should be set in the pressure window. Above 18,000 feet MSL there is adequate terrain clearance above the highest mountains, so vertical separation from other aircraft is the main concern. Having a common setting of 29.92 in. Hg gives all high-flying aircraft a common pressure level from which their flight level is measured, avoiding any conflict caused by altimeter settings from different geographic locations.

With standard pressure 29.92 set, the altimeter indicates *pressure altitude*. It is usual to remove the last two zeros of a pressure altitude and refer to it as a *flight level*. For example, an altimeter reading 21,000 feet with 29.92 in. Hg set, is referred to as FL210 (flight level two one zero).

Different Altimeter Presentations

You must be able to interpret the altimeter reading correctly since it provides absolutely vital information. Lives have been lost in the past because pilots have misread the altimeter by 10,000 feet. Learn how to interpret the altimeter pointers correctly! The most common altimeter presentation consists of *three pointers* of varying shapes and sizes:

- the pointer with a long, fine needle and a splayed tip indicates 10,000s of feet. If it is on 1 (or just past it), it is indicating 10,000 feet. This pointer is particularly easy to misread. Note that some altimeters have a very short, medium thickness 10,000 feet pointer, rather than the usual long, fine needle;

- the short, fat pointer indicates 1,000s of feet. It will move once around the dial for a change of 10,000 feet. If it is on 4 (or just past it), it is indicating 4,000 feet. To reinforce that the airplane is below 10,000 feet, a striped sector is visible which gradually becomes smaller as 10,000 feet is approached; and
- the long, medium-thickness pointer indicates 100s of feet. It will move once around the dial for each 1,000 feet change in altitude. If it is on 7, it means 7 × 100 = 700 feet.

All taken together, the altimeter shown in figure 10-15 reads 4,700 feet.

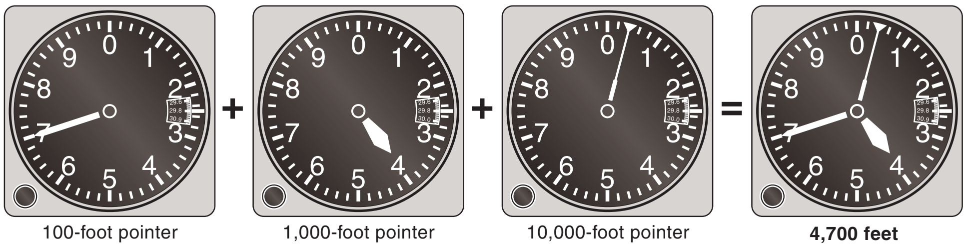


Figure 10-15 Altimeter presentation.

Check Altimeter Accuracy on the Ground

The altimeter uses air pressure to measure altitude above (or below) the reference pressure level selected in the pressure window. The only place you can check the accuracy of an altimeter is while the airplane is on the ground at an airport where the elevation is accurately known. With the local altimeter setting in the pressure window, the altimeter should indicate approximate airport elevation (to within ±75 feet).

During this check, allow for the fact that the published airport elevation is the height above MSL of the highest point on any of the usable runways. If you have any doubts about the accuracy of the altimeter, refer it to an appropriately rated repair station for evaluation and possible correction. The only place you can check the accuracy of the altimeter is on the ground at an airport where the elevation is known.

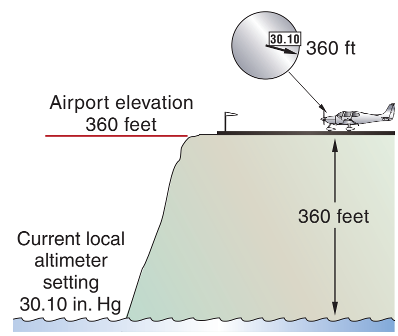


Figure 10-16
On the ground, the altimeter should read airport elevation.

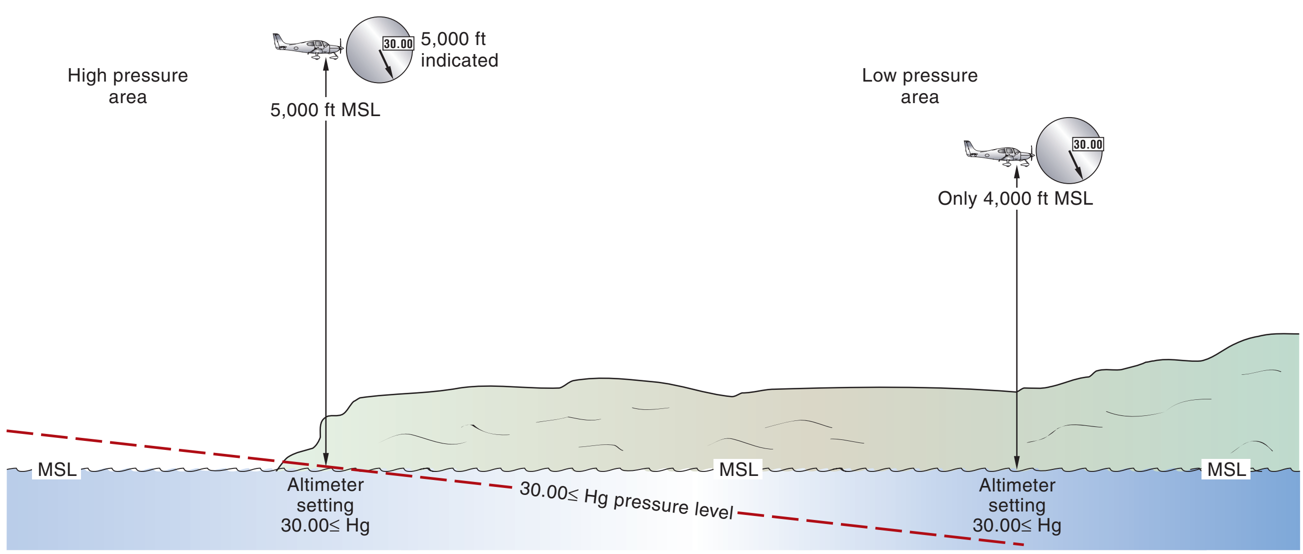


Figure 10-17 Always update your altimeter setting.

Whenever the current local altimeter setting is set in the pressure window, the altimeter will indicate the altitude—the approximate height of the airplane above MSL. This will enable the pilot to fly at an altitude that is well separated vertically both from terrain and other aircraft.

"From high to low—look out below!"

If you are flying at a constant indicated altitude from a high-pressure area toward a low-pressure area, and you neglect to set the lower altimeter settings periodically given by a local FSS or ATC, then the airplane will be gradually descending even though the altimeter reading is not changing. This could be dangerous. Remember, "From high to low look out below!"

Note. The pilot reads indicated altitude on the altimeter. For the reading to be correct, the altimeter setting must be correct.

Altimeter Errors

A number of errors are evident in altimeters.

Instrument Errors. Imperfections in the design, manufacture, installation, and maintenance of the individual altimeter will cause errors.

Instrument Lag. Because the altimeter takes a second or two to respond to rapid pressure changes, the indicated altitude will lag behind the actual altitude.

Position Error. Poor design may place the static vent in a position where the static pressure is not representative of the free atmosphere in that vicinity, resulting in an inaccurate altimeter reading.

Blockages of the Static Vent. If ice or insects (or anything) block the static vent completely, then that static pressure will remain fixed in the line to the altimeter. A constant altitude will be indicated, even though the airplane may be changing altitude.

If ice forms over the static vent on a climb-out, the altimeter will continue to read the altitude at which the static vent froze over, and not indicate the higher altitude that the airplane is actually at.

Similarly on a descent, a blocked static vent will cause the altimeter to indicate a constant altitude which is higher than the actual altitude, a dangerous situation.

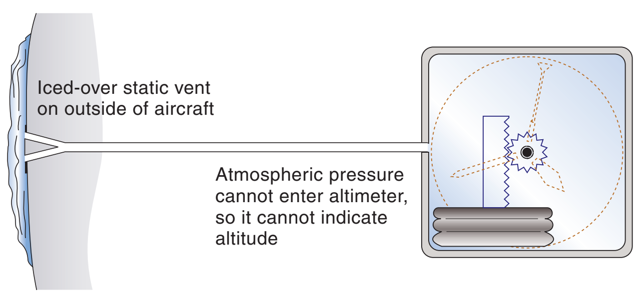


Figure 10-18 A blocked static vent—altimeter indication constant regardless of airplane altitude.

Temperature Error. The altimeter is calibrated to read the height above the pressure level selected in the pressure window as if the characteristics of the existing atmosphere (temperature, density and humidity) are identical to the International Standard Atmosphere. Since this is rarely the case, the altimeter indication will differ by some extent from the real or true altitude. Normally, this does not present a problem, since all airplanes in the one area will have their altimeters affected identically, and so vertical separation between aircraft will not be affected.

While the temperature error is of little significance for most flight operations, it may occasionally require some consideration during precision instrument approaches.

The altimeter in warmer air will read low.

In very warm air, the density will be less than standard and the pressure levels will be expanded. Therefore a given pressure level will be higher in a warm atmosphere compared with the standard atmosphere. After climbing a *true* 1,000 feet, the altimeter will sense less than 1,000 feet difference in pressure in the thinner air and will *indicate* a climb of less than 1,000 feet, and the altimeter will read low. This is easily remembered as *hi-lo* (higher temperature than standard—lower altimeter reading).

An altimeter in colder air will read high—"from high to low, look out below."

Conversely, in air colder than ISA, the altimeter will indicate higher than the airplane actually is, a hazardous situation. Remember *lo-hi* (lower temperature than standard—higher altimeter reading) or the saying "from high to low, look out below."

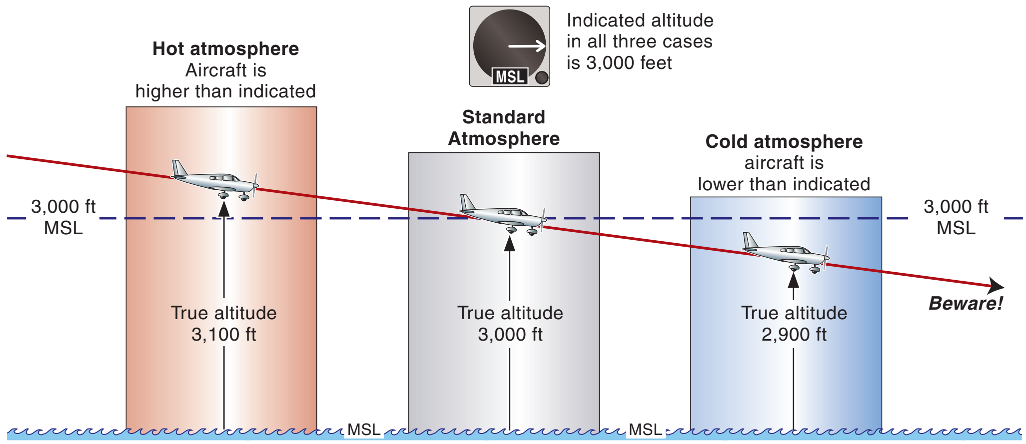


Figure 10-19 Temperature error often causes idicated altitude to differ from true altitude.

Altitude Measurement

Indicated Altitude. Indicated altitude is what you read on your altimeter when the *local altimeter setting* is set in the pressure window, as is the case when you are operating at or below 18,000 feet MSL in the United States. Indicated altitude is approximate height above MSL.

Pressure Altitude. Pressure altitude is what you read on your altimeter when *standard pressure* (*29.92 in. Hg* or *1,013.2 hPa*) is set in the pressure window, as is the case when you are operating above 18,000 feet MSL in the United States.

True Altitude. True altitude is the actual altitude above MSL, and cannot be determined in flight by the altimeter alone. It is rarely required in flight. True altitudes of airports, mountains, radio masts, and so on are measured by survey and shown on charts. The difference between indicated and true altitude is usually no more than 100 feet.

Absolute Altitude. Absolute altitude means height above ground level or *height AGL*. To determine this, you need to know both airplane altitude MSL and ground elevation.

Density Altitude. Density altitude is one means of describing air density, and is used in performance calculations. It is computed from pressure altitude and air temperature.

Encoded Altitude. Encoded altitude is not seen by the pilot, but by the radar controller—the aircraft's encoding altimeter sends altitude information to the aircraft's transponder which transmits position and altitude information to radar stations.

Vertical Speed Indicator (VSI)

Figure 10-20
VSI.

While you can form some idea of how fast you are changing altitude by comparing the altimeter against a stopwatch, the vertical speed indicator provides a direct readout of the rate of change of altitude. The VSI converts a rate of change of static pressure to a rate of change of altitude, which is expressed in hundreds of feet per minute (fpm or ft/min).

If you begin a descent, the airplane will be moving into air with a progressively increasing static pressure. The new and higher pressure at the lower level is fed directly from the static vent into a flexible capsule inside the VSI case. The same pressure is also fed into the casing that surrounds this capsule, but via a metering valve that introduces a slight delay to the increase in pressure. This means there is a small differential pressure within the instrument. The capsule therefore expands and drives a pointer around the VSI scale (graduated in fpm) to indicate a rate of descent, such as 500 fpm. It will take some seconds before a stabilized rate is indicated, because of the inherent lag in the VSI.

If the *static vent* became iced-over or *blocked*, then the two pressure areas (inside the capsule and surrounding it) would equalize and the VSI would read zero, even though the airplane's altitude might be changing.

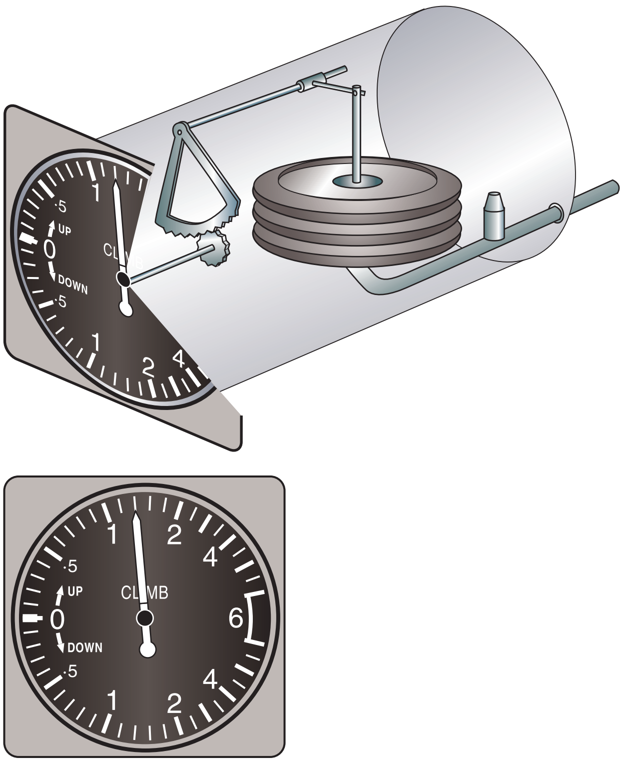


Figure 10-21 The vertical speed indicator.

Gyroscopic Instruments

Gyroscopes

A gyroscope is basically a rotating wheel, mounted so that its axis is free to move in one or more directions. A characteristic of rotating masses, such as gyroscopes, is their tendency to maintain their original alignment in space despite what goes on around them, a property referred to as *rigidity in space*. This means that a gyro is able to remain stable in space while the airplane in which it is mounted moves around it. Gyroscopes are therefore useful as the basis for indicators that show direction and attitude.

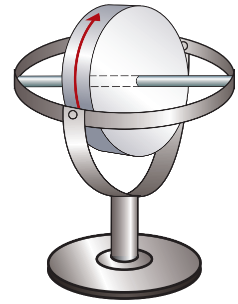


Figure 10-22
Gyroscopes are rotating masses.

The degree of rigidity of a gyroscope depends on the mass of the rotor, the speed at which it is rotating, and the radius at which the mass is concentrated. A large mass concentrated near the rim and rotating at high speed provides the greatest directional rigidity.

A gyroscope has another characteristic called *precession*. If a force is applied to the gyroscope, the change in direction brought about by the force is not in line with the force, but is displaced 90° in the direction of rotation. This gyroscopic effect is quite common (you use it every time you lean your bicycle over to turn a corner).

There are various ways of mounting a gyroscope on one or more axis of rotation (*gimbals*), depending on the information required from that gyroscopic instrument. Gyroscopes are used in the turn coordinator/turn indicator, the attitude indicator and the heading indicator.

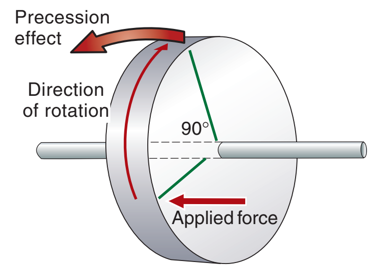


Figure 10-23
Gyroscopic precession.

Vacuum-Driven Gyroscopes

Many gyroscopes are operated by a vacuum system which draws high-speed air through a nozzle and directs it at the gyro rotor blades. A vacuum pump that draws air through is generally preferable to a pressure pump that blows air through, since the air may pick up contaminants such as oil from the pressure pump which could affect the very sensitive rotor.

The amount of suction is shown on a gauge in the cockpit and is approximately 4.5 to 5.4 inches of mercury, which is 4.5 to 5.4 in. Hg *below* atmospheric pressure. If the *numerical* vacuum reading is too small, the airflow will be reduced, the rotor(s) will not be up-to-speed, and the gyros will be unstable or will only respond slowly. If the numerical vacuum reading is too high, the gyro rotors may spin too fast and be damaged.

The vacuum in most airplanes is provided by an engine-driven vacuum pump, but some older airplanes may have the vacuum provided by an externally mounted venturi-tube (making the gyroscopic instruments unusable until after several minutes at flying speed following takeoff).

Figure 10-24
Suction (vacuum) gauge.

Electrically Driven Gyroscopes

When the electrical master switch first goes on, you will probably hear the electrically driven gyroscope(s) start to spin up. They should self-erect and red power-failure warning flags (if provided on the instrument face) should disappear.

If the master switch is left on, when the engine is shut down on the ground, these instruments will be drawing power from the battery and the battery will gradually discharge. So ensure that there is no power to the electrically driven gyroscopes when leaving the airplane for any length of time.

Errors in Gyroscopic Instruments

If the gyroscope is not up-to-speed, the instrument may indicate erratically, respond only slowly to changes in attitude and/or heading, or indicate incorrectly.

Check for a *red power-failure warning flag* on *electrically driven* instruments, and check for correct *suction* on *vacuum-driven* instruments. In many airplanes the attitude indicator and the heading indicator are driven by suction, but the turn coordinator is driven electrically. This guards against the loss of all three instruments simultaneously.

Check that the heading indicator is aligned with the magnetic compass during steady straight-and-level flight. Check that the attitude indicator, if it has a caging (locking) device, has been uncaged. Do this in steady straight-and-level flight or in a level attitude on the ground.

Turn Coordinator/Turn Indicator

Figure 10-25
Turn coordinator.

The turn coordinator and turn indicator both use *rate* or *tied gyros*. The rotating mass has freedom to move about two of its three axes and is designed to show the rate of movement of the airplane about the third axis (in this case turning about the vertical axis). This rate of movement is indicated in the cockpit on one of two possible types of presentation—either a *turn coordinator* (which has a symbolic airplane), or a *turn indicator* (which has a vertical needle or "bat").

Both the turn coordinator and turn indicator show the airplane's *rate of turn*, which is not bank angle. However, because the gyro in the turn coordinator is mounted slightly differently to that in the turn indicator, the *turn coordinator* will also show *roll rate*. It will respond when an airplane banks, even before the turn actually commences. Note that the symbolic airplane on the turn coordinator (even though it resembles that on an attitude indicator) does not give pitch information.

If the airplane is turning to the left, the gyroscope will experience a turning force, (see figure 10-27). However this force will precess through a further 90° in the direction of rotation and will cause the gyro to tilt. The greater the turning force, the greater the tendency to tilt.

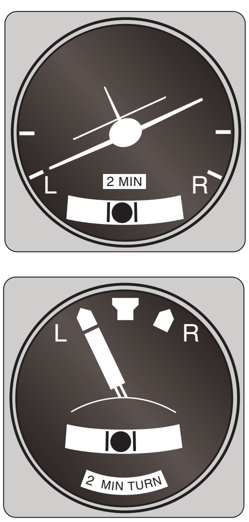


Figure 10-26
The modern turn coordinator (top), and the older turn indicator, each indicating standard-rate turns to the left.

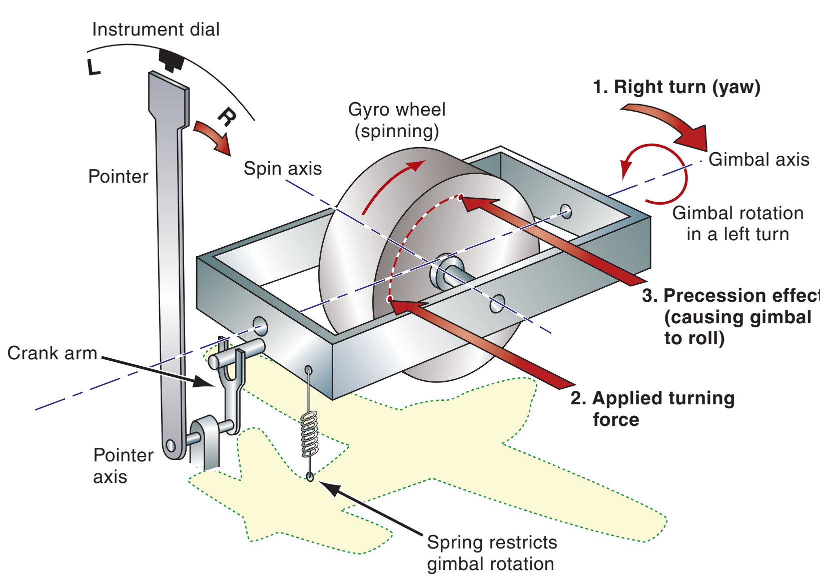


Figure 10-27 Workings of the turn indicator.

The tilting of the gyroscope stretches a spring, which makes the gyro precess with the airplane turn until the rates match up, when further tilt ceases. A pointer moved by the action of the gimbal tilting indicates the rate of turn against a scale. The scale is graduated to show a *standard-rate* turn of 3° per second. You can check the accuracy of the turn indicator by timing yourself through a steady indicated standard rate turn of 180° and see if it takes 60 seconds (3° per second).

The gyroscope may be rotated at high speed by an electric motor, or it may be spun by a small jet of air generated by a vacuum system, and directed at small "buckets" cut into the edge of the gyro wheel. Preflight checks for the serviceability of the turn coordinator should include:

- a check of the gyro rotation speed (whirring sound and no failure flags if electrically driven, correct vacuum if pressure-driven); and
- correct indications in a turn while taxiing ("turning left, skidding right—turning right, skidding left"), and, if in any doubt, a timed turn in flight.

Attitude Indicator (AI)

As the airplane changes its attitude, the *earth gyro* that is the basis of the attitude indicator (AI) retains its alignment (rigidity) at right angles to the earth's surface. This means that the airplane moves around the gyro rotor of the attitude indicator which has a vertical spin axis. Attached to the gyroscope is a picture of the horizon, around which the airplane (and the instrument panel) moves. The attitude of the airplane relative to the real horizon is symbolized by the artificial horizon line attached to the gyro and a small symbolic airplane attached to the instrument dial. This small model airplane is referred to as the miniature airplane or index airplane.

Figure 10-28
Attitude indicator.

The attitude indicator shows *pitch attitude* and *bank angle*. Pitch attitude is indicated by the position of the center dot of the miniature airplane relative to the artificial horizon. Bank attitude is indicated by the relationship of the wings of the miniature airplane to the artificial horizon.

The AI shows a picture of the airplane's attitude, but tells you nothing about the performance of the airplane. For instance, a nose-high attitude could occur in a steep climb or in a stalled descent—to know the performance of the airplane you need to refer to the airspeed indicator, altimeter, and vertical speed indicator.

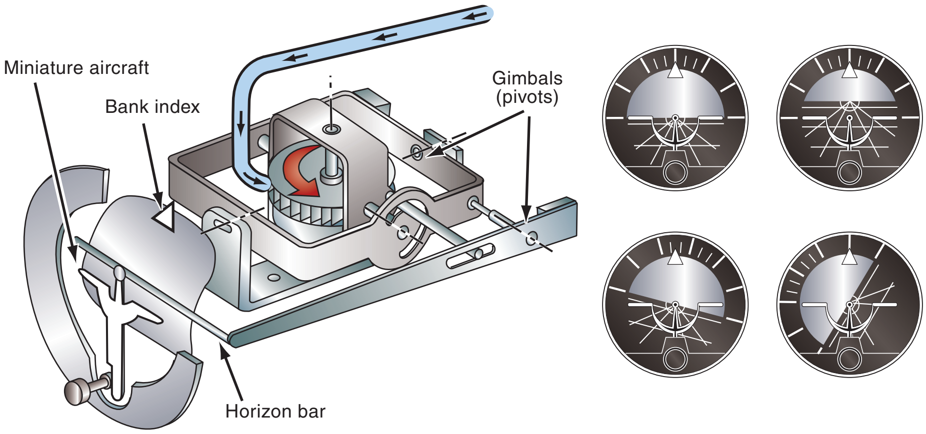


Figure 10-29 The attitude indicator displays pitch attitude and bank angle.

You should always check the power source of the attitude gyro. Some attitude indicators, especially the vacuum-driven ones, have limits of pitch and bank which, if exceeded, may cause the gyro to tumble and give erroneous readings. The miniature airplane should be aligned with the artificial horizon on the instrument when the airplane is in straight-and-level flight or on the ground. The small knob at the base of the AI adjusts the miniature airplane alignment. Some older types of gyroscope need to be caged when not being used. The attitude indicator is also called the *artificial horizon* and *gyro horizon*.

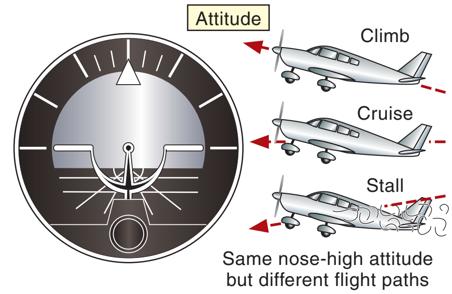


Figure 10-30
Pitch attitude displayed on the AI does not reflect climb/descent performance.

Heading Indicator (HI)

Figure 10-31
The heading indicator.

The magnetic compass is the primary indicator of direction in most airplanes. It is, however, difficult to read in turbulence and subject to acceleration and turning errors, making it a difficult instrument to fly by accurately. The heading indicator (HI) is a gyroscopic instrument that you should keep aligned with the magnetic compass in flight. Although it takes its directional reference from the compass, it is not subject to the same acceleration and turning errors. This makes accurate turns and a constant heading possible.

There are mechanical factors present in the HI (mainly friction) that will cause it to drift off its original alignment with magnetic north because of gyroscopic precession. This is called mechanical drift. In addition, because the airplane is flying over a rotating earth, a line in space from the airplane to north will steadily change. This causes apparent drift. Both mechanical and apparent drift can be corrected by simply realigning the HI with the magnetic compass periodically, as described below.

You should check the power source of the HI prior to flight and, when taxiing, check the correct turn indications on the HI ("turning right, heading increases—turning left, heading decreases"). The HI has a *slaving knob* that enables the pilot to realign the HI with the magnetic compass, correcting for both mechanical drift and apparent drift. This should be done every 10 or 15 minutes. Some older heading indicators have to be uncaged after realigning with the magnetic compass. Advanced airplanes have HI gyros that are aligned automatically.

Manually Aligning HI with Magnetic Compass

To manually align the heading indicator with the magnetic compass:

- choose a reference point directly ahead of the airplane, aim for it and fly steadily straight-and-level;
- keep the nose precisely on the reference point, and then read the magnetic compass heading (when the compass is steady);
- maintain the airplane's heading toward the reference point and then refer to the HI, adjusting its reading (if necessary) to that taken from the magnetic compass; and
- check that the airplane has remained steadily heading toward the reference point during the operation (if not, repeat the procedure).

Coordination Ball or Inclinometer

The coordination ball is a simple device that is usually incorporated into the turn coordinator/turn indicator. It is a useful mechanical device that indicates the direction of the g-forces—the combined effect of the earth's gravity force and any turning force. It has no power source. It is also known as the inclinometer, the slip-skid indicator, the balance ball, or the coordination ball.

The coordination ball is simply a small ball, free to move like a pendulum bob, except that it moves in a curved cylinder filled with damping fluid. In straight flight it should appear at the lowest point in the curved cylinder (like a pendulum bob hanging straight down), and the airplane is said to be coordinated, or in balance.

In a *skid*, the ball will move to one side in the same way as a pendulum bob would swing out, and you will feel a force pushing you outward. In a *slip*, the ball will fall to one side, and you will feel as if you are falling inward.

In a coordinated turn, you will feel no sideways forces, nor will the ball, which should remain centered. Any sideways force (either a *slip* in toward the turn or a *skid* out away from the turn) will be shown by the coordination ball and felt by you.

If the ball is out to the right, apply right rudder pressure to center it. Use same-side rudder pressure to center the ball. Some instructors say, "Step on the ball."

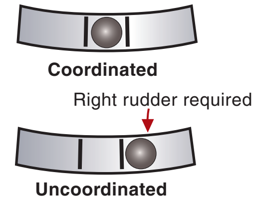


Figure 10-32
The coordination ball.

Figure 10-33
The coordination ball.

For coordinated flight, "Step on the ball."

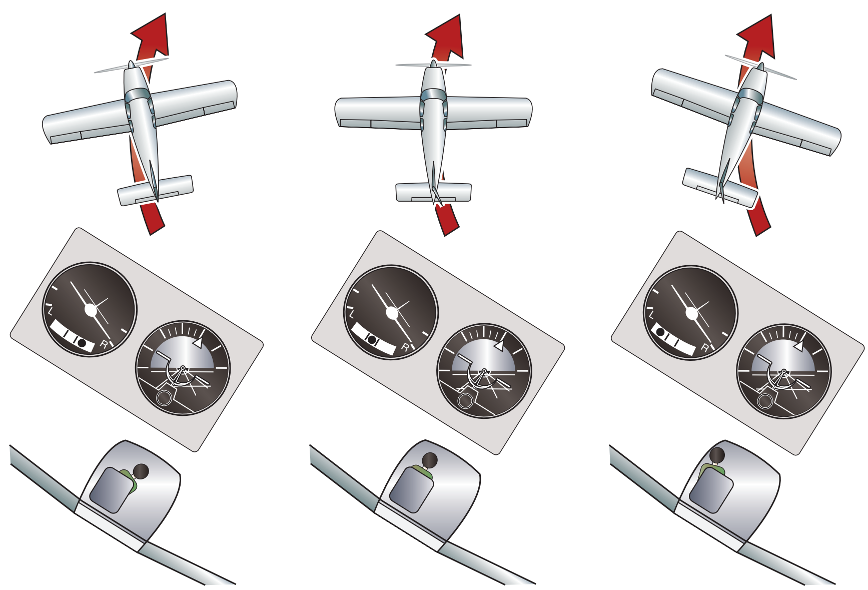


Figure 10-34 Slipping turn; more right rudder required (left). A comfortable and coordinated turn (center). A skidding turn (right).

Figure 10-35 Magnetic compass.

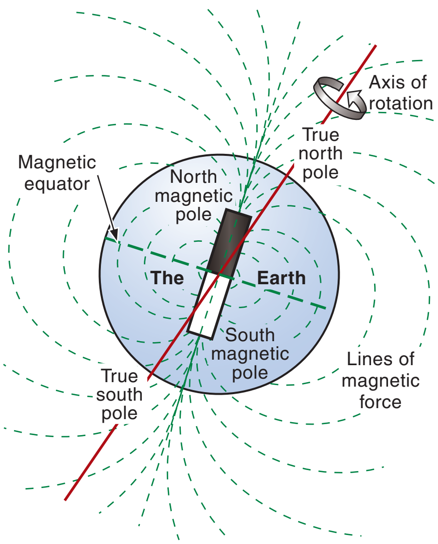


Figure 10-36
The earth has a magnetic field.

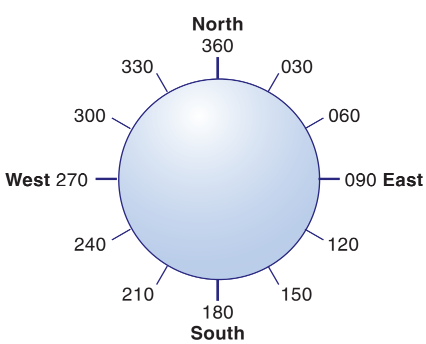


Figure 10-37 Direction.

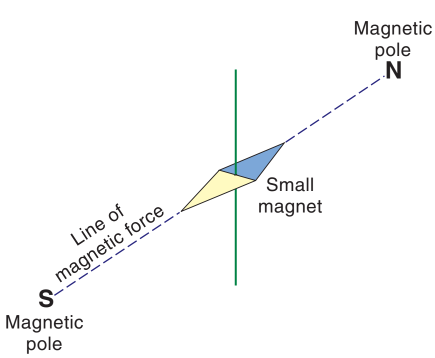


Figure 10-38 A simple bar magnet.

The Magnetic Compass

In most light airplanes, the magnetic compass is the primary source of direction information to which other direction indicators are aligned. In steady straight-and-level flight, the reference line of the magnetic compass indicates the *magnetic heading* of the airplane. Magnetic compass readings will not be accurate while the airplane is accelerating or turning, or when entering a climb or descent, nor will they be accurate if magnetic objects are placed near the compass.

The Earth's Magnetic Field

The earth acts like a very large and weak magnet. The surface of the earth is surrounded by a weak magnetic field, consisting of lines of magnetic force that begin deep within the earth near Hudson Bay in Canada and flow toward a point deep within the earth near South Victoria Land in Antarctica.

Because of their proximity to the north and south geographical poles which are known as *true north pole* and *true south pole*, the magnetic poles are referred to as the *north magnetic pole* and the *south magnetic pole*.

Direction

There are two common ways to describe direction: using the cardinal points of north, south, east, and west; or by using a graduated circle of 360 degrees going clockwise from true or magnetic north.

Direction is almost always expressed as a three-figure group such as 251, 340, or 020. The only exception is runway direction, where the numbers are rounded off to the nearest 10°. A runway bearing 247° magnetic would be referred to as RWY 25, and its reciprocal, bearing 067°M, would be RWY 7.

A bar magnet that is freely suspended horizontally will swing so that its axis points roughly north-south. The end of the magnet that points toward the earth's *north magnetic pole* is called the north-seeking pole of the magnet.

Magnetic Variation

The latitude-longitude grid shown on charts is based on *true* north and *true* south. Our small compass magnet, however, does not point exactly at true north but at the north magnetic pole. The angular difference between true north and magnetic north at any particular point on the earth is called *variation*. If the magnet points slightly east of true north, then the variation is said to be east. If the compass points to the west of true north, then the variation is west. Magnetic variation is the same for all aircraft in a given vicinity.

Isogonic Lines

On charts, as well as the lines forming the latitude-longitude grid, there are dashed lines joining places that have the same magnetic variation, known as *isogonic lines* or *isogonals*.

For example, the 10° east isogonic line is drawn through all the places having a variation of 10°E. If you are anywhere on this line, magnetic north will be 10° east of true north. As you can see from the left inset in figure 10-39, a magnetic heading of 105° will correspond to a true heading of 115°. The line joining places where the variation is zero is called the *agonic line*.

Two easy ways to remember the relationship between true and magnetic are:

- "variation east, magnetic least; variation west, magnetic best"; and
- "east is least; west is best."

Variation east, magnetic least;
variation west, magnetic best.

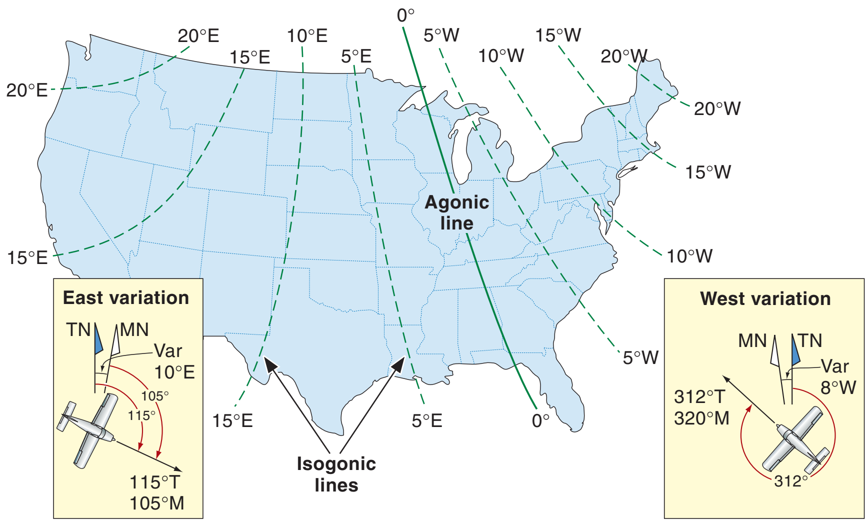


Figure 10-39 Variation is the angle between true and magnetic; isogonic lines join places of equal magnetic variation.

Example 10-1

If the magnetic variation in your area is 10° east and your airplane is heading 295 on the magnetic compass, what is your true heading?

Variation east, magnetic least: so 295°M is 295 + 10 = 305° true.

Example 10-2

If your compass indicates due east, and the magnetic variation where you are is 4° west, what is your heading related to true north?

Variation west, magnetic best: so 090 – 4 = 086° true.

Deviation

Unfortunately, the magnet in each compass is affected not only by the magnetic field of the earth, but also by any other magnetic field it is exposed to. Metal airframe components, the rotating parts of an engine, and electrical equipment all generate their own magnetic fields. The combined effect of these fields in a particular airplane on its magnetic compass is called *deviation*. Deviation causes the compass to deviate, or deflect, from precisely indicating magnetic north. The precise deviation can only be established once the compass is installed in the particular airplane, and test measurements made with the airplane on different headings.

In each airplane is a small placard, known as the *deviation card*, which shows the pilot the corrections to be made to the compass reading to obtain the magnetic direction. This correction usually involves only a few degrees and is an easy mental calculation to do in flight.

DEVIATION CARD

FOR	N	30	60	E	120	150
STEER	001	031	060	089	118	149
FOR	S	210	240	W	300	330
STEER	181	213	242	271	301	330

ON [X] RADIOS [ ] NO

Figure 10-40 Deviation card.

Do not place these cockpit items near the magnetic compass: headphones, ferrous metals, portable radios, calculators, or books with metal binders

The deviation card is filled out by a mechanic to reflect the deviation present when the compass was tested. If any other magnetic influences are introduced into the airplane at a later time, they will not be allowed for, even though they may significantly affect the compass. Therefore, ensure that no metal or magnetic materials are placed anywhere near the compass. Many pilots have become lost as a result of random deviations in the compass readings caused by these extraneous magnetic fields.

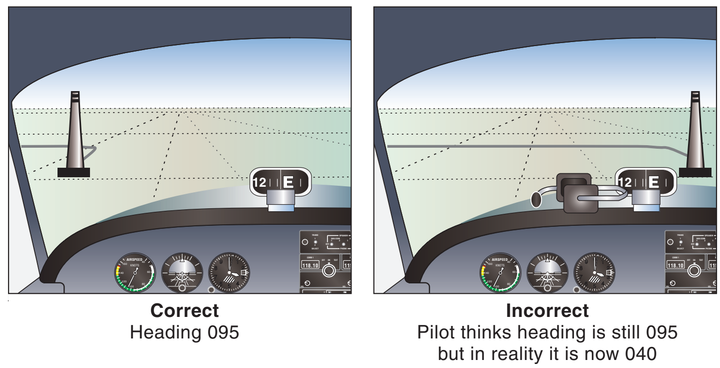


Figure 10-41 Keep foreign objects away from the magnetic compass.

Compass Construction and Serviceability

The modern airplane has a direct-reading compass, usually filled with a liquid in which a float partially supporting a bar magnet is pivoted. The liquid supports some of the weight, decreases the friction on the pivot and, most importantly, dampens the oscillations of the magnet and float during flight. This allows the compass to give a steadier indication and makes it easier to read.

Attached to the pivot is the combined magnet and compass card. The compass card is graduated in degrees and can be read against a reference line which is attached to the bowl of the compass, and therefore to the rest of the airplane. Remember that it is the airplane that turns around the magnet, while the magnet continues to point to magnetic north at all times.

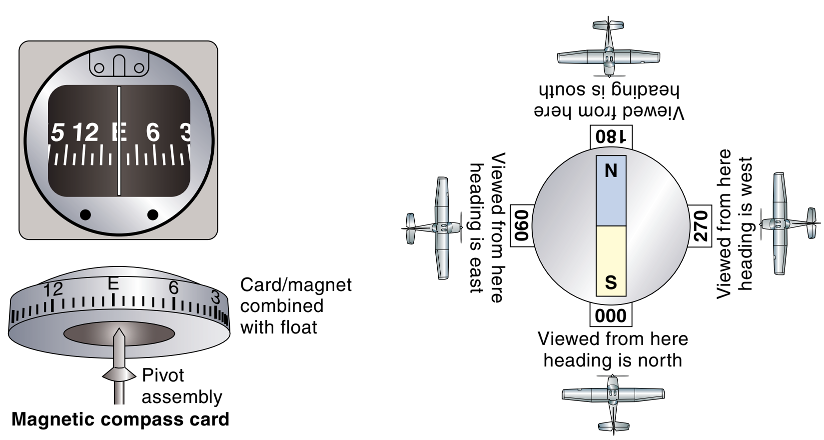


Figure 10-42 The magnetic compass.

Pilot Serviceability Checks

During preflight, you should check that the compass is securely installed and can be easily read. The liquid in which the magnet is suspended should be free of bubbles and should not be discolored. The glass should not be broken, cracked or discolored, and it should be secure. Then locate the position of the compass deviation card in the cockpit.

When you are taxiing out prior to takeoff, check the compass is working correctly by turning the airplane left and right and note the response of the magnet. In addition, before takeoff cross-check the compass reading with the runway direction. Runway 18 will point approximately 180° magnetic.

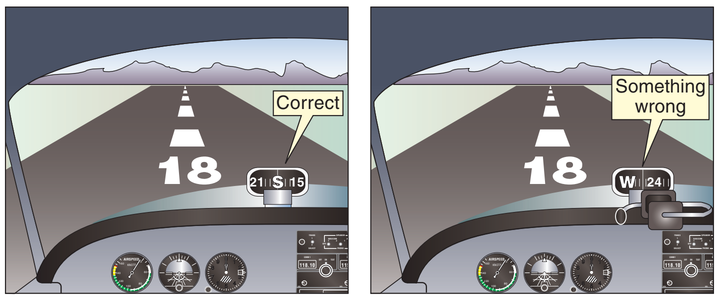


Figure 10-43 Always cross-check compass direction.

Magnetic Dip and Compass Errors

Near the magnetic equator, the lines of magnetic force are parallel to the surface of the earth. As the magnetic poles are approached, the lines of magnetic force dip toward them and any magnet bar will also try to dip down and align itself with these lines of force. The angle of dip, called *magnetic dip*, is approximately 70° in the United States. Magnetic dip is zero at the magnetic equator and increases to 90° at the magnetic poles.

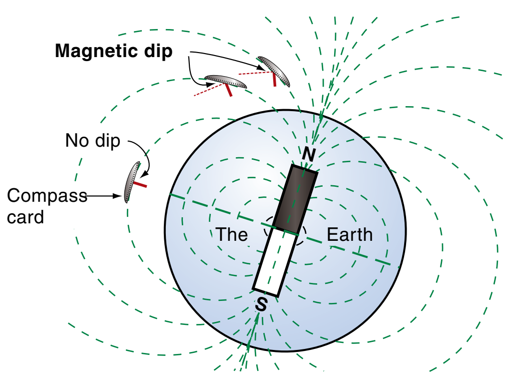


Figure 10-44 Magnetic dip is strongest nearest the poles.

Magnetic Dip Effect

The earth's *magnetic field* can be resolved into two components: a horizontal one parallel to the surface of the earth (which is used to align the compass with magnetic north), and a vertical component, which causes the compass magnet to dip down.

At the magnetic equator, the horizontal component of the earth's magnetic field is at its strongest and so the magnetic compass is very stable and accurate.

However, at higher latitudes, the horizontal component parallel to the surface of the earth is weaker, making the compass magnet less effective as an indicator of horizontal direction. At latitudes higher than 60° north or south, the magnetic compass is not very reliable.

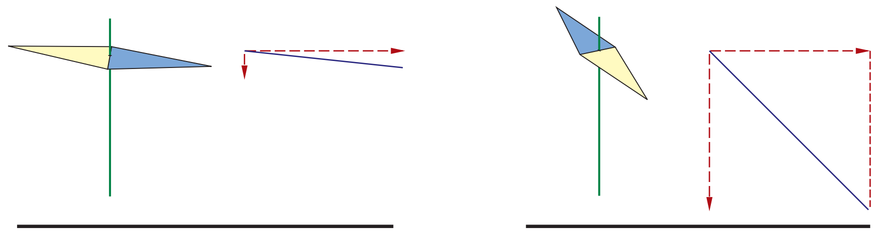


Figure 10-45 Dip is caused by the vertical component of the earth's magnetic field.

Compass Design to Minimize Dip Effect

To keep the magnet as close to horizontal as possible, the airplane compass is cleverly designed so that the point from which the magnet is suspended is well above its center of gravity. As the magnet aligns itself with the earth's magnetic field, the more it tries to dip down, the further out its center of gravity is displaced. This sets up a balancing couple which reduces the remaining dip, which is known as residual dip, to less than 5° from the horizontal.

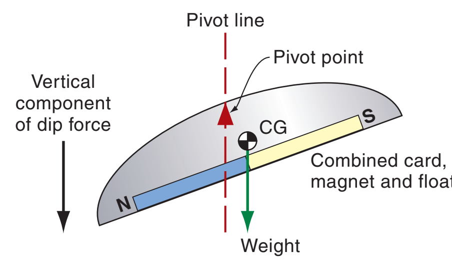


Figure 10-46 Magnet suspension.

Acceleration Errors

If you change airspeed, either by accelerating or decelerating, transient indication errors occur with a magnetic compass, especially on easterly and westerly headings. They disappear after the speed stabilizes.

As the airplane accelerates, it takes the compass and the pivot along with it. The compass magnet, being suspended like a pendulum, is left behind because of its inertia. Its weight, not being directly under the pivot, will cause the compass magnet to swing away from the correct magnetic direction as the pivot accelerates away. The compass card attached to the magnet rotates a little and indicates a new direction, even though there has been no change in direction.

Once a new steady speed is maintained, the magnet will settle down and the compass will read correctly once again.

Accelerating East or West

Accelerating toward the east or west, the center of gravity of the magnet, near the south-seeking end, is left behind. This swings the compass card so that it indicates an *apparent turn to the north*. After acceleration is completed you should allow the compass to settle down before adjusting the airplane heading (if necessary).

Decelerating East or West

Decelerating toward the east or west, the pivot slows down with the rest of the airplane and the center of gravity of the magnet, because of its inertia, tries to advance. The compass card rotates to indicate an *apparent turn to the south*.

Accelerating North and South

Accelerating and decelerating (toward the north or south) will *not* cause apparent turns, because the pivot and the CG of the magnet will lie in the same N-S line as the acceleration or deceleration. On other headings, the acceleration errors will be greater the closer you are to due east or west.

> **Note.** These effects are valid only for the Northern Hemisphere. In the Southern Hemisphere, the effects are reversed. Also, the closer to the magnetic poles you are, the greater the effect because the dip is greater. Magnetic dip is the major source of compass indication errors.

Remember: acceleration and deceleration errors on easterly and westerly headings in the Northern Hemisphere may be summarized by the mnemonic "A N D S." Accelerate—apparent turn North; Decelerate—apparent turn South. The situation in the Southern Hemisphere is reversed.

When accelerating or decelerating on an easterly or westerly heading, use: "A N D S:" Accelerate—apparent turn North; Decelerate—apparent turn South.

Turning Errors

Turning is also an acceleration, because of the change in direction. In a turn, a centripetal force acts on the compass pivot, which is attached to the airplane, and accelerates it toward the center of the turn. The compass magnet (and compass card), being suspended like a pendulum, is left behind because of inertia. This leads to a transient error in the direction indicated by the compass, which will gradually disappear after the wings have been leveled. The result is that when turning through north the compass lags behind.

Turning Through North

For example, when turning from 310° to 040° you should level the wings at about 020°, before reaching 040°. This is because once the airplane stops turning the compass reading will continue rotating for a few seconds because of the lag.

Turning Through South

When turning through south the compass heading turns ahead of the airplane. If you turn from 130° to 210° you should level the wings at about 230°. Once the compass settles down it should read 210°.

Remember: Turning errors of the magnetic compass may be summarized by the mnemonic "U N O S:" Undershoot heading through North; Overshoot heading through South.

When turning onto a heading use: "U N O S:" Undershoot heading through North; Overshoot heading through South.

> **Note.** Do not align the heading indicator with the magnetic compass if you are changing speed or direction, or entering a climb or descent, as the magnetic compass will be experiencing acceleration or turning errors. When aligning the heading indicator with the compass keep the wings level and maintain a constant speed.

One of the advantages of a heading indicator is that it is *not* subject to turning or acceleration errors. However its accuracy depends on it being correctly aligned with magnetic north.

A magnetic compass only reads accurately in straight unaccelerated flight.

Glass Cockpit Flight Instruments

The Primary Flight Display (PFD) combines the information of all the flight instruments onto one computer screen, but the information supplied to the computer must still come from standard sources. This is especially true with the pitot-static system.

Figure 10-47 Conventional steam gauge flight instruments.

Figure 10-48 Glass cockpit PFD depiction of flight instruments.

In order for the information to be presented on the PFD it must be processed and interpreted electronically. The computerized PFD still has a Pitot-Static system as described earlier in this chapter. The pitot tube still collects ram air and the static ports still collect static air pressure just as they do with round dials. Yet the air in the pitot and static lines do not go to the back of the instrument, instead they go to an air data computer. The air data computer calculates the speed of the air from the pitot line and the pressure of the air from the static line and presents that information electronically on the PFD. The air data computer also calculates the change in pressure as the airplane climbs or descends and presents that information as an electronic vertical speed indicator, complete with the same lag time that a round mechanical VSI would have.

The air data computer also collects outside air temperature data and uses that to calculate true airspeed. Finally the air data computer passes on the altitude information to the Mode C transponder so ATC can also see the airplane's altitude on their RADAR screens. FAA certification of glass cockpits also requires the installation of several round mechanical instruments as back-ups. The traditional airspeed indicator and altimeter, run through the standard pitot-static system is still required.

Primary Flight Display and Gyroscopic Instruments

The traditional attitude gyro, heading indicator and turn coordinator display information taken from spinning mechanical gyroscopes as described earlier in this chapter. These gyroscopes turn with either air pressure, as in a vacuum-driven system, or as an electric motor. In either case there is an actual gyro spinning inside the round mechanical instrument. Glass cockpit airplanes are still required to have a mechanical attitude gyro and standard magnetic compass. The attitude gyro, used as a back-up, is normally an electric spinning gyro and the magnetic compass still determines direction by the Earth's magnetic field.

AHRS

The major leap in technology that is seen on the PFD is contained in the electronic attitude and heading indicators. The system does not use actual spinning gyroscopes. Instead it uses an electronic gyro called a laser ring gyro.

The laser ring gyro device is by itself not new. Position has been determined using this device in accelerometers for years, however cost was prohibitive for light aircraft. The bottom of the line accelerometer would cost about $75,000 each. The reason the cost dropped to a manageable level was largely due to the Global Positioning System (GPS).

When computer programmers were able to combine information from a laser ring gyro with GPS position information and a magnetometer, the results became an affordable attitude heading and reference system or AHRS. It was the invention of a low-cost replacement to mechanical gyros, like AHRS, that made the explosion of technology in general aviation aircraft possible.

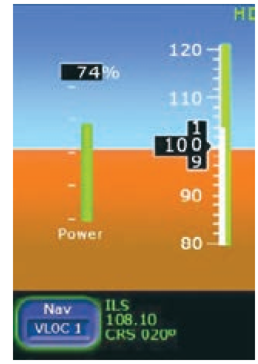


Figure 10-49
Glass cockpit PFD airspeed indicator.

Figure 10-50
Glass cockpit PFD altimeter.

Figure 10-52
Glass cockpit PFD heading indicator.

Laser Ring Gyro

The laser ring gyro has no moving parts and works on what is called the Sagnac effect. In the early part of the 1900's a French physicist named G. Sagnac discovered that two beams of light traveling in opposite directions, but on a closed course, would take different travel times, if the device was rotated.

It was not until the laser beam was invented in the 1960's that Sagnac's discovery found a practical use and it was first used in aircraft with the introduction of the Boeing 757. Two laser lights are pointed in opposite directions each toward a mirror. The angle of the mirrors deflects the light toward a receiver. The path that the light takes is actually not a round ring, but a triangle (see figure 10-53). If the device has no motion, the laser light is emitted in opposite directions will both hit the angled mirror and both arrive at the receiver at the exact same time.

The receiver does not measure the time it takes for the laser beams to arrive, instead it measures the frequency of the light when it arrives. What Sagnac discovered is that if the device is rotated, the beam that is traveling in the same direction as the rotation will have a lower frequency and the beam that is traveling away from the rotation will arrive at the receiver with a higher frequency.

Figure 10-51
Glass cockpit PFD VSI.

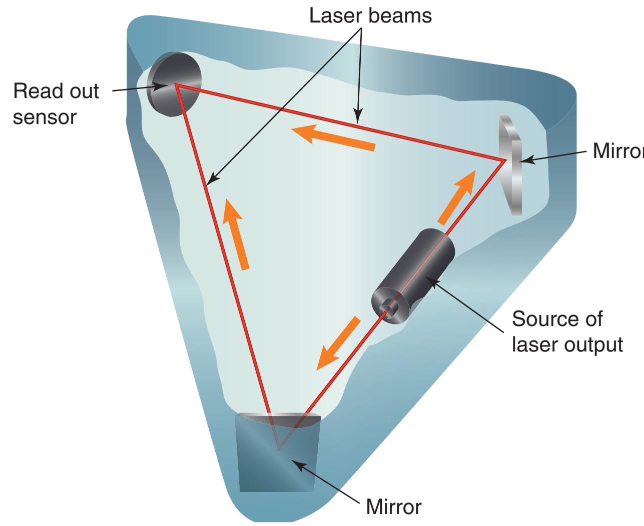


Figure 10-53 Glass cockpit PFD Laser ring gyro.

The laser ring gyro calculates the difference in frequencies between the two beams and from that determines that direction and magnitude of the motion. The platform that the laser ring gyro is mounted is the airplane itself, so whenever the airplane moves, the laser ring gyro can determine which direction it moved and just how fast it moved. The position, as determined by the laser ring gyro, is then confirmed by GPS and the magnetometer.

The AHRS takes all this information and displays it on the PFD.

Magnetometer

The regulations require that all aircraft have a Magnetic Compass.,The magnets of this compass float in a fluid and is susceptible to all kinds of errors as discussed earlier in this chapter. The magnetometer solves these problems.

The magnetometer still uses the earth's magnetic field for information, but translates that information electronically to the AHRS. The magnetometer continually updates the direction that the airplane is facing and since laser ring gyros have no precession the pilot never has to reset the heading indicator. The magnetometer is installed as far away from other electronics as possible, usually in a wing. Be careful not to use magnetized tools when working on or around the magnetometer.

Review 10

Flight Instruments

Pressure Instruments

1. How is static pressure measured?
2. What does the pitot tube collect?
3. Why are electrical pitot heaters fitted in airplanes?
4. What does the VSI measure?
5. Which pressure(s) does the ASI use?
6. The pitot tube/static vent provides total or impact pressure for which instrument(s)?
7. Will the altimeter be affected if the pitot tube becomes clogged, but the static vents remain clear?
8. Will the airspeed indicator be affected if the pitot tube becomes clogged, but the static vents remain clear?
9. Which instrument(s) will be affected if the static vents become clogged?
10. If a static vent ices over, what will the altimeter show during a climb?
11. What color arc on the ASI indicates the following:
    - **a.** the caution airspeed range of an airplane?
    - **b.** the normal-operating airspeed range of an airplane?
    - **c.** the normal flap-operating range of an airplane?
12. Which color on the ASI identifies the never-exceed speed?
13. Which color on the ASI identifies the power-off stalling speed with wing flaps and landing gear in the landing configuration?
14. With wings-level and full flaps extended, what is stall speed indicated as on the ASI?
15. Where is stall speed, with wings-level and no flaps extended, indicated on the ASI?
16. Is it permissible to fly at speeds in the yellow caution range in smooth air?
17. True or false? The maximum flaps-extended speed corresponds to the high-speed end of the green arc.
18. Is the altimeter a pressure instrument?

Refer to figure 10-54 for questions 19 to 21.

19. What is the caution range of the airplane?
20. What is the full flap operating range for the airplane?
21. What is the maximum flaps-extended speed?

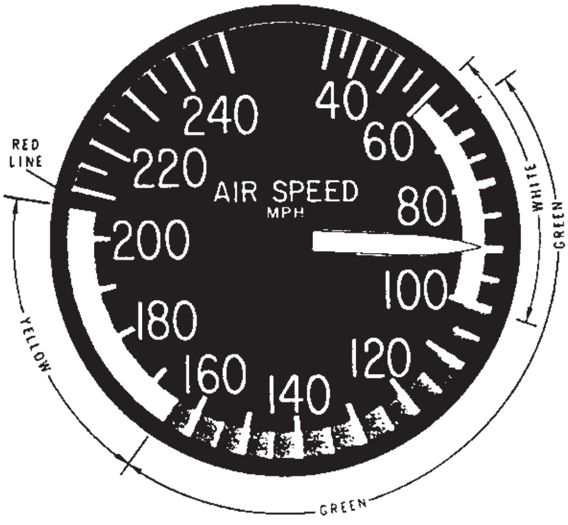


Figure 10-54 Airspeed indicator.

22. What is standard MSL pressure? Give your answer in both in. Hg. and hectopascals.
23. If 30.05 is set in the pressure window, what will the altimeter indicate when the airplane is in flight?
24. If the current altimeter setting is set in the pressure window, what will the altimeter indicate when the airplane is in flight?
25. If the current airport altimeter setting is set in the pressure window, what will the altimeter indicate when the airplane is on the runway?
26. What is absolute altitude?
27. What is density altitude?
28. What must you set in the pressure window of the altimeter prior to takeoff and landing?
29. What is usually set in the pressure window when cruising below 18,000 feet in the United States? Explain why this is done.

Refer to figure 10-55 for question 30.

30. What is the altitude depicted by:
a. altimeter A?
b. altimeter B?
c. altimeter C?

31. You are departing from an airport where you cannot obtain an altimeter setting. You should:
a. set 29.92 in. Hg in the pressure window of the altimeter.
b. set the altimeter to read field elevation.
c. set the altimeter to read zero.

32. If a pilot changes the altimeter setting from 30.11 to 29.96, what is the approximate change in indication?

33. You change the setting in the pressure window of an altimeter from 29.92 to 29.98. What will happen to the indicated altitude?

34. The current altimeter setting is 30.32 in. Hg. If an airplane is flying at an altitude of 6,500 feet MSL, what is its approximate pressure altitude?

35. What does a cruising level of FL230 signify?

36. True or false? If you fly from an area of high pressure into an area of low pressure without adjusting the altimeter setting while maintaining a constant indicated altitude, the airplane will be at the indicated altitude.

37. On warmer than standard days, the pressure and density levels are raised. What effect does this have on the indicated altitude in relation to true altitude?

38. What conditions are required for the pressure altitude to be equal to the true altitude?

39. Under what conditions will true altitude be higher than indicated altitude?

40. True or false? The altimeter will indicate a lower altitude than actually flown (true altitude) when the air temperature is lower than standard.

41. If the outside air temperature increases during a flight at constant power and at a constant indicated altitude, what will happen to the true altitude?

42. What does an encoding altimeter send electronic altitude information to?

Gyroscopic Instruments

43. Is the miniature airplane of an AI adjustable?

44. During a turn to the left, where will the left wing of the miniature airplane appear in relation to the horizon bar of the AI?

45. What sort of information does the turn indicator give?

46. What sort of information does the turn coordinator give?

47. Does the turn coordinator gives pitch information?

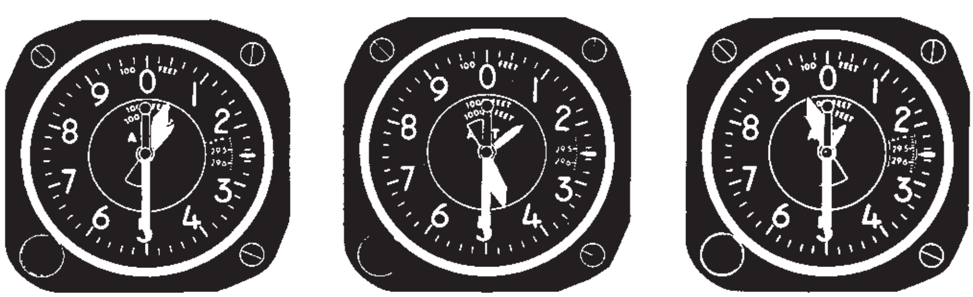
48. Most turn coordinators have markings to indicate a standard-rate turn left or right. What is standard rate (° per second)?

49. What should the gyroscopic heading indicator be regularly realigned with?

50. The vacuum pump operates which instruments?

51. Slip or skid is indicated on which instrument?

52. Failure of the electrical supply to an electrically driven attitude indicator may be indicated by:
a. a low ammeter reading.
b. a red warning flag.
c. low suction.



A B C

Figure 10-55 Altimeter presentation.

53. Some airplanes have an electrically driven turn coordinator with the other gyroscopic instruments being vacuum-driven. Why?

54. Which instrument provides direct pitch attitude information?

55. Which instrument provides rate of turn information?

56. To receive accurate indications during flight from a heading indicator, the instrument must be:
- **a.** set prior to flight on a known heading.
- **b.** calibrated on a compass rose at regular intervals.
- **c.** periodically realigned with the magnetic compass as the gyro precesses.

Magnetic Compass

57. The earth rotates about its axis. This axis intersects the surface of the earth at which points?

58. The lines of magnetic force surrounding the earth flow to which points on the earth?

59. What is the difference between true north and magnetic north at any point on earth called?

60. Is the difference between true north and magnetic north constant over the earth?

61. If a perfect magnetic compass points 10° to the right of true north at a particular point on earth, what is the magnetic variation?

62. Your airplane is headed due east (090° true or TH 090). What will the compass indicate (MH) if magnetic variation at that position on earth is:
- **a.** 10° east?
- **b.** 4° east?
- **c.** 5° west?

63. What do you call lines drawn on charts joining places of equal magnetic variation?

64. What line joins places where the variation is zero (i.e. where the directions to true north and magnetic north coincide)?

65. How would you depict a heading of magnetic south?

66. How would you depict a heading of southwest?

67. What is magnetic variation the result of?

68. What is deviation in a magnetic compass caused by?

69. Deviation varies with which factor(s)?

70. During flight, the indications of a magnetic compass are accurate:
- **a.** in straight-and-level unaccelerated flight.
- **b.** if the airspeed is constant, even in turns.
- **c.** in straight-and-level flight, even if accelerating.

71. What does the reference line of the magnetic compass indicate?

72. Runway 32 at a particular airport could have a bearing of approximately:
- **a.** 032°M.
- **b.** 322°M.
- **c.** 032°T.

73. Acceleration errors for a magnetic compass occur on which headings?

74. You are heading MH 010 in the Northern Hemisphere and want to make a left turn to a heading of MH 300. What should you do?

75. You are heading MH 210 in the Northern Hemisphere, and want to make a left turn to MH 160. What should you do?

76. What affects the amount of magnetic dip?

77. Turning and acceleration errors of the magnetic compass will be greater in Alaska than in Florida. Why?

78. In the Northern Hemisphere, a magnetic compass may initially indicate a turn toward the east if:
- **a.** it decelerates while on a southerly heading.
- **b.** it accelerates while on a northerly heading.
- **c.** it turns left from a northerly heading.

79. During flight, when are the indications of a magnetic compass accurate?

80. In the Northern Hemisphere, a magnetic compass will normally indicate a turn toward the north if:
- **a.** a right turn is entered from an east heading.
- **b.** a left turn is entered from a west heading.
- **c.** the aircraft is accelerated while on an east or west heading.

Answers are given on page 771.

Weight and Balance 11

Airframe Limitations

Figure 11-1
Load carefully.

An airplane must only be flown within certificated limits of weight and balance to ensure that it remains controllable, performs adequately and is not overstressed. Correct weight and balance means:
- maximum allowable weight is not exceeded; and
- center of gravity (CG) is within a specified range.

Weight

The main force created to counteract the weight and allow the airplane to be maneuvered is lift. In straight-and-level flight the lift will be approximately equal to the weight. In certain maneuvers it may considerably exceed the weight—increased lift means an increase in wing loading and load factor (see pages 161–162).

For instance, in a 2g maneuver such as a 60° banked turn, where the load factor is 2, the load on the wings is double the weight. If the airplane weighs 3,000 pounds, the wings will be carrying a load of 6,000 pounds.

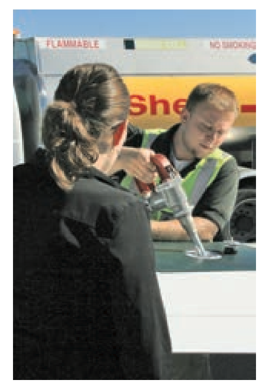


Figure 11-2
Consider fuel quantity and balance.

The heavier an airplane is, the poorer its performance will be. In particular, it will have:
- a higher stall speed;
- a higher takeoff speed and a longer takeoff run;
- poorer climb performance (poorer climb angle and climb rate);
- a lower cruising level;
- less maneuverability;
- higher fuel consumption, and less range and endurance;
- reduced cruise speed for a given power setting;
- a higher landing speed and a longer landing distance; and
- greater braking requirements when stopping.

This is not to suggest that following a takeoff at maximum permissible weight, the airplane will not perform perfectly safely; it simply draws attention to the effect of weight on performance.

On the other hand, if the airplane is actually *overweight*, that is, above any weight limitations imposed by the manufacturer, then not only will it perform poorly but it will also be difficult to control. If turbulence is encountered, or other than gentle maneuvers performed, the resulting wing loading may be so great that structural damage will result.

Never fly an overloaded airplane!

On a more mundane (but possibly expensive) level, operating an overloaded airplane may render your insurance invalid. Limiting weights include maximum takeoff weight, maximum landing weight, maximum zero fuel weight and maximum ramp weight. For weight-and-balance purposes we also need to take account of the following weights:

Figure 11-3
Weight and balance affect all aspects of airplane performance.

Empty Weight

The *empty weight* of an airplane is a precise, measured weight for that particular airplane. It is included in its weight-and-balance documents as the licensed empty weight.

The empty weight includes:

- the airframe and the powerplant;
- all permanently installed operating equipment (such as radios); and
- all nondrainable fluids (including unusable fuel, hydraulic fluid, and undrainable oil—see note below).

Note. For some airplanes, the certificated empty weight specifically includes full oil. You should check this point carefully in all your weight-and-balance problems—if full oil is *not* included, then you must add its weight and moment.

Items that the empty weight does *not* include are:

- pilot(s) and their equipment and baggage;
- passenger(s);
- baggage, cargo and temporary ballast added for balance; and
- full oil (unless specifically included).

If the airplane has new equipment installed (such as a new GPS receiver), then a qualified person should amend the empty weight and the empty-weight CG position and moment in the weight-and-balance documents.

Gross Weight (GW)

The *gross weight* is the actual total weight of the airplane and its contents at any particular time. In other words, gross weight is the empty weight plus pilot(s), payload (passengers and cargo), added ballast and fuel load.

The gross weight should not exceed the maximum weight permissible for any particular maneuver. On *takeoff*, it must not exceed the structural maximum takeoff weight or the performance-limited takeoff weight; on *landing*, gross weight must not exceed the structural maximum landing weight or the performance-limited landing weight. If you wish to operate the airplane in the utility category, rather than in the normal category, you must ensure that the lower maximum permissible gross weight for the utility category is not exceeded.

The Weight of Fuel and Oil

Note the following:

- one gallon of AVGAS weighs 6 pounds (lb);
- one liter of AVGAS weighs 1.56 lb (0.71 kg); and
- one gallon of oil weighs 7.5 pounds (so 8 quarts or 2 gallons weighs 15 pounds).

Caution. Be careful when ordering fuel in foreign countries—some places measure fuel quantity in units such as liters rather than US gallons.

Other Weight Limitations

There may be other weight restrictions specified in your airplane's weight-and-balance documents or on placards in the airplane—for instance, a maximum baggage compartment load, or a maximum zero fuel weight (ZFW).

Be familiar with your airplane's weight limitations.

The more familiar you are with the weight limitations applicable to your airplane, the easier weight-and-balance problems will become. In the following table, we show the important data for the loading of any airplane, and you should consider using this for any airplane you fly.

MTOW (structural)	= ______ lb
MLW (structural)	= ______ lb
Empty weight	= lb ______ (with/without oil)
Maximum fuel load	= ______ gal = ______ lb
Taxi allowance	= ______ lb
Maximum number of passengers	= ______ gal = ______ lb
Maximum baggage compartment load	= ______ lb
Maximum fuel ______ gallons (total)	Mains ______ gal = ______ lb Aux ______ gal = ______ lb

Table 11-1 Typical loading table.

Note. In most small airplanes, it is *not* possible to carry both a full fuel load and a full passenger-and-baggage load and remain within the maximum permissible gross weight.

Balance

The Moment of a Force

The *moment* of a force is its *turning effect*, and it depends on two things:

- the *size* (magnitude) of the force; and
- its moment *arm*, which is the distance from the point at which the force is applied to the pivot point (or fulcrum).

If the force being applied (weight) is measured in pounds (lb) and the arm is in inches (in.), then the moment is expressed in *pound-inches* (lb-in), or *inch-pounds* (in-lb).

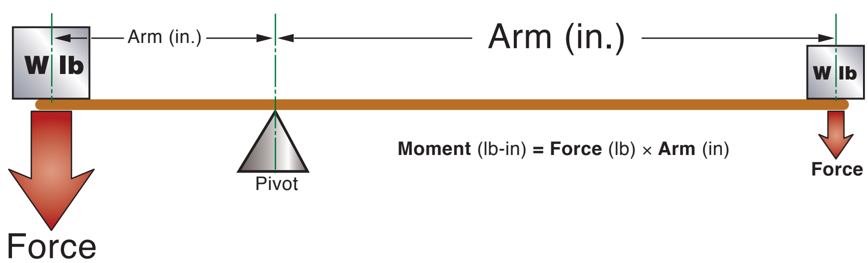


Figure 11-4 Force, arm and moment.

We are all familiar with the effect of a lever—the longer the lever arm, the smaller the force required to achieve the same turning effect. In the case of an airplane, we are not trying to rotate it, but to balance it—to stop it rotating or pitching. This is like a balanced beam, where the moments trying to turn it clockwise are perfectly balanced by the moments wanting to turn it counterclockwise.

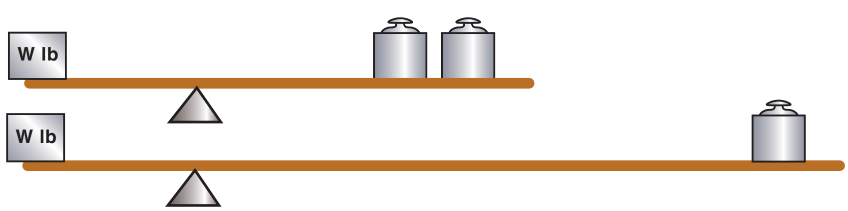


Figure 11-5 Balancing (or turning) moment depends on weight and moment arm.

We can see in figure 11-5 that the same turning effect (moment) is achieved by placing half the original weight at double the distance. For instance:

- a 2 pound weight, with an arm of 10 inches, has a moment of 2 × 10 = 20 lb-in; and
- a 1 pound weight, with an arm of 20 inches, has a moment of 1 × 20 = 20 lb-in.

Balancing a Loaded Beam (or Airplane)

To balance a beam, we need to provide a supporting force at its central position.

To balance a loaded beam (or airplane), we need to provide a supporting force at the point where the total weight may be considered to be concentrated, and where the counterclockwise turning moments are balanced by the clockwise turning moments. This position is called the *center of gravity* (CG). The magnitude of the supporting force will need to equal the total weight. For a beam, the supporting force may be provided by a pivot or by a rope; for an airplane, the supporting force is provided by the lift.

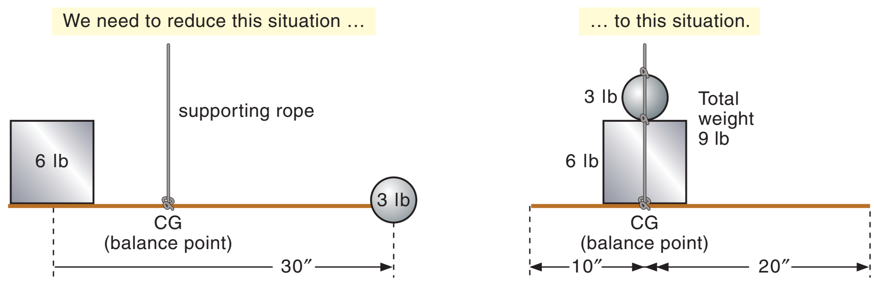


Figure 11-6 Finding the total weight and CG position.

In this case you have probably already estimated the position of the CG to be closer to the 6 pounds weight, in fact about 10 inches from it. If the supporting force is provided at this CG position, the beam will balance.

For an airplane to be in balance, its CG must lie somewhere near the point where the lift is produced by the wings.

Finding the Position of the CG

To calculate the position of the CG (rather than just estimate it), we need to calculate the total moment—the sum of the turning effects of the individual weights. Then we find the position (CG arm) where a *single* weight (equal to the sum of the individual weights) will have the same total moment. The CG arm can be found using the equation:

$$\text{Total weight} \times \text{CG arm} = \text{total moment}$$

The CG position remains the same regardless of datum position.

To do this we need to know the individual moment arms as measured from an appropriate datum. It does not matter which point we choose as the datum—the results for the CG position will always be the same. We will take time out to illustrate this important point. By convention, moment arms to the left of the chosen datum are negative; arms to the right of the datum are positive.

Conclusion

Refer to figures 11-7, 11-8 and 11-9. The choice of datum makes no difference to the results for CG position.

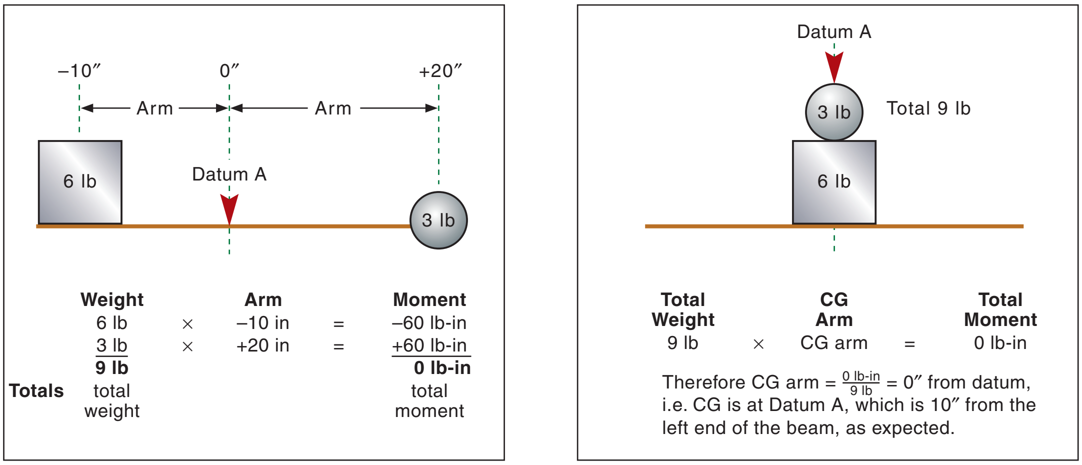


Figure 11-7 Using the estimated CG position as datum.

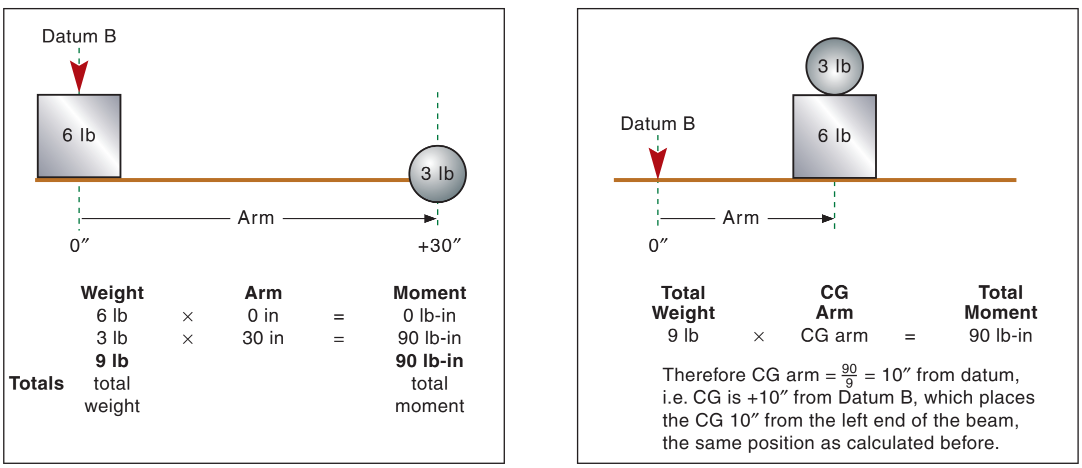


Figure 11-8 Using another datum, the left end of the beam.

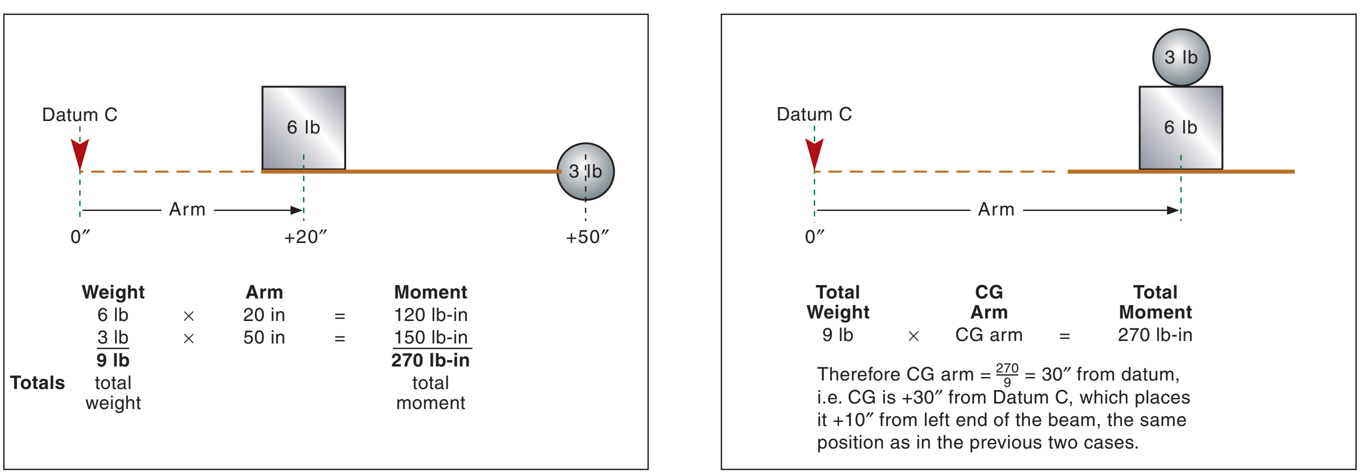


Figure 11-9 Using an external datum, 20 inches left of the beam.

Airplane Datums

In the case of airplanes, the manufacturer specifies a datum point in the weight-and-balance data supplied. Some manufacturers choose the nose of the airplane as the datum; others choose the firewall behind the engine; and others choose an external point along the extended longitudinal axis, ahead of the nose. The datum point for your particular airplane will be stated in its weight-and-balance documents.

The position of the datum is often referred to as "station zero" (or STA 0). Other positions may be specified relative to the station zero datum—for instance, a point 40 inches aft of the datum is called "STA 40." If the datum is behind the nose, then all weights forward of this datum will have a negative arm and a negative moment. The advantage of having a datum at or forward of the nose is that all moments are positive, making the calculations easier.

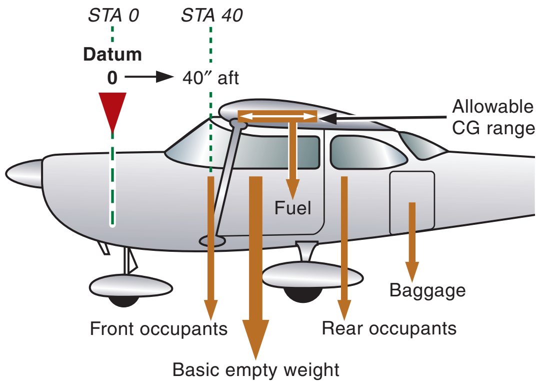


Figure 11-10
The datum can be at any convenient point on the longitudinal axis.

Effect of CG Position on Airplane Handling

The CG of an airplane is on the longitudinal axis and must lie within a specified range for the airplane to be controllable and to fly safely (and legally). The main supporting force in flight counteracting the total weight of the loaded airplane is the lift generated by the wings. It is considered to be concentrated at the center of pressure (CP), usually situated somewhere on the forward section of the wing—its position varies depending on angle of attack and other factors. A small balancing force (usually downward) is provided by the horizontal stabilizer.

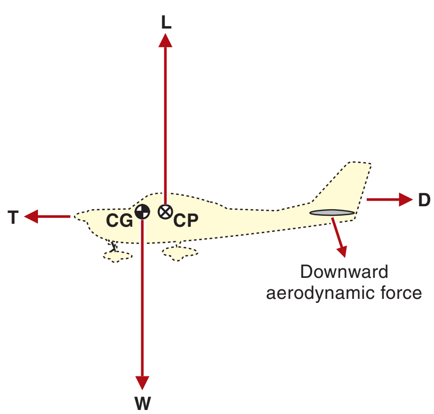


Figure 11-11
Final balance is provided by the horizontal stabilizer.

If loaded with the *CG well forward*, the horizontal stabilizer has a long moment arm, the airplane will be very stable longitudinally, and resist any pitching moment. The forward position of the CG is limited to ensure that the elevator has sufficient turning moment to overcome the nose-heaviness and excessive longitudinal stability, ensuring that you are able to rotate the airplane for takeoff and flare it for landing at relatively low airspeeds.

If the *CG is well aft*, the airplane will be tail-heavy and less stable longitudinally, because of the shorter moment arm from the CG to the CP. The aft position of the CG is limited to ensure that the airplane remains sufficiently stable so that a reasonably steady nose position can be held without excessive and frequent control movements being necessary, and so that the elevator-feel experienced through the control column remains satisfactory.

If the CG is too far aft, the airplane might not recover from a spin.

With a CG that is too far aft, the airplane will be very tail-heavy, will be difficult to control, and tend to stall and/or spin more easily—a situation from which it may be more difficult (or even impossible) to recover.

A Simple Layout for Weight-and-Balance Calculations

The CG is the position through which all of the weights, combined into a gross weight (or total weight), may be considered to act. The total weight should have the same turning moment as the sum of the individual moments.

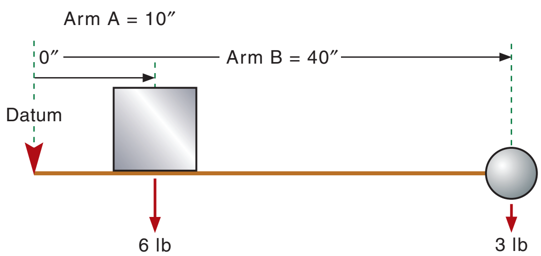


Figure 11-12 The actual situation.

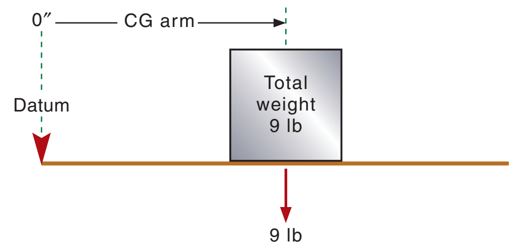


Figure 11-13 The modified situation.

Sum of individual moments	=	total moment	=	total weight	×	its moment arm
$(6 \times 10) + (3 \times 40)$	=	180 lb-in	=	9 pounds	×	CG arm

The CG position can now be found by dividing the total moment by the total weight.

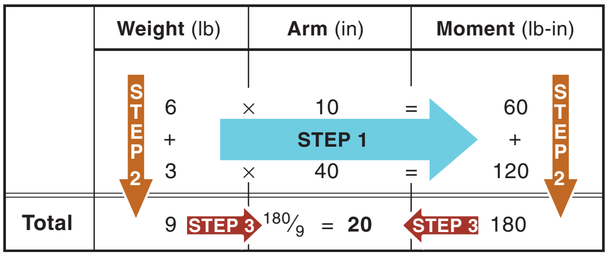
$$\text{CG arm} = \frac{\text{total moment}}{\text{total weight}} = \frac{180 \text{ lb-in}}{9 \text{ lb}} = 20 \text{ inches}$$

Therefore the CG position is 20 inches aft of the datum. This can be neatly laid out in tabular form, which is the way we do many of our airplane weight-and-balance problems.

	Weight (lb)	Arm (in)	Moment (lb-in)
	6	10	60
	3	40	120
Totals	9	20 CG position	180

Take particular note when doing these problems that you *cannot add the individual arms* to obtain the location of the CG. This answer can be found only by dividing the sum of all the moments by the total weight.

To help you visualize the method by which you can solve this type of problem, the figure below shows the pattern of the steps to be taken—and this pattern can be applied to almost all airplane weight-and-balance problems.



To find the CG position:

1. calculate the individual moments;
2. calculate the total weight and the total moment; and
3. find the CG arm:

$$\frac{\text{total moment}}{\text{total weight}}$$

Figure 11-14 How to find CG position.

Finding the CG for a Loaded Airplane

Using a tabulated layout, like that suggested above, will make all airplane weight-and-balance problems easy to do, and easy to check.

Example 11-1

Given the following information regarding a loaded airplane, calculate total moment and CG position:

- maximum gross weight 2,400 pounds;
- CG limits are 35 inches forward limit and 47.3 inches aft limit;
- empty weight 1,200 pounds acting at position 40 inches aft of the datum;
- pilot and passenger in front seat (arm 36 inches) 300 pounds;
- passengers in rear seat (arm 72 inches) 400 pounds;
- baggage in baggage compartment (arm 100 inches) 35 pounds;
- fuel 30 gallons (arm 50 inches); and
- oil 8 quarts (arm – 10 inches).

Note the following:

1. oil is obviously in front of the datum, since it has a negative arm (it may be that the datum on this airplane is the firewall behind the engine);
2. a calculator will help you in these weight-and-balance problems;
3. using the tabular form provided in most POHs will keep things neat; and
4. a diagram of the airplane is not necessary, but we show one here to help you visualize the situation.

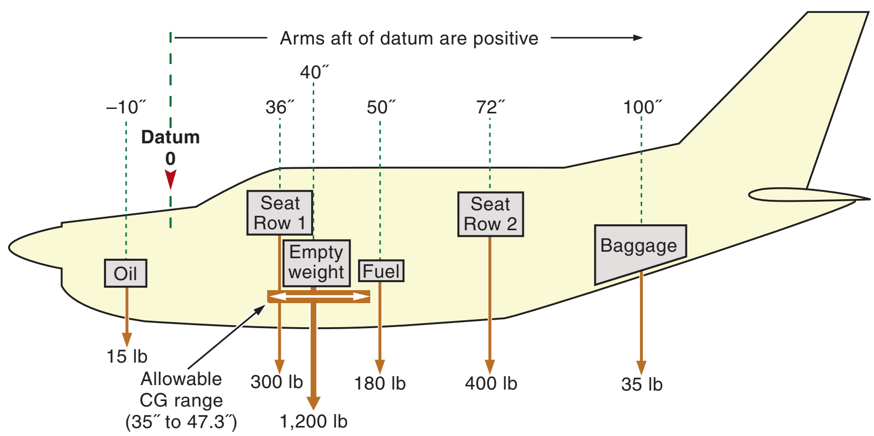


Figure 11-15 The loaded airplane.

Item	Weight (lb)	Arm (in)	Moment (lb-in)
Empty weight	1200	40	48000
Pilot + front passenger	300	36	10800
Rear passengers	400	72	28800
Baggage	35	100	3500
Fuel: 30 gal (× 6 lb)	180	50	9000
Oil: 8 qt (2 gal × 7.5 lb)	15	–10	–150
Totals	2130	**46.9**	99950

Figure 11-16 Flow chart of CG calculation.

Total moment (99,950 lb-in) = total weight (2,130 pounds x C arm)

Therefore:

$$\text{CG arm} = \frac{99{,}950 \text{ lb-in}}{2{,}130 \text{ lb}} = 46.9 \text{ in aft of datum}$$

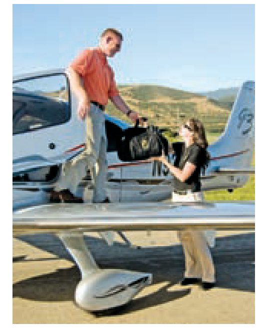


Figure 11-17
Consider passenger distribution.

With every weight-and-balance problem, you should always check that:

- no weight limit is exceeded; and
- the CG is within limits.

For this airplane, maximum gross weight is 2,400 pounds, so 2,130 pounds is OK. Center of gravity limits are 35 inches forward limit and 47.3 inches aft limit, which means the CG must lie between 35 and 47.3 inches aft of the datum, so 46.9 inches is OK. Therefore this airplane is loaded correctly.

Weight and/or CG Outside Limits

If the airplane was shown to be loaded incorrectly, then you would have to reorganize the loading so that it is within the weight and CG limits:

- if the airplane is *too heavy*, then you must remove some of the load, which is baggage, passenger(s) or fuel (make your choice!); and
- if the airplane is *out of balance*, with the CG outside the specified limits, then you must move the CG position. There are three ways in which this can be done:

1. *shift the load*—for example, move the CG forward by moving baggage forward from the baggage compartment to an empty seat (where you would need to restrain it);
2. *remove some of the load*—for example, move the CG forward by removing some baggage from the baggage compartment, or by leaving one of the rear passengers behind; or
3. *add ballast*—for example, move the CG aft by adding ballast to the baggage compartment.

Later in this chapter we will show how to ensure that the CG position is within the allowable CG range, and that it remains between the forward and aft limits throughout the flight as fuel is used.

Index Units

When calculating the weight and balance of an airplane, the moments are often quite large numbers, such as 28,800 lb-in. The size of these numbers can be reduced, for instance by dividing them by 1,000 to give *moment/1,000* and 28,800 lb-in would therefore equal 28.8 index units, where 1 index unit = 1,000 lb-in.

In some cases, you will see the moment divided by 100 to give *moment/100* and 28,800 lb-in would then equal 288 index units, where 1 index unit = 100 lb-in.

Example 11-2

If you are given moment/1,000 = 93.2 lb-in/1,000, then the moment = 93,200 lb-in (found by multiplying the index unit by 1,000 in this case).

Example 11-3

If you are given moment/100 = 1,617 lb-in/100, then the moment = 161,700 lb-in (found by multiplying the index unit by 100 in this case).

Graphical Presentation of Weight-and-Balance Data

To eliminate the need to calculate moments or index units, some airplane manufacturers provide a small loading graph that you can use to find the moment in index units. Enter with the weight in pounds on the left-hand side of the graph, move across horizontally to the appropriate guideline (for front seat position, fuel position, and so on), and then vertically down to read off the moment in index units (in this case moment/1,000).

> **Note.** In this graph, you will notice provision is made to use weight in kilograms and moment in kg-mm. Make sure you use the correct scales.

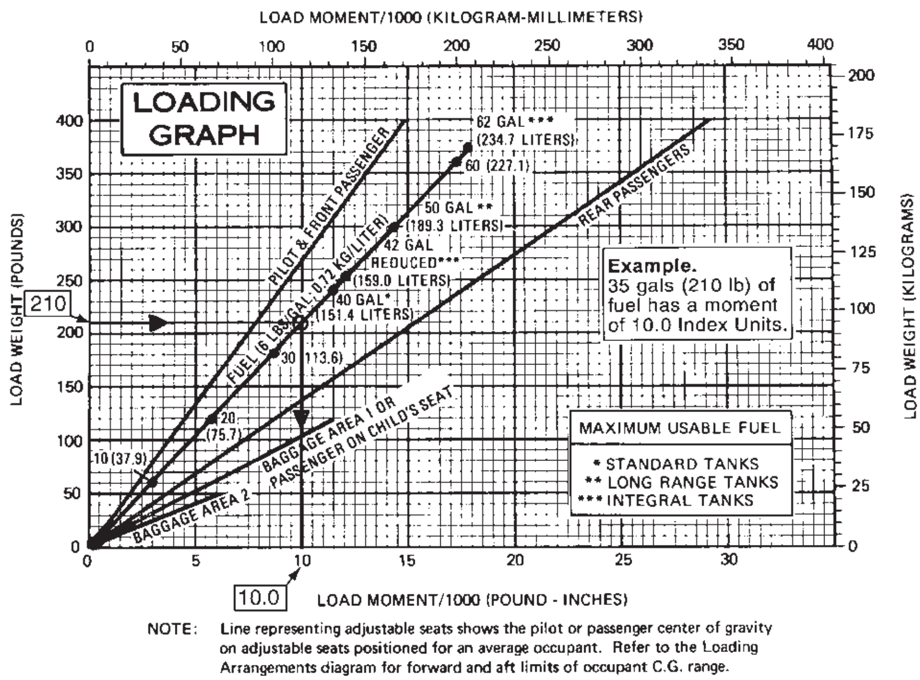


Figure 11-18 Graphical weight-and-balance data. See the table below for calculations.

	Sample Loading Problem	Weight (lb)	Mom/1,000 (lb-in./1,000)
1	Basic empty weight (includes unusable fuel and full oil)	1463	56.9
2*	Usable fuel (35 gallons)	210	10
3	Pilot and front passenger	390	14.5
4	Rear passenger	260	19
5	Baggage area 1	54	5
6**	Baggage area 2	-	-
7	Ramp weight and moment	2377	105.4
8	Fuel allowance for start, taxi and runup	-7	-0.3
9***	Takeoff weight and moment	2370	105.1

Note that given figures are entered in white boxes. Calculated figures are in blue boxes.
*35 gal @ 6 lb/gal = 210 lb. Enter loading graph with 210 lb, go across fuel line, and then read down to get 10.0 mom/1,000
**Add items 1 to 6
***Plot on CG Moment envelope Graph in figure 11-19 (page 299)

Having found the total weight and moment, we can check either of the next two graphs to ensure that:

- the weight is within limits; and
- the airplane is balanced correctly.

The two graphs (figure 11-19) tell us the same thing, albeit in a slightly different manner. You need refer to only one of them.

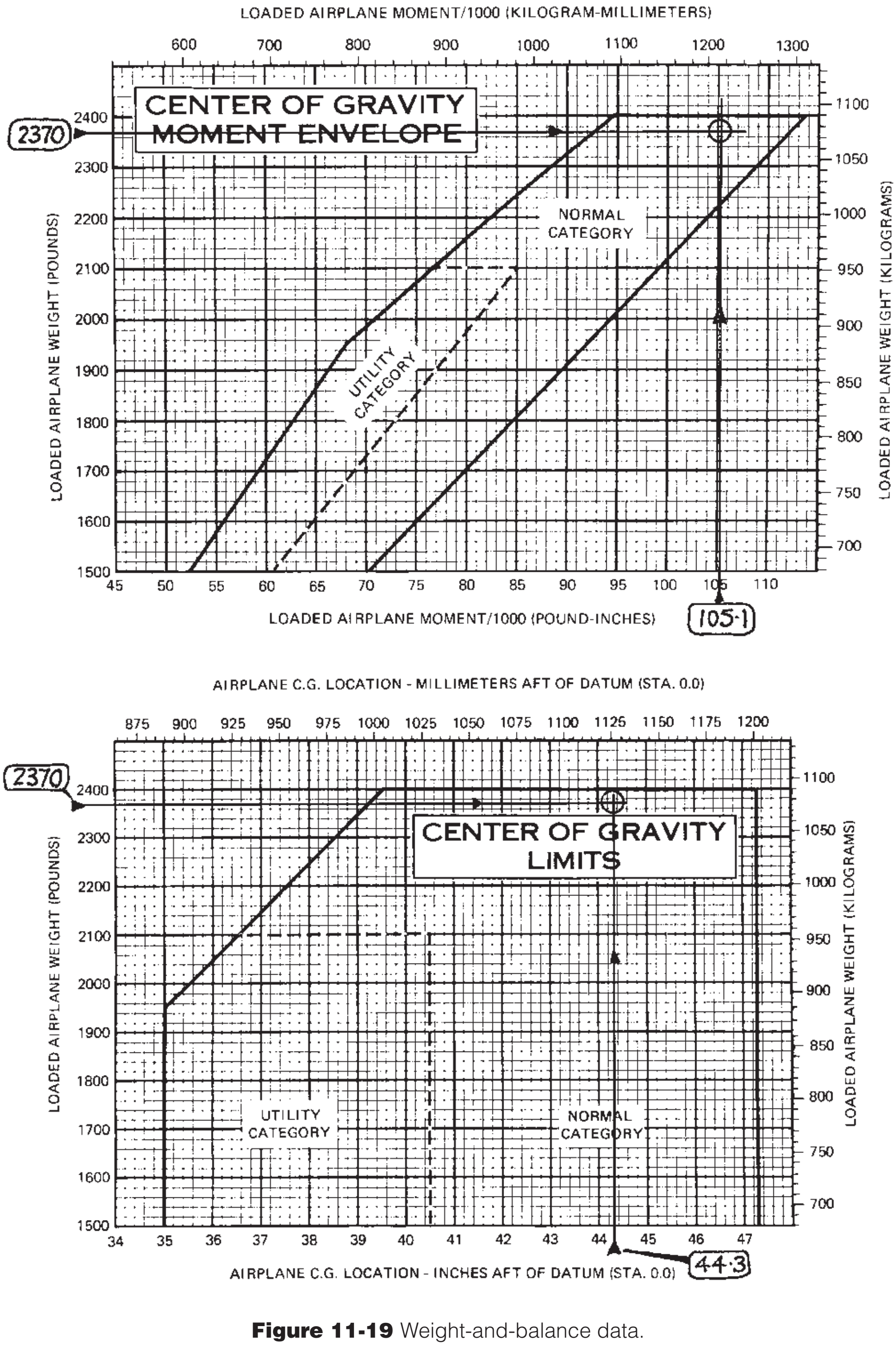


Figure 11-19 Weight-and-balance data.

The maximum weight is specified on both graphs: 2,400 pounds for normal category operations; and 2,100 pounds for utility category operations:

- the total weight should not exceed the specified maximum weight;
- if the total moment lies within the CG moment envelope (top graph), then the airplane is in balance with the CG within limits (even though you may not have calculated the actual position of the CG, but only the total moment); or
- if the center of gravity lies within the CG limits (on the lower graph), then the airplane is in balance—but finding the CG involves the extra calculation:

$$\text{CG position} = \frac{\text{total moment}}{\text{total weight}}$$

Using the top graph (figure 11-19) avoids the need to calculate the CG position. To illustrate this point, notice that total weight 2,400 pounds and total moment 113,500 pound-inches places the airplane on the extreme limit of the CG moment envelope. If you go ahead and calculate the CG position for this case, you will get:

This puts you at the extreme limit of the CG limits graph, which is the same message in a slightly different form.

$$\text{CG position} = \frac{113{,}500 \text{ lb-in}}{2{,}400 \text{ lb}} = 47.3 \text{ inches}$$

Weight and Balance for the Private Knowledge Exam

The airplane weight-and-balance graphs used in the Private Pilot Knowledge Exam are used in exactly the same way as the Cessna 172 weight-and-balance data. The following example uses these graphs, shown in figure 11-20.

Example 11-4

Using the graphs in figure 11-20, determine the airplane loaded moment and aircraft category with the following data.

	Weight (lb)	Mom/1,000
Empty weight	1,350	51.5
Pilot and front passenger	340	
Full fuel (standard tanks)	Full (38 gallons)	
Oil, 8 quarts		
Gross weight		

Answer: 74.8 pound-inches, utility category.

1. Fill in the table as far as possible.

	Weight (lb)	Mom/1,000 (lb-in/1,000)
Empty weight	1,350	51.5
Pilot and front passenger	340	12.5
Full fuel (standard tanks)	228	11
Oil, 8 quarts	15	-0.2
Gross weight	1,933	74.8

Read the notes carefully. The bottom note states that the empty weight does not include oil and therefore it must be considered separately. Note 2 gives the oil's weight and moment index units. (Do not omit the minus in the index unit.) The maximum usable fuel in standard tanks is shown in the top graph and is 38 gallons at 6 lb/gal. The fuel therefore weighs 38 × 6 = 228 lb and has an index unit of 11 pound inches. Similarly, to find pilot and front passenger index unit move horizontally across at 340 lb until you meet the pilot and front passenger line and then vertically down to read off the moment index of 12.5.

2. Add up the gross weight and its index unit. Then using the bottom center of gravity moment index, plot the gross weight and moment index unit to discover it falls within the envelope in the utility category.

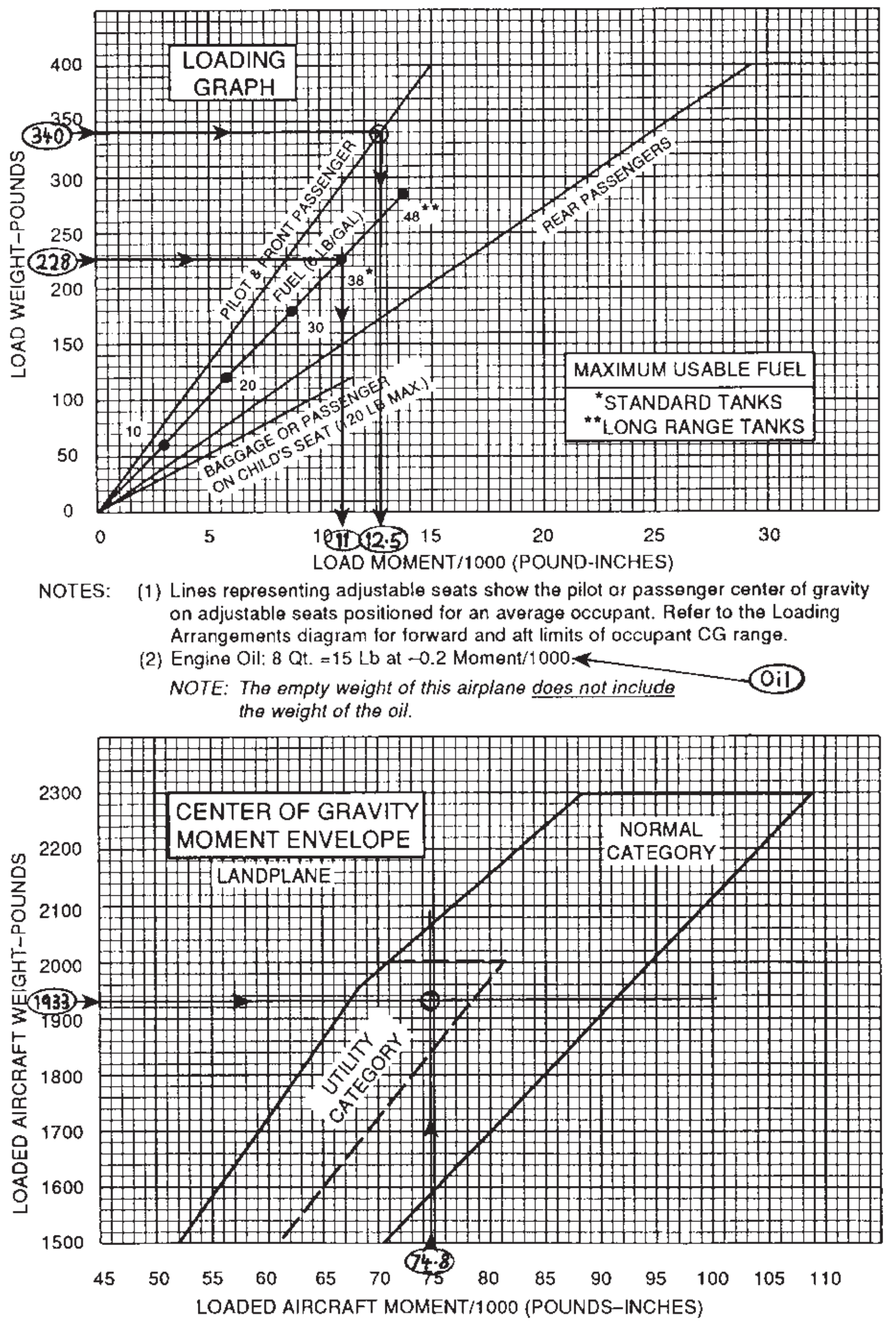


Figure 11-20 Loading and CG envelope charts.

Tabular Presentation of Weight-and-Balance Data

Some manufacturers present their weight-and-balance data, not in graphical form, but in the form of tables as shown in figures 11-21 and 11-22. From figure 11-21, the empty weight is 2,015 pounds (the * indicating that full oil, 10 quarts, has been included in the empty weight), with an empty weight moment of 1,554 mom/100 (155,400 lb-in). Since full oil is included here, there is no need to consider it separately in your calculations.

USEFUL LOAD WEIGHTS AND MOMENTS

OCCUPANTS

FRONT SEATS ARM 85		REAR SEATS ARM 121	
Weight	Moment/100	Weight	Moment/100
120	102	120	145
130	110	130	157
140	119	140	169
150	128	150	182
160	136	160	194
170	144	170	206
180	153	180	218
190	162	190	230
200	170	200	242

USABLE FUEL

MAIN WING TANKS ARM 75		
Gallons	Weight	Moment/100
5	30	22
10	60	45
15	90	68
20	120	90
25	150	112
30	180	135
35	210	158
40	240	180
44	264	198

BAGGAGE OR 5TH SEAT OCCUPANT ARM 140

Weight	Moment/100
10	14
20	28
30	42
40	56
50	70
60	84
70	98
80	112
90	126
100	140
110	154
120	168
130	182
140	196
150	210
160	224
170	238
180	252
190	266
200	280
210	294
220	308
230	322
240	336
250	350
260	364
270	378

AUXILIARY WING TANKS ARM 94

Gallons	Weight	Moment/100
5	30	28
10	60	56
15	90	85
19	114	107

***OIL**

Quarts	Weight	Moment/100
10	19	5

*Included in basic Empty Weight

Empty Weight ~ 2015

MOM / 100 ~ 1554

MOMENT LIMITS vs WEIGHT

Moment limits are based on the following weight and center of gravity limit data (landing gear down).

WEIGHT CONDITION	FORWARD CG LIMIT	AFT CG LIMIT
2950 lb (takeoff or landing)	82.1	84.7
2525 lb	77.5	85.7
2475 lb or less	77.0	85.7

Figure 11-21 Loading and CG limits in tabular format.

Figure 11-21 allows you to extract the moment (as an index unit) for a series of weights at each station, without having to multiply the weight by the arm. This tabular presentation saves time and is sufficiently accurate.

MOMENT LIMITS vs WEIGHT (Continued)

Weight	Minimum Moment / 100	Maximum Moment / 100
2100	1617	1800
2110	1625	1808
2120	1632	1817
2130	1640	1825
2140	1648	1834
2150	1656	1843
2160	1663	1851
2170	1671	1860
2180	1679	1868
2190	1686	1877
2200	1694	1885
2210	1702	1894
2220	1709	1903
2230	1717	1911
2240	1725	1920
2250	1733	1928
2260	1740	1937
2270	1748	1945
2280	1756	1954
2290	1763	1963
2300	1771	1971
2310	1779	1980
2320	1786	1988
2330	1794	1997
2340	1802	2005
2350	1810	2014
2360	1817	2023
2370	1825	2031
2380	1833	2040
2390	1840	2048
2400	1848	2057
2410	1856	2065
2420	1863	2074
2430	1871	2083
2440	1879	2091
2450	1887	2100
2460	1894	2108
2470	1902	2117
2480	1911	2125
2490	1921	2134
2500	1932	2143
2510	1942	2151
2520	1953	2160
2530	1963	2168
2540	1974	2176
2550	1984	2184
2560	1995	2192
2570	2005	2200
2580	2016	2208
2590	2026	2216
2600	2037	2224
2610	2048	2232
2620	2058	2239
2630	2069	2247
2640	2080	2255
2650	2090	2263
2660	2101	2271
2670	2112	2279
2680	2123	2287
2690	2133	2295
2700	2144	2303
2710	2155	2311
2720	2166	2319
2730	2177	2326
2740	2188	2334
2750	2199	2342
2760	2210	2350
2770	2221	2358
2780	2232	2366
2790	2243	2374
2800	2254	2381
2810	2265	2389
2820	2276	2397
2830	2287	2405
2840	2298	2413
2850	2309	2421
2860	2320	2428
2870	2332	2436
2880	2343	2444
2890	2354	2452
2900	2365	2460
2910	2377	2468
2920	2388	2475
2930	2399	2483
2940	2411	2491
2950	2422	2499

Figure 11-22 CG limits.

Finding the Moment Index for an Item

To find the mom/100 for any item, there are two ways to proceed. For example, find the mom/100 for a pilot weighing 180 pounds in the front seats.

a. *Using tabular data*: from front-seat table, enter with 180 pounds and extract 153 mom/100.

b. *Mathematically*: moment = weight 180 lb × arm 85 in. = 15,300 lb-in, or 153 mom/100.

Nontabulated Weights

For nontabulated weights, it will be necessary to interpolate when using the tabular data. For example, find the mom/100 for a passenger weighing 177 pounds in the rear seat. There are several ways of interpolating, as follows:

- for a difference of 10 pounds between 170 pounds and 180 pounds, there is a mom/100 difference of 12. A moment/100 difference of 12 for 10 pounds = 1.2 per pound—therefore, for 7 pounds = 7 × 1.2 = 8.4 mom/100, plus the 206 gives 214 mom/100; or
- for a difference of 7 pounds between 170 pounds and 177 pounds, there will be a mom/100 difference of 7⁄10 of 12 = 8.4 (say 8), and for a weight of 177 pounds, the mom/100 = 206 + 8 = 214.

Note. For nontabulated weights, or for weights outside the table, it is easier to use the mathematical method to find the moment index.

$$\begin{aligned} \text{Moment} &= \text{weight 177 pounds} \times \text{arm 121 inches} \\ &= \text{21,417 lb-in, or 214.17 mom/100} \end{aligned}$$

Weight-Shift Calculations

If, after calculating the weight and balance, you find that the CG is outside the limits of the CG range, it will be necessary to *shift* some weight to bring the CG position back within limits.

Note. The tabulated method shown here does not require the use of a formula. Some instructors prefer to use a formula for weight-shift and weight-change problems. We discuss the formula method at the end of this chapter in the section for commercial pilots.

Example 11-5

You have calculated the total weight to be 4,000 pounds with the CG located at 100 inches aft of datum. What is the new CG position if you shift 50 pounds of baggage from the rear baggage area at station 200 to the forward baggage area at station 50?

	Weight (lb)	Arm (in)	Moment (lb-in)
Original totals	4,000	100	400,000
Rear baggage out	-50	200	-10,000
Forward baggage in	50	50	2,500
New totals	4,000	98.13	392,500

Answer. 98.13 inches aft of datum. Remember: *Moment Weight = Arm*. You cannot add the arm values to derive total arm.

Example 11-6

You have calculated the total weight to be 4,000 pounds with the CG located 100 inches aft of datum. You wish to move the CG to 98 inches aft of datum, by shifting some baggage from the rear baggage area at station 200 to the forward baggage area at station 50. How much should you shift (to the nearest pound)?

Answer. 53.3 lb. Assume that you shift "w" lb.

	Weight (lb)	**Arm (in)**	**Moment (lb-in)**
Original totals	4,000	100	400,000
Rear baggage out	-w	200	-200w
Forward baggage in	+w	50	+50w
New totals	*4,000*	*98*	*400,000 - 150w*

$$\text{CG position} = \frac{\text{total moment}}{\text{total weight}}$$

$$98 = \frac{400{,}000 - 150\text{ w}}{4{,}000}$$

Multiply both sides of the equation by 4,000:

$$4{,}000 \times 98 = 400{,}000 - 150\text{ w}$$

$$392{,}000 = 400{,}000 - 150\text{ w}$$

$$150\text{ w} = 400{,}000 - 392{,}000 = 8{,}000$$

$$\therefore \text{w} = \frac{8{,}000}{150} = 53.5\text{ lb}$$

You should do a quick check as follows:

$$\text{New moment (lb-in)} = 400{,}000 - 150\text{ w}$$

$$\text{therefore new moment} = 400{,}000 - (150 \times 53.3) = 392{,}005$$

$$\text{therefore new arm} = \frac{392{,}005}{4{,}000\text{ (wt)}} = 98\text{ inches}$$

Weight-Change Calculations

Having calculated the weight and balance, you may decide to *change* the weight, perhaps because the airplane is overweight (reduce the load), perhaps because the airplane is below maximum weight (you can add extra load), or perhaps because the CG is out of limits and you want to shift it (by removing weight or adding ballast). You can work out a formula to assist in this calculation, but the simplest approach is to follow your now-familiar tabular pattern.

Example 11-7

Your airplane total weight is 4,100 lb with the CG located at 100 inches aft of datum. Maximum permissible weight is 4,000 lb, so you decide to remove 100 lb of baggage from the baggage compartment at station 200. What is the new CG position?

Answer: 97.5 inches aft of datum.

Item	**Weight** (lb)	**Arm** (inches)	**Moment** (lb-inches)
Original totals	4100	100	410000
Baggage change	–100	200	–20000
Revised totals	4000	**97.5**	390000

STEP 1 · STEP 2 · STEP 3

Figure 11-23 Flow chart of calcuation.

Example 11-8

You have calculated the total weight to be 2,400 lb with the CG located at 73.5 inches, which is 1.5 inches outside the aft limit of 72 inches. Maximum permissible weight is 2,400 lb and the airplane is fully loaded, with no possibility of shifting the load. What is the minimum baggage (to the next pound) you must remove from station 150 to bring the CG within limits for takeoff?

Answer: 47 lb. Set up the table and assume you remove "w" lb of baggage.

	Weight (lb)	**Arm (in)**	**Moment (lb-in)**
Original totals	2,400	73.5	176,400
Baggage change	-w	150	-150w
Revised totals	*2,400 - w*	*72.0*	*176,400 - 150w*

$$\text{New CG position } 72.0 = \frac{\text{total moment}}{\text{total weight}}$$

$$72.0 = \frac{176{,}400 - 150\text{ w}}{2{,}400 - \text{w}}$$

Multiplying both sides by (2,400 - w) (note that the (2,400 w) cancels out on side of the equation):

$$72 \times (2,400 - w) = 176,400 - 150\ w$$
$$172,800 - 72\ w = 176,400 - 150\ w$$
$$150\ w - 72\ w = 176,400 - 172,800$$
$$78\ w = 3,600$$
$$72.0 = \frac{3,600}{78} = 46.15$$

To the next pound to be on the safe side, this is 47 lb.

Weight-Shift/Change Calculations

A more usual occurrence is for there to be a change in both the location and weight of passengers, fuel or baggage.

Example 11-9

You have calculated the TOW to be 2,800 lb, with the CG moment at 2,296 mom/100 index units. Before departure you are advised that a passenger weighing 180 lb and seated at STA 85.0 will not be traveling, and will be replaced by another person weighing 200 lb and carrying 40 lb of luggage. This passenger will be seated at STA 85.0 and the accompanying luggage stowed at STA 140.0. Calculate the new CG moment in index units, and how far the CG has moved forward or aft.

	Weight (lb)	Arm (in)	Moment (lb-in)
TOW	2,800	82.0	2,296
Passenger OUT	-180	85.0	-153
New totals	2,620	-	2,143
Passenger IN	+200	85.0	+170
Baggage IN	+40	140.0	+56
New TOW	*2,860*	*82.83*	*2,369*

Answer: The new mom/100 = 2,369, and the CG has moved (82.83 - 82.0) = 0.83 inches aft.

CG Movement

The center of gravity moves during flight as fuel is used.

Up to this point, we have ignored the fact that during flight, the gross weight of the airplane decreases as fuel is used. This change in weight will cause the position of the CG to move gradually. The amount of movement of the CG will depend on the location, and therefore the moment arm of the fuel tanks. The airplane designer ensures that the fuel tanks are positioned so that their effective arms, when full and empty, are not much displaced from the fore-and-aft CG limits of the airplane.

To be precise in your weight-and-balance calculations, you should confirm that the CG position (or total moment) is within limits throughout the flight. This is done by checking that the CG is within limits at both the *takeoff weight* (TOW) and *zero fuel weight* (ZFW).

Note. If you considered weight and balance at the landing weight (rather than at the zero fuel weight), and found that the CG was right on the rear limit, then any further fuel burn-off (say for an emergency diversion) may take you out of the CG envelope. Therefore, it is better to consider the moment at the ZFW, rather than at the LW. Despite this, you may be asked in the Knowledge Exam to compute the weight and balance at landing, and some airplane loading data may require it (see the note on figure 11-26).

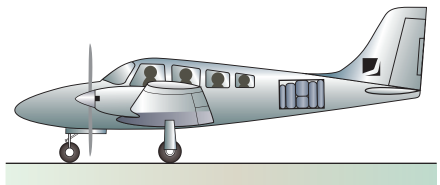


Figure 11-24 Zero fuel weight.

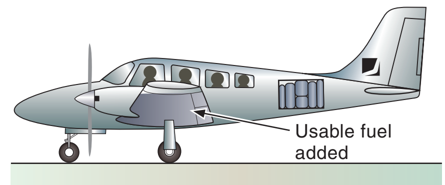


Figure 11-25 Gross weight.

Example 11-10

You have calculated the loaded weight and moment of your airplane to be 3,400 lb and 180 lb-in/1,000. The fuel on board is 60 gallons. Is the airplane loaded satisfactorily? If not, offer a suggestion. (Refer to the graphs in figure 11-22.)

Answer:

	Weight (lb)	Mom/1,000 (lb-in/1,000)
Takeoff weight	3,400	180 (OK—just within limits)
Fuel: 60 gal	-360	-15.5 (Moment from top graph)
Zero fuel weight	3,040	164.5 (NOT OK—outside limits)

At takeoff, the total moment is right on the rear limit. As fuel burns off, however, the CG moment position on the graph will move toward the ZFW CG moment position, which is *outside limits.* Therefore this flight should *not* commence unless the airplane is loaded differently—a solution could be to shift passengers or baggage forward if possible. Then you should recalculate the weight and balance to confirm within limits.

Suppose you decide to move a 150 lb passenger from a rear seat to an empty center seat. Total weight will be unchanged, but the moment for this passenger will change from 15.0 in the rear seat to 10.7 in the center seat, a decrease of 4.3 lb-in/1,000. Now recalculate the weight and balance.

	Weight (lb)	Mom/1,000 (lb-in/1,000)
Original TOW and Moment	3,400	180
Adjustment-move 150 lb passenger from rear to center	0	-4.3
New TOW Moment	3,400	175.7 (OK—within limits)
Fuel: 60 gal	-360	-15.5 (OK—within limits)
Now ZFW and Moment	3,040	160.2

To help in deciding how much weight you have to move in order to bring the ZFW within the CG limits, you can easily establish the required minimum change in moment from the graph. In this example we find:

ZFW 3,040, actual moment	164.5 mom/1,000
for ZFW 3,040, limiting rear moment	160.5
therefore minimum *change required in moment* =	*4.0 mom/1,000*

Since 164.5 is outside the rear limit, this required change must be forward. Moving from the rear seat to the center gives a moment change of 4.3; this is slightly more than the minimum and is therefore acceptable.

Note. It is unlikely that you will encounter zero fuel weight problems until operating a twin-engine aircraft.

Example 11-11

State if the CG is within the allowable CG envelope for the following load configuration. (See figure 11-26.)

Empty weight (oil included)	2,260 lb
Empty weight moment	93.2 lb-in/1,000
Pilot + front seat passenger	380 lb
Center passengers	240 lb
Aft passengers	220 lb
Baggage	120 lb
Fuel	75 gal

Note. A convenient way to tabulate your answer is to calculate the ZFW and moment (without fuel) and then add the fuel weight and moment to find the takeoff weight and moment.

Answer. Yes, the CG is within limits throughout the flight.

	Weight (lb)	Mom/1,000 (lb-in/1,000)
Empty weight	2,260	93.2
Pilot and front seat passenger	380	14
Center passengers	240	17
Aft passengers	220	22
Baggage	120	16.5
ZFW	3,220	162.7 (OK)
Fuel: 75 gal	450	19.2
Total weight	3,670	181.9 (OK)

Review 11

Weight and Balance

Weight and Balance

1. What term describes the maximum allowable gross weight permitted for takeoff?
2. True or false? A short runway may not allow you to land at the MLW (structural) but at a lighter performance-limited landing weight.
3. True or false? Landing weight = takeoff weight minus fuel burn-off.
4. The empty weight of an airplane includes which of the following items:
   a. airframe.
   b. powerplant.
   c. permanently installed equipment.
   d. full fuel.
   e. unusable fuel.
   f. full oil.
   g. unusable oil.
   h. hydraulic fluid.
   i. pilots.
   j. passengers.
   k. baggage.
5. How many pounds do the following weigh:
   a. one gallon of AVGAS?
   b. 26 gallons of AVGAS?
6. An aircraft is loaded 110 pounds over maximum certificated gross weight. If fuel (AVGAS) is drained to bring the aircraft weight within limits, how much fuel should be drained?
7. True or false? If the CG is located at the rear limit, the airplane be very stable longitudinally.
8. True or false? The longer the moment arm from the CG, the greater the turning effect of a given force.
9. The CG of an aircraft may be determined by:
   a. dividing total arms by total moments.
   b. dividing total moments by total weight.
   c. multiplying total weight by total moments.
10. If 1 index unit = 100 lb-in, what is the moment for 176 index units?
11. If all index units are positive when computing weight and balance, the location of the datum would be at the:
    a. centerline of the mainwheels.
    b. nose, or out in front of the airplane.
    c. centerline of the nose or tailwheel, depending on the type of airplane.
12. Given the following data, what is the maximum amount of fuel (in pounds and gallons) that you can carry if the maximum takeoff weight is 2,400 lb? Tank capacity is 50 gallons. (No need to consider CG position.)

Empty weight	1,432 lb
Front seat occupants	320 lb
Rear seat occupants	340 lb
Baggage	20 lb
Oil	8 qt 15 lb

13. Given the following data, what is the maximum weight of baggage that can be carried when the airplane is loaded for a takeoff that is performance-limited to 2,910 lb, because of a high elevation airport and high temperatures? (No need to consider balance.)

Basic empty weight (incl. full oil)	2,015 lb
Front seat occupants	369 lb
Rear seat occupants	267 lb
Fuel (36 gal)	—

14. Where is the CG located in the following situation? (No mention of oil, so assume full oil in empty weight.)
    a. 92.44.
    b. 94.01.
    c. 119.8.

	Wt (lb)	Arm (in)	Mom (lb-in)
Empty weight	1,495.0	101.4	151,593.0
Pilot and passengers	380.0	64.0	—
Fuel (30 gal usable)	—	96.0	—

Weight-and-Balance Calculations

Use the loading graphs in figure 11-20 (page 301) for questions 15 to 17.

15. Given the following data:
a. calculate the loaded index units (moments/1,000) of the airplane.
b. determine in which category you may operate it.

	Weight (lb)	Mom/1,000
Empty weight	1,350	51.5
Pilot and front passenger	310	—
Rear passengers	96	—
Fuel (38 gal)	—	—
Oil (8 qt)	—	–0.2

16. Given the following data:
a. calculate the loaded moment (normal category).
b. determine if it is within limits.
c. determine where the CG is.

	Weight (lb)	Mom/1,000
Empty weight	1,350	51.5
Pilot and front passenger	380	—
Fuel (48 gal)	—	—
Oil (8 qt)	—	—

17. What is the maximum amount of fuel that may be in the tanks when the airplane is loaded as given below:
a. 24 gallons.
b. 32 gallons.
c. 40 gallons.

	Weight (lb)	Mom/1,000
Empty weight	1,350	51.5
Pilot and front passenger	340	—
Rear passengers	310	—
Baggage	45	—
Oil (8 qt)	—	—

Use the tables in figures 11-21 and 11-22 (pages 302 and 303) for questions 18 to 20.

18. Calculate the maximum weight of baggage that can be carried when the airplane is loaded as follows:

Front seat occupants	387 lb
Rear seat occupants	293 lb
Fuel	35 gal

19. Given the following:
a. determine the weight.
b. determine the balance.
c. calculate if the CG and weight of the airplane are within limits.

Front seat occupants	350 lb
Rear seat occupants	325 lb
Baggage	27 lb
Fuel	35 gal

20. Is the following weight and balance within limits?

Front seat occupants	415 lb
Rear seat occupants	110 lb
Baggage	32 lb
Fuel	63 gal

Weight–Shift Calculations

Refer to figures 11-21 and 11-22 (pages 302 and 303) for questions 21 to 25.

21. Which action can adjust the airplane's weight to the maximum gross weight and the CG located within limits for takeoff, when it is loaded as given below?
a. Drain 12 gallons of fuel.
b. Drain 9 gallons of fuel.
c. Transfer 12 gallons of fuel from the main tanks to the auxiliary tanks.

Front seat occupants	425 lb
Rear seat occupants	300 lb
Fuel (main tanks)	44 gal

22. On landing, the front passenger (180 lb) departs the airplane. A rear passenger (204 lb) moves to the front passenger position. What effect does this have on the CG if the airplane weighed 2,690 lb and the mom/100 was 2,260 prior to the passenger transfer?
- **a.** CG moves forward approx. 3 inches.
- **b.** Weight changes, but CG is unaffected.
- **c.** CG moves forward approx. 0.1 inch.

23. With the following loading:
- **a.** can you carry 100 lb of baggage (if not, what action could be taken to carry it)?
- **b.** what is the final CG position?

Pilot	180 lb
2 passengers on rear seats	2 × 170 lb
Minimum fuel required	30 gal

24. What effect does a 35 gal fuel burn have on the weight and balance, if the airplane weighs 2,890 lb and the mom/100 is 2,452 at takeoff?
- **a.** Weight reduced by 210 lb, and CG is aft of limits.
- **b.** Weight reduced by 210 lb, and CG is unaffected.
- **c.** Weight reduced to 2,680 lb, and CG moves forward.

25. Given the following:
- **a.** can you take off under the following conditions and, if not, what ballast must be added in the baggage locker?
- **b.** calculate the landing weight and CG location (assume auxiliary fuel used first).

Pilot & passenger (front)	300 lb
Passenger (rear)	180 lb
Baggage	60 lb
Fuel (44 mains + 15 aux)	59 gal
Planned fuel burn-off to landing	35 gal

Answers are given on page 772.

Navigation

Charts 12

If you want to navigate an airplane efficiently from one place to another over long distances or in poor visibility, you need to refer to some representation of the earth. This representation must be smaller in size than the earth and portray a picture of a "reduced earth."

The simplest and most accurate reduced representation of earth is a globe, which retains the spherical shape of the earth and displays the various oceans, continents, cities, and so on. A cumbersome globe is not the ideal navigation tool to have in a cockpit or to carry in a navigation bag, especially if detailed information is required, hence the need for maps or charts that can be folded and stowed away. The task of the "map-maker" or cartographer is to project a picture of a reduced-earth globe onto a flat surface and make a map or chart from this.

Maps represent the earth's surface, or parts thereof, on a flat surface; *charts* are maps which show additional information or special conditions, sometimes using only an outline of geographical features such as the coastline. Since most maps that pilots use show specific aeronautical and navigational data, they are referred to as charts.

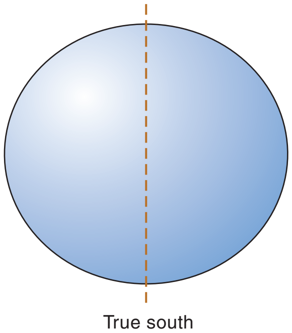


Figure 12-1
The earth is a slightly flattened (oblate) sphere.

The Form or Shape of the Earth

The exact shape of the earth's surface is constantly changing. Volcanoes erupt and grow, new islands form and others disappear, landslides and earthquakes cause large land movements, the ocean surface continually changes in height with the tides, and, on a very long-term basis, the continents gradually move.

The regular geometric shape that the earth resembles most is a sphere, but even when all the surface bumps are ironed out, the earth is still not a perfect sphere. It is slightly flat at the North and South Poles, forming a flattened (oblate) spheroid, the polar diameter being approximately 23 nautical miles (NM) less than the equatorial diameter (6,865 NM as against 6,888 NM). For the purposes of practical navigation, however, the earth can be treated as a sphere.

The earth rotates on its own axis as well as moving in an orbit about the sun. This axis of rotation is called the geographic *polar axis*, and the two points where it meets the surface of the sphere are called:

- the northern geographic pole or *true north*; and
- the southern geographic pole or *true south*.

If you stand anywhere on earth and face toward the northern geographic pole, then you are facing true north.

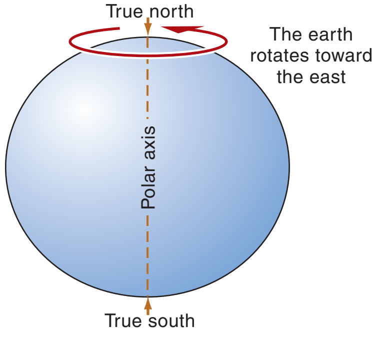


Figure 12-02
The earth rotates about its own axis.

> **Note.** The earth's axis is tilted in relation to its orbital path around the sun. It is shown as vertical here for ease of explanation.

Imaginary Lines on the Earth's Surface

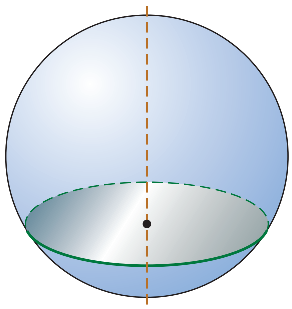


Figure 12-3
The plane of a small circle does not pass through the center of a sphere.

A *great circle* drawn on the earth's surface is one whose plane passes through the center of the earth. Great circles have some significant properties, including those in figure 12-4:

- a great circle is the largest circle that can be drawn on the surface of the earth or on any sphere;
- the shortest distance between any two points on the surface of a sphere is the arc of a great circle; and
- only one great circle can be drawn between two points on the surface of a sphere (unless the two points are diametrically opposed, as are the geographic poles).

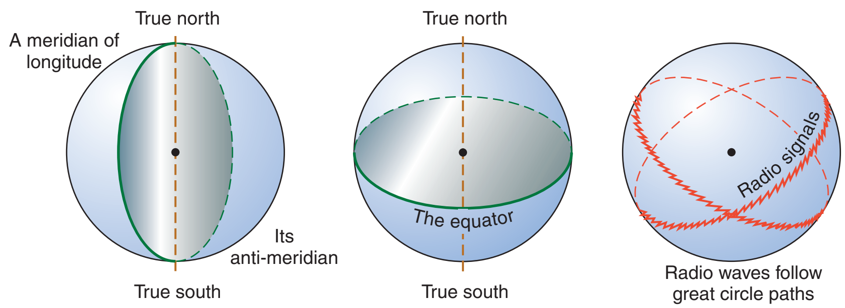


Figure 12-4 The great circle has the center of the earth as its axis.

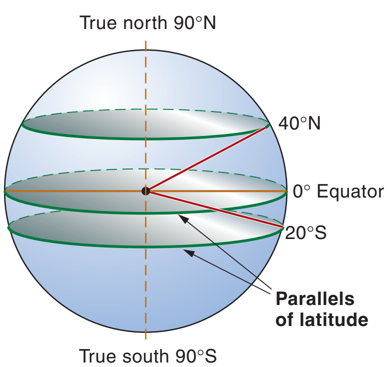


Figure 12-5
Latitude.

Some examples of great circles are: meridians of longitude, the equator, and the paths that radio waves follow. A *small circle* is any circle on the surface of a sphere that is not a great circle and therefore the center of a small circle is not at the center of the earth. Parallels of latitude (other than the equator) are small circles.

Latitude and Longitude

A convenient way of specifying the position of any point on earth is to relate it to the imaginary lines that form the *latitude* and *longitude* grid on the earth's surface.

Latitude

The reference for latitude is the plane of the *equator*, the great circle whose plane is perpendicular (at right angles, or 90 degrees) to the polar axis.

The *latitude* of a place is its angular distance in degrees from the equator, measured at the center of the earth and designated either north or south. For instance, Detroit, Michigan is at 42°N latitude.

A *parallel of latitude* joins all points of the same latitude and (except for the equator) is a small circle. Detroit, Boston, Barcelona in Spain, Rome in Italy, Istanbul in Turkey, Tashkent in Uzbekistan and Shenyang in China are all about 42° north of the equator, and therefore the line joining them is called the 42°N parallel of latitude.

Parallels of latitude are parallel to the equator and to each other.

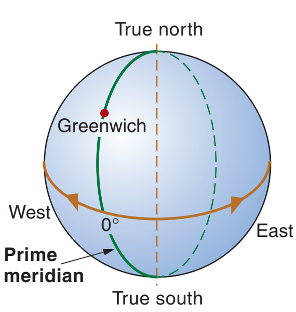


Figure 12-6
The prime meridian.

The longest parallel of latitude is the equator (latitude 0°). The other parallels, as you move away from the equator toward the higher latitudes, progressively decrease in size until the 90° parallels of latitude become just points at the north and south geographic poles.

Longitude

The basic reference for longitude is the *Greenwich meridian*, which is also known as the *prime meridian*. It is that half of the great circle which contains the polar axis (about which the earth rotates), and passes through the Greenwich Observatory situated near London, England, as well as the north and south geographic poles. The prime meridian is designated as *longitude 0°*.

The other half of the same great circle that makes up the prime meridian is on the other side of the earth from Greenwich. It passes down the western side of the Pacific Ocean and is known as *longitude 180°*. It can be reached by traveling 180 degrees either east or west from the prime meridian. Therefore longitude 180° can be called either 180°E or 180°W. It is also called the *anti-meridian* of Greenwich:

- all of the great circles containing the polar axis (and therefore the north and south geographic poles) are called *meridians of longitude*; and
- meridians of longitude are specified by their angular difference in degrees east or west from the prime meridian.

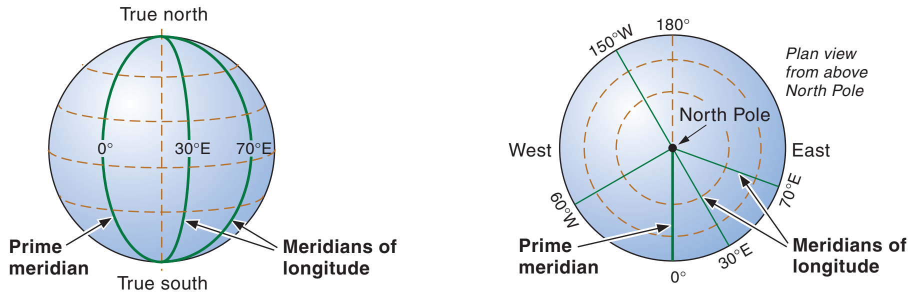


Figure 12-7 The longitude of a place is the angle between its meridian of longitude and the prime (Greenwich) meridian, measured east or west from the prime meridian.

Specifying Position

The parallels of latitude and meridians of longitude form an imaginary grid over the surface of the earth. Position of any point on the earth can be specified by:

- its *latitude*—the angular position N or S of the plane of the equator; together with
- its *longitude*—the angular position E or W of the prime meridian.

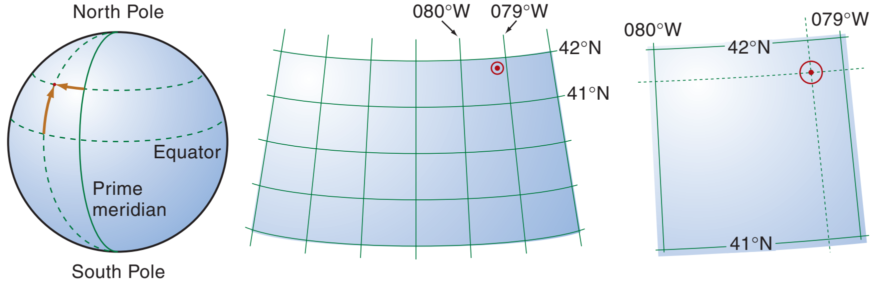


Figure 12-8 The position of Warren in Pennsylvania is 41°50′N, 79°08′W.

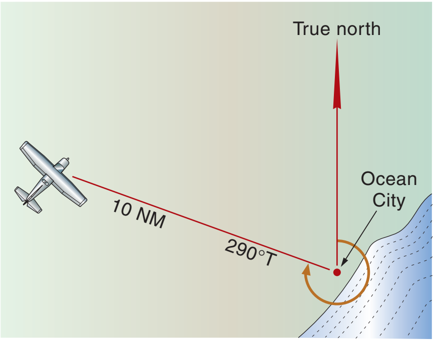


Figure 12-9 Specifying position on the earth by range and bearing.

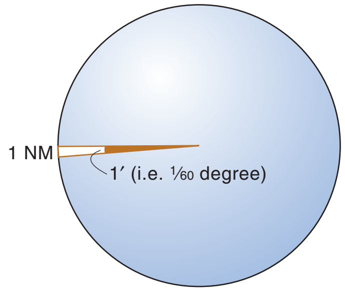


Figure 12-10 1 NM is the length of 1 minute of arc of a great circle on the earth.

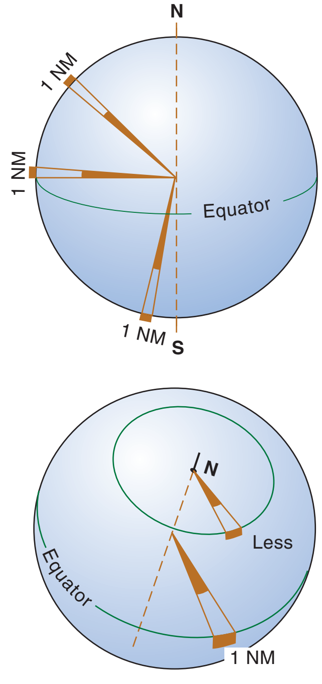


Figure 12-11
1 minute of latitude = 1 NM;
1 minute of longitude varies in length.

It is usually sufficiently accurate to specify the latitude and longitude of a place in degrees and minutes (one minute is 1⁄60 of one degree). For more accuracy, each minute is divided into 60 seconds of arc. The symbols used are degrees (°), minutes (′), and seconds (″). For example, the position of Warren in Pennsylvania is 41°50′N, 079°08′W, accurate to the nearest minute.

Modern electronic navigation systems are very accurate, requiring latitude and longitude to be expressed to an accuracy of 0.1′ of arc (6 seconds of arc is the same as 0.1′ of arc). To cater for these systems, aeronautical charts and documents such as the Airport/Facility Directory would show position N52°20′36″, W105°25′6″ as N52°20.6′, W105°25.1′.

Latitude and longitude are the normal means to indicate a particular position on earth. They are most commonly used at the flight planning stage when preparing the charts and flight plan. Once in flight, however, there are other means of specifying the position of the aircraft, such as by position over or abeam a landmark or radio beacon (for instance, "*Over Tuscaloosa, Abeam Mansfield, Over Casa Grande VOR*") or by range (distance) and bearing from a landmark or radio beacon (for instance, "*10 NM on a bearing of 290°M from Ocean City*").

> **Note.** The use of place names needs to be confined to places that are likely to be known to the recipient of the message, and that are shown on the commonly used aeronautical charts. In the United States, place names are frequently duplicated and can be misleading.

Distances

The standard unit of distance in navigation is the *nautical mile* (NM), which is the length of 1 minute of the arc of any great circle on earth. There are 360 degrees in a circle and 60 minutes in a degree, making 60 × 360 = 21,600 minutes of arc in a circle. The circumference of the earth is therefore 60 × 360 = 21,600 minutes of arc, which is 21,600 NM.

Latitude (the angular distance north or south of the equator) is measured up and down a meridian of longitude (which is a great circle) and therefore:

- 1 minute of latitude at any point on earth = 1 nautical mile; and
- 1 degree of latitude at any point on earth = 60 nautical miles.

This is very useful for measuring distances on a chart, although the usual means of measuring distance is to use the scale line or a plotter.

Longitude is measured around the parallels of latitude (all small circles, except for the equator), and so 1 minute of longitude varies in length, depending on where it is on the earth's surface. The only place where 1 minute of longitude is equal to 1 NM is around the equator—the higher the latitude, the further away from the equator the place is, and the shorter the length of 1 minute of longitude in that region.

Angles

The most fundamental reference from which angles are measured is that of true north, from 000°T, through 090°T, 180°T, 270°T, to 360°T. As figure 12-12 shows, if an airplane follows a long-range great circle course, the course direction will gradually change. A great circle route will therefore cross successive meridians at a gradually changing angle. Sometimes it is convenient to fly a course whose direction remains constant when referred to true north, so that the course crosses all meridians of longitude at the same angle. This is known as a *rhumb line*.

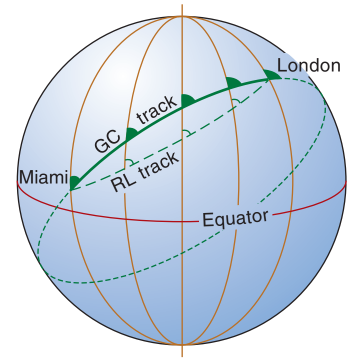


Figure 12-12 The great circle and the rhumb line tracks between two places.

The rhumb line and great circle between two places coincide only if the two places lie on either the same meridian of longitude (which is a great circle) or on the equator which is also a great circle. In practical terms, the great circle direction and the rhumb line direction may be considered to be the same over short distances of less than 200 NM.

Direction is the angular position of one point to another without reference to the distance between them. It is expressed as the angular difference from a specified reference direction. In air navigation this reference direction is either:

- north (for *true* or *magnetic* bearings); or
- the heading (or the nose) of the aircraft (for *relative* bearings).

You must always be very clear as to whether you are referring direction to true north or to magnetic north, the difference between the two being the magnetic variation. In this chapter, we are referring direction to true north.

A true course of 085°T (85° measured clockwise from true north) may be written as TC 085. A magnetic course of 130°M (130° measured clockwise from magnetic north) may be written as MC 130.

It is usual to refer to direction as a three-figure group to prevent any misunderstanding. For example, north is referred to as 360 or 000, east is referred to as 090, south-west as 225.

Direction is usually specified as a three-figure group.

Representing the Spherical Earth on Flat Charts

The latitude-longitude grid is translated onto maps and charts by cartographers whose major task is to represent the spherical surface of the earth on a flat sheet of paper. The process consists of:

- scaling the earth down to a reduced earth; and then
- projecting the reduced earth's surface onto a flat piece of paper.

The process always leads to some distortion of areas, distances, angles or shapes. By using certain mathematical techniques when projecting the spherical earth onto a flat chart, the cartographer can preserve some properties, but not all. Some property will always be distorted to a greater or lesser extent depending on how the points on the surface of the reduced spherical earth are transferred onto the flat chart.

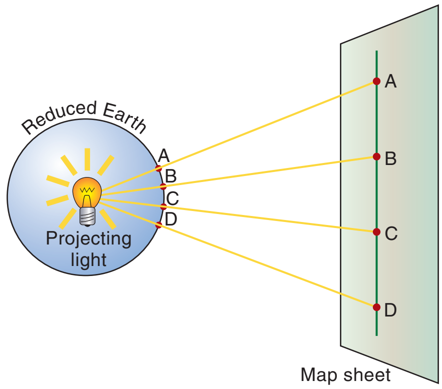


Figure 12-13 Making a chart.

Unlike a sphere, certain other curved surfaces (such as a cylinder or a cone) can be cut and laid out flat. By projecting points on the surface of the reduced earth onto either a conical or cylindrical surface (which can then be flattened out to form a sheet), less distortion occurs and a better chart results, compared with a projection onto an already flat sheet like that illustrated in figure 12-13.

A simplified view of chart-making is to think of a light projecting the shadows of the latitude-longitude grid of the reduced sphere onto a cone (Lambert conical projection) or onto a cylinder (Mercator cylindrical projection). The cone or cylinder is then laid out flat to form a chart.

Charts based on conic and cylindrical projections are widely used in aviation, mainly because they:

- *preserve shapes* (or at least minimize distortions);
- *preserve angular relationships* (in mathematical terminology, charts that exhibit this important property are said to be *conformal* or *orthomorphic*); and
- have a reasonably *constant scale* over the whole chart.

Scale

There are various ways of describing just how much the earth is scaled down on a particular chart. Scale is defined as the ratio of the chart length compared to the earth distance that it represents.

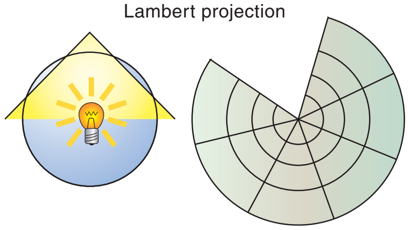


Figure 12-14
A conical projection (Lambert) and a cylindrical projection (Mercator).

$$\text{Scale} = \frac{\text{chart length}}{\text{chart distance}} \quad \text{(with both items in the same unit)}$$

The greater the chart length for a given earth distance, the *larger* the scale and the more detail that can be shown. A large-scale chart covers a small area in detail. For example, a 1:250,000 (one to one-quarter million) chart has a larger scale and can show more detail than a 1:500,000 (one to one-half million) aeronautical chart. The sample excerpts in figures 12-16 and 12-17 cover the same physical area.

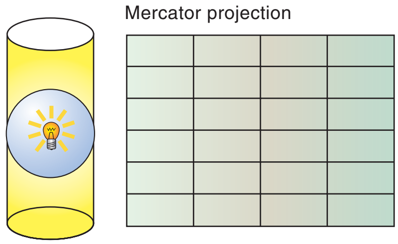


Figure 12-15
A conical projection (Lambert) and a cylindrical projection (Mercator).

Large scale charts cover small areas in detail.

Scale can be expressed in various ways:

- as a *representative fraction*. For instance, sectionals are 1:500,000 charts (one to one-half million), where 1 inch on the chart represents 500,000 inches (7 nautical miles) on the earth, or where 1 NM on earth is represented by 1 half-millionth of a nautical mile on the chart;
- as a *graduated scale line*, situated at the bottom of the chart. A graduated scale line allows you to measure off the distance between two points on the chart and match it against the scale line. Make sure that you use the correct scale line (usually nautical miles), since there may be various ones so that nautical miles, statute miles or kilometers can be measured; and
- in *words*—for instance, "1 inch equals 5 NM," which means that 5 NM on the earth's surface is represented by 1 inch on the chart.

Figure 12-16
Sample excerpt from 1:250,000 Terminal Area.

Figure 12-17 Sample excerpt from 1:500,000 Sectional VFR chart.

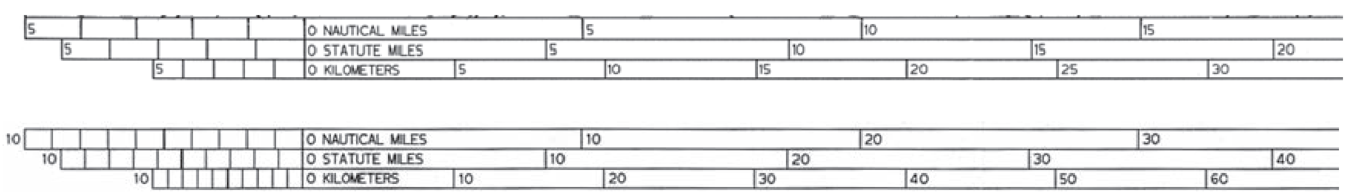


Figure 12-18 Scale lines from a 1:250,000 chart (top) and a 1:500,000 chart.

Topographical Charts

When navigating by visual reference to the ground, the pilot refers to land features. A *topographical* chart showing the surface features of the area in detail is therefore of great value. There are various topographical charts available for visual navigation in the United States, including (in order of importance):

- *Sectional Charts*, which are the most common charts used for visual navigation; their scale is 1:500,000 (half-million);
- *VFR Terminal Area Charts*, scale 1:250,000 (quarter-million), showing more detail around busy airports; and
- *1:1,000,000 Navigation Charts*, which have a small scale and are sometimes used for long-distance visual navigation.

Most aviation charts are based on the Lambert conformal conic projection. The chart sheet is formed from a cone that cuts the sphere representing the reduced earth at two standard parallels of latitude. Just which two parallels of latitude are chosen by the cartographer depends on which part of the earth, and how much of it, he wants to represent on that particular chart.

The standard parallels are usually mentioned on the title section of the chart—for example, on the Seattle Sectional the standard parallels are stated to be 41°20 and 46°40. The scale at the standard parallels is correct. Between them it contracts, and outside of them it expands. For practical purposes however, you can assume a constant scale over the whole chart.

The Sectional and VFR Terminal Area charts have the following properties:

- they are conformal—angles and bearings are accurate;
- constant scale over the whole chart in practical terms;
- shapes are preserved in practical terms; and
- the true course between two places is a straight line.

SEATTLE
SECTIONAL AERONAUTICAL CHART
SCALE 1:500,000
Lambert Conformal Conic Projection Standard Parallels 41° 20´ and 46° 40´
Horizontal Datum: North American Datum of 1983
Topographic data corrected to October 1993

VFR TERMINAL AREA CHART
SEATTLE
SCALE 1:250,000
Lambert Conformal Conic Projection Standard Parallels 33° and 45°
Horizontal Datum: North American Datum of 1983
Topographic data corrected to April 1993

Figure 12-19 Most charts are based on the Lambert conformal conic projection.

Sectional Charts

Sectionals are colorful charts that show significant ground details, such as height of terrain, position of rivers and lakes, cities, railroads, roads, and so on, as well as aeronautical details in the airspace above, including federal airways and airspace boundaries and altitudes. The aeronautical information also includes ground features such as airports, which are sometimes easy to see from an airplane and sometimes not, as well as the position of navigation aids.

Ground Features

Ground features may change according to season.

Topographical information shown on sectionals are those considered to be of most value to visual navigation. Features shown on the chart will be evident on the ground. It is impossible to show everything. For example, an isolated rocky outcrop may not be considered significant by the cartographer and therefore will not be shown. You might spot it on the ground, yet not find it depicted on the chart.

If, however, there is an isolated rock shown on the chart, it will certainly exist on the ground. The same thing may be said about cultural features depicted on charts, such as radomes and golf courses. If they are shown on the chart, then they may be suitable as landmarks for visual navigation.

Drainage and Water Features

Drainage and water features (hydrographic features) are usually depicted in blue. Hydrographic features include creeks, streams, rivers, canals, lakes, reservoirs, swamps, marshes, shorelines, tidal flats, and so on. Just how they are depicted on the chart is explained by the chart legend, but bear in mind that after a flood, for instance, what might be shown as a small stream on the chart may have become a raging torrent.

Relief

There are various ways of bringing ground contours into relief so that an impression of hills, mountains, valleys, and so on is obtained when you look at the chart. Sectionals charts show *contours*—lines joining places of equal elevation above mean sea level—to depict relief. The closer that the contour lines are together on the chart, the steeper the terrain.

The basic contour interval on sectionals is in 500-foot vertical steps, with 250-foot contour intervals in gently rolling areas—for example, 250 feet MSL, 500 feet MSL, 750 feet MSL.

Color or layer tinting in 1,000-foot steps up to 2,000 feet MSL, then in 2,000-foot steps, is used in conjunction with the contour lines to give even more relief. The colors or tints used for the various ground elevations are shown on a table on the chart legend. The shades of color start with light green for low land just above sea level, then go through shades of brown, gradually darkening as the ground becomes higher. Remember that a particular color may indicate ground elevation up to the level of the next contour above it. Refer to the legend and chart excerpts on pages 329–333.

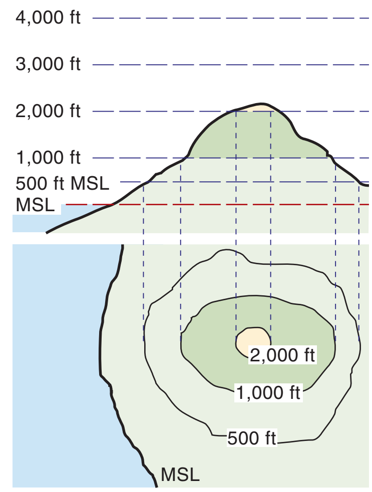


Figure 12-20
Contour lines represent changes in height MSL.

Hill Shading

Hill shading is used to give a three-dimensional effect on some aeronautical charts. Hill shading shows darkened areas on the low side of high ground where you would expect to see shadows with the light coming from the northwest (a graphic standard).

Spot Elevations

Spot elevations (or spot heights) are shown using a black spot with an adjacent number to indicate the elevation (height MSL—above mean sea level) in feet. These elevations are generally accurate (unless amended by NOTAM), or unless shown on the chart by an *x* instead of a •. Doubtful locations are indicated by omission of the • or *x*.

Spot elevations are normally used to show local peaks and other critical elevations that are significantly higher than the surrounding terrain. The spot heights may not be higher than all other terrain in the general area, so you should always check hypsometric tints as well as spot heights. The highest point on each chart has its elevation printed slightly larger than the rest. It also rates a mention on the color-tint table, and its position in latitude and longitude is specified there.

Obstructions

Obstructions are shown on sectionals using their own symbols, differing slightly for obstructions 1,000 feet above ground level (AGL) and higher, and for those below 1,000 feet AGL. A bold number gives the elevation MSL of the highest point on the obstruction, and a lighter number in parentheses gives its height AGL. Be aware that guy wires may extend outward from some structures. You can determine the elevation of the terrain at the base of the obstruction by subtracting the obstruction height AGL from its elevation MSL. Lighted obstructions have flash lines radiating from the top of their symbols.

Maximum Elevation Figures

MEFs concern the highest known feature including terrain and obstructions.

Maximum elevation figures (MEFs) for specified areas are shown on sectionals. Thousands of feet are shown as a large number, with the hundreds shown as a smaller number beside it—for example, 31 (3,100 feet MSL), and 56 (5,600 feet MSL). MEFs concern the highest known feature lying within the specified latitude-longitude quadrangle, and include terrain and obstructions. Elevations are rounded up to the next 100 feet, or higher if thought appropriate.

If you fly 500 feet higher than the MEF, you will clear all terrain and obstacles in that quadrangle by 500 feet vertically, which is normal minimum VFR clearance when flying over open terrain. Over congested areas, you are required by Part 91 of the regulations to have a clearance of 1,000 feet vertically, in which case you would add 1,000 feet or more to the MEF.

Hazards to Aviation

Hazards to aviation information are also depicted. These include certain aerial activities such as parachuting and hang-gliding, as well as permanent obstructions such as radio masts and elevated cables.

Cultural Features

Cultural features are of great help in visual navigation. It is not possible to show every town or house on the chart, so a choice is made to show what is significant. A group of, say, 100 houses is obviously of little significance if it lies in the middle of a city the size of Los Angeles, and therefore will not be specifically depicted on the chart. Yet in the western desert areas it may be extremely significant and will be shown.

Roads and railroads can be of great assistance for visual air navigation. Those that are most significant will be clearly shown on the chart. Distinctive patterns such as curves, roads running parallel to and crossing railroad lines, road or railroad junctions, forks, overpasses and tunnels are especially useful.

Pilots are requested to fly no lower than 2,000 feet AGL over national wildlife refuges.

Many other easily seen cultural features, such as isolated golf courses, hospitals, factories, microwave stations, ranches, sawmills, and so on may also be shown. Pilots are requested to fly no lower than 2,000 feet AGL over national wildlife refuges, where there may be a lot of bird activity, and where a certain amount of tranquillity might be appreciated. Examine the chart legend carefully and become familiar with the symbols.

Aeronautical Information on Sectionals

Most people are familiar with topographical and cultural information, since these are surface features which are shown on a road map and in an atlas. A pilot, however, operates in a three-dimensional environment and therefore requires information on the airspace above the surface of the earth as well.

Aeronautical information is vital information for a pilot, showing not only the position of airports on the ground, but also the division of airspace, the location on the ground of navigation aids such as VORs and NDBs, and of course other information such as special use airspace.

Use the legend to explain chart information.

Sectional chart legends explain this information clearly and thoroughly, although sometimes you have to search for the information in the legend and its associated notes. It is a good idea to memorize the most commonly used symbols for airports, airspace, obstructions, and so on. If in doubt, check the legend.

Airports

Airports are shown on sectionals as:

- circles, for airports with runways that are not hard-surfaced;
- shaded circles, showing hard-surfaced runways 1,500–8,000 feet long; or
- shaded runways, for hard-surfaced runways longer than 8,000 feet.

Blue indicates airports equipped with control towers. *Magenta* is used for all other airports. If fuel is available and the airport is attended in normal working hours, four small ticks are shown around the basic airport symbol. A star ☆ near the airport symbol indicates a rotating beacon from sunset to sunrise. Further information regarding airport lighting, navigation aids, and services may be found in the Airport/Facility Directory (A/FD).

The identifier for each airport shown on the Sectional chart will have the following where appropriate:

- the airport name—for example, Seattle Tacoma International (Intl), Boeing Field, King County Intl, Renton, McChord Air Force Base (AFB);
- the control tower frequency, for example, CT 120.1 (a star ★ indicates part-time, NFCT indicates a Non-Federal Control Tower, a C indicates the Common Traffic Advisory Frequency—CTAF);
- the ATIS frequency—for example, ATIS 134.85;
- field elevation, lighting, longest runway, UNICOM frequency—for example, *313 L 115 122.95,* which means: field elevation 313 feet MSL, lighting in operation sunset to sunrise (★ *L* if on-request, part-time, or pilot-controlled), longest runway 11,500 feet, and UNICOM frequency 122.95 MHz; and
- FSS above the airport name, where a Flight Service Station is at the airport (with advisory services available on 123.6 MHz if no tower in operation).

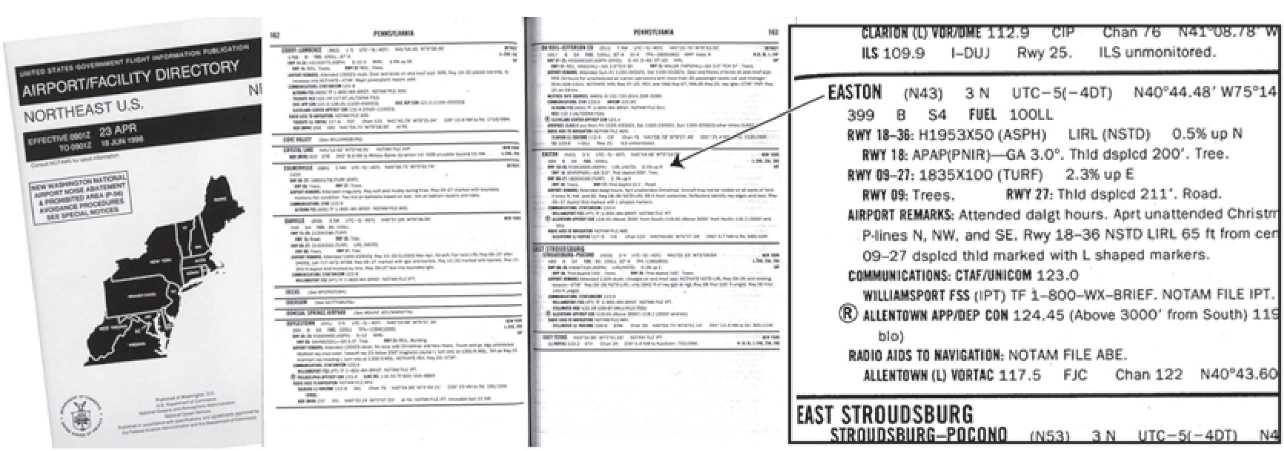


Figure 12-21 The Airport/Facility Directory (A/FD).

Radio Frequencies

When the control tower is operating, use tower frequency.

Communications boxes shown on sectional charts indicate frequencies to be used. At airports *with* operating control towers, you should use the control tower frequency. At airports *without* operating control towers, you should use the common traffic advisory frequency (CTAF), which may be:

Use CTAF frequency at airports without operating control towers.

- the FSS advisory frequency at airports without control towers but with FSS;
- the control tower frequency if there is a control tower, but it is not attended (in which case there may be no wind or runway-in-use information available, and you would have to use the UNICOM to obtain this information);
- the UNICOM frequency if there is no tower or FSS (UNICOM is a nongovernment frequency); or
- MULTICOM 122.9 MHz if there is no tower, FSS or UNICOM.

When inbound to or outbound from an airport *without* an operating control tower, you should communicate your position and monitor traffic on the CTAF within a 10-mile radius of the airport.

Navigation Facilities

Navigation facilities shown on sectionals include VORs, VORTACs, VOR/DMEs, and NDBs. NDBs are surrounded by a small circle lightly shaded with magenta-colored dots. VORs, VORTACs and VOR/DMEs are shown in blue, and have a large compass rose aligned with *magnetic* north centered on them to help in plotting radials where necessary.

The direction of true north is indicated by the meridians of longitude, and the angle between this and magnetic north on the VOR compass rose depends on the magnetic variation in that area.

Information on each radio facility is shown nearby in a NAVAID information box. The hazardous in-flight weather advisory service (HIWAS) is available on NAVAID frequencies whose information box has a white H in a solid circle symbol in its upper right corner. Transcribed en route weather broadcasts (TWEB) are available if a white *T* in a solid-circle symbol appears in the upper right-hand corner of the information box.

Position Information on Sectionals

The latitude/longitude grid is clearly marked on sectional charts. True bearings are measured from a meridian of longitude, which is the direction of true north. The east/west *parallels of latitude* indicate degrees north or south of the equator (north in the United States of course). They are labeled at either side of the 1:500,000 sectional chart in one-degree (1°) intervals, which are also 60 NM intervals. Each degree is divided into 60 minutes (′), with marks each 1′ and 10′, and a full line across the chart at 30′. In the northern hemisphere, latitude is measured up from the bottom of the chart (from the equator toward the pole).

The north-south *meridians of longitude* are labeled at the top and/or bottom of the chart in degrees east or west of the prime meridian. Each degree is divided into 60 minutes, with marks each 1′ and 10′, and a full line up the chart at 30′.

Magnetic Information

Isogonals are lines on a chart joining places of equal variation.

Isogonic lines, or *isogonals*, join places of equal magnetic variation. They are indicated on sectional charts by dashed magenta lines. Magnetic bearings can be found by applying the magnetic variation to the true bearing.

The *agonic line* (where true north and magnetic north are the same direction, and variation is zero) lies in between the areas experiencing west variation and those experiencing east variation. The agonic line passes through the eastern side of the United States.

Because the earth's magnetic poles are gradually moving, the amount of magnetic variation at a particular place will also gradually change over a period of years. Every year the isogonic information on the charts is updated. Compass roses aligned with *magnetic* north are shown around VORs, since VOR radials are magnetic courses away from a VOR.

VOR radials are magnetic courses away from a VOR.

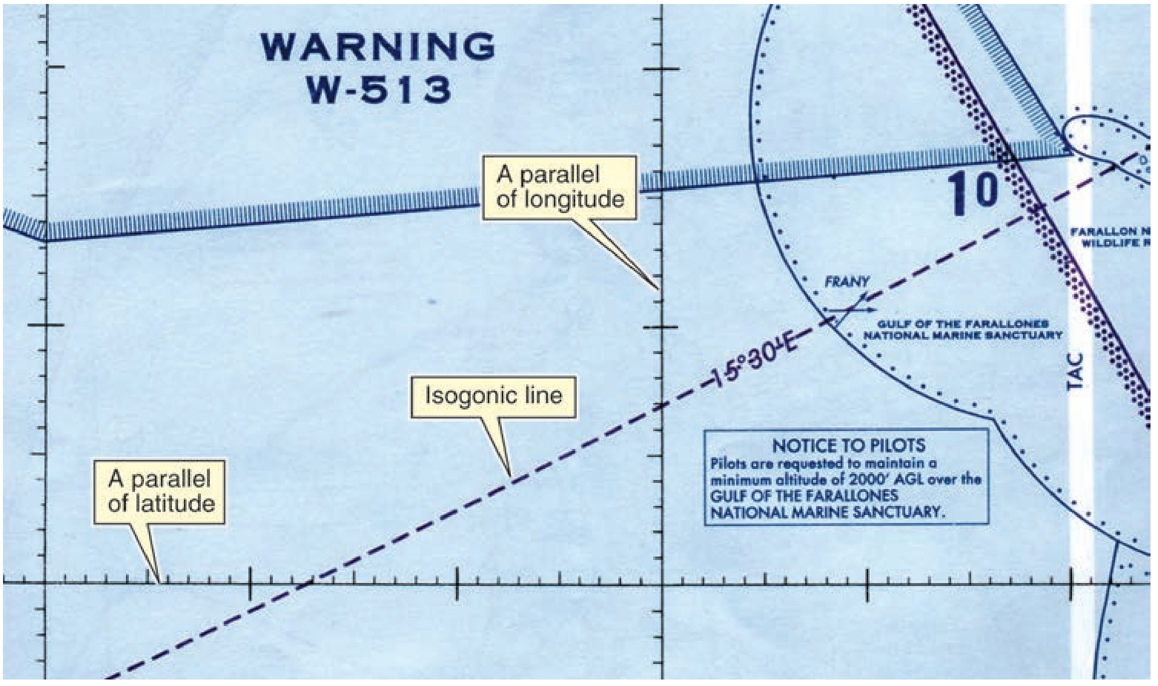


Figure 12-22 Grid of the 1:500,000 series.

VFR Terminal Area Charts

VFR Terminal Area Charts have a larger scale (1:250,000, or quarter-million) than Sectionals (1:500,000) and are used to show more detail around busy terminal areas. They look similar to sectional charts in that they also display both topographical and aeronautical information. On the rear face of many VFR Terminal Area Charts are *VFR Flyway Planning Charts*, which show suggested VFR flyways and altitudes designed to help VFR pilots avoid major controlled traffic flows in busy terminal areas. These charts are not to be used as your primary navigation chart. Ground references shown on the VFR Flyway Planning Charts only provide a guide for improved visual navigation. A sample excerpt of a VFR Terminal Area Chart is shown on page 335.

1:1,000,000 Navigation Charts

As you can imagine, charts having a scale of one to one million cover quite a lot of territory compared to the quarter-and half-million charts. This scale is often used when large distances are involved to provide pilots mainly with topographical information (mountains, lakes, rivers, deserts, coastlines, and so on) and cultural information (cities, towns, highways, country roads, railroads, and so on). Aeronautical information is shown, but it is not as detailed as that shown on Sectionals or VFR Terminal Area Charts.

There are two major series of 1:1,000,000 aeronautical charts:

- the Operational Navigation Chart (ONC) series; and
- the ICAO World Aeronautical Chart (WAC) series.

Both series use much the same symbols and are based on the same projection as the half-million charts, the Lambert conformal conic projection. Detail such as isogonic lines, restricted airspace, obstructions, irrigation channels, railroads and road systems change from time to time, and so the charts are reprinted regularly—about every two years for busy areas and every five or six years for more remote parts of the world. As with all aeronautical charts, ensure that you use only the latest edition and study the legend carefully prior to flight.

The *ONC* series originates from military sources but is available to civil pilots for most areas of the world.

The *ICAO World Aeronautical Chart* (WAC) series originates from civil aeronautical sources. It is widely used in those parts of the world where the 1:1,000,000 scale is better suited to en route navigation, such as the Far East, South-East Asia and Australia, because of the large distances involved. Each country producing charts in the WAC series does so according to the ICAO standards.

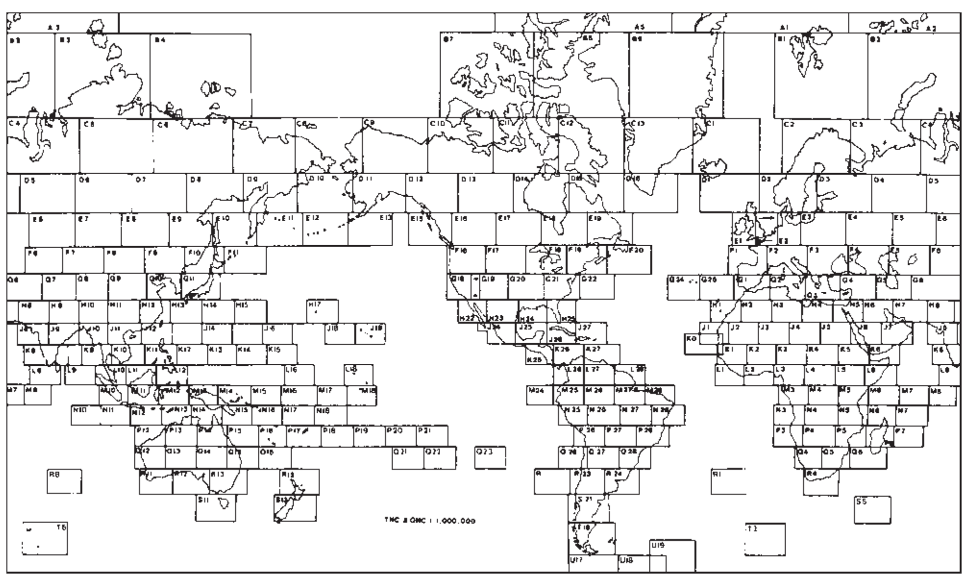


Figure 12-23 ONC world coverage.

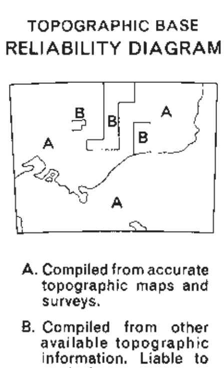


Figure 12-24
A WAC reliability panel.

NOTAM amendments are sometimes issued for WACs; these corrections are added by hand on the appropriate chart (known as manuscript amendments). As some areas of the world have not been charted accurately, there is a small reliability diagram at the bottom left hand corner of each WAC that will alert you to the reliability of the chart information. A sample WAC excerpt is shown on page 334.

Figure 12-25 Sectional chart excerpt no. 1.

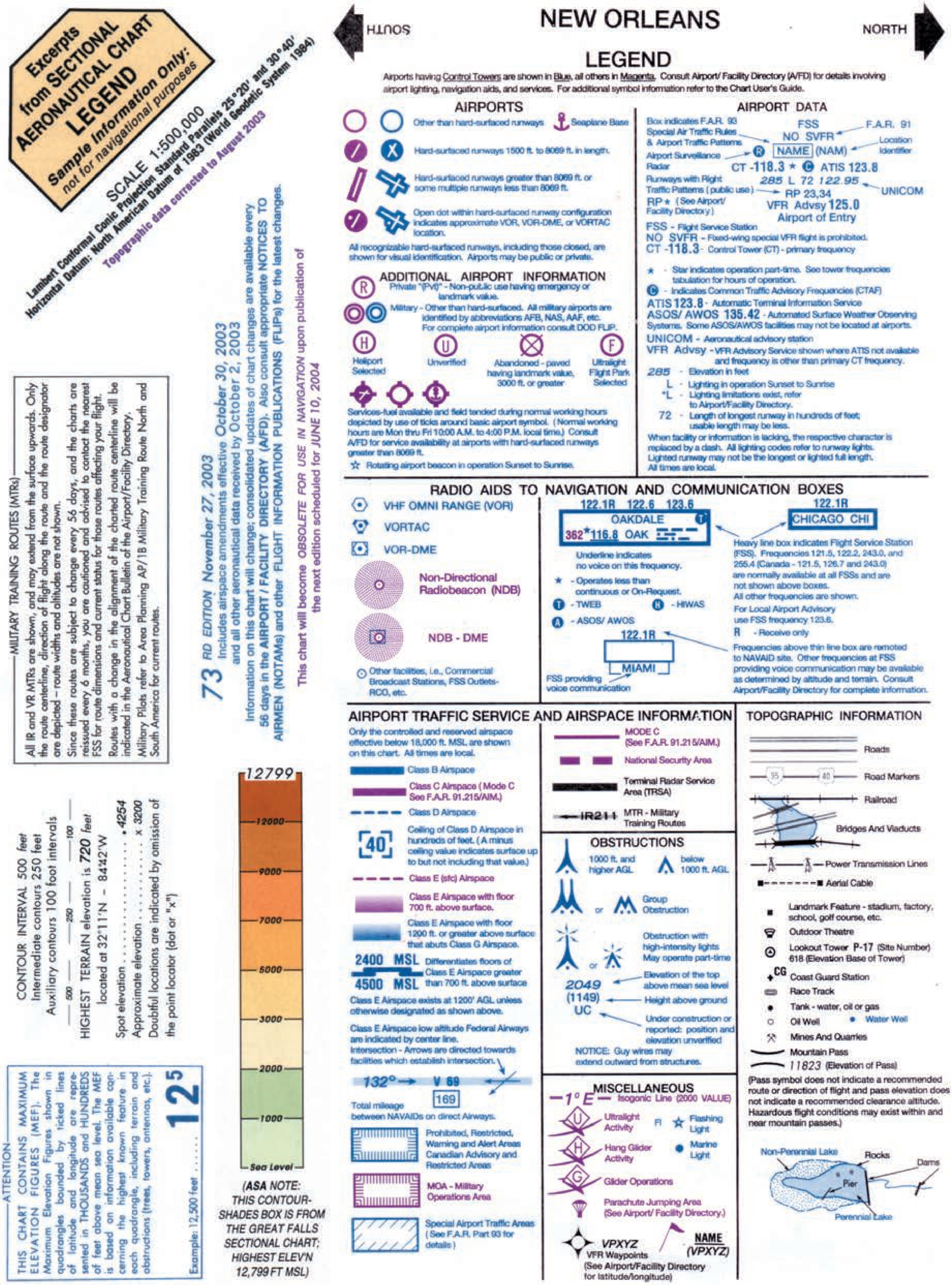


Figure 12-26 Sectional chart legend.

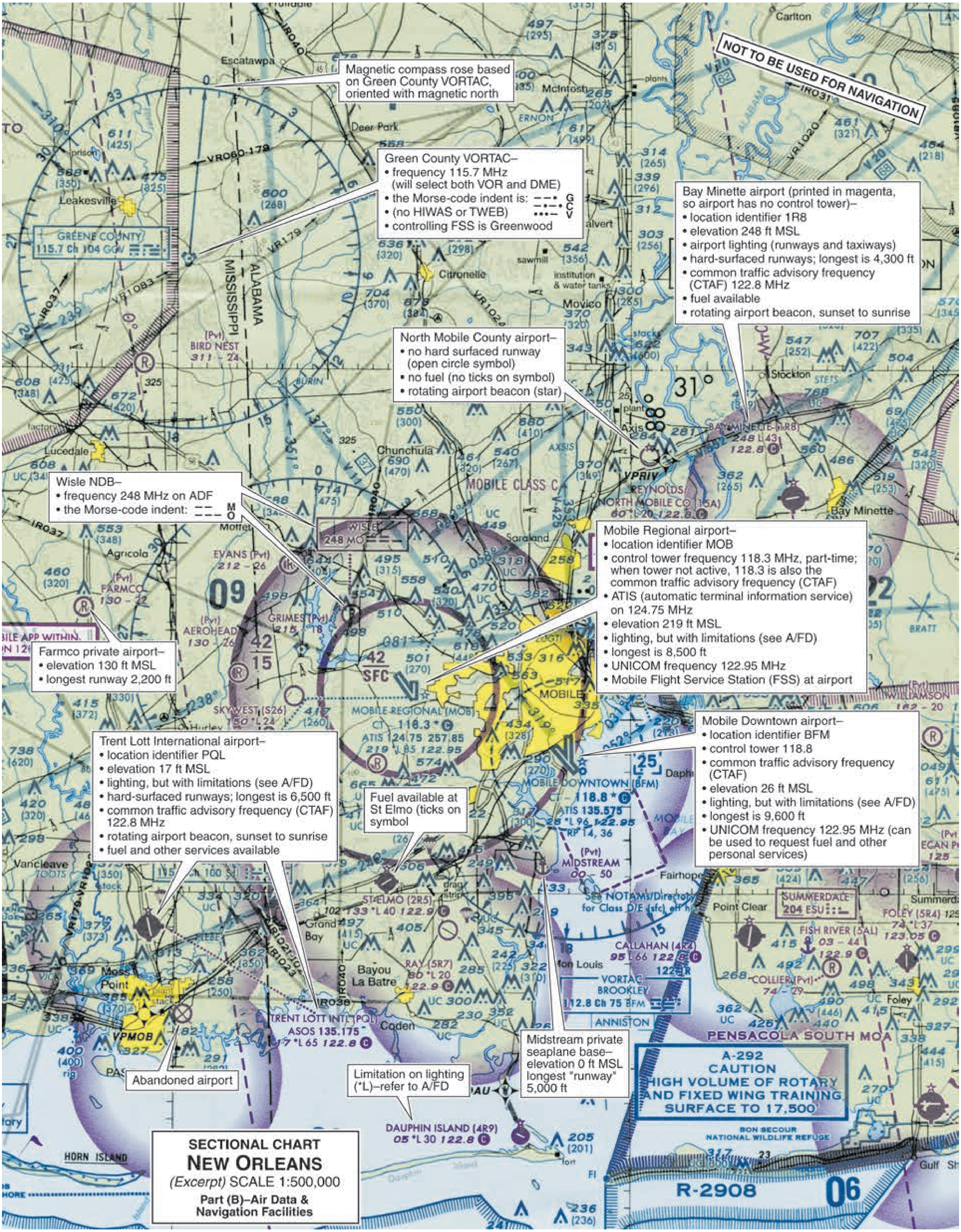


Figure 12-27 Sectional chart excerpt no. 2.

Figure 12-28 Sectional chart excerpt no. 3.

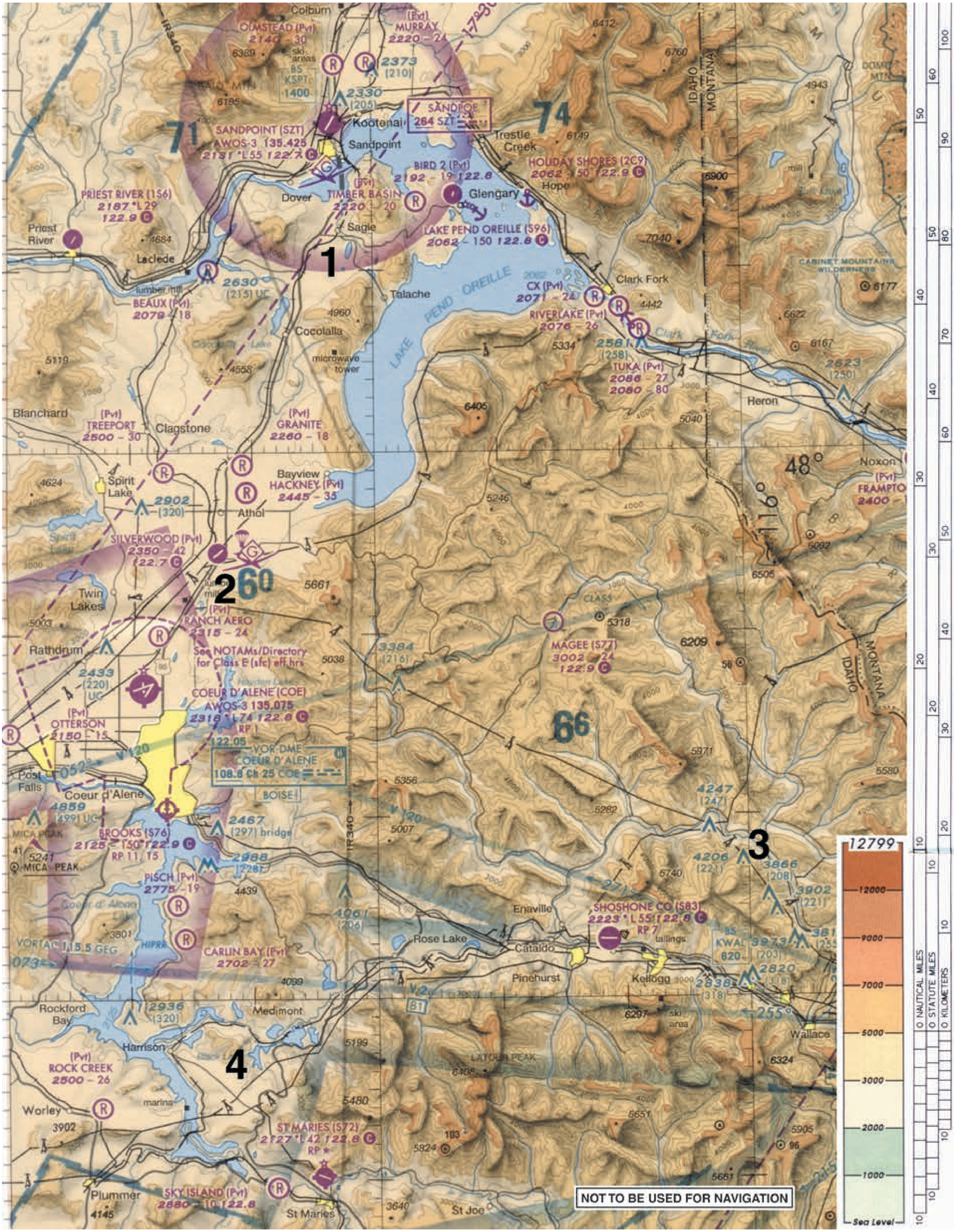


Figure 12-29 Sectional chart excerpt no. 4.

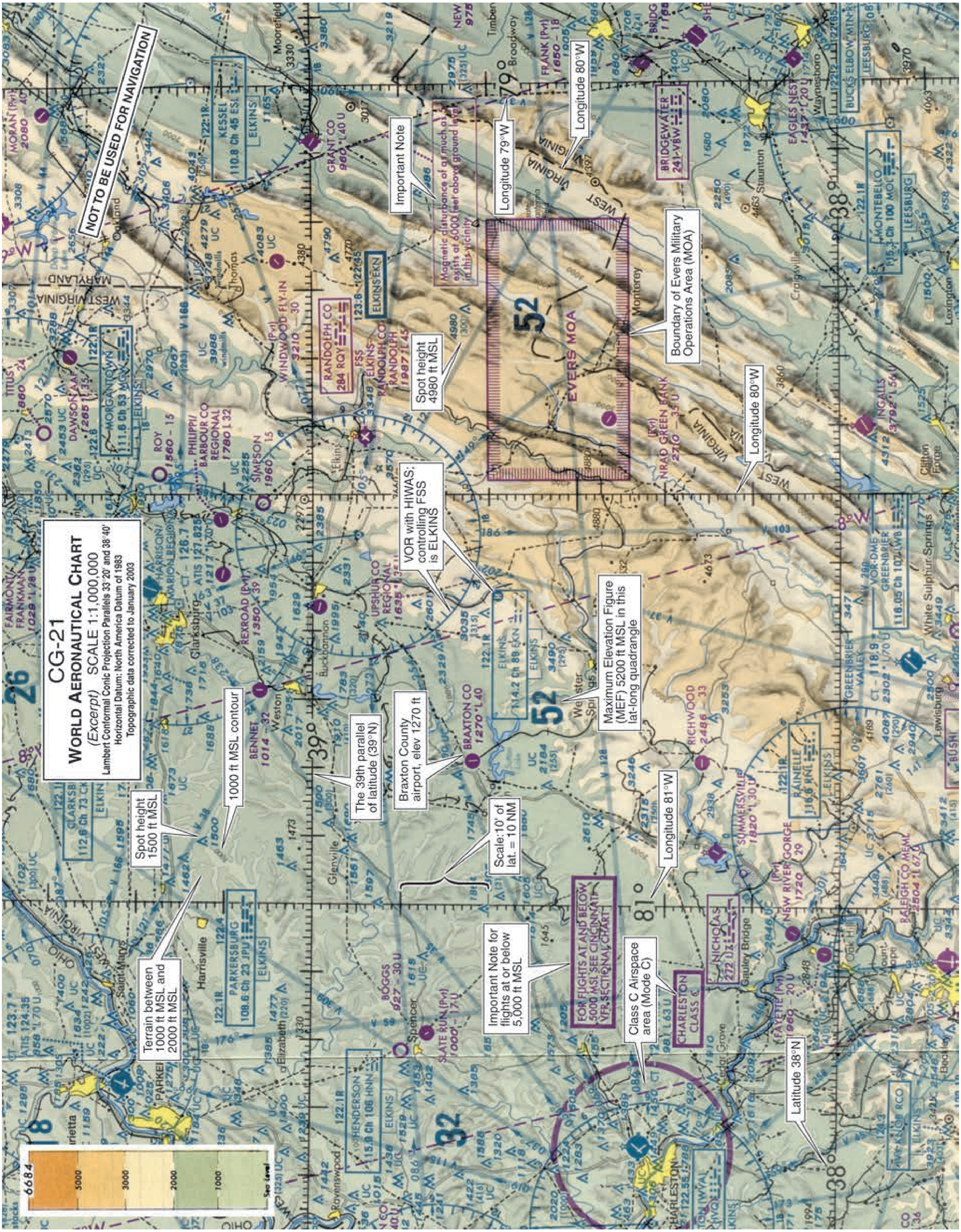


Figure 12-30 World aeronautical chart.

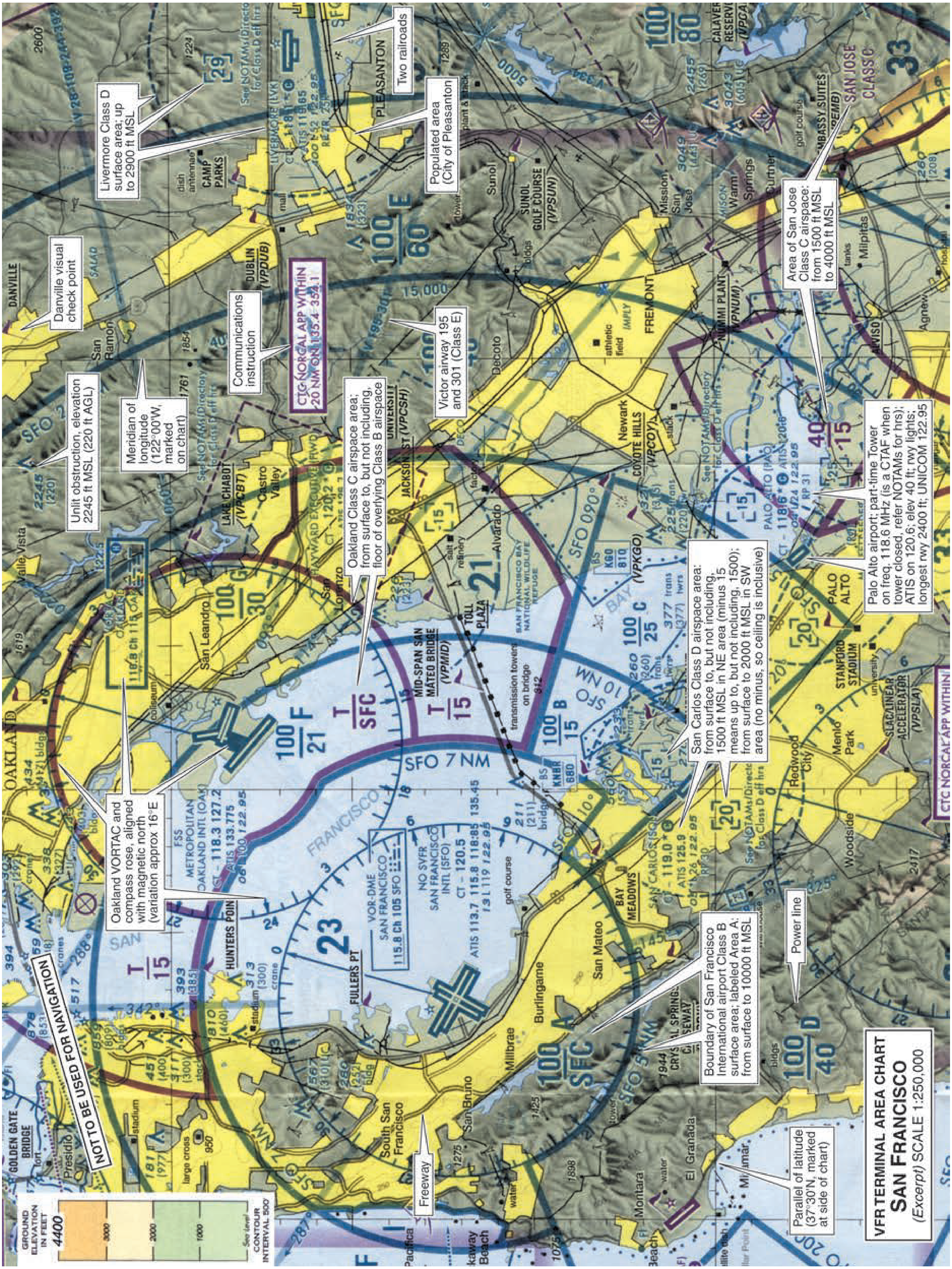


Figure 12-31 VFR Terminal area chart.

Figure 12-32 Canadian charts.

Review 12
Charts

Aeronautical Charts

1. Does the plane of a great circle on the earth pass through the center of the earth?
2. What is meant by the term "small circle?"
3. True or false? Parallels of latitude are parallel to the equator and to each other.
4. What is the basic reference for longitude?
5. What well-known landmark does the basic reference for longitude pass through?
6. True or false? Meridians of longitude all pass through the north and south geographic poles.
7. True or false? Meridians of longitude are small circles.
8. Define "longitude."
9. What is the length (NM) of one minute of arc of a great circle on the earthís surface?
10. 1 degree of latitude is equivalent to how many nautical miles?
11. With respect to topography, what is meant by the term "scale?"

VFR Charts

Refer to Sectional Chart Excerpt No. 2 (page 331).

12. What is the minimum altitude required to clear the single obstacle 6 NM to the SE of Mobile Regional Airport?

Refer to the Sectional Chart Excerpt No. 4 (page 333) and figure 12-33 (page 338) when required for questions 13 to 24.

13. The obstacle 4 NM northeast of Sandpoint is 210 feet AGL. What minimum altitude is necessary to clear it by 500 feet?
14. Which frequency should be used at Coeur díAlene Tower to monitor airport traffic?
15. What UNICOM frequency is to be used at Coeur díAlene Tower to request fuel?
16. What should you should refer to for information about parachute jumping and glider operations at Silverwood Airport?
17. In comparing Silverwood airport (area 2) with Shoshone County Airport (area 3):
    - **a.** is Silverwood airport further north?
    - **b.** does Silverwood have a higher northerly latitude?
    - **c.** is Silverwood further east?
    - **d.** does this mean that Silverwood has a more easterly longitude?
18. Answer the following with reference to Shoshone County Airport (area 3).
    - **a.** What is the latitude and longitude?
    - **b.** What is its elevation?
    - **c.** Does it have lighting?
    - **d.** What is the runway surface like?
    - **e.** What is the length of the longest runway?
    - **f.** What does the color magenta indicate?
    - **g.** Which frequency is the CTAF on?
    - **h.** Which radio is used to select the CTAF?
19. Answer the following with reference to Silverwood airport (area 2).
    - **a.** What is the latitude and longitude?
    - **b.** What is its elevation?
    - **c.** Does it have lighting?
    - **d.** What is the runway surface like?
    - **e.** What length is the longest runway?
    - **f.** Which frequency is the CTAF on?
    - **g.** What aeronautical activity, apart from aircraft, can you expect in the vicinity?
    - **h.** Which document would you refer to for further information about this activity?
20. Give the following with reference to the airport located N48°18′ W116°34′ (approx).
    - **a.** What airport is this?
    - **b.** It lies in which direction from the town?
    - **c.** Is fuel available?
    - **d.** Is there an FSS located on the airport?
    - **e.** What navigation aid is situated near the airport?
    - **f.** What is its frequency?
    - **g.** What equipment could you use to select it?
    - **h.** How could you identify that you have selected it correctly?

21. Answer the following with reference to Coeur d'Alene airport.

- **a.** What is the latitude and longitude?
- **b.** It lies in which direction from the town?
- **c.** What does the color magenta indicate?
- **d.** What is its elevation?
- **e.** Does it have lighting?
- **f.** What are the runway surfaces like?
- **g.** What is the length of the longest runway?
- **h.** Which radio would you use to select this?
- **i.** Automatic weather information is available on which frequency?
- **j.** Which radio would you use to select this?
- **k.** Which class of airspace is this airport surrounded by?
- **l.** To clear the highest obstacle in the latitude-longitude quadrangle surrounding Coeur d'Alene airport by 500 feet, what altitude would you need to fly at?

22. You wish to fly from Shoshone County airport to Silverwood airport.

- **a.** What is the magnetic course?
- **b.** What is the distance?

23. What is the flag symbol at Mica Peak to the SW of Coeur d'Alene airport?

24. Which statement is true relating to the blue and magenta colors used to depict airports on Sectional Aeronautical Charts?

- **a.** Airports having control towers are shown in blue; all others are shown in magenta.
- **b.** Airports having runways capable of handling large aircraft are shown in blue; all others are shown in magenta.

COEUR D'ALENE

§ **COEUR D'ALENE AIR TERM** (COE) 9 NW UTC-8(-7DT) 47°46'27"N 116°49'11"W **GREAT FALLS**

2318 B S4 **FUEL** 80, 100, JET A OX 1,2 **H-1B, L-9A**

RWY 05-23: H7400X140 (ASPH) S-57, D-95, DT-165 HIRL 0.7% up NE **IAP**

RWY 05: MALSR. **RWY 23:** REIL. VASI(V4L)—GA 3.0°TCH 39'.

RWY 01-19: H5400X75 (ASPH) S-50, D-83, DT-150

RWY 01: Rgt tfc.

AIRPORT REMARKS: Attended Mon-Fri 1400-0300Z‡. Rwy 23 REIL's out of service indefinitely. ACTIVATE HIRL Rwy 05-23; MALSR Rwy 05—122.8. Rwy 19 is designated calm wind rwy. Control Zone effective Mon-Fri 1400-0300Z‡.

COMMUNICATIONS: CTAF 119.1 **UNICOM** 122.8

SPOKANE FSS (SFF) TF 1-800-527-3960. NOTAM FILE COE.

RCO 122.1R 108.8T (SPOKANE FSS)

Ⓡ **SPOKANE APP/DEP CON** 125.8

TOWER 119.1 (1700-2300Z‡ Sat-Sun ocassional Mon-Fri). **GND CON** 121.8

RADIO AIDS TO NAVIGATION: NOTAM FILE GEG.

SPOKANE (H) VORTAC 115.5 GEG Chan 102 47°33'54"N 117°37'33"W 048° 35 NM to fld. 2760/21E.

(T) VOR/DME 108.8 COE Chan 25 47°46'26"N 116°49'11"W at fld. 2290/19E. NOTAM FILE COE.

LEENY NDB (LOM) 347 CO 47°44'35"N 116°57'36"W 053° 6.0 NM to fld.

ILS 110.7 I-COE Rwy 05 LOM LEENY NDB.

SAMPLE ONLY not to be used in conjunction with flight operations or flight planning

Figure 12-33 Coeur d'Alene A/FD excerpt.

Answers are given on page 776.

Airports and Airport Operations 13

Airports come in all shapes and sizes. Some have long, hard-surfaced runways, others have short, grass runways, some have operating control towers to regulate the flow of traffic in the airspace around the airport as well as on the ground (known as *controlled* airports, *towered* airports, or *tower-controlled* airports), and others have no active control tower (known as *uncontrolled* airports or *nontowered* airports), where the traffic is self-regulating according to specified FAA procedures.

An *ATC clearance* is authorization for a VFR aircraft to proceed under specified conditions in Class B, C or D airspace. An ATC clearance to takeoff at a controlled airport should be obtained from the control tower if it is in operation. Time references will be in UTC (Coordinated Universal Time).

An ATC clearance is required for you to operate in Class B, C or D controlled airspace.

A very good source of information for correct procedures is the *Aeronautical Information Manual* (AIM), which contains an entire chapter on airport operations.

Taxiway and Runway Markings

Study the airport chart prior to taxiing at an unfamiliar airport so that your taxi route from the parking area to the takeoff holding point follows the shortest and most expeditious route. The same applies when taxiing back to the parking area after landing.

Study the airport chart before operating at an unfamiliar airport.

Further airport information may be found in the Airport/Facility Directory (A/FD). A full explanation of all terms is found at the front of the A/FD.

Runways are named according to their magnetic direction, rounded-off to the nearest 10°. For instance, a runway whose direction is 274°M is named RWY 27. When used in the opposite direction (094°M), it is named RWY 9.

Runway directions are rounded-off to the nearest 10°.

Taxiway Markings

Taxiway markings are *yellow.* The taxiway *centerline* may be marked with a continuous yellow line, and the *edges* of the taxiway may be marked by two continuous yellow lines 6 inches apart. Airplanes should taxi with their nosewheel on the yellow centerline.

Taxiway markings are yelllow.

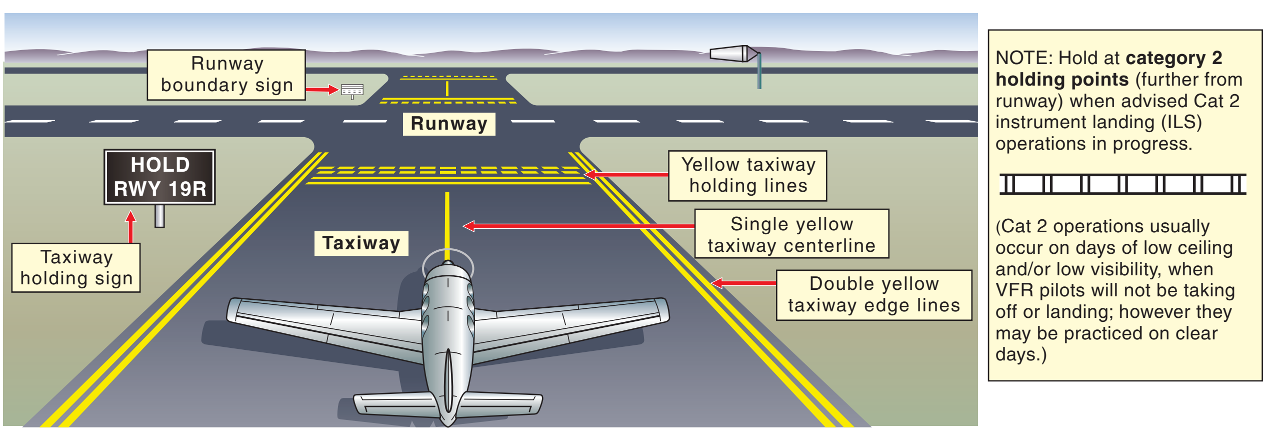


Figure 13-1 Taxiway markings are in yellow.

Figure 13-2
Runway holding position sign.

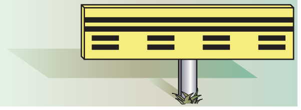


Figure 13-3 Runway boundary sign.

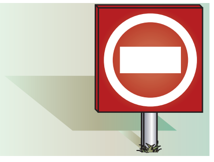


Figure 13-4 No-entry sign.

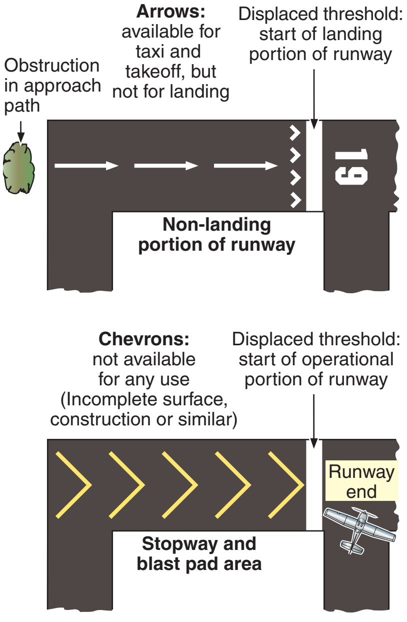


Figure 13-5
Displaced threshold markings.

Taxiway *holding lines*, across the width of the taxiway, consist of two continuous and two dashed yellow lines, spaced 6 inches between dashes. The two continuous lines are on the side from which an aircraft will approach a runway when taxiing, and if you are instructed to hold short of the runway or if you are not cleared onto the runway, you should stop with no part of the aircraft extending beyond the holding line.

Taxiway and Runway Signs

Next to the holding line at the edge of the taxiway there may be *runway holding position signs* with white characters on a red background. There may also be a *runway boundary sign* that faces the runway and is visible to pilots exiting the runway. It will also be adjacent to the holding position marked on the pavement and may even be painted on the rear face of the holding sign. The sign has black markings on a yellow background. After landing, you will be clear of the runway when your aircraft is completely past this sign and the holding lines on the pavement. A *no-entry sign* (red and white) prohibits the entry of an aircraft.

Runway Markings

Runway markings vary in complexity according to the operations likely to occur on that particular runway. To assist pilots landing and stopping at the conclusion of a successful precision instrument approach, some precision instrument runways have very specific markings, as shown in figure 13-7.

Ensure that you know whether the full length of the runway is available for landing or not. A *displaced threshold* showing the start of the landing portion of the runway will be indicated by white arrows pointing to a thick white solid line across the runway, or by yellow chevrons. If arrows are used, that part of the runway may be available for takeoff, but not for landing. If chevrons, rather than arrows are used, then that part of the runway is only suitable for use during an aborted takeoff (as a stopway). If the whole runway is totally unusable, it will have a large cross (×) at each end.

Figure 13-6 Closed runway (or taxiway).

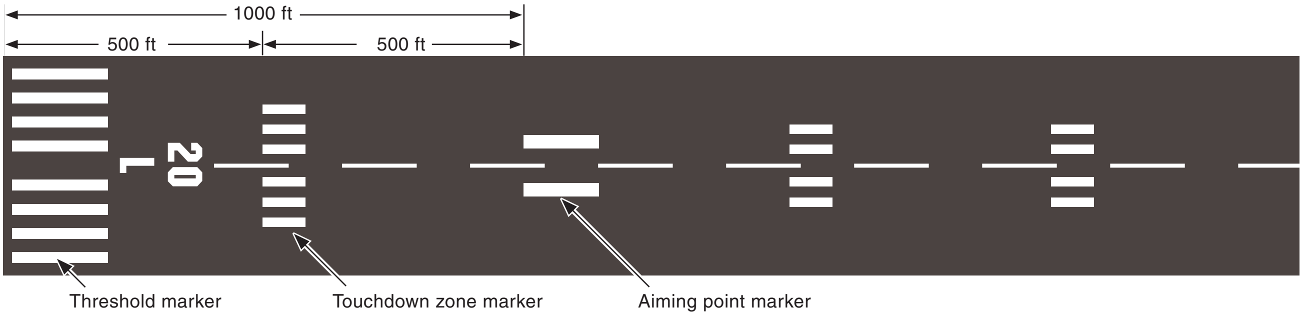


Figure 13-7 Markings on a precision instrument runway.

Airport Lighting

The main aeronautical lighting provided at an airport to assist pilots to maneuver their airplanes at night consists of:
- taxiway lighting;
- runway lighting;
- an airport beacon;
- approach lighting;
- visual approach slope indicators (VASI); and
- red warning lights on significant obstacles.

The approach lights and runway lights at an airport are controlled by:
- the control tower personnel (when the tower is active);
- the FSS, at some locations where no control tower is active; or
- the pilot (at certain airports).

The pilot may request ATC or FSS to turn the lights on (or off), or to vary their intensity if required. On a hazy day with restricted visibility, but with a lot of glare, maximum brightness might be necessary; on a clear dark night, a significantly lower brightness level will be required.

Pilot-Controlled Lighting Systems

For pilot-controlled lights at maximum intensity, select the frequency and key the mike seven times within five seconds. Activation lasts 15 minutes.

At selected airports, when ATC and/or FSS facilities are not manned, *airborne* control of the lights is possible using the NAV-COM. The Airport/Facilities Directory (A/FD) specifies the type of lighting available, and the NAV-COM frequency used to activate the system. To use an FAA-approved *pilot-activated* lighting system, simply select the appropriate VHF frequency on the NAV-COM, and depress the microphone switch a number of times. Key the mike 7 times within 5 seconds, to activate the lights at maximum intensity, and then key it a further 5 or 3 times, for medium or low intensity lights respectively, if desired.

All lighting is activated for 15 minutes from the time of the most recent transmission. If pilot-activated lights are already on as you commence an approach, it is good airmanship to reactivate them and thereby ensure good lighting throughout the approach and landing.

Taxiway Lights

Taxiway lights are either centerline green or blue edge.

Taxiways are lit in one of two ways for the guidance of pilots, with either:
- two lines of taxiway *blue edge* lights; or
- one line of *centerline green* taxiway lights.

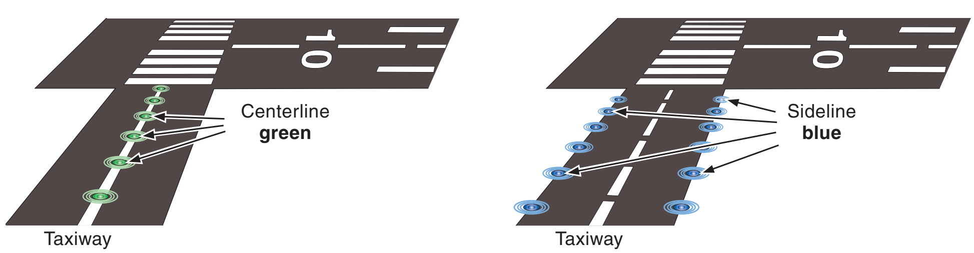


Figure 13-8 Taxiway lighting.

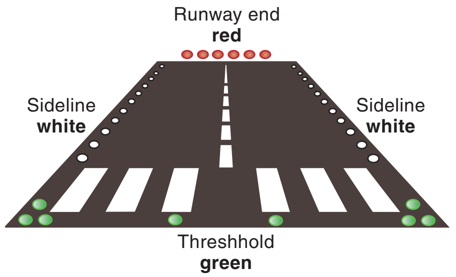


Figure 13-9 Basic runway lighting at night.

At some airports, there is a mixture of the two types, centerline green on some taxiways, and blue edge on others. Taxiway lights are omnidirectional, which means they shine in all directions, since a taxiing aircraft may be coming from any direction.

At certain points on the taxiway, there may be *red stop-bars* installed, to indicate the position where an airplane should hold position, for instance before entering or crossing an active runway.

Runway Lighting

Runway lighting defines the boundaries of the actual landing area. Some advanced systems on precision instrument approach runways also provide you with distance-down-the-runway information.

Runway edge lights are white, and outline the edges of runways during periods of darkness or restricted visibility. The *runway end lights* each have two colors, showing green at the near end to aircraft on approach, and red to airplanes stopping at the far end.

Note. Runway lighting is the extent of the airport lighting at basic airports.

Advanced runway edge lights are classified according to the intensity or brightness they are capable of producing:

- HIRL—high intensity runway lights;
- MIRL—medium intensity runway lights; and
- LIRL—low intensity runway lights.

Runway edge lights are white, except on instrument runways where amber replaces white for the last 2,000 feet (or last-half on runways shorter than 4,000 feet) to form a *caution* zone for landings in restricted visibility.

Runway End Identifier Lights (REIL)

Runway end identifier lights consist of a pair of synchronized white flashing lights located each side of the runway threshold at the approach end. They serve to:

- identify a runway end surrounded by many other lights;
- identify a runway end which lacks contrast with the surrounding terrain; and
- identify a runway end in poor visibility.

In-Runway Lighting

In-runway lighting is embedded in the runway surface of some precision approach runways. It consists of:

- *touchdown zone lighting* (TDZL)—bright white lights either side of the runway centerline in the touchdown zone (from 100 feet in from the landing threshold to 3,000 feet or the half-way point, whichever is the lower);
- *runway centerline lighting* (RCLS)—flush centerline lighting at 50 feet intervals, starting 75 feet in from the landing threshold to within 75 feet of the stopping end. RCLS also includes *runway-remaining lighting*, where the centerline lighting seen by a stopping airplane is:
  - initially all white;
  - alternating red and white from 3,000 feet-to-go point to 1,000 feet-to-go;
  - all red for the last 1,000 feet; and
- *taxiway turn-off lights*—a series of green in-runway lights spaced at 50 feet intervals defining a curved path from the runway centerline onto the taxiway.

Approach Light Systems (ALS)

At many airports, an approach lighting system (ALS) extends out from the approach end of the runway to well beyond the physical boundaries of the airport, possibly into forested or built-up areas. Approach lights do *not* mark the boundaries of a suitable landing area—they simply act as a lead-in to a runway for a pilot on approach to land.

ALS lighting is a standardized arrangement of white and red lights, consisting basically of extended centerline lighting, with crossbars sited at specific intervals back along the approach path from the threshold before the runway is reached.

Visual Approach Slope Indicators (VASI)

In conditions of poor visibility and at night, when the runway environment and the natural horizon may not be clearly visible, it is often difficult for a pilot to judge the correct approach slope of the airplane toward the touchdown zone of the runway. A number of very effective visual approach slope indicators provide visual slope guidance to a pilot on approach.

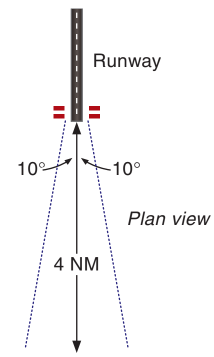


Figure 13-10
The extent of useful VASI information.

Lateral guidance is provided by the runway, the runway lights or the approach light system. The slope guidance provided by a *visual approach slope indicator* (VASI) is to the touchdown zone, which will probably be some 1,000 feet in from the runway threshold. The VASI slope is typically 3°.

The typical *2-bar VASI* has two pairs of wingbars alongside the runway, usually at 500 feet and 1,000 feet from the approach threshold. It is sometimes known as the *red-on-white* system, since these two colors are used to indicate to the pilot whether the airplane is on slope, too high or too low. The pilot will see:

- all bars white if high on approach;
- the near bars white and the far bars red if right on slope; and
- all bars red if low on slope.

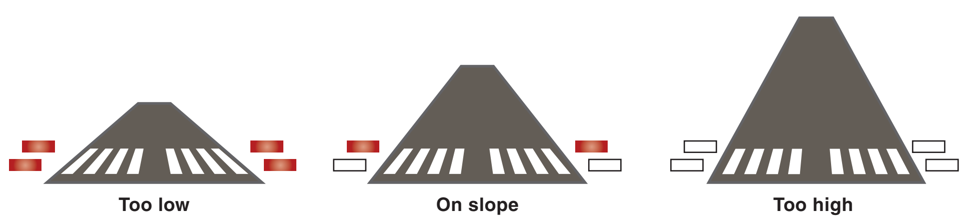


Figure 13-11 Perspectives on approach using a 2-bar VASI fly "red-on-white."

During the approach, the airplane should be maintained on a slope within the *white* sector of the near bars and the *red* sector of the far bars. If the airplane flies above or below the correct slope, the lights will change color from white to pink, to red, or visa versa.

The plane of the VASI approach slope only provides guaranteed obstacle clearance in an arc 10° left or right of the extended centerline out to a distance of 4 nautical miles (NM) from the runway threshold, even though the VASI may be visible in good conditions out to 5 NM by day and 20 NM by night.

There are other operational considerations when using the *red-on-white* VASI. At maximum range, the white bars may become visible before the red bars, because of the nature of red and white light. In haze or smog, or in certain other conditions, the

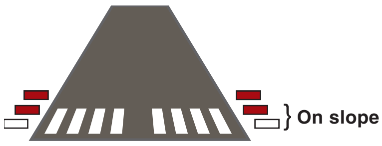


Figure 13-12
Correct view for the pilot of a smaller airplane using the 3-bar VASI.

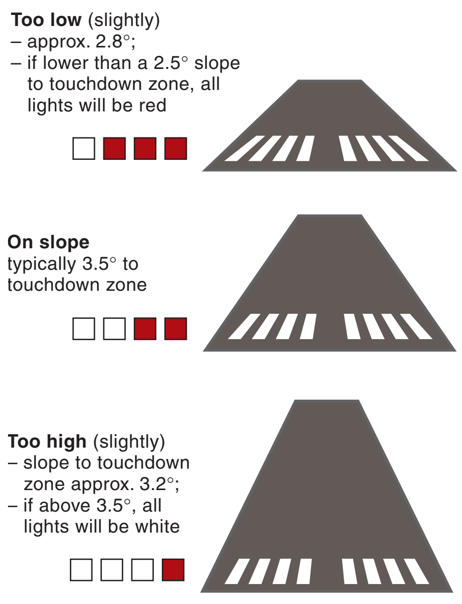


Figure 13-13 Slope guidance using PAPI.

white lights may have a yellowish tinge about them. In addition, if water collects in or on the light lens false indications may occur.

When extremely low on slope, the two wingbars (all lights red) may appear to merge into one red bar—at close range to the threshold this would indicate a critical situation with respect to obstacle clearance, and the pilot must take urgent action.

Some VASI systems use a reduced number of lights, in which case they may be known as an *abbreviated VASI* or *AVASI*.

The *3-bar VASI* has an additional wingbar at the far end, intended to assist the pilots of large passenger airliners. Pilots of such airplanes will use the second and third wingbars, and ignore the first to allow for the extra length of the airplane.

Pilots of smaller airplanes should refer only to the two nearer wingbars, and ignore the further "long-bodied" wingbar. On slope, the indications should be (top bar red and ignored), middle bar red and lower bar white.

The *precision approach path indicator* (PAPI) is a development of the VASI, and also uses red/white light signals for guidance in maintaining the correct approach angle, but the lights are arranged differently and their indications must be interpreted differently. PAPI has a single wingbar, which will consist of four light units on one or both sides of the runway adjacent to the touchdown point. There is no pink transition stage as the lights change from red to white.

If the airplane is on slope, the two outer lights of each unit are white and the two inner lights are red. Above slope, the number of white lights increase, and below slope the number of red lights increase.

A *pulsating visual approach slope indicator* (PVASI) consists of a single light unit, positioned on the left side of a runway adjacent to the touchdown point, which projects three or four different "bands" of light at different vertical angles, only one of which can be seen by a pilot on approach at any one time.

The indications provided by a typical PVASI are:

- pulsing white—above glide slope;
- steady white—on glide slope (alternating red/white on some systems); and
- pulsing red—below glide slope.

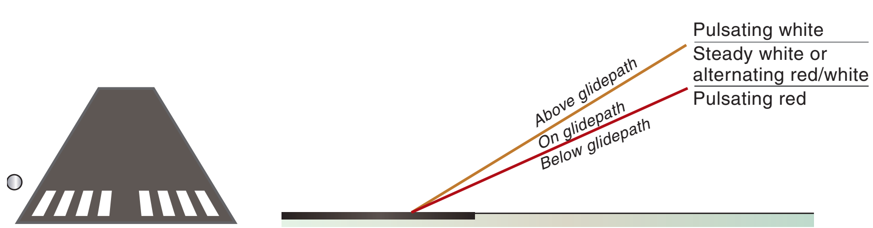


Figure 13-14 The PVASI.

The *tri-color VASI* is a short-range visual slope aid (½ mile by day, 5 miles by night), and consists of a single-light unit that indicates:

- amber if above slope;
- green if on slope; and
- red if below slope.

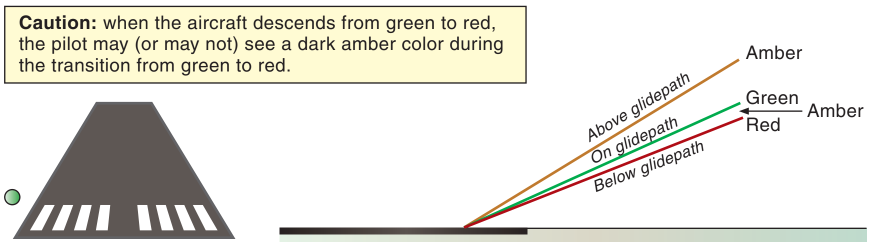


Figure 13-15 The tri-color VASI.

The *T-VASI* is a system that has a horizontal bar of white lights either side of the runway aiming point. If the airplane is right on slope, you will see the horizontal bar only. If you are high on slope, single lights will appear above this bar, forming an inverted-T, and indicating fly down. If you are low on slope, single lights will appear below the bar, forming a T, and indicating fly up. The number of vertical lights give an indication of how far off slope you are. If extremely low, the lights turn red.

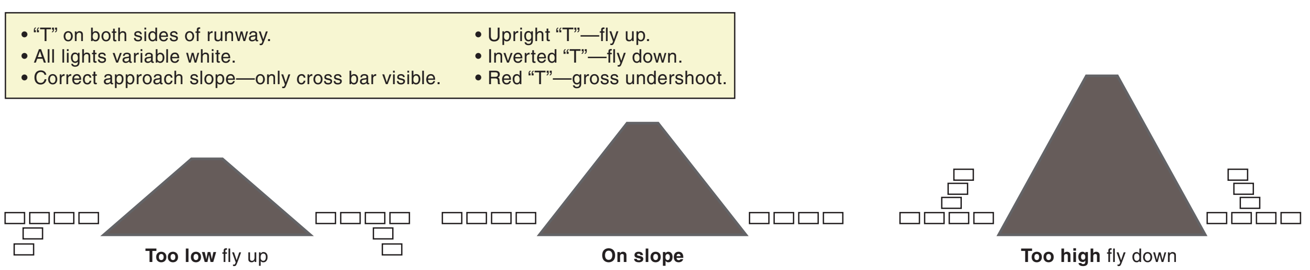


Figure 13-16 T-VASI.

Airport Beacon

The airport beacon is designed to help the pilot visually locate the airport from some distance away. Some airport beacons rotate, others transmit pulses of light, the effect being the same—flashes of one or two alternating colors, which are:

- green/white/green/white—at *civil land airports*;
- green/white-white/green/white-white—at *military land airports*;
- green/yellow/white—at *lighted heliports*; and
- white/yellow—at *lighted water ports*.

An airport rotating beacon that is operating during daylight hours indicates that weather in the Class B, C or D airspace around that airport, which will have an operating control tower, is below basic VFR weather minimums (ground visibility less than 3 miles and/or ceiling less than 1,000 feet). This is a good warning for VFR pilots.

Airport Operations

There are two types of airport:

- controlled; and
- uncontrolled.

A controlled airport has an active control tower and all movements must be approved. An uncontrolled airport relies on pilot-to-pilot communications for traffic awareness and safe separation. Radio procedures for each are defined

Basic Communications Procedures for Uncontrolled Airports

The standard calls for a nontowered airport, or when the tower is closed, is described in table 13-1.

Facility at Airport	Frequency Use	Communication/Broadcast Procedures		
		Outbound	Inbound	Practice Instrument Approach
UNICOM (no tower or FSS).	Communicate with UNICOM station on published CTAF frequency (122.7, 122.8, 122.725, 122.975, or 123.0). If unable to contact UNICOM station, use self-announce procedures on CTAF.	Before taxiing and before taxiing on the runway for departure.	10 miles out. Entering downwind, base, and final. Leaving the runway.	
No tower, FSS, or UNICOM.	Self-announce on MULTICOM frequency 122.9	Before taxiing and before taxiing on the runway for departure.	10 miles out. Entering downwind, base, and final. Leaving the runway.	Departing final approach fix (name) or on final approach segment inbound.
No tower in operation, FSS open.	Communicate with FSS on CTAF frequency.	Before taxiing and before taxiing on the runway for departure.	10 miles out. Entering downwind, base, and final. Leaving the runway.	Approach completed/ terminated.
FSS closed (no tower).	Self-announce on CTAF.	Before taxiing and before taxiing on the runway for departure.	10 miles out. Entering downwind, base, and final. Leaving the runway.	
Tower or FSS not in operation.	Self-announce on CTAF.	Before taxiing and before taxiing on the runway for departure.	10 miles out. Entering downwind, base, and final. Leaving the runway.	

Table 13-1 Recommended communication procedures.

Lost Communications Procedures

If a pilot experiences a radio failure, it may be the receiver only. The procedure is to remain outside or above Class D airspace if possible, advise the tower of the loss of reception, make the usual position calls, squawk 7600 on your transponder, join the standard traffic pattern, and look for light signals from the tower. If the transmitter fails but the pilot can receive, listen to the ATC frequency and join the pattern.

If all communications are lost, join the pattern after establishing landing direction and traffic, and look for light signals. The standard light signals to an aircraft in flight, are shown in figure 13-17.

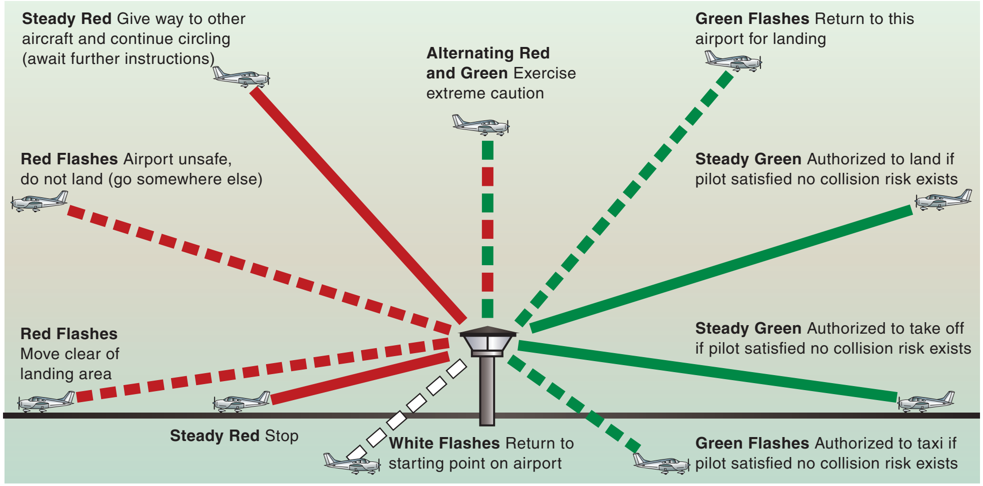


Figure 13-17 Standard light signals to aircraft.

Traffic Pattern and Wind Indicators

Landing direction—and therefore all legs of the traffic pattern—relate to wind direction. There are several types of wind indicators. In the absence of an active control tower, the pilot selects the pattern and landing direction in accordance with the traffic pattern indicators and the wind direction indicator. These are shown in figure 13-18.

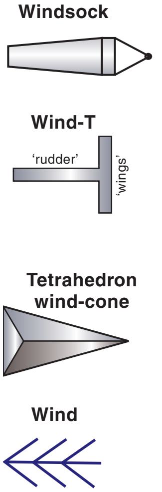


Figure 13-18 Wind and landing direction indicators.

Radar Traffic Information Service

Traffic advisories and air traffic control may provide additional services, such as safety alerts, traffic advisories vectoring if requested, and sequencing of traffic in higher density areas. In certain locations, a *terminal radar service area* (TRSA) may be implemented to provide separation for participating VFR and all IFR aircraft operating within its area. Class C or B service may be provided. Advisories take the form of a radio call, such as, "*You have traffic in your 11 o'clock, 3 miles, crossing left to right, Cessna, 3,000 feet.*"

> **Note.** The clock code from radar is based on your track and not your heading as it would be if you were reporting traffic to your instructor. Therefore, drift has an effect which must be considered.

Collision Avoidance

Collision avoidance for VFR aircraft rests largely with the pilot. An effective scan pattern must be practiced, as the eyes tend to rest and not focus at a distance. Also, a continuous scan may miss traffic. It is necessary to scan a little and then pause, then scan a little further and pause again. This is called the *saccade/rest cycle*. It is also essential to scan by turning the head—not just sweep with eye movement. The aircraft has many blind spots. Therefore, the flight path may need to be varied to look under or over the nose or wings—don't forget that faster traffic can approach from behind.

Prevent a runway incursion: read back all crossing and/or hold instructions, review airport layouts as part of preflight planning, know airport signage, review NOTAMs for runway/taxiway closures, and request progressive taxi instructions when unsure of taxi route.

Runway Incursion Avoidance

The most serious risk of collision is around and on an airport. Even on the ground, it is essential to be vigilant and scan for traffic—especially if approaching a runway or holding point, crossing another strip or taxiway, landing on a crossing runway, or landing behind another aircraft. Have lights on, and if in doubt, stop and ask the tower or another aircraft for directions. Never enter or cross a runway if there is any doubt about it being active or if there is an aircraft visible on that runway.

The Standard Traffic Pattern

To maintain some form of safe and orderly flow of traffic at an airport, and to allow easy and safe access to the active runway, aircraft are flown in a standard traffic pattern. For good operational reasons, the preferred direction of takeoff and landing is into the wind, therefore the same direction will generally be used by aircraft both taking off and landing.

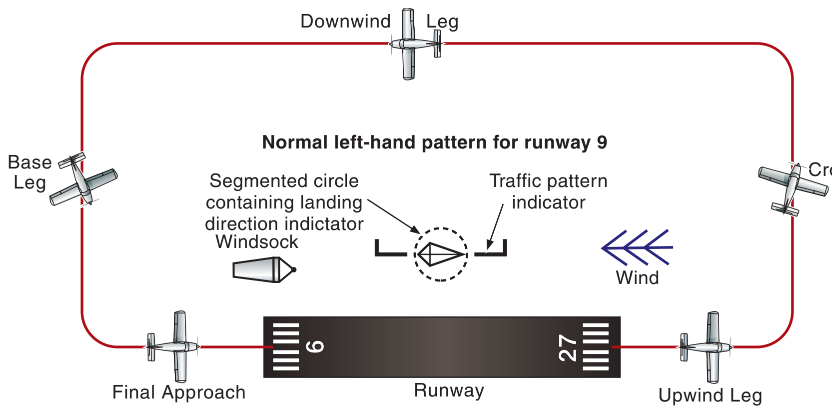


Figure 13-19 The traffic pattern is rectangular.

The standard traffic pattern is left hand.

The traffic pattern is a rectangular ground path based on the runway in use. The *standard pattern* is to the left of the runway with all turns being made to the left. At some airports and on some particular runways, however, the patterns are right-hand to avoid built-up areas, high terrain or restricted airspace.

The tower will advise takeoff and landing direction.

At tower-controlled airports takeoff and landing directions will be advised from the tower or on the ATIS.

At airports *without* an operating control tower, make use of any *segmented circle* with its associated wind indicator and traffic pattern indicators to assist you in determining which runway to use and the direction of the traffic pattern. You should comply with any FAA traffic pattern established for a particular airport (see A/FD).

At non-towered airports, comply with any FAA traffic pattern established for that particular airport.

Some airports have *parallel runways*, with a left traffic pattern off Runway Left, and a right traffic pattern off Runway Right, and with a "no transgression zone" between the two patterns.

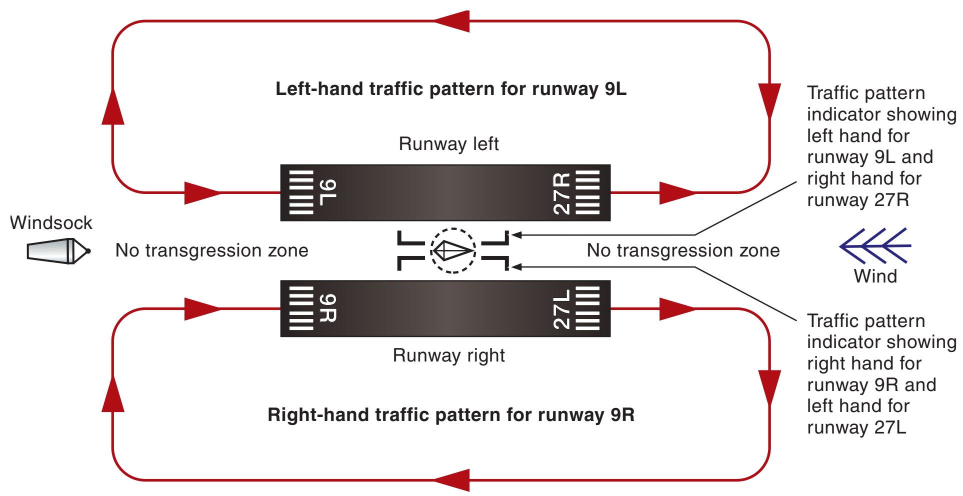


Figure 13-20 Left and right traffic patterns for parallel runways.

The traffic pattern is referenced to the runway on which it is based, for example, "left traffic for Runway 36" refers to the pattern based on Runway 36. The 36 indicates that the runway heading is somewhere in the range 355°–360°–005°.

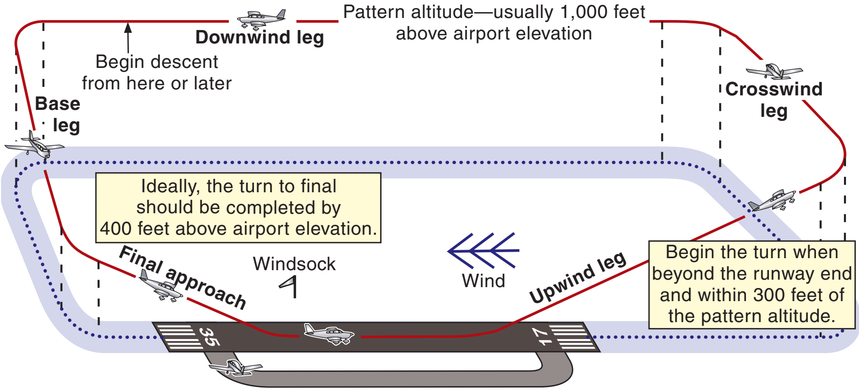


Figure 13-21 The normal traffic pattern.

Ensure that the current altimeter setting is set in the pressure window, so that the altimeter will read altitude above mean sea level (MSL). This enables you to accurately determine when you have reached pattern altitude. If the airport has an elevation of 890 feet, and the pattern is to be flown 1,000 feet above this, then traffic pattern altitude is reached when the altimeter indicates (890 + 1,000) = 1,890 feet MSL.

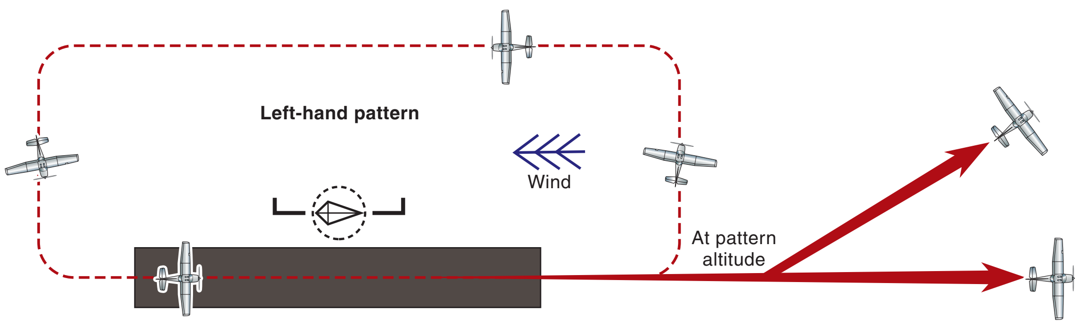


Figure 13-22 Departing the traffic pattern.

Airport Radar Services

Radar has greatly simplified ATC procedures by enabling the controller to see a picture on the radar screen of the air traffic in his area of responsibility. The transponder carried in the aircraft can provide the radar controller with further information on the screen, such as aircraft identification and altitude. Unless otherwise authorized, VFR aircraft should squawk transponder *code 1200*.

Normal transponder code for VFR is 1200.

When passing traffic information to you, the radar controller will often use the clock system to specify the other aircraft's position relative to your track, and also give its distance in miles, direction of flight, and altitude. The controller sees your *track*, rather than your heading, and so you will have to allow for any wind drift angle when you look out the window and search for other traffic. Note that, even in a radar environment, the pilot has the ultimate responsibility to see and avoid other traffic.

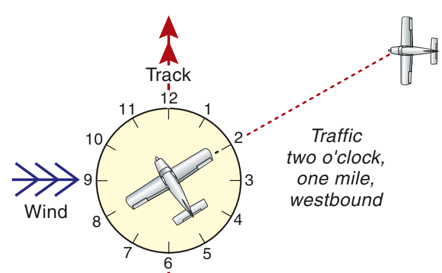


Figure 13-23
Radar traffic information service.

Various levels of radar service are available, depending on the particular airspace, the nature of the operation (IFR/VFR), and the controller's workload.

Following radio communications failure, keep a good lookout, squawk code 7600, observe the traffic flow, enter the traffic pattern, and watch for light signals from the tower.

If you ever experience *radio failure*, you should squawk *7600* on your transponder. This will alert the tower controller to your radio communications failure. You should observe the traffic flow, enter the traffic pattern keeping a particularly good lookout, and watch for light signals from the tower (see figure 13-17). If the radio failure occurs on the ground, you would normally not takeoff but taxi back to a parking position for repairs or clarification.

Basic Radar Service

Basic radar service can provide traffic advisories and limited radar vectoring on a workload-permitting basis to VFR aircraft arriving at Class D airports and occasionally at airports in Class E or G airspace. Basic radar service exists primarily to aid tower controllers sequencing arriving and departing traffic.

Traffic Sequencing for Pilots

Basic service with traffic sequencing is provided to adjust the flow of arriving VFR and IFR aircraft into the traffic pattern and to provide traffic information to departing VFR aircraft. VFR aircraft may be assigned specific headings to fly (vectors), as well as specific altitudes, to aid controllers in facilitating traffic separation.

Full Radar Services

Full service provides sequencing and separation for all participating VFR and IFR aircraft, and is typically encountered in and around busy Class B, C, and D airspace. IFR traffic is always accorded the highest level of radar service during all segments of flight.

In a radar environment, pilots of *arriving aircraft* should contact approach control on the published frequency, usually at approximately 25 miles, and give callsign, aircraft type, position, altitude, transponder code, destination, ATIS information received, and request traffic information. Approach control will issue wind and runway, except when the pilot states "*have numbers*" or "have ATIS information." Traffic information will be advised on a workload-permitting basis. Radar service is automatically terminated when approach control advises the pilot to contact the control tower for further landing instructions.

Note. "Have numbers" does not mean "Have ATIS," it means you have wind, runway and altimeter information only.

Pilots of *departing* aircraft are encouraged, on initial contact with ground control, to request radar traffic information in the proposed direction of flight, for example:

San Carlos ground control, Mike seven three two, Cessna one seventy two, ready to taxi, VFR southbound at two thousand five hundred feet, have information Charlie, request radar traffic information.

After receiving a takeoff clearance from the tower and becoming airborne, the tower will advise when to contact departure control.

When departing and being advised that the radar service is being terminated, you should set the *normal VFR code 1200* in your transponder. Be careful not to pass through any of the emergency codes when selecting 1200: 7500 — unlawful interference, 7600 — radio failure, or 7700 — emergency.

Review 13

Airports and Airport Operations

Airports

1. In terms of runway orientation, what do the numbers 9 and 27 on a runway indicate?
2. *Refer to figure 13-24.*
   - **a.** What is area C on the airport depicted classified as?
   - **b.** Landing may be commenced at which position for runway 12?
   - **c.** What may the portion of runway 12 identified by the letter A be used for?

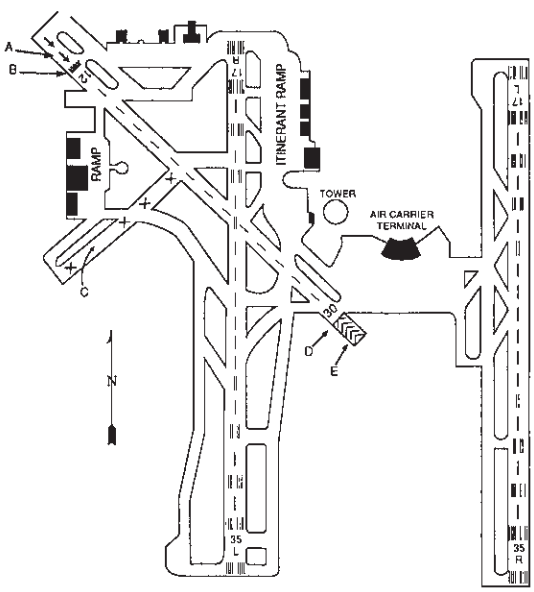


Figure 13-24 Question 2.

3. What does an airport's rotating beacon operated during daylight hours indicate?
4. How is PAL activated at maximum intensity?
5. How are airport taxiway edge lights identified at night?
6. What color are taxiway centerline lights?
7. When using PAPI, what do three white lights and one red light indicate?
8. What does a red light signal from a tri-color VASI indicate?
9. What is the below glide slope indication from a pulsating approach slope indicator?

Airport Operations

10. *Refer to figure 13-25.*
    - **a.** Which is the proper traffic pattern and runway for landing?
    - **b.** What does the segmented circle indicate?

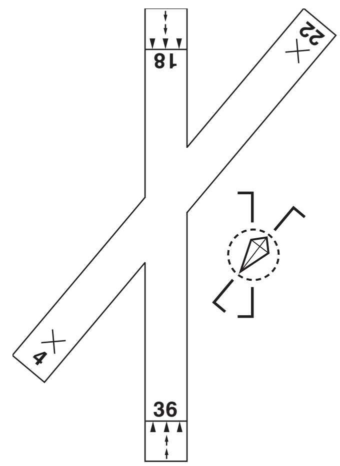


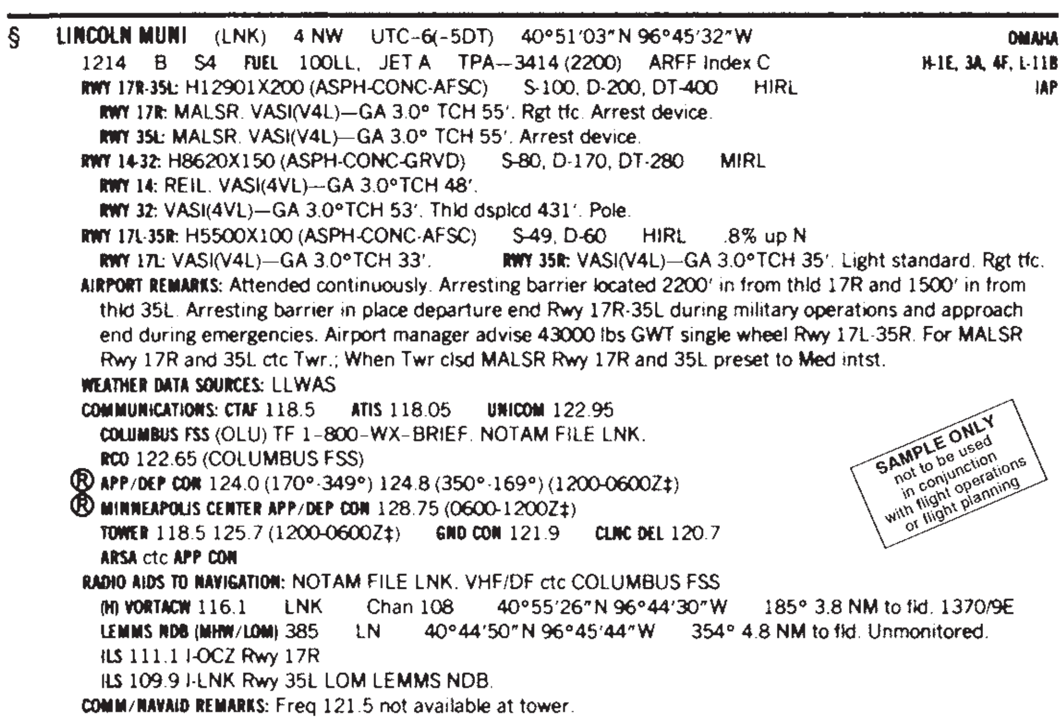
Figure 13-25 Question 10.

11. If two-way radio communication fails at an airport with a tower and cannot be restored, what is the recommended procedure?
12. What does a steady green light signal directed from the control tower to you while on the ground indicate?
13. What is indicated by the following directed to you in flight from the control tower:
    - **a.** an alternating red and green light?
    - **b.** a flashing red light signal?
    - **c.** a steady red light signal?

Refer to figure 13-26 for questions 14 to 23. You may refer to the legend of any A/FD to help you (the legend will be provided in the Knowledge Exam).

14. What is the three-letter identifying code for Lincoln Municipal Airport?
15. What is the elevation of Lincoln Municipal Airport?

16. What is the traffic pattern altitude (TPA) at Lincoln Municipal Airport? (Give your answer in feet MSL and feet AGL)
17. With respect to Runway 17 Right at Lincoln Municipal Airport:
    a. what sort of surface does it have?
    b. how long is it?
    c. how wide is it?
18. What is the CTAF at Lincoln Municipal Airport?
19. What frequency is the ATIS at Lincoln Municipal Airport on?
20. What is the recommended communications procedure for landing at Lincoln Municipal Airport during the hours when the tower is not in operation?
21. You approach Lincoln Municipal Airport at noon local time. What is this in UTC (or Z)?
22. When is Lincoln Municipal approach control active?
23. Which frequency would aircraft approaching Lincoln Municipal from the east use?
24. You require radar service when departing a primary airport in Class D airspace. When should you request this?
25. You are on a heading MH 090 and the ATC radar facility issues you the advisory: "Traffic 3 o'clock, 2 miles, westbound."
    a. Which way should you look?
    b. In which direction is this?
26. True or false? A clearance to taxi to the active runway at an airport with an operating control tower permits you to taxi via the taxiways, to cross intersecting nonactive runways, but not to enter the active runway.
27. An ATC radar facility issues the following advisory to a pilot flying north in a calm wind: "Traffic 9 o'clock, 2 miles, southbound…" Where should the pilot look for this traffic?


§ **LINCOLN MUNI** (LNK) 4 NW UTC–6(–5DT) 40°51′03″N 96°45′32″W **OMAHA**
1214 B S4 **FUEL** 100LL, JET A TPA—3414 (2200) ARFF Index C **H-1E, 3A, 4F, L-11B**
RWY 17R-35L: H12901X200 (ASPH-CONC-AFSC) S-100, D-200, DT-400 HIRL **IAP**
RWY 17R: MALSR. VASI(V4L)—GA 3.0° TCH 55′. Rgt tfc. Arrest device.
RWY 35L: MALSR. VASI(V4L)—GA 3.0° TCH 55′. Arrest device.
RWY 14-32: H8620X150 (ASPH-CONC-GRVD) S-80, D-170, DT-280 MIRL
RWY 14: REIL. VASI(4VL)—GA 3.0°TCH 48′.
RWY 32: VASI(4VL)—GA 3.0°TCH 53′. Thld dsplcd 431′. Pole.
RWY 17L-35R: H5500X100 (ASPH-CONC-AFSC) S-49, D-60 HIRL .8% up N
RWY 17L: VASI(V4L)—GA 3.0°TCH 33′. **RWY 35R:** VASI(V4L)—GA 3.0°TCH 35′. Light standard. Rgt tfc.
AIRPORT REMARKS: Attended continuously. Arresting barrier located 2200′ in from thld 17R and 1500′ in from thld 35L. Arresting barrier in place departure end Rwy 17R-35L during military operations and approach end during emergencies. Airport manager advise 43000 lbs GWT single wheel Rwy 17L-35R. For MALSR Rwy 17R and 35L ctc Twr.; When Twr clsd MALSR Rwy 17R and 35L preset to Med intst.
WEATHER DATA SOURCES: LLWAS
COMMUNICATIONS: CTAF 118.5 **ATIS** 118.05 **UNICOM** 122.95
COLUMBUS FSS (OLU) TF 1-800-WX-BRIEF. NOTAM FILE LNK.
RCO 122.65 (COLUMBUS FSS)
Ⓡ **APP/DEP CON** 124.0 (170°-349°) 124.8 (350°-169°) (1200-0600Z‡)
Ⓡ **MINNEAPOLIS CENTER APP/DEP CON** 128.75 (0600-1200Z‡)
TOWER 118.5 125.7 (1200-0600Z‡) **GND CON** 121.9 **CLNC DEL** 120.7
ARSA ctc **APP CON**
RADIO AIDS TO NAVIGATION: NOTAM FILE LNK. VHF/DF ctc COLUMBUS FSS
(H) VORTACW 116.1 LNK Chan 108 40°55′26″N 96°44′30″W 185° 3.8 NM to fld. 1370/9E
LEMMS NDB (MHW/LOM) 385 LN 40°44′50″N 96°45′44″W 354° 4.8 NM to fld. Unmonitored.
ILS 111.1 I-OCZ Rwy 17R
ILS 109.9 I-LNK Rwy 35L LOM LEMMS NDB.
COMM/NAVAID REMARKS: Freq 121.5 not available at tower.

SAMPLE ONLY not to be used in conjunction with flight operations or flight planning

Figure 13-26 Questions 14 to 23.

Answers are given on page 777.

Visual Navigation Fundamentals 14

Air Navigation

Air navigation involves basic principles that apply to all airplanes, from the simplest trainers to the most sophisticated passenger jets. Our objective in *The Pilot's Manual* is to show you navigation techniques that will not increase your workload in the cockpit to an unacceptable degree, and still allow time to fix your position and navigate the airplane safely to your desired destination. We make the assumption that you already know how to fly the airplane; the objective here is to add the basic principles of air navigation to those flying skills. Other aspects that have a bearing on the conduct of a cross-country flight are covered in the chapters to follow.

This chapter concentrates on accurate navigation of a light aircraft, flown by a single pilot in VFR conditions. When flying cross-country you are the pilot, the navigator and the radio operator. You must:

- primarily fly the airplane safely and accurately;
- navigate correctly; and
- attend to the radio and other aspects of your duty in the cockpit.

In short, you must, "*Aviate*, *navigate*, and *communicate*."

To conduct a cross-country flight efficiently, the navigation tasks must be coordinated with (and not interfere with) the smooth flying of the airplane. It is most important that you, as pilot/navigator, clearly understand the basic principles underlying navigation so that correct techniques and practices can be applied quickly and accurately without causing too much distraction or apprehension.

Remember the key words: "aviate, navigate, communicate" in that order.

Navigating an airplane, unlike a car or ship, is *three-dimensional*—you must think of *altitude* (vertical navigation) as well as *direction* (horizontal navigation). Also, you must think of *time.*

Horizontal Navigation

Types of Navigation

Visual Navigation

The basic method of visual navigation, called *pilotage*, is chart-reading and correlating information from the chart with what is seen on the surface of the earth, and thus determining position. Pilotage requires more or less continuous visual reference to the ground, and the ability to chart-read is restricted in poor visibility or if above partial cloud cover, and at night. Pilotage involves comparing the chart to the ground features and determining your actual position relative to the planned course.

Pilotage is determining position by correlating chart information with what is seen on the ground.

Pilotage is a skill learned by practice. Learning to match shapes of lakes and rivers as seen out the window from aloft to how they look on the chart (e.g. looking for railroad tracks in the right places, finding and using radio towers for correlation to towers marked on charts, discerning one town from another by the location of a water tower or how the railroad tracks come into and leave that town) are all skills acquired from practice. Teach yourself how to estimate distances over the ground between two objects seen on the ground by looking up how long a certain lake is, or how far apart two towns are on the chart, and then remembering what that distance looks like out the window. Learn to use section lines, a mile apart and laid out true north-south-east-west.

Dead reckoning is determining position by calculating headings, distances and times.

As a back-up to pilotage you can use deduced reckoning, commonly known as *dead reckoning* or *DR*. This allows you to apply current conditions of speed, direction, and wind to your latest known position (*a fix*) and thus predict where you should be at a certain time.

When navigating, pilotage and DR always go together. Using the two methods together always produces more accurate navigation than when only one of the two methods are used. DR solutions, figured out during preflight, tell you where (and when) you should be somewhere, and about when to be looking for a particular feature on the ground. Pilotage, on the other hand, tells you where you are at the moment. Learn to work the two together. Practice even when using electronic navigation systems, for the day will surely come when those systems will fail you. You may find yourself wishing to fly where there are no electronic NAVAIDs, or only one (GPS), which, if used by itself, can leave you *very* lost if it fails. As a pilot, it is your responsibility to improve and maintain your DR/pilotage skills by practice.

Navigation with Electronic Aids

Navigation may use electronic aids.

Navigation may use radio equipment installed in the airplane and tuned to ground-based or satellite radio beacons. This enables the pilot to fly along radio position lines, without visual reference to the ground, although pilotage should always be used to back up radio navigation when the ground can be seen. Typical navigation systems are VOR, NDB, and DME, with the more advanced area navigation systems of LORAN C, RNAV and GPS (these are discussed in Chapter 15). The VFR pilot may use these navigation aids to assist in visual navigation.

Before Flight

Flight plan carefully.

Being properly prepared is essential if a cross-country flight is to be successful. Always *flight plan* carefully and meticulously. This sets up an accurate base against which you can measure your in-flight navigation performance. Preflight consideration should be given to the following items:

- serviceability of your watch or aircraft clock. *Time* is vital to accurate navigation;
- contents of your "nav bag", including pencils, flight computer, protractor and scale (or a plotter), suitable aeronautical charts, and relevant flight information publications;
- preparation of the appropriate maps and charts;
- desired route;
- terrain en route;
- airspace en route (Class B, C, D, E, G, special use);
- suitability of the destination airport and any alternate airports;
- *forecast* weather en route and at the destination and alternate airports (plus any reports of *actual* weather that might be available);
- calculation of accurate headings, groundspeeds and estimated time intervals; and
- consideration of fuel consumption, and accurate fuel planning.

It sounds like a lot, but each item considered individually is simple to understand.

In Flight

Fly accurate headings, check times, and keep a flight log.

Since you spent considerable time preparing an accurate flight plan, it is important to fly the plan accurately. Once the airplane is in flight, flying a reasonably accurate *heading* (which involves reference to both the heading indicator and outside cues) is essential if the airplane is to track toward the desired destination. Maintaining *cruise airspeed*, and comparing your progress and actual *times of arrival* at various fixes with those estimated at the flight planning stage will normally ensure a pleasant and drama-free journey.

Speed

Speed is the rate at which distance is covered, or more precisely, *distance per unit time*. The standard unit for speed is the knot, (abbreviated *kt*). 1 knot equals 1 nautical mile per hour. The speed of the airplane through the air is its *true airspeed* (TAS), which may have to be calculated from the indicated airspeed (IAS) using a flight computer, or obtained from tabulated values in the Pilot's Operating Handbook (POH). TAS is the actual speed of the airplane relative to the air mass.

Because of the design of the airspeed indicator in the airplane, the airspeed that it indicates is usually *less* than the true airspeed because of the lower air density at altitude. The flight computer can be used to convert the indicated airspeed that you read in the cockpit into a true airspeed. Some airspeed indicators have a correction scale incorporated in their design (see figure 14-1).

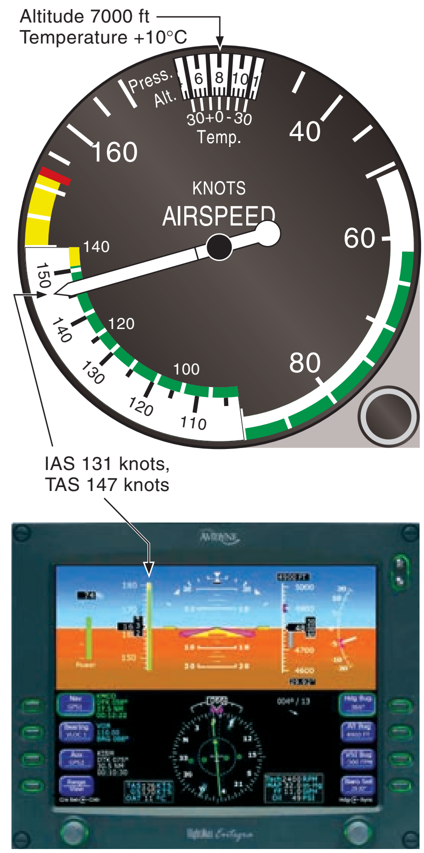


Figure 14-1 IAS and TAS indicator.

Direction and Speed Combined

An airplane flies in the medium of air. Its motion relative to the air mass is specified by its direction (known as *heading*) and its speed through the air mass (*true airspeed*). When considered together HDG/TAS constitute what is known as a *vector* quantity, which requires both *magnitude* (in this case *TAS*) and *direction* (here *HDG*) to be completely specified. HDG/TAS is the *vector* (direction and speed) of the airplane through the air. HDG/TAS is symbolized by a single-headed arrow ——>——. The direction of the arrow indicates the direction of movement along the vector line.

The HDG/TAS vector fully describes the motion of the airplane relative to the air mass.

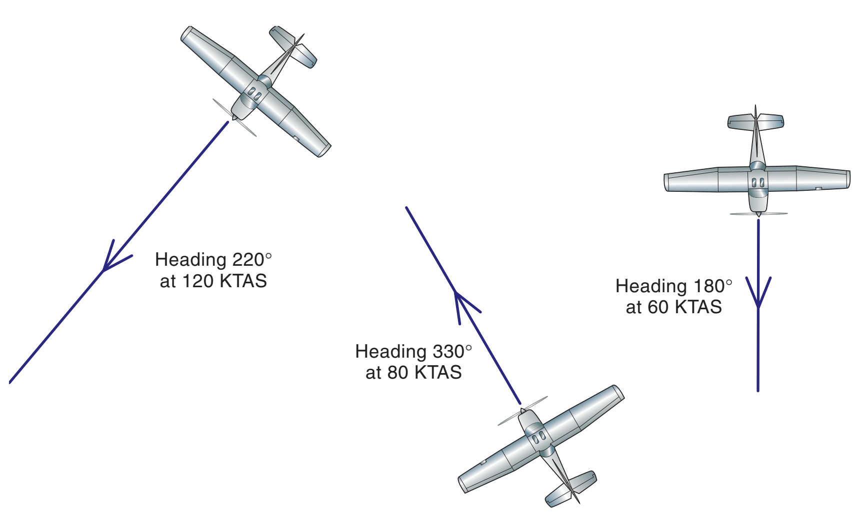


Figure 14-2 Examples of the HDG/TAS vector.

The Effect of Wind

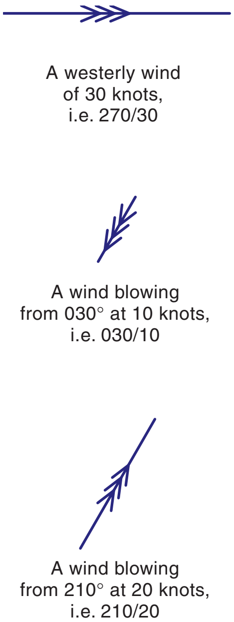


Figure 14-3
Examples of the WN vector.

The general movement of air relative to the ground is called *wind vector* and is abbreviated to *W/V*. Like HDG/TAS, W/V is a *vector* quantity because both direction and magnitude are specified. By convention, the wind direction is expressed as the direction *from* which it is blowing. For example, a northerly wind blows from the north toward the south. W/V is symbolized by a triple-headed arrow .

With a W/V of 230/20, the air mass will be moving relative to the earth's surface from a direction of 230 degrees at a rate of 20 NM per hour. In a 6 minute period, for example, the air mass will have moved 2 NM (6 minutes = 1⁄10 hour; 1⁄10 of 20 NM = 2 NM) from a direction of 230 degrees (and therefore toward 230 - 180 = 050 degrees).

The motion of the airplane relative to the surface of the earth is made up of two velocities: the airplane moving relative to the air mass (HDG/TAS); and the air mass moving relative to the surface of the earth (W/V). Adding these two vectors together gives the resultant vector of the airplane moving relative to the surface of the earth. This is the track and groundspeed (TR/GS), which is symbolized by a double headed arrow . The angle between the HDG and the actual ground track (TR) is called the *drift angle*.

An airplane flying through an air mass is in a similar situation to a swimmer crossing a fast-flowing river. If you dive in at position A and head off through the water in the direction of B, the current will carry you downstream toward C. To an observer sitting overhead on a tree branch, you will appear to be swimming a little bit sideways as you get swept downstream, even though in fact you are swimming straight through the water.

Careful! Surface wind velocities are usually reported in statute miles per hour, not knots.

In the same way, it is quite common to look up and see an airplane flying somewhat sideways in strong-wind situations. Of course the airplane is not actually flying sideways through the air, rather it is flying straight ahead relative to the air mass and it is the wind velocity (W/V) which, when added to the airplane's motion through the air (HDG/TAS), gives it the resultant motion over the ground (TR/GS).

These three vectors form what is known as the *triangle of velocities*. It is a pictorial representation of the vector addition: HDG/TAS + W/V = TR/GS.

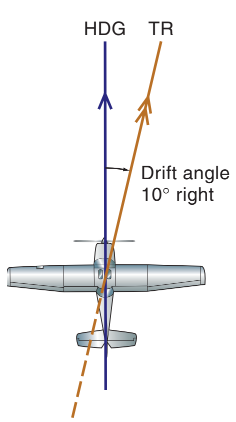


Figure 14-4
Drift is the angle between heading and ground track.

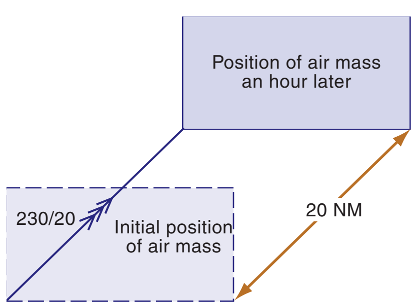


Figure 14-5
A wind of 230/20.

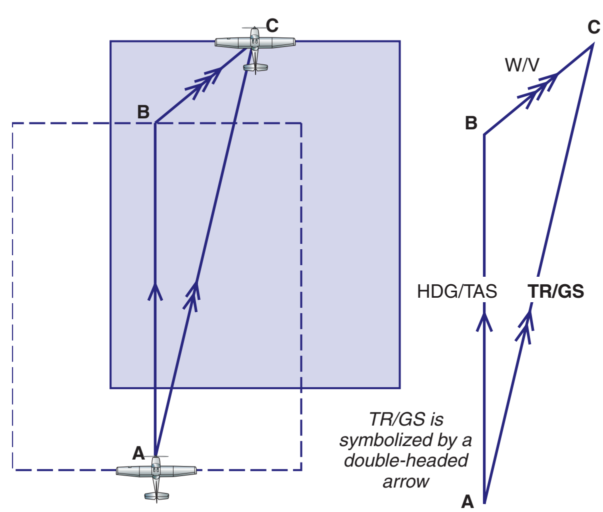


Figure 14-6
HDG/TAS + WN = TR/GS—
the triangle of velocities.

Achieving the Desired Course (CRS)

Apply a wind correction angle (WCA) to counteract drift, and thereby achieve the desired course.

Your objective during visual navigation is to steer a heading so that the *track* made good over the ground exactly overlies the desired *course*. At the flight planning stage you will know the desired course (also known as course required) and will have obtained a forecast wind velocity. Using the planned true airspeed, you will be able to calculate the *heading* required to "make good" the desired course by applying a *wind correction angle* (WCA) into the wind to counteract drift. You will also be able to calculate the expected groundspeed.

Later on during the flight you may find that, even though you have flown the HDG/TAS accurately, your *actual* ground track differs from the *desired* course; in other words there is a *tracking error*. This error could be specified as either distance off-course, or degrees off-course. The tracking error is most likely caused by the *actual* wind being different from the *forecast* wind that you used at the flight planning stage. You will then have to make adjustments to the HDG in order to achieve your desired course.

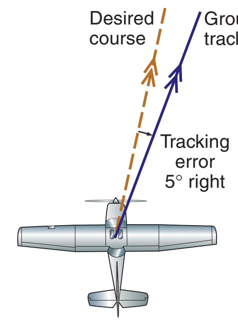


Figure 14-7 Tracking error is the angle between desired course and actual track.

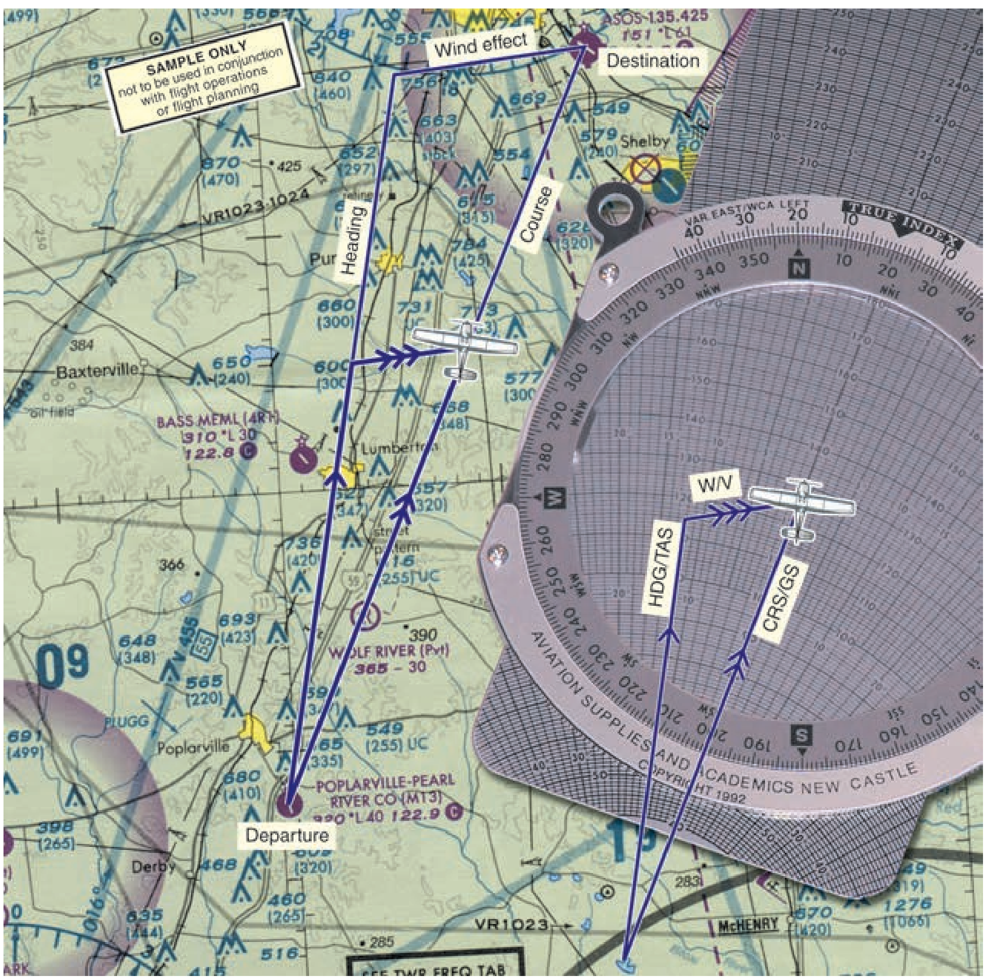


Figure 14-8 The triangle of velocities—calculating a heading to achieve the desired course.

Vertical Navigation

Navigating an airplane requires three-dimensional awareness. Correct vertical navigation using the altimeter is important for three basic reasons:

- for *terrain clearance*, to ensure that you will not collide with terrain or fixed obstacles on the ground;
- for *traffic separation*, to allow you to cruise at an altitude different from that of nearby aircraft, and so to ensure safe vertical separation; and
- to be able to calculate the *performance capabilities* of the aircraft and its engine, so as to operate safely and efficiently.

For aviation purposes, the standard unit of altitude is the *foot* in the United States and the western world. In other parts of the world, such as Eastern Europe and some of Asia, the unit used is the *meter.*

Terrain elevation is given as altitude in feet above mean sea level (MSL).

On maps and charts in the United States the altitude of terrain is given as altitude in feet above mean sea level (MSL). It is therefore essential that you know the aircraft's altitude above mean sea level so that you can compare this with the altitude of any terrain or obstructions and determine if there is sufficient vertical separation. Normally you would plan on at least 500 feet vertical separation when flying over open country, and at least 1,000 feet over congested and mountainous areas. Most cross-country flights occur much higher than this.

Mean sea level pressure varies from place-to-place, from day-to-day, and indeed from hour-to-hour, as the various high and low pressure systems move across the surface of the earth. This will require you to periodically adjust the pressure window in your altimeter.

Periodically update the altimeter setting.

Flying cross-country below 18,000 feet MSL in the United States, you need to periodically update the altimeter setting so that the altimeter continues to indicate altitude based on the *current* sea level pressure in that area. You should use a current reported altimeter setting of a station along your route and within 100 NM of your position (Part 91 of the regulations).

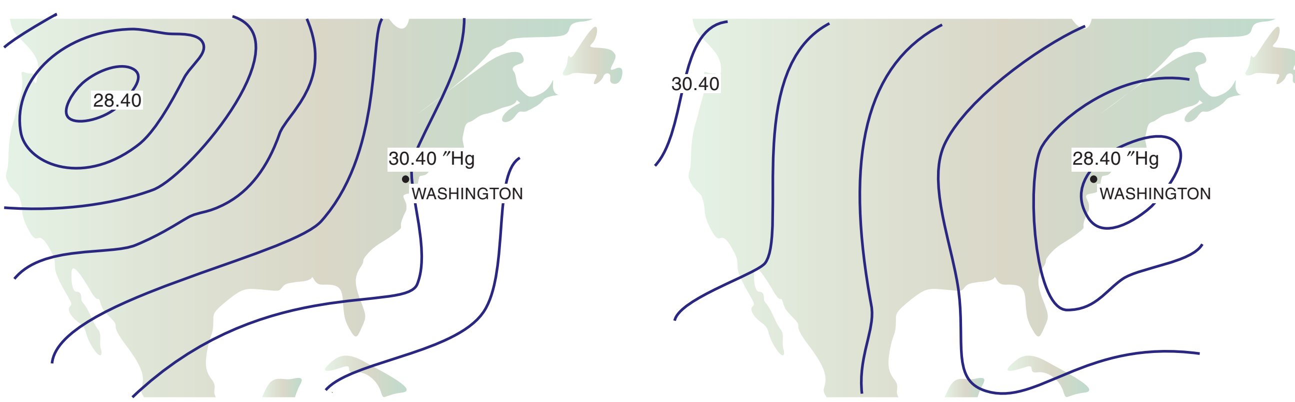


Figure 14-9 Two different synoptic situations at different times.

Flying higher than 18,000 feet MSL, separation from terrain is not a problem in the United States. All aircraft above 18,000 feet should be operating on standard pressure (29.92 in. Hg) so that their altimeters are all measuring altitude above the same datum. This will ensure vertical separation from other high-flying aircraft. An indication of 23,000 feet on the altimeter with 29.92 in. Hg set is called *flight level* 230, abbreviated as FL230.

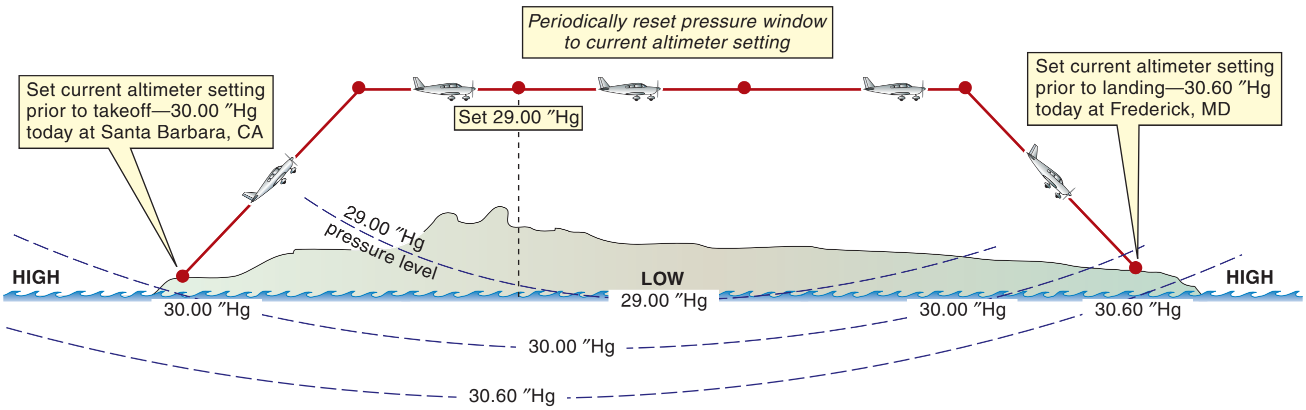


Figure 14-10 Periodically reset current reported altimeter setting.

VFR Cruise Altitude

To separate different types of traffic, Part 91 specifies that aircraft flying higher than 3.000 feet above the surface (AGL) according to the Visual Flight Rules (VFR) should cruise at "full thousands plus 500 feet."

To vertically separate VFR aircraft flying in opposing directions, VFR cruise altitudes are specified according to the direction in which they are flying:

- on a magnetic course of magnetic north to MC 179: *odds+500 feet* (for example 3,500 feet MSL, 5,500 feet MSL, 7,500 feet MSL); and
- on a magnetic course of MC 180 to MC 359: *evens+500 feet* (for example 4,500 feet MSL, 6,500 feet MSL, 8,500 feet MSL).

IFR traffic is operating at even and odd thousands, 500 feet above or below VFR traffic.

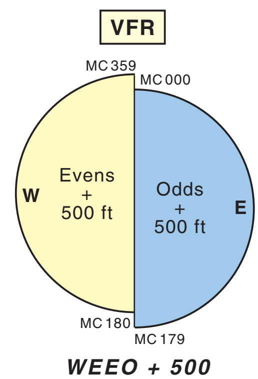


Figure 14-11
VFR cruise altitudes above 3,000 feet AGL.

Safety Altitude

Part 91 specifies *minimum safe altitudes* (MSA) which you must comply with. They are a minimum of 500 feet above the surface in noncongested areas, 1,000 feet above the highest obstacle within a 2,000 feet radius in congested and mountainous areas, and sufficient altitude to glide clear if an engine fails.

Where possible on cross-country operations, choose a suitable cruise level above these minimums that will ensure adequate terrain clearance and vertical separation from other aircraft. A suitable technique is to determine a *safety altitude* which will ensure adequate terrain clearance, then select an appropriate cruise level above this safety altitude according to your magnetic course.

> **Note.** In certain circumstances it may not always be possible to cruise above the calculated safety altitude, for example due to overlying controlled airspace around a major airport. In such cases, extra care to avoid terrain and obstructions should be taken, particularly in minimum visibility, until it is possible to climb above the safety altitude.

To determine a safety altitude determine the highest obstacle en route to a set amount either side of course, then add a safety clearance altitude above this.

There are no hard and fast rules as to how far either side of course you should scrutinize, or how high above obstacles you should fly. Reasonable values are 1,000 feet or 1,500 feet above the highest obstacle within 5 NM or 10 NM either side of course. This allows for navigation errors. Over long distances or mountainous areas, 15 or 20 NM might be more appropriate.

To assist you in determining the highest obstacle, it is a good idea to mark in lines 5 NM (or 10 NM) either side of course. Another approach to finding a reasonable buffer is to add 10% to the elevation of the highest obstacle en route plus a further 1,500 feet.

If you remain above your calculated safety altitude, there should be sufficient buffer to absorb any indication errors in the altimeter (position, instrument and temperature errors) and to stay out of any turbulent areas near the ground, where a downdraft or windshear could be dangerous. In certain circumstances (such as in standing waves downwind of mountain ridges), it may be advisable to add more vertical clearance than usual to give sufficient safety margin.

Example 14-1

Elevation of the highest obstacle within 5 NM of course is 438 feet MSL. A reasonable safety altitude in good conditions would be 438 + 1,000 feet = 1,438 feet. If the highest obstacle within 10 NM of course is 798 feet, and you wish to be more conservative, then a reasonable safety altitude would be 798 + 1,000 = 1,798 feet. Because these are below 3,000 feet AGL, you do not need to apply the *WEEO + 500* rule.

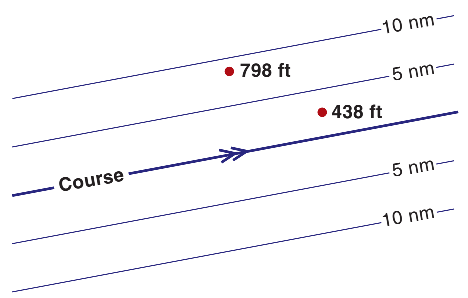


Figure 14-12 Example 14-1.

Example 14-2

Calculate a conservative safety altitude above an obstacle 2,117 feet MSL.

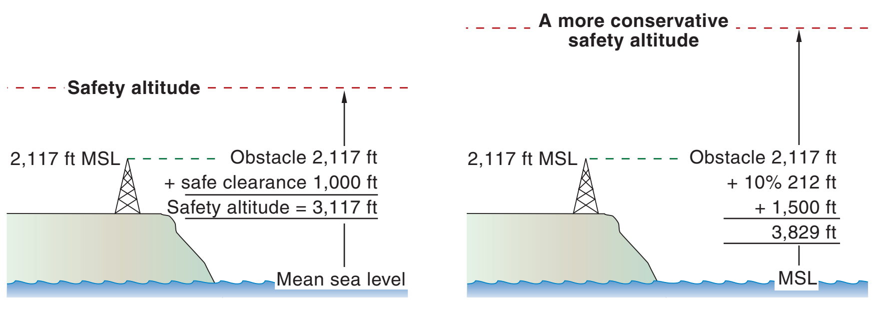


Figure 14-13 Example 23-2 using 1,000 feet clearance and using 10% plus 1,500 feet.

Time

Time is of great importance to the air navigator, and the clock is one of the basic instruments used in the cockpit. Time enables you to:

- regulate affairs on board your airplane;
- measure the progress of your flight;
- compute arrival time (ETA) at certain positions;
- calculate a safe endurance for flight and manage fuel consumption;
- estimate when weather conditions at the destination are likely to improve or get worse; and
- measure rest periods between flights.

For flight planning and navigation purposes we usually do not refer to the year or the month, but only the *day* of the month as the *date*, followed by the *time* in *hours and minutes*. As most air navigation occurs within a few hours, and only rarely in excess of 30 hours, we can be reasonably confident of which year and month we are talking about, and so there is no need to specify them. Seconds, which are 1⁄60 of a minute, are usually too short a time interval for us to be concerned with in practical navigation. It is usual to express date/time as a six-figure date/time group.

In the six-figure date/time group:

- the *date* is a two-figure group for the day of the month from 00 to 31; and is followed by
- the *time*, written as a four-figure group on a 24 hour clock—the first two figures representing the hours from 00 to 24, and the last two figures representing the minutes from 00 through to 59.

Example 14-3

Express September 13, 10:35 a.m. as a six-figure date/time group. (Answer*:* 131035.)

Date	Time	
13	10	35
day	hour	minute

Example 14-4

Express 3:21 p.m. on March 17, as a six-figure date/time group. (Answer*:* 171521.)

$$\begin{array}{rl} \text{3:21 p.m.} = & 1200 \\ + & \underline{\ 321} \\ & 1521 \text{ on the 24 hour clock} \end{array}$$

In the eight-figure date/time group, to specify the *month*, the six-figure date/time group is preceded by two figures representing the month, and so is expanded into an eight figure time-group. This is often used in NOTAMs (Notices to Airmen):

- the first two numbers refer to month;
- the second two numbers refer to the date; and
- the last four numbers refer to the time.

Example 14-5

5:45 p.m. on September 30 may be written as:

- SEP 30 17 45;
- 09 30 17 45; or
- 09301745.

The Relationship Between Longitude and Time

In one day, the earth makes about one complete rotation of 360° with respect to the chosen celestial body, which is the sun. The time of day is a measure of this rotation and indicates how much of that day has elapsed or, in other words, how much of a rotation has been completed.

As observers on the earth, we do not feel its rotation about its own axis, but rather we see the sun apparently move around the earth. In one mean solar day the sun will appear to have traveled the full 360° of longitude around the earth. 360° of longitude in 24 hours is equivalent to *15° per hour*.

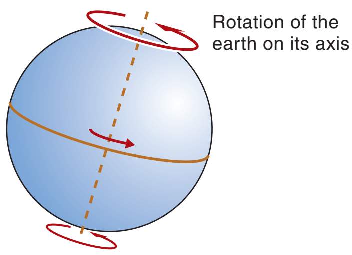


Figure 14-14
The earth rotates at 15° of longitude per hour.

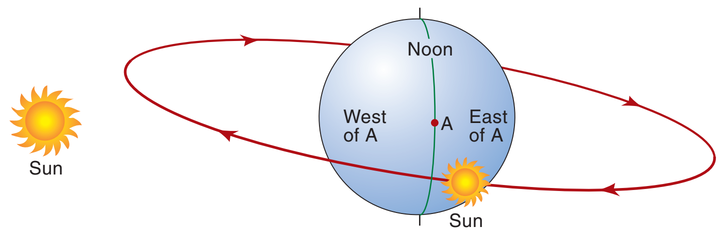


Figure 14-15
The apparent motion of the sun around the earth.

Local Time

Meridians of longitude further east are ahead in local time; meridians of longitude further west are behind in local time.

Time is a measure of the rotation of the earth, and any given time interval can be represented by a corresponding angle through which the earth turns. Suppose that the sun (the celestial reference point) is directly overhead at noon. For every point along that same meridian of longitude, the sun will be at its highest point in the sky for that day.

Example 14-6

Place A is 45° of longitude west of Place B. How much earlier or later will noon occur at A compared to B?

Answer. At the rate of 15° per hour, 45° arc of longitude = 3 hours, and because A is to the west of B, noon will occur three hours later at A.

Coordinated Universal Time (UTC)

Longitude east—Universal least; Longitude west—Universal best.

UTC is the local mean time at the 0° meridian of longitude that runs through the observatory at Greenwich, England, and is known as the *prime meridian*. Until recently the international time standard was the well known *Greenwich Mean Time* (GMT). This term has now been replaced by *Coordinated Universal Time* (UTC), which is also known as *Zulu* (Z). UTC is a universal time, and all aeronautical communications around the world are expressed in UTC. For this reason, you need to be able to convert quickly and accurately from local time to UTC, and vice versa. UTC is approximately equal to the old GMT.

Standard or Local Time

Standard times operate in a similar fashion to time zones in that all clocks in a given geographical area are set to the local mean time of a given standard meridian. This is known as *standard time* or *local time* for that area. When involved in flights between different time zones, it is easiest to work entirely in UTC and convert the answer at the end.

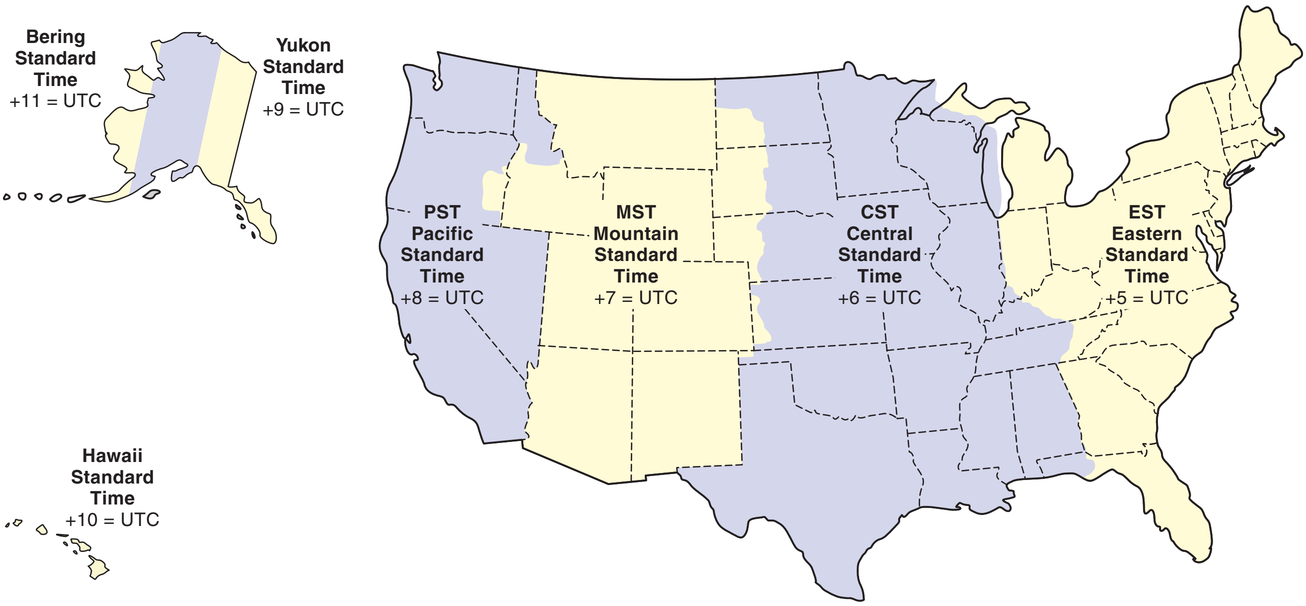


Figure 14-16 Standard time zones in the United States.

To Change UTC Time to Local Time	Time Zone	To Change Local Time to UTC Time
Subtract 4 hours	Eastern Daylight	Add 4 hours
Subtract 5 hours	Eastern Standard	Add 5 hours
Subtract 5 hours	Central Daylight	Add 5 hours
Subtract 6 hours	Central Standard	Add 6 hours
Subtract 6 hours	Mountain Daylight	Add 6 hours
Subtract 7 hours	Mountain Standard	Add 7 hours
Subtract 7 hours	Pacific Daylight	Add 7 hours
Subtract 8 hours	Pacific Standard	Add 8 hours
Subtract 9 hours	Yukon Standard	Add 9 hours
Subtract 10 hours	Alaska, Hawaii Standard	Add 10 hours
Subtract 11 hours	Bering Standard	Add 11 hours

Table 14-1 U.S. time zones in relation to UTC.

Example 14-7

You depart New York, NY at 0945 Eastern Standard Time on a flight of 6 hours 10 minutes duration to Denver, Colorado. At what time should your friends meet you in Denver?

Depart NY	09 45	EST
	+5	
	14 45	UTC
Flight time	6 10	
Arrive Denver	20 55	UTC
	-7	
	13 55	MST

Answer: 1355 Mountain Standard Time.

Light from the Sun

The sun's rays strike different parts of the earth at different angles depending on latitude and season.

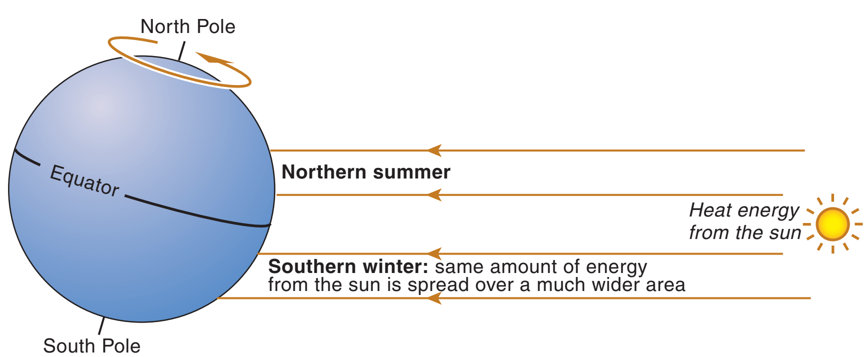


Figure 14-17 The sun does not shine evenly on the earth.

Sunrise occurs when the upper limb of the sun (the first part visible) is on the visible horizon and *sunset* occurs when the upper limb of the sun (the last part visible) is just disappearing below the visible horizon. *Sunlight* occurs between sunrise and sunset.

As we have all observed when waking early, it starts to become light well before the sun actually rises, and it stays light until well after the sun has set. This period of incomplete light, or if you like, incomplete darkness, is called *twilight*. Civil twilight is when the sun is 6° below the horizon. While the sun is less than 6° below the horizon, there is generally enough light to see significant objects on the ground, unless the overcast is heavy. Civil twilight is generally considered the end (evening) or beginning (morning) of when there is enough light to land on an unlit airstrip.

The period from the start of morning twilight until the end of evening twilight is called *daylight*. In the tropics the sun rises and sets at almost 90° to the horizon, which makes the period of twilight quite short, and the onset of daylight or night quite dramatically rapid.

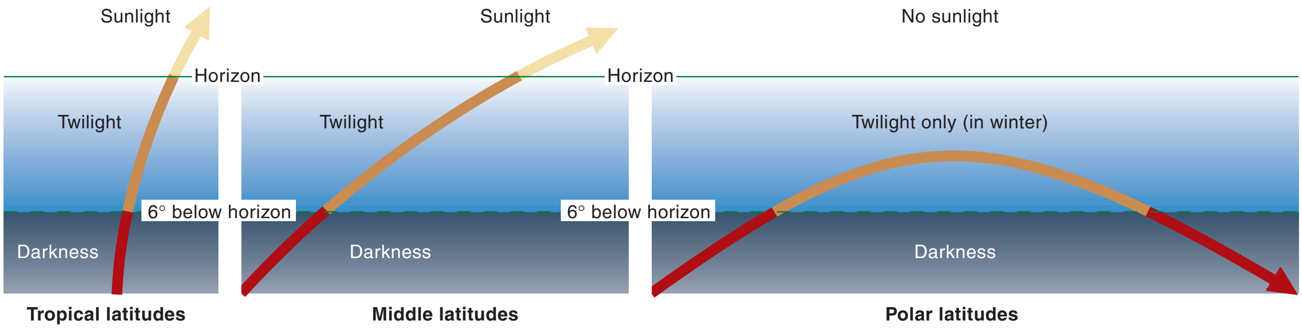


Figure 14-18 The higher the latitude, the longer the twilight.

In the higher latitudes, toward the North and South Poles, the sun rises and sets at a more oblique angle to the horizon, consequently the period of twilight is much longer and the onset of daylight or darkness far more gradual than in the tropics. At certain times of the year inside the Arctic and Antarctic Circles, the period of twilight occurs without the sun actually rising above the horizon at all during the day. This is the winter situation.

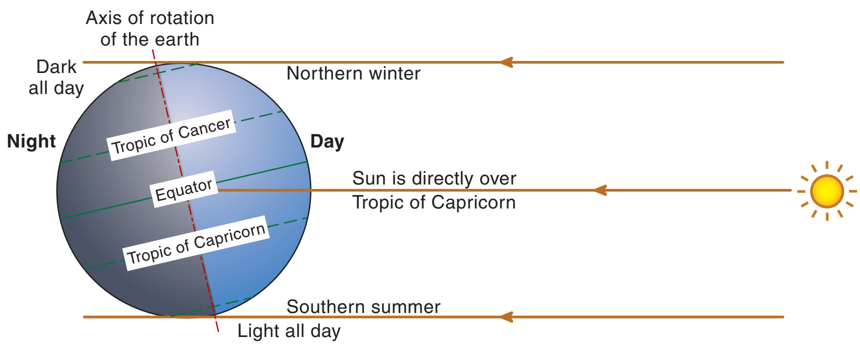


Figure 14-19 The sun does not shine evenly on the earth.

While to an observer at sea level the sun may appear to have set and the earth is no longer bathed in sunlight, an airplane directly overhead may still have the sun shining on it. In other words, the time at which the sun rises or sets will depend on the altitude of the observer. In fact, it is possible to take off after sunset at ground level and climb to an altitude where the sun appears to rise again and shine a little longer on the airplane. This is especially noticeable in polar regions when the sun might be just below the horizon, as seen from sea level, for long periods of time (twilight).

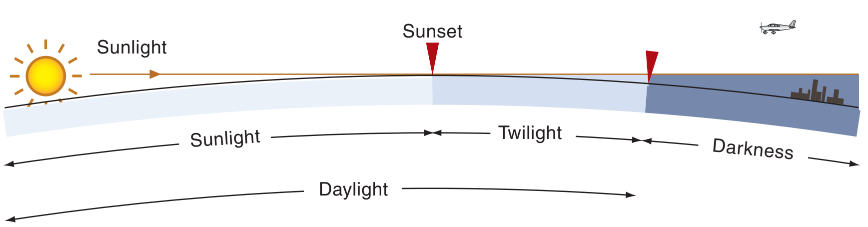


Figure 14-20 An airplane can be in sight of the sun after it has set on the earth below.

It is easy to be deceived by brightness at altitude only to find a few minutes later after a descent to near ground level, and possibly under some cloud cover, that it has become very dark. High ground to the west of an airport will also reduce the amount of light from the sun reaching the vicinity of the airport as night approaches (an important point to remember when flying). Good airmanship may dictate using an earlier arrival time than the end of daylight when planning a flight, if, for example, the destination airport has high ground to the west, or the weather forecast indicates poor visibility or cloud cover approaching from the west, as in a cold front. Another important consideration related to sunset is that many smaller airports close at sunset. This may also apply to the alternate airport(s) chosen for a flight.

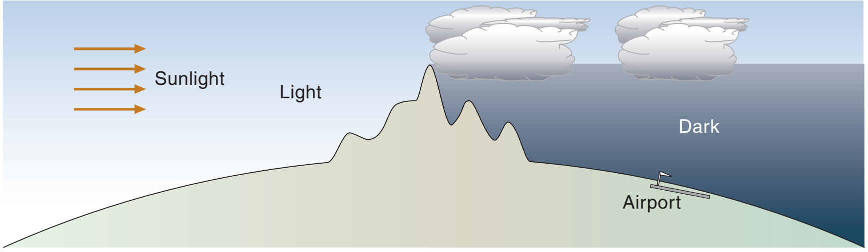


Figure 14-21 Local sunrise and sunset is affected by terrain.

The times at which sunrise and sunset occur depend on two things:

- the *date*—in summer sunrise is earlier and sunset later, therefore the daylight hours are longer in summer. The reverse occurs in winter; and
- the *latitude*—in the northern summer for instance, place B in the figure below is experiencing sunrise while place A is already well into the day, and it is still night at place C, yet all are on the same meridian of longitude. Because of this they all have the same local time, but are experiencing quite different conditions of daylight because they are on different latitudes.

Figure 14-22 Places A, B & C, although on the same meridian, experience different sunrise and sunset times because they are on different latitudes.

The official source in the United States for times including sunrise, sunset, and beginning and end of daylight is the *American Air Almanac*.

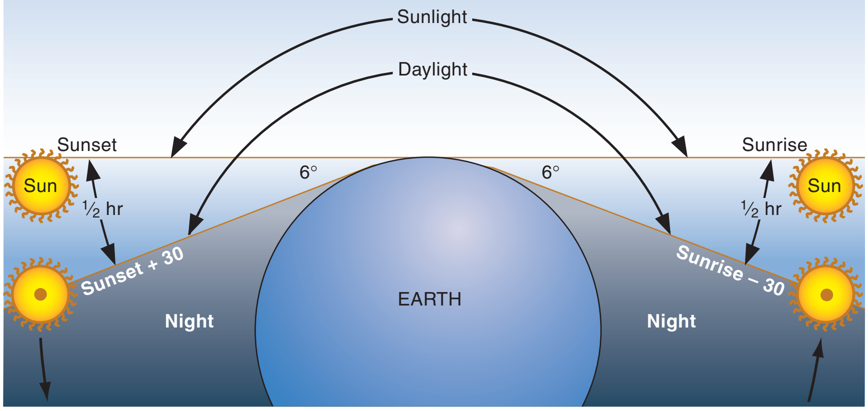


Figure 14-23 In the United States, official night commences at sunset approximately +30 minutes and night ends at sunrise aproximately -30 minutes.

Daylight Time

Spring, (clocks) forward.
Fall, (clocks) back.

To take advantage of the longer daylight hours and the better weather in summer, the clocks in many countries are put forward in the spring, usually by one hour, to give a new standard time known as *daylight time*. For example, in New York, 1200 EST becomes 1300 Eastern Daylight Time.

Make allowances for these when planning a flight that may end near the onset of darkness. It is good airmanship to plan on arriving well before the end of daylight. Common sense would encourage you to increase this margin on long journeys or on flights where it is difficult to estimate accurately your time of arrival. Remember also that the further south you are in the United States the shorter the twilight time.

The Dateline

Suppose that the time at the Greenwich meridian is 261200 (261200 UTC). Now, if you instantaneously travel *eastward* from Greenwich to the 180° east meridian, the local mean time there is 12 hours ahead of the local mean time at Greenwich, that is 262400 local mean time at 180°E, or midnight on the 26th local mean time at 180°E. If, however, you travel *westward* from Greenwich to the 180° west meridian, then the time there is 12 hours behind Greenwich, 260000 or, as it is usually written, 252400 at 180°W, midnight on the 25th. Note that the time is midnight in both cases but, on one side of the 180° meridian it is midnight on the 25th, and on the other side it is midnight on the 26th.

The 180°E and 180°W meridians are the same meridian, the anti-meridian to Greenwich. In its vicinity, midnight occurs on different dates, depending on which side of the 180° meridian you are on. Making a complete instantaneous trip around the world, you would lose a day traveling westward or gain a day traveling eastward.

To prevent the date being in error and to provide a starting point for each day, a *dateline* has been fixed by international agreement, and it basically follows the 180° meridian of longitude, with minor excursions to keep groups of islands together. Crossing the dateline, you alter the date by one day—in effect changing your time by 24 hours to compensate for the slow change during your journey around the world.

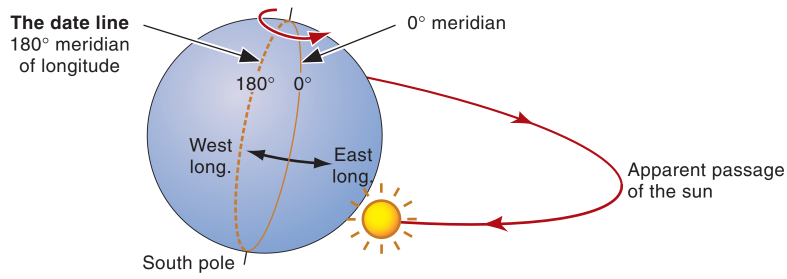


Figure 14-24 The dateline runs basically along the 180° meridian.

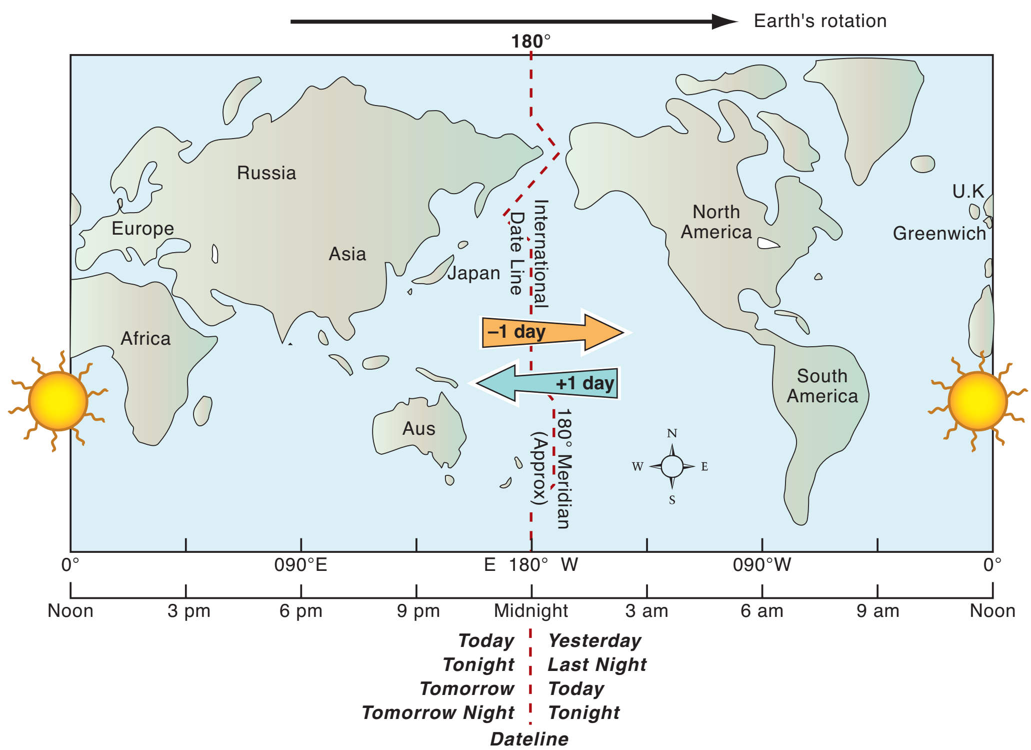


Figure 14-25
Crossing the dateline traveling eastward—subtract one day; traveling westward—add one day.

Review 14

Visual Navigation Fundamentals

Navigation

1. What is distance stated in for most navigation purposes?
2. What is the usual navigation unit for airspeed? (State how many nautical miles per hour this is equivalent to.)
3. What is the accepted unit of length for shorter distances, such as runway length?
4. What is the accepted unit for altitude?
5. How many feet are there in 1 nautical mile?
6. As a simple method of expressing direction, we divide a full circle into 360 degrees and number them from 000 through 090, 180, 270 to 360. Is this in a clockwise direction?
7. Define "true airspeed (TAS)."
8. What two things need to be specified in order to fully describe the motion of an airplane relative to an air mass?
9. How is the heading/true airspeed vector symbolized?
10. Define the following:
- **a.** wind.
- **b.** wind direction.
- **c.** groundspeed.
- **d.** heading.
- **e.** track.
- **f.** drift.
- **g.** tracking error.

Refer to figure 14-26 for questions 11 and 12.

11. What is the shaded angle known as?
12. The drift in this figure is:
- **a.** left.
- **b.** right.

Refer to figure 14-27 for questions 13 and 14.

13. What is the shaded angle known as?
14. The tracking error in this figure is:
- **a.** left.
- **b.** right.

Refer to figure 14-28 for questions 15 and 16.

15. Label the vectors A and B and the angle D with their appropriate navigation terms.
16. Which statement best fits the situation in this figure?
- **a.** TAS exceeds GS.
- **b.** GS exceeds TAS.
- **c.** Drift is left.

17. The earth rotates on its axis. What are the two points at which this axis meets the earth's surface?

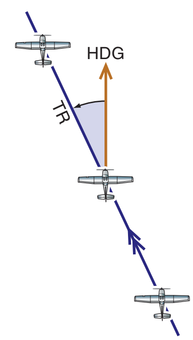


Figure 14-26 Questions 11 and 12.

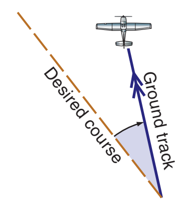


Figure 14-27 Questions 13 and 14.

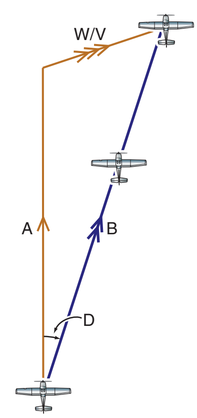


Figure 14-28 Questions 15 and 16.

Time

18. Express the following dates and times as a six-figure date/time group and as an eight-figure date/time group:
- **a.** November 29, 10:15 a.m.
- **b.** July 19, 3:17 p.m.
- **c.** April 1, 5 p.m.

19. Convert the following time intervals to arc units:
- **a.** 1 hour.
- **b.** 9 hours 30 minutes.

20. It's 1200 Pacific Standard Time in Los Angeles. What time is it in New York? (Give your answer in both UTC and Eastern Standard Time.)

21. It's 0500 Mountain Daylight Time in Denver. What time is it in San Francisco? (Give your answer in Zulu and Pacific Daylight Time.)

Refer to figure 14-29 for questions 22 and 23.

22. An aircraft departs an airport in the central standard time zone at 0930 CST for a 2-hour flight to an airport located in the Mountain Standard Time zone. The landing should be at what time?

23. An aircraft departs an airport in the eastern daylight time zone at 0945 EDT for a 2-hour flight to an airport located in the Central Daylight Time zone. The landing should be at what coordinated universal time?

24. Convert 150° of arc to time.

25. You depart Santa Barbara, California at 0600 Pacific Standard Time for a 5 hour 30 minute flight to Denver, Colorado. What time do you expect to arrive? (Give your answer in UTC and MST.)

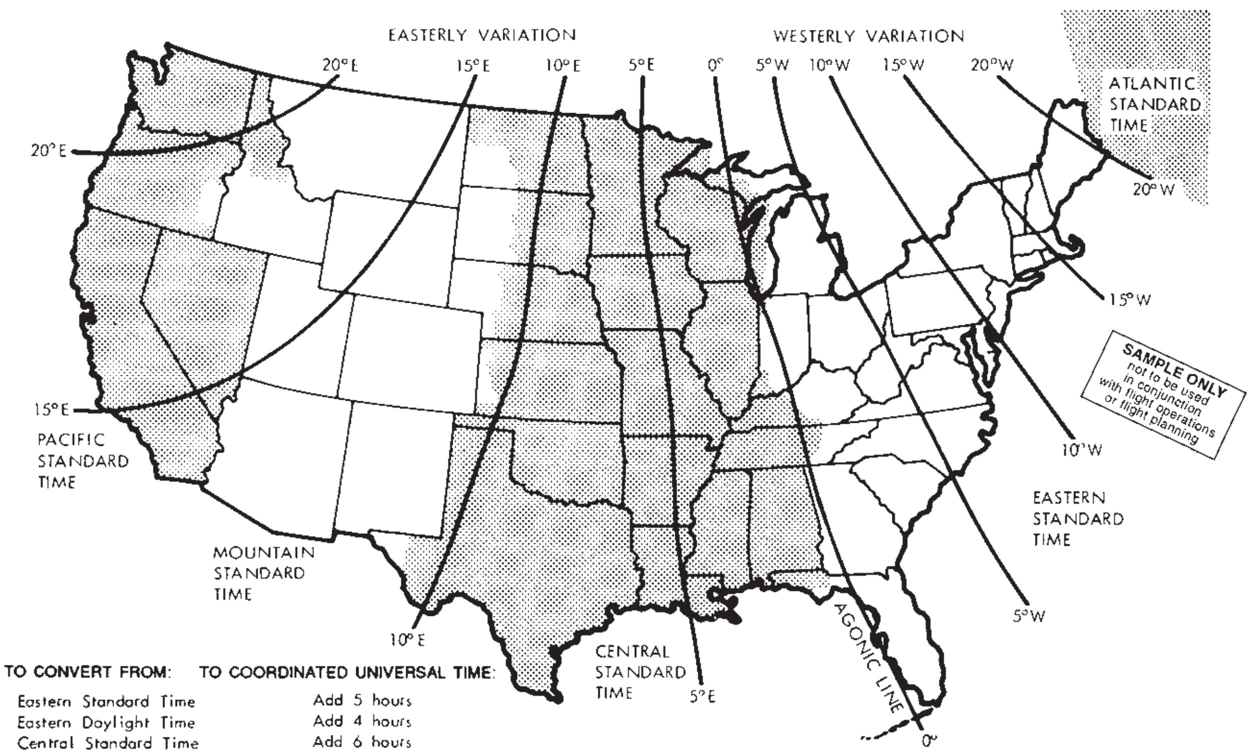
26. True or false? Traveling eastward across the dateline from Hong Kong to Hawaii, you would expect to gain 1 day.

27. What is the official source of sunrise and sunset times?

28. True or false? High ground to the west of an airport causes an earlier onset of darkness.

29. What two things do sunrise and sunset times vary with respect to?

30. For Daylight Time, clocks are advanced by how many hours?



TO CONVERT FROM:	TO COORDINATED UNIVERSAL TIME:
Eastern Standard Time	Add 5 hours
Eastern Daylight Time	Add 4 hours
Central Standard Time	Add 6 hours
Central Daylight Time	Add 5 hours
Mountain Standard Time	Add 7 hours
Mountain Daylight Time	Add 6 hours
Pacific Standard Time	Add 8 hours
Pacific Daylight Time	Add 7 hours

MAGNETIC VARIATION CHART - TIME CONVERSION TABLE

Figure 14-29 Questions 13 and 14.

Answers are given on page 777.

Global Positioning Systems (GPS) 15

Precise point-to-point navigation is possible using satellite navigation systems that can compute aircraft position and altitude accurately by comparing signals from a global network of navigation satellites. The first global positioning systems (GPS) were designed for the U.S. Department of Defense, but in the early 1990s, GPS was made available for civilian use. Later, full system accuracy was also made available.

Basically, three elements make up GPS:

1. a space element, consisting of a constellation of satellites orbiting the earth every 12 hours in six orbital planes, at an altitude of 11,000 NM (21,300 km);
2. a satellite control ground network responsible for orbital accuracy and control; and
3. a navigation receiver in the aircraft (many are small enough to be hand held) capable of receiving and identifying several satellites at a time.

Each satellite transmits its own computer code packet on frequency 1,575.42 MHz (for civilian use) 1,000 times a second. The satellite constellation typically guarantees that at least four satellites are in view and usable for positioning at any one time from any position on earth. GPS pinpoints an aircraft's horizontal position in lat.-long. coordinates which is similar to other long-range navigation systems, for instance the VLF/Omega. In the case of most aviation units, it then turns the information into a graphical moving map display which shows the aircraft's position in relation to surrounding airspace on an LCD or CRT screen. Most GPS receivers can also display a CDI presentation, along with track, present position, actual time (to an accuracy of a few nanoseconds), groundspeed, time and distance to the next waypoint, and the current altitude of the aircraft.

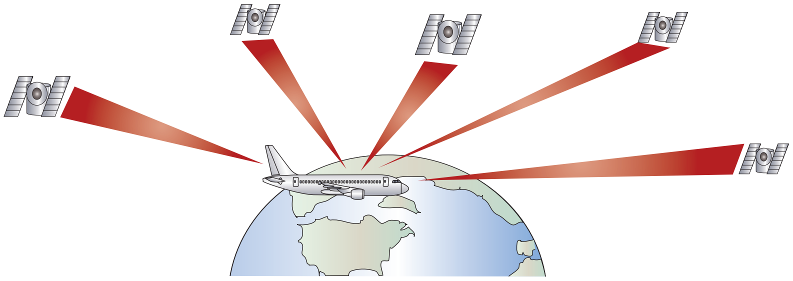


Figure 15-1
Signals from satellites are received to establish an aircraft's position.

GPS units have been approved for both en route and approach navigation, but, as with LORAN, not all units are approved for anything other than situational awareness. IFR units must have their databases updated on a regular basis to remain IFR certified.

Nonprecision GPS approaches are available at most U.S. airports today. Precision GPS approaches are also now available which uses a ground station to augment the satellite signals. This *wide area augmentation system* (WAAS) will allow GPS to be used as the primary NAVAID from takeoff through to approach.

Some manufacturers have produced *multi-function displays* (MFDs) which combine data from conventional flight instruments and on-board fuel/air data sensors for light aircraft. Typical GPS panels are shown in figure 15-2.

Figure 15-2
GPS and NAV management receivers.

As stated earlier, GPS has three functional elements:

- a space segment;
- a control segment; and
- a user segment (the airborne receivers).

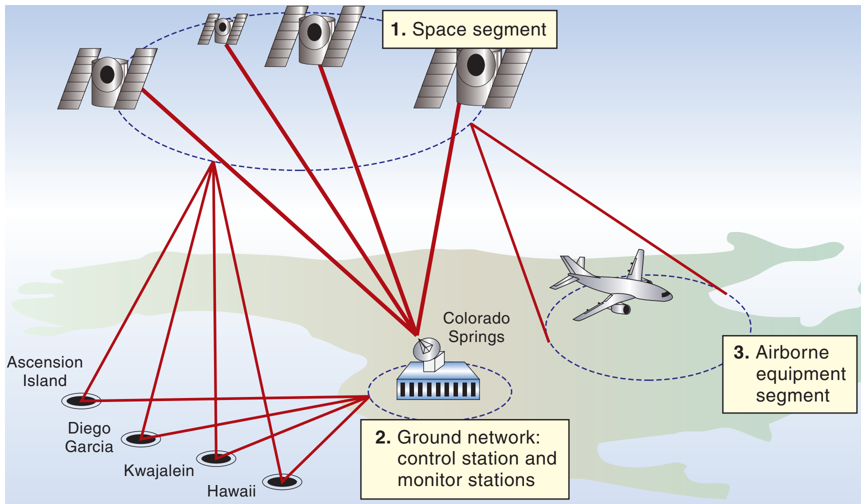


Figure 15-3 The GPS consists of three basic segments.

Space Segment

The space segment consists of a constellation of 24 satellites orbiting the earth at an altitude of 11,000 NM (21,300 km) in six strategically defined orbital planes. Three of the satellites are operating as spares, with the remaining 21 in the constellation sufficient to provide global navigation coverage. The objective of the GPS satellite configuration is to provide a window of at least five satellites in view from any point on earth.

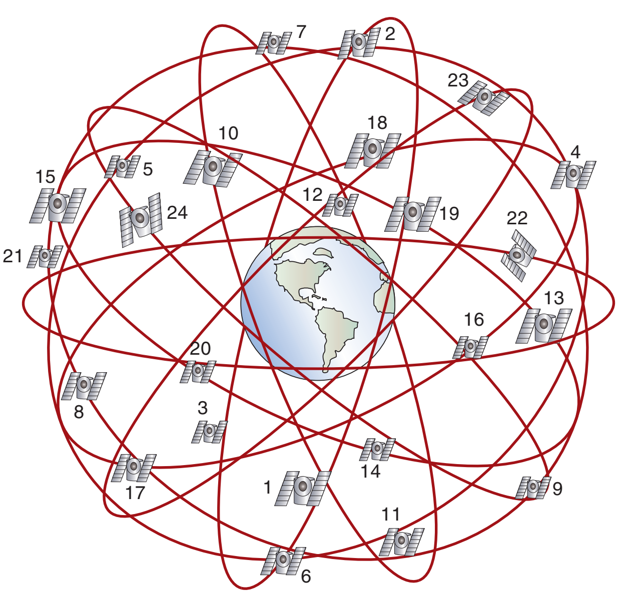


Figure 15-4 The relative orbital positions of GPS satellites.

The satellites orbit at an inclination angle of 55°, taking approximately 12 hours to complete an orbit, and the orbital position of each satellite is known precisely at all times.

Note. As a point of interest, the GPS space segment consists of so-called Block II and IIA satellites and upgraded versions known as Block IIR satellites. The service they provide is identical as far as a user is concerned. They will be the basis of the system for at least the next decade.

Pseudo-Random Code

Each satellite transmits its position and precise time of transmission, and a separate signal is used by the receiver to establish range from the satellite. This is achieved by the satellite RF carrier transmissions being modulated with a 50 bit/second navigation message and a unique encoded signal known as a *pseudo-random code*. It repeats itself every millisecond and is used by the GPS receivers to recognize and track individual satellites for ranging purposes.

There are two types of pseudo-random code:

- a *coarse acquisition* (C/A) *code* (sometimes referred to as the *standard positioning service* (SPS)) available for general civilian use, which provides accuracy in the order of l00 meters in position and 140 feet in altitude with a 95% probability given a quality receiver; and
- a *precision* (P) *code* (also known as the *precise positioning service* (PPS)), which permits extremely precise position resolution (formerly available for authorized military users only but now available to all users).

As will be discussed, a minimum of three satellites is required to determine a two-dimensional fix if altitude is known. For a three-dimensional fix, four satellites are required. The navigation message contains information on satellite ephemeris, GPS time reference, clock corrections, almanac data, and information on system maintenance status.

Control Segment

The controlling authority is the United States Department of Defence. By letter of agreement between the United States Government and ICAO, civilian access via the C/A code only is permitted on a no-cost basis for the foreseeable future. The deliberate degrading of the accuracy of the system for civilian users, i.e. the standard positioning service (SPS) accessed via the C/A code, is known as *selective availability* (SA).

Note. In early 2000, the U.S. Department of Defence turned SA off.

The control segment includes monitoring stations at various locations around the world, ground antennas and up-links, and a master station. The stations track all satellites in view, passing information to a master control station, which controls the satellites' clock and orbit states and the currency of the navigation messages.

Satellites are frequently updated with new data for the compilation of the navigation messages transmitted to system users. Assuming the current level of space vehicle technology, the planned life span of a GPS satellite is around seven to eight years.

User Segment (the Receiver)

As previously mentioned, the receiver identifies each satellite being received by its unique pseudo-random code, i.e. the C/A code for civilian operations. It then starts to receive and process navigation information. Ephemeris data takes about 6 seconds to transmit, but almanac data takes about 13 seconds. For this reason, almanac data is stored in the receiver's memory. During operation, almanac data in the receiver is changed on a continuous basis. On start-up, the receiver recalls the data that was last in memory on the preceding shutdown. From this information and the stored almanac data, the receiver determines which satellites should be in view and then searches for their respective C/A codes. It then establishes ranges to the satellites, and by knowing their position, computes aircraft position, velocity, and time. This process is known as *pseudoranging.*

Range determination is a simple matter of measuring the period between the time of transmission and the time of reception of each satellite's C/A code and multiplying that time interval by the speed of light in free space. The GPS receiver, in fact, does this by emitting its own code at the same time as the satellite's and uses it and the time the signal from the satellite is received to establish the time interval. Timing is critical. This is the reason why the time reference is provided by synchronized, high-precision atomic clocks in the satellites.

Fixing Position

A three-dimensional position in space (position and altitude) is accomplished by the receiver determining where it must be located to satisfy the ranges to four or more appropriately positioned satellites. A two-dimensional fix requires only three satellites in view if altitude is known. The synchronization of the receiver's time reference with that of the satellite is important in this process.

Timing errors are detected and eliminated by the receiver's computer. Figure 15-5 shows a two-dimensional position established, assuming the respective clocks are synchronized perfectly.

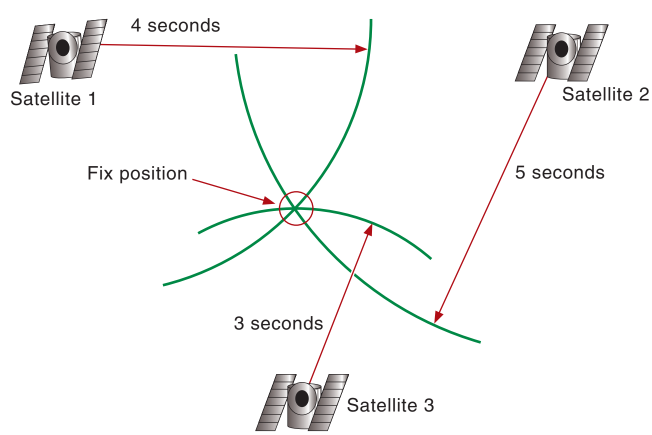


Figure 15-5 Two-dimensional fix established with perfect timing.

However, if the receiver's clock is, say, one second fast, as is the case in figure 15-6, the period between transmission and reception with respect to each of the three satellites interrogated will be sensed initially as taking one second longer. This will be represented as a gross error in all three ranges and thus, rather than producing a precise fix, will create a very large area anywhere in which the receiving aircraft could be positioned. The receiver's computer senses this and immediately begins a trimming process until it arrives at an answer which allows all ranges to arrive at the one and only position possible. This process automatically eliminates the effect of receiver clock error for subsequent tracking and position fixing.

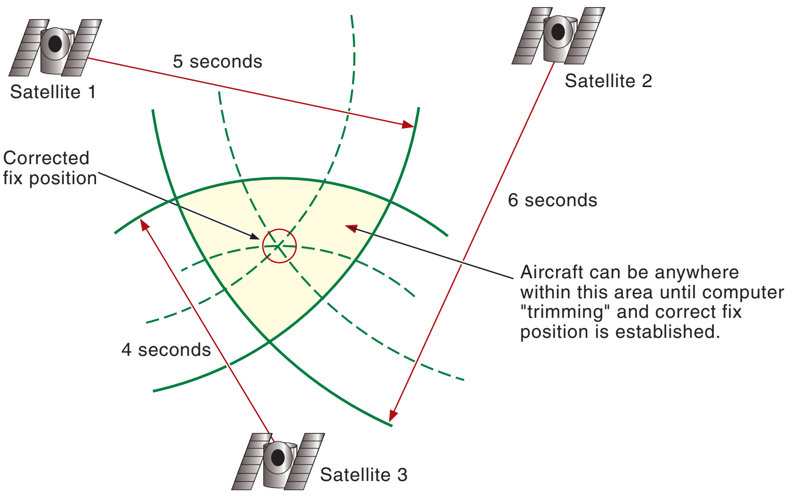


Figure 15-6 Effect of receiver clock error of one second on a two-dimensional fix.

Receiver Design

The capability of making range calculations to three, four or more satellites has an impact on the design, cost, and accuracy of GPS receivers, namely, whether they are single-channel receivers operating sequentially or the more expensive and accurate receivers providing multiple channels operating simultaneously. GPS receivers approved as a supplemental- or primary-means navigation aid have multiple channels and come under the provisions of an FAA Technical Service Order (TSO C129). IFR/primary navigation certification specifications for GPS equipment include a requirement for multiple receiver channels and a navigation integrity monitoring system, known as *receiver autonomous integrity monitoring* (RAIM).

Receiver Autonomous Integrity Monitoring (RAIM)

RAIM is a special receiver function which analyzes the signal integrity and relative positions of all satellites which are in view, so as to select only the best four or more, isolating and discarding any anomalous satellites. At least five satellites must be in view to have RAIM find an anomalous situation and six to actually isolate the unacceptable satellite.

When operating, it ensures that the minimum acceptable level of navigation accuracy is provided for the particular phase of flight. In the process, it ensures that a potential error, known as the *position dilution of precision* (PDOP) or *geometric dilution of precision* (GDOP), is minimized. The PDOP depends on the position of the satellites relative to the fix. The value of the PDOP determines the extent of range and position errors.

When the satellites are close together, the tetrahedron formed covers a large area and results in a high PDOP value (see figure 15-7).

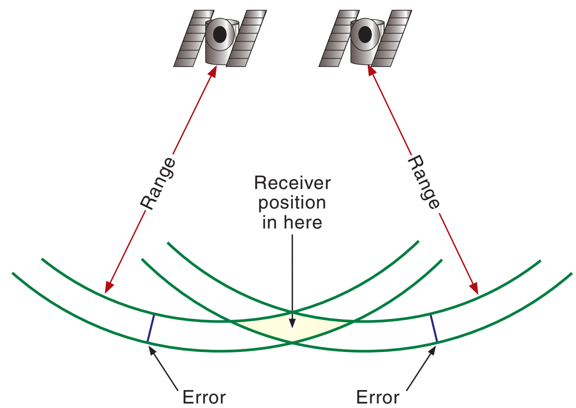


Figure 15-7 Poor satellite geometry resulting in high PDOP.

However, when the selected satellites are far apart, the area covered by the tetrahedron is much more compact, resulting in a lower PDOP value and therefore greater accuracy. A PDOP value of less than six is acceptable for en route operations. A value of less than three will be required for nonprecision approaches.

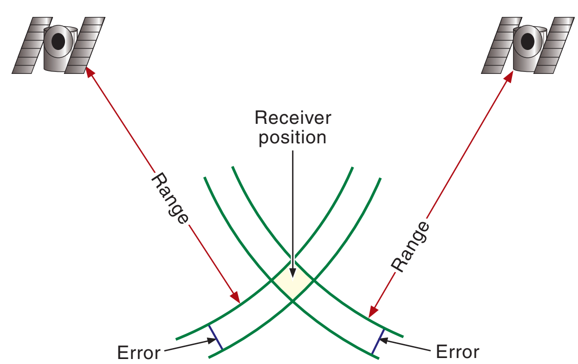


Figure 15-8 Good satellite geometry resulting in low PDOP.

Barometric Aiding

Barometric aiding is the process whereby the digital data of the pressure altimeter is used by the GPS receiver as, in effect, the range readout of a (simulated) additional satellite. It is only applicable when there are less than five satellites in view and RAIM alone cannot be effective. Barometric aiding provides additional redundancy and RAIM capability and therefore increases the navigation coverage of GPS.

Masking Function

The masking function in the GPS receiver software ensures that any satellites in view which lie below a fixed angle of elevation relative to the receiver are ignored. This is due to the range errors that will be generated because of the greater distances that their signals will have to travel through the ionosphere and troposphere to reach the receiver. The fixed angle stored in the receiver is known as the *mask angle.* In some receivers, it is selected automatically by the receiver, depending on the strength of the transmitted signals at low angles of elevation, receiver sensitivity and acceptable low-elevation errors. When fixed, it is typically set at around 7.5° (figure 15-9).

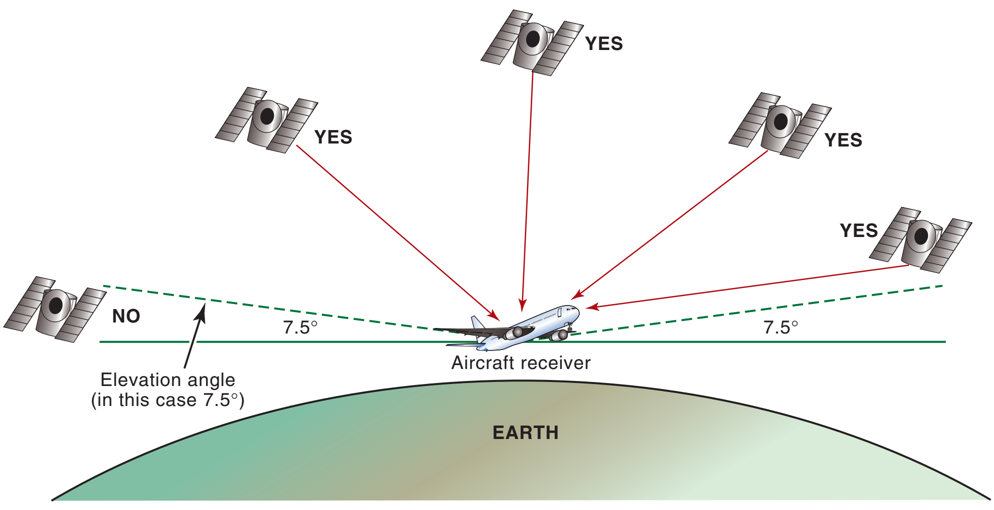


Figure 15-9 Mask angle.

Receiver Displays

Displays for the pilot vary from one GPS unit to another. Flight planning data is usually entered via an appropriate keypad on a control display unit (CDU) or control panel. The usual navigation information (i.e. position, track, groundspeed, EET, and, with a TAS input, TAS and wind) is displayed. The unit must also be capable of showing satellite status, satellites in view and being tracked, the value of PDOP, RAIM status, and signal quality.

Operating Modes

GPS receivers normally provide three modes of operation:

- navigation with RAIM;
- navigation (two or three dimensional) without RAIM; and
- loss of navigation (annunciated as DR in some receivers).

Differential GPS

The accuracy standards available for 95% of the time have already been mentioned. However, for the GPS to be of any value as a primary navigation source for precision approach/departure operations, a much higher order of accuracy is required. Furthermore, the higher accuracy standard should be available 99.99% of the time. We know that GPS is capable of providing unprecedented levels of accuracy with P-code access, i.e. the PPS. This standard of accuracy is now available to civilian users, assuming direct interrogation of GPS.

One ingenious way of improving the accuracy available for civilian users is with an enhancement known as *differential GPS* (DGPS). A GPS receiver is installed at a ground station located in the terminal area. The station compares the GPS computed position with the actual (surveyed) position of the station and determines the difference, if any, which, of course, would be common to other airborne GPS receivers operating in the area. The station transmits the appropriate error-correction signal by data links to the aircraft, with the result that an accuracy in the order of 10 meters is achievable. Figure 15-10 shows the simplicity of the concept.

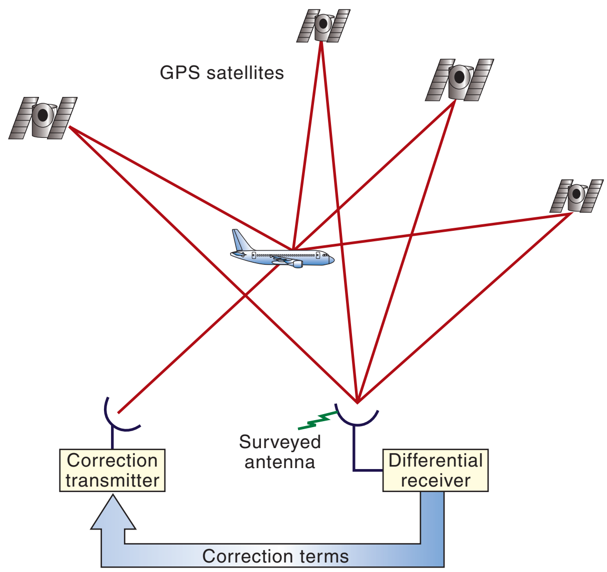


Figure 15-10 Differential GPS.

This enhanced standard of accuracy is acceptable for nonprecision instrument procedures but not for precision approaches. However, a lot of research and development work is being undertaken, particularly by the FAA, to improve the accuracy even further. In fact, the FAA have confidently predicted that Category II and III precision approach navigation capability using GPS will be possible in the future.

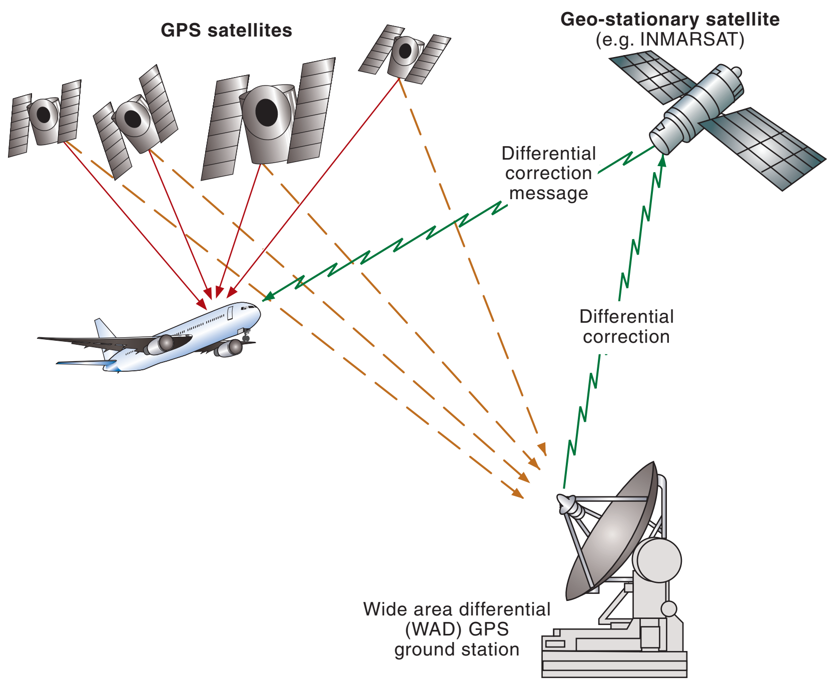


Figure 15-11 Concept of wide area differential GPS.

As well as developing differential GPS for precision operations, a much wider network of ground receivers, with geostationary navigation receiver and communication satellites and relays, is being developed for en route operations. The enhanced network is known as a *wide area augmentation system* (WAAS).

Note. It is important to point out that GPS (GNSS) is still a developing technology as far as civil air operations are concerned. At the time of publication, GPS equipment meeting system integrity standards and operated in accordance with specified limitations and procedures is approved as a primary-means navigation aid for IFR en route operations and specified IFR arrival procedures.

Operations Without RAIM

Without RAIM capability, the pilot has no assurance of the accuracy of the GPS position.

GPS NOTAMs must be specifically requested during preflight briefings.

If RAIM is lost, the accuracy of the system is unacceptable for both navigation and ATC separation purposes. Loss of satellite reception and RAIM warnings may occur due to aircraft dynamics (changes in pitch or bank angle). Antenna location on the aircraft, satellite position relative to the horizon, and aircraft attitude may affect reception of one or more satellites. RAIM availability should always be checked. RAIM information can be obtained for a period of 3 hours (ETA hour and 1 hour before to 1 hour after the ETA hour) or a 24 hour duration at a particular airport. FAA briefers will provide RAIM information for a period of 1 hour before to 1 hour after the ETA, unless a specific time frame is requested by the pilot. If flying a published GPS departure, a RAIM prediction should also be requested for the departure airport. RAIM can also be predicted using the GPS receivers in the aircraft.

If RAIM is not available, another type of navigation and approach system must be used, another destination selected, or the trip delayed until RAIM is predicted to be available on arrival. On longer flights, pilots should recheck the RAIM prediction for the destination during the flight.

If a RAIM failure/status annunciation occurs prior to the final approach waypoint (FAWP), the approach should not be completed. The receiver performs a RAIM prediction by 2 NM prior to the FAWP to ensure RAIM is available at the FAWP as a condition for entering the approach mode. The pilot should ensure the receiver has sequenced from "Armed" to "Approach" prior to the FAWP (normally occurs 2 NM prior). Failure to sequence may be an indication of the detection of a satellite anomaly, failure to arm the receiver (if required), or other problems which preclude completing the approach.

If the receiver does not sequence into the approach mode or a RAIM failure/status annunciation occurs prior to the FAWP, the pilot should not descend to Minimum Descent Altitude (MDA), but should proceed to the missed approach waypoint (MAWP) via the FAWP, perform a missed approach, and contact ATC as soon as practical. Refer to the receiver operating manual for specific indications and instructions associated with loss of RAIM prior to the FAF.

If a RAIM failure occurs after the FAWP, the receiver is allowed to continue operating without an annunciation for up to 5 minutes to allow completion of the approach. If the RAIM flag/status annunciation appears after the FAWP, the missed approach should be executed immediately.

Review 15
Global Positioning System (GPS)

1. The space element of GPS consists of how many satellites orbiting the earth?
2. How often do these satellites complete an orbit?
3. At what altitude are these satellites located?
4. At least how many satellites must be observed for a GPS three-dimensional fix?
5. Compared to a sole means navigation system, which two performance requirements are not necessarily satisfied in a primary navigation system?
6. For civilian GPS operations, what is the pseudo-random code used? What is the service provided known as?
7. What is the deliberate degrading of the accuracy of GPS for civilian use known as?
8. How is the range from a satellite determined?
9. What feature of the TSO-approved GPS system provides additional redundancy and RAIM capability?
10. What are the three operating modes normally provided by a GPS receiver?
11. How are ionospheric effects offset by the GPS receiver?
12. How are tropospheric effects minimized by the GPS receiver?
13. What should all data entered into the GPS, either manually or automatically, be checked against?

Answers are given on page 778.

Radar & ADS-B 16

In the high-volume traffic environment of today's airspace, *radar* is the primary tool used by Air Traffic Control to provide many vital services to IFR (and VFR) aircraft, such as radar vectoring, radar separation and sequencing. The air traffic controller is presented with an electronic map of the area of responsibility, showing the position of aircraft within it. Among the advantages of this system are:

- reduced air-ground radio communication; for instance, there is no need for a pilot to transmit regular position reports;
- an ability to handle an increased number of aircraft in the same volume of airspace, with reduced, but still safe, separation distances;
- an ability to *radar vector* an aircraft along any desired course by passing headings to steer directly to the pilot; and
- an ability to sequence aircraft—that is, to feed them onto final approach to land, either to the commencement of a published instrument approach procedure such as an ILS (instrument landing system), or until the pilot has visual contact with the runway environment, without the need for excessive pre-approach maneuvering and with more than one airplane on the approach at any one time.

Radar used for these purposes is called *surveillance radar*. In the U.S. there are two basic types of surveillance radar in use:

- *air route surveillance radar* (ARSR) is a long-range radar system used by Air Route Traffic Control Centers (ARTCCs) to monitor aircraft during the en route phase of flight. ARSR sites are widely distributed to provide continuous coverage of airspace over most of the continental U.S.
- *airport surveillance radar* (ASR) is a relatively short-range system that is used to monitor aircraft operating within the airspace immediately surrounding an airport.

ATC radar that is approved for approach control is used for:
- *track guidance to final approach course;*
- *ASR radar instrument approaches; and*
- *monitoring nonradar approaches.*

FAA radar units operate continuously at the locations shown in the Airport/Facility Directory (A/FD). Their primary role is to provide positive direction and traffic separation for IFR flights, but they are also used to provide a varying level of service to VFR flights, depending on the facilities available, the type of airspace, and controller workload.

The radar controller can also provide a *radar traffic information service* to notify pilots of other nearby and possibly conflicting traffic.

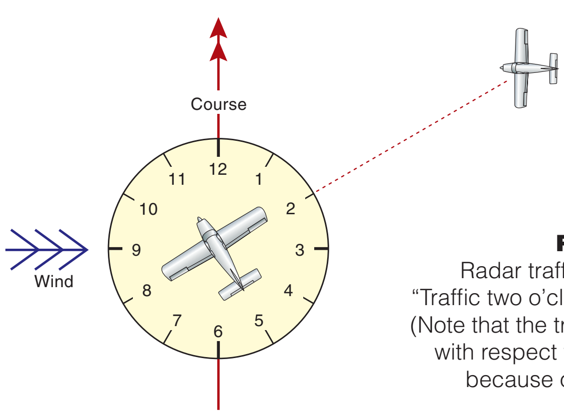


Figure 16-1
Radar traffic information service, "Traffic two o'clock, one mile, westbound." (Note that the traffic is actually at 3 o'clock with respect to the nose of the aircraft because of the drift allowance.)

Even if you are receiving this service, you are still responsible, in suitable conditions, for continual vigilance to "see and avoid" other traffic. The radar controller will pass what he or she considers relevant information using the clock system to specify the position of the other traffic relative to your course. The controller sees your course on a screen rather than your heading, so you will have to allow for the drift angle when you look out the window for other traffic.

An important component of the surveillance radar systems used in the U.S. is the *air traffic control radar beacon system* (ATCRBS), sometimes referred to as *secondary surveillance radar*, or SSR. The operating principles of this system, and its advantages over primary radar, will be explained later in this chapter.

An essential component of the SSR system is the *transponder*, a piece of equipment common in most aircraft. A transponder transmits a unique reply signal in response to radar signals received from the ground, allowing a radar controller to identify and track individual aircraft with greater accuracy and safety. The term *transponder* is a contraction of *transmitter/responder.*

At some airports, ATC may use SSR information to provide course guidance down a final approach path for what is known as an *airport surveillance radar* (ASR) approach, usually referred to simply as a *surveillance approach*. This procedure is normally only considered if equipment failure has ruled out all other types of instrument approach. It is a back-up procedure only.

A very small number of airports are equipped with a special type of approach radar equipment, known as *precision approach radar* (PAR), which enables ATC to provide extremely accurate guidance, along both a specific final approach course and a descent slope, to land on a particular runway. The PAR approach is rarely used by civilian pilots.

We will consider radar vectoring and then look at radar approaches to land. We will reserve consideration of the principles of radar until the end of the chapter.

The availability of radar at a particular airport is indicated on FAA instrument approach charts by the letters ASR near the communications frequencies, and on *Jeppesen* instrument approach charts by the letter (R) in brackets following the particular communications frequency. There are many airports and much airspace in the world that is in a nonradar environment. Without the protection of radar, you should comply with any published departure and approach procedures, and expect ATC to request additional reports to enable them to monitor the progress of your flight.

Figure 16-2 Typical SSR transponders.

Radar Vectoring

Radar vectoring is a procedure in which a radar controller passes a *heading* to steer to a pilot, with an instruction like:

Seven zero seven four delta
Turn left heading two five zero

The aim of the controller when issuing these headings is to get the aircraft to follow a particular *course* over the ground. Because the radar controller will not know precisely the actual wind at your level, or the amount of drift it is causing, he or she will occasionally issue modified vectors to achieve the desired course.

No navigation instruments are required in the aircraft to follow radar vectoring, but radio communication is essential. The pilot concentrates on attitude flying (maintaining the desired heading, altitude and airspeed), while the radar controller concentrates on getting the aircraft to follow the desired course. This does not, however, relieve the pilot of the responsibility to be aware of the aircraft's approximate position at all times, especially in the vicinity of high terrain or obstructions—such an awareness is essential in the event of a communications failure, or controller error.

Departures

Radar vectors may be assigned by ATC during a *radar departure* from a terminal area. On initial radio communication with the departure controller, you should ensure that he or she uses the phrase *"Radar contact"* during the reply, which indicates that your aircraft has been positively identified. This may occur while still below the minimum vectoring altitude, and you are still responsible for terrain and obstruction clearance. Once the controller starts giving radar vectors, ATC will assume responsibility for monitoring terrain and obstruction clearances, however you should still retain an awareness of where you are and height above terrain and obstructions. Termination of radar vectoring by ATC will be indicated to you by the phrase *"Resume own navigation,"* as in:

Intercept Victor 55, resume own navigation.

En Route

En route radar vectoring off a previously assigned course or airway may be used by ATC for traffic separation, terrain clearance or weather avoidance purposes. Vectors will continue to be assigned until you are reestablished on the assigned route, with ATC indicating termination of vectoring by giving your present position, and then adding the phrase, "Resume own navigation."

Approach

Radar vectors during the approach phase are often used extensively for flights into suitably equipped airports, either for guidance to intercept an instrument approach procedure or establish the airplane in the traffic pattern for a visual approach.

When you are being radar vectored prior to commencing an instrument approach, ATC will aim to have the airplane established on the final approach course before the final approach fix (FAF). Clearance for the approach is normally issued with a suitable final intercept vector (usually about a 30° intercept of the final approach course) but, for traffic separation or sequencing purposes, ATC may sometimes vector you through the final approach course. In this case, they are required to inform you of this additional maneuvering, using such phraseology as:

Expect vectoring across final approach course...

If you haven't been given this advisory but a vector is taking you through the approach course, stay on your heading and query the controller.

It is most important that you maintain the last assigned heading and/or altitude until you are in receipt of a positive approach clearance, signified by phraseology like:

Turn right heading 180
Maintain 3,600 until established on the localizer
Cleared for ILS Runway 21 approach

Minimum vectoring altitudes will keep you inside controlled airspace and clear of obstacles.

Minimum vectoring altitudes (MVAs) are established for each part of a terminal area, and it is ATC's responsibility to ensure that aircraft being radar vectored remain at or above the appropriate MVA. MVAs are designed to provide at least 1,000 feet clearance from terrain and obstructions (2,000 feet in designated mountainous areas), and are not less than 300 feet above the lower limit (floor) of controlled airspace. Minimum vectoring altitudes are known to the radar controller, but not to the pilot. All the same, as a pilot you should always keep in mind what is a reasonable altitude by reference to your en route and approach charts.

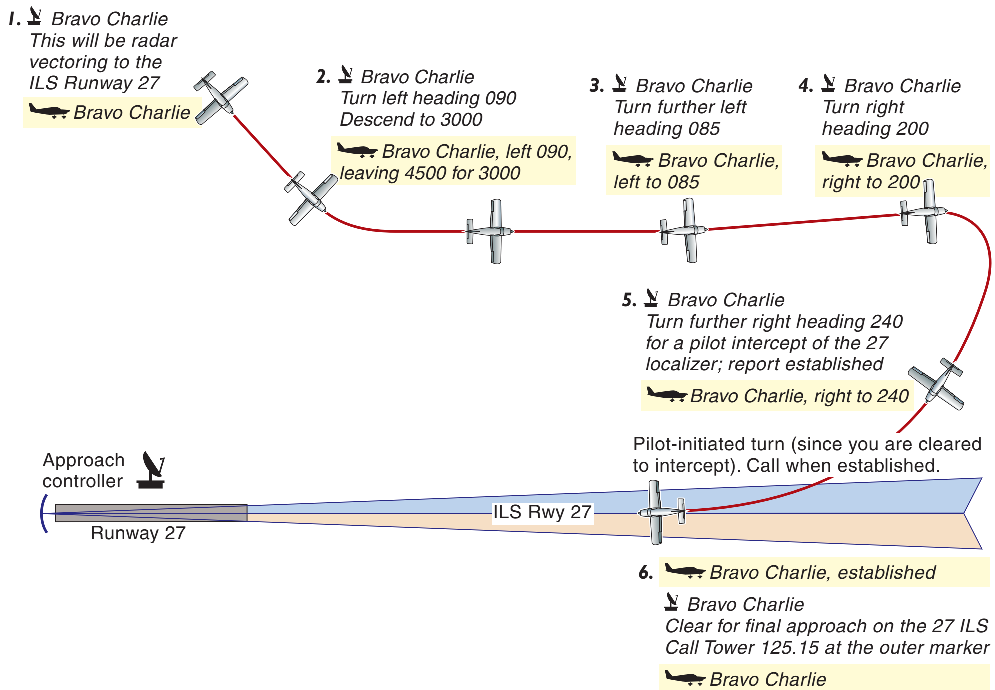


Figure 16-3 Typical radar vectoring in the vicinity of an airport.

When being radar vectored for an approach, keep well ahead of the airplane by organizing and reviewing your approach NAVAIDs in preparation for resuming your own navigation once you intercept the final approach course. Remember that each approach aid must be identified before you may use it for navigation. Stay aware of your altitude above terrain, and be prepared at all times to resume pilot-navigation in case of radio failure.

On *visual approaches* that are being monitored by the approach radar controller, radar service is terminated without advising the pilot when the landing is completed, or when instructed to change to the advisory frequency at nontowered airports, whichever occurs first. Approaches can be terminated by the pilot by advising ATC "runway in sight." If there is a *radar failure*, ATC will use *procedural separation*, which is separating aircraft vertically and horizontally using pilot position reports.

Using the Transponder

Most aircraft are equipped with a transponder (XPDR) that transmits a strong responding signal to a secondary ground radar, which can provide ATC with additional information such as aircraft identification and altitude. The theory of secondary surveillance radar (SSR or ATCRBS) is discussed in detail at the end of this chapter. The operating techniques are considered here.

The transponder is usually warmed-up in the *standby* (SBY) position while taxiing prior to takeoff. (It should also go to SBY at the end of a flight before the master avionics switch is moved to OFF). The four-figure discrete code to be used for the flight will probably be assigned by ATC when they issue an IFR clearance, and this should be selected immediately by the pilot.

The transponder should be selected to the ON position, or the ALT position if it is a Mode C system, as the airplane lines up on the runway for takeoff. If your airplane is equipped with a serviceable transponder, then it must be used in flight, even when you are operating in airspace where its carriage is not mandatory.

Even though transponders produced by various manufacturers vary slightly in design, they are all operated in basically the same manner. However, as a responsible pilot, you should become thoroughly familiar with your particular transponder.

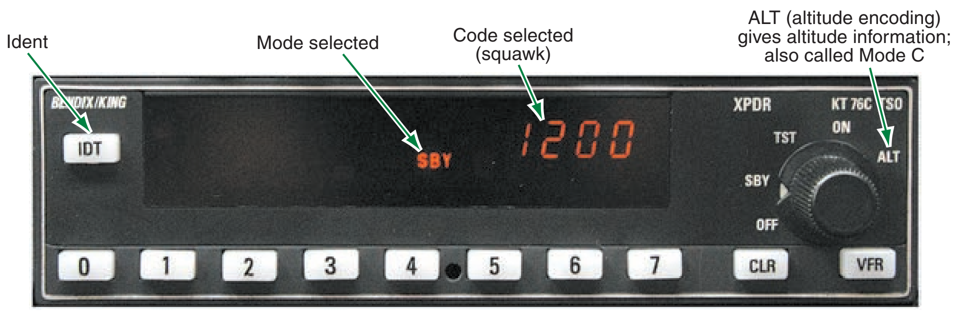


Figure 16-4 Typical transponder panel.

The Function Selector Knob

This enables you to select the transponder on and off, and to operate it in one of its various modes. Typical transponder operating modes include the following.

OFF

The transponder is deactivated completely.

STANDBY

The transponder is warmed up and ready for immediate use. This is the normal position while taxiing before and after flight. Select ALT or ON just before starting your takeoff run. "Squawk standby" may be requested by the radar controller to prevent overly strong blips appearing on the screen from aircraft close to the interrogating antenna. After landing, you would normally switch to STANDBY or OFF for the same reason.

ON

The transponder transmits the selected code in Mode 3/A (to assist with aircraft identification only) at the normal power level.

ALT

This is the altitude-reporting mode (Mode C), which may be used if the aircraft is fitted with a suitable altitude encoding device, either an encoding altimeter or a blind encoder. These feed the current pressure altitude to the transponder for transmission onto the ATC radar screen. The ATC radar computer adjusts pressure altitude to read out actual altitude on the radar screen. (If not installed, the transponder still transmits in Mode A aircraft identification without altitude reporting).

TST

This mode tests the transponder by causing it to generate an internal self-interrogation signal — correct operation is indicated by illumination of the reply monitor light.

> **Note.** This tests only the transmitter section of the transponder, so is no guarantee the transponder and encodes are working correctly. The only true test is to confirm what ATC is seeing on the radar screen.

Code Selection

Suitable knobs are provided to allow selection of the required code on the transponder, the selected code being prominently displayed in digital form.

Whenever codes are selected or altered, it is important to avoid passing through such vital codes as 7700 (for emergencies), 7600 (for radio failure) and 7500 (for hijack) when the transponder is switched ON, as these codes will activate unnecessary alarms in nearby ATC radar facilities. This can be prevented by making it your standard procedure to select SBY while the transponder code is being changed.

The Reply-Monitor Light

The reply light flashes to indicate that the transponder is replying to an interrogation pulse from a ground station. The reply-monitor light will glow steadily when you:

- press the TEST button, or move the function switch to the TEST position (depending on the design of your particular transponder), to confirm correct functioning;
- transmit an *ident* pulse (when requested by ATC); or
- are in a very busy terminal area.

The IDENT Switch or Button

The IDENT button is pressed whenever the radar controller requests the pilot to "*squawk ident*." A special reply pulse is transmitted by the transponder to the interrogating ground station, which causes a special symbol to appear for a few seconds on the radar screen alongside the normal return from your aircraft, thus allowing positive identification by the radar controller.

> **Note.** Your particular transponder may have minor variations to the functions described above, but will certainly be fundamentally the same. It may, for instance, have a separate mode selector to select Mode A (position reporting) or Mode C (position and altitude reporting).

Radio Terminology for Transponder Operation

The term *squawk* that is commonly used by ATC in connection with transponder operation is basically intended to mean "transmit." It is usually followed by an instruction describing the type of transmission required by the controller, for instance: squawk ident, squawk code 4000, squawk mayday (7700).

ATC: "... (callsign) squawk code 4000."

Pilot response is to read back: "... (callsign) code 4000," and to select the transponder to that code.

ATC: "... (callsign) squawk code.... and ident."

Pilot response is to change the code and then press the IDENT button, allowing the radar controller to identify you positively on the screen.

ATC: "... (callsign) squawk standby."

Pilot response is to move the function switch from ALT or ON to the STANDBY position, for a temporary suspension of transponder operation (maintaining present code).

ATC: "... (callsign) squawk normal."

Pilot response is to reactivate the transponder from STANDBY to ON, or to ALT if it is a Mode C system, retaining the existing code.

ATC: "... (callsign) stop squawk."

Pilot response is to select the transponder to OFF or stand by.

ATC: "... (callsign) stop altitude squawk."

Pilot response is to move the function selector from ALT to ON, so that the altitude information is removed from the transponder's reply signals. Further information on transponder operating procedures may be found in the Aeronautical Information Manual (AIM).

Transponder Modes

Two different types, or modes, of transponder equipment are fitted in civil aircraft:

- Mode 3/A: the basic transponder type, with 4,096 different codes selectable by the pilot; and
- Mode C: the same as Mode 3/A sets, but with an automatic altitude-reporting capability (provided the aircraft is fitted with an encoding altimeter, or a "blind" encoder). This sends altitude information to the controller based on 29.92 in. Hg regardless of what the pilot has set in the pressure window.

So that a radar controller can distinguish a particular aircraft from others operating in its vicinity, ATC will usually assign a discrete transponder code to each aircraft, using the phraseology "*Squawk code....*" When this code is selected by the pilot, the aircraft's alphanumeric identification (N number or flight number, whatever the controller desires) is displayed on the radar screen next to its position symbol.

If the aircraft is fitted with a Mode C transponder, then its current altitude will be automatically displayed (to the nearest 100 feet), no pilot or controller input being necessary. If the radar display is an automated type, then the current groundspeed, as calculated by the radar's digital processor, can also be called up and displayed by the controller. All this information assists the controller in the rapid interpretation of the situation presented on a radar screen, and eases the task in separating aircraft and maintaining a safe and efficient traffic flow.

You may be specifically requested by ATC to "squawk ident," when they want positive identification of an aircraft. This is the only time that you should touch the ident button on your transponder. Pressing this button once will cause a special "ID" symbol to appear adjacent to the aircraft's position on the screen. The ident button should not be held in, just firmly pressed once and released.

Transponder Codes

A total of 4,096 different codes can be selected on a transponder, but not all of them are available to be assigned as discrete codes to assist with identification.

There are certain standard codes allocated for military and civilian use. For instance, all transponder-equipped VFR aircraft should squawk Code 1200, unless they are assigned another discrete code. Other standard codes are allocated for use in emergencies only, and will trigger visual and aural alarms in ATC facilities:

- emergency situations—7700;
- radio communications failure—7600; and
- hijack—7500.

Mandatory Transponder Requirements

The regulations require carriage and use of a transponder with *altitude-reporting* capability in a considerable amount of US airspace. This is primarily to assist in reducing the risk of midair collisions in congested airspace where the old "see-and-avoid" system of traffic separation is considered inadequate.

A Mode C transponder must be carried (and operational) by all aircraft operating:

- in Class A airspace, Class B airspace and Class C airspace, and, within the lateral boundaries of Class B and C airspace areas designated for an airport, up to 10,000 feet MSL;
- from the surface up to 10,000 feet MSL when operating within 30 NM of an airport listed in Appendix D, Section 1, of 14 CFR Part 91 (list contains most major US airports, including Atlanta, Denver, Los Angeles, Miami, Minneapolis, both New York airports, St. Louis, Seattle & both Washington airports);
- in all airspace of the 48 contiguous states and the District of Columbia at or above 10,000 feet MSL (except when flying at or below 2,500 feet AGL); and
- from the surface to 10,000 feet MSL within a 10-NM radius of any airport in 14 CFR Part 91 Appendix D, section 2, except the airspace below 1,200 feet outside the lateral boundaries of the surface area of the airspace designated for that airport; (currently no airport meets this criterion, so there is none listed in section 2 of Appendix D).

Mode S

A new type of transponder, known as Mode S, and also referred to as the *discrete address beacon system,* has been developed to reduce the workloads of both controllers and pilots, as well as reducing the congestion on normal radio communications frequencies.

In addition to the altitude information provided by Mode C systems, Mode S transponders can automatically transmit an aircraft's registration and type whenever it is interrogated by ground-based radar. This eliminates the need for the controller to enter the identification of each aircraft manually into the ATC computer, and means that a pilot does not have to select a discrete code. This improvement is significant enough on its own, but fully optioned Mode S installations will provide further benefits.

By a process known as *select addressing*, it is possible for ATC to transmit other information, such as weather reports, ATIS, and clearances to a specific aircraft, which can then be displayed on a suitable screen or printer in the cockpit. This promises to decrease the volume of radio transmissions considerably.

How Radar Works

The remainder of this chapter discusses the basic theory of radio waves, and of radar in particular. It is not essential knowledge but it will help your understanding of radio, radar and NAVAIDs.

Radio utilizes the ability to transmit electromagnetic energy, in the form of radio waves, from one place to another. Radio has played a vital role in the development of aviation—*radar* is an important type of radio system.

Waves of electromagnetic energy emanating from a radio transmitter can carry information, such as speech, music, and Morse code out into the surrounding environment. Radio receivers tuned to the same frequency may detect and utilize these signals, often at quite long distances from the transmitter.

Important aeronautical uses of radio include:

- air/ground voice communication;
- navigation (the ADF/NDB combination, VOR and ILS); and
- radar.

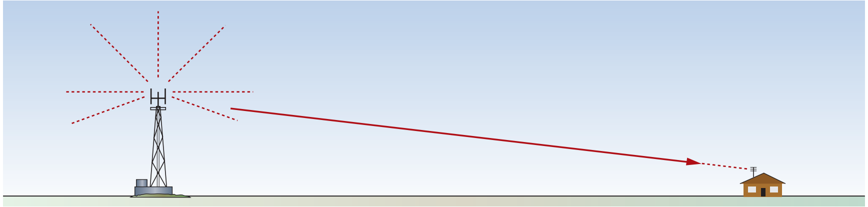


Figure 16-5
Radio involves the transmission and reception of electromagnetic energy.
The distanc is calculated from the time the signal takes to reach and return.

The Reflection of Radio Waves

Radio waves and light waves are both forms of electromagnetic radiation, differing only in their frequency.

Electromagnetic radiation can be reflected from certain surfaces. Light waves, for instance, will be reflected by the metallic coating on a mirror. Similarly, radio waves of certain frequencies will be reflected from metallic and other surfaces, some of the radio energy returning to the point from which it was transmitted as a return echo. Other surfaces and objects, such as wood, may not cause reflection of the radio waves, which will simply pass through like X-rays pass through a body.

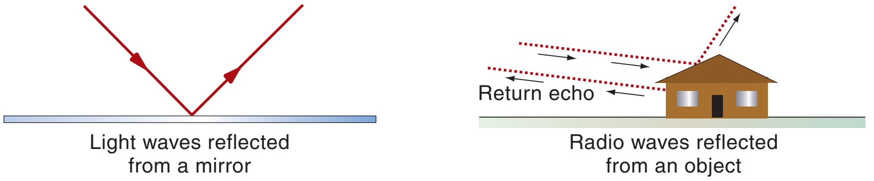


Figure 16-6 Some radio waves can be reflected in a similar way to the light waves.

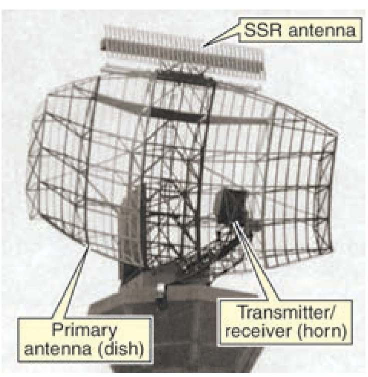


Figure 16-7
A typical radar head.

Radar

The detection of reflected radio waves back at the point from which they were originally transmitted is the fundamental basis of radar. The basic operating principles of radar were first developed during the late 1920s, and subsequent rapid improvements in the ability to detect objects, such as aircraft, and to measure their range, was often a decisive factor during World War II (1939–45). The term *radar* was derived from *ra* dio *d* etection *a* nd *r* anging.

A typical radar system consists of a combined transmitter-receiver unit, which is equipped with a parabolic dish antenna that is designed to be efficient both in the transmission of a focused beam of radio signals, and in the reception of any reflected signals from the same direction. The dish can be rotated slowly, so that the whole sky can be scanned systematically, if desired.

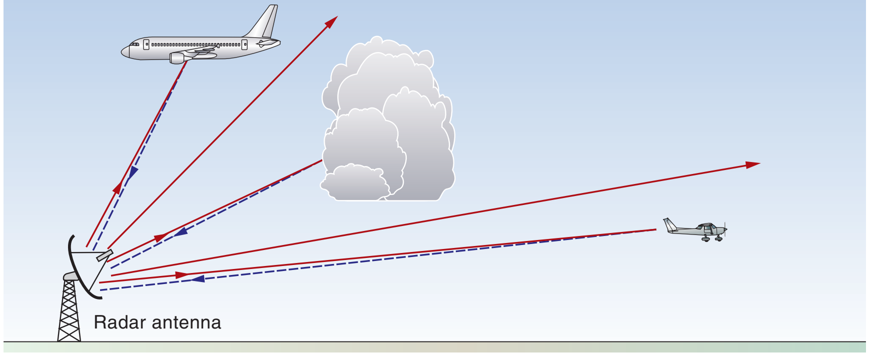


Figure 16-8 Radar is the transmission of electromagnetic radio energy and the detection of some of the reflected energy back at the point of transmission.

Radars usually operate in the UHF (ultra-high frequency) and SHF (super-high frequency) bands.

The properties and behavior of radio waves (their reflectivity and range) depends on their frequency. Radio signals from the upper range of the radio frequency spectrum, with very short wavelengths, are the most suitable for use in radar systems. Radars usually operate in the UHF (ultra-high frequency) and SHF (super-high frequency) bands.

The Relationship of Time and Distance

All electromagnetic energy travels at the speed of light, 162,000 nautical miles per second (300,000 kilometers per second), the equivalent of almost eight journeys around the world in one second. Some common forms of electromagnetic energy are light, radio waves, X-rays, ultraviolet radiation and infrared radiation.

It is possible to measure the elapsed time between the transmission of a very short burst, or pulse, of radio energy, and the reception of any reflected echo back at the source. Given the known velocity of radio waves, a relatively simple mathematical calculation will allow determination of the distance or range of the reflecting object from the transmitter.

Radar converts an elapsed *time* to a *distance*:

$$\frac{\text{distance}}{\text{time}} = \text{speed}$$

Multiplying both sides of this equation by *time* gives an expression for *distance* in terms of the known speed of light and the measured elapsed time:

$$\text{distance} = \text{speed} \times \text{time}$$

During the elapsed time between transmission of the pulse and reception of its reflection (measured electronically at the radar site), the distance between the radar site and the object will have been traveled twice, once out and once back, so the elapsed time needs to be halved. This is done electronically.

The speed of light being so great means that the time intervals involved are extremely short. A stream of rapidly repeating pulses can be transmitted, with reception of any echoes still being possible during the intervening short time periods between each pulse transmission.

As a matter of interest, the time taken for a radar pulse to travel to and from a reflector 20 NM away (a total of 40 NM) is 0.000250 seconds, or 250 millionths of a second:

$$40 \text{ NM } (2 \times 20) \textit{ at speed of light } 162{,}000 \text{ NM/second} = \frac{40}{162{,}000}$$
$$= 0.000250$$

- If the measured elapsed time interval is 250 millionths of a second, then the object is 20 NM distant.
- If the measured elapsed time interval is 750 millionths of a second, then the object is 60 NM distant.
- If the measured elapsed time interval is 125 millionths of a second, then the object is 10 NM distant.
- If the measured elapsed time interval is 12.5 millionths of a second, then the object is 1 NM distant. A time interval of 12.5 millionths of a second (or microseconds) can be thought of as a radar mile (distance between antenna and target).

At What Range Can Radar Detect Targets?

Radar uses ultra-high frequency (UHF) transmissions, which basically follow a straight line-of-sight path, so that signal coverage will be limited by significant obstructions (buildings and terrain), and by the curvature of the earth. They will cause radar shadows, and objects in these shadow areas will not be detected.

The curvature of the earth means that the higher an aircraft is flying, the greater the distance at which it can be detected by radar. The relationship between the maximum detection distance (in nautical miles) and aircraft altitude is given by the expression:

$$\text{Radar range in NM} = \sqrt{1.5 \times \text{altitude in feet}}$$

Note. $\sqrt{1.5 \times \text{altitude}}$ is the same as $1.22 \times \sqrt{\text{altitude}}$, which some pilots prefer. It is a similar expression, since the square root of 1.5 is 1.22.

Example 16-1

At 5,000 feet AGL over flat terrain with no obstructions, an aircraft will be detected up to approximately 87 NM.

$$\begin{aligned}\text{Radar range (NM)} &= \sqrt{1.5\ \text{ht (ft)}} & &= 1.22\sqrt{\text{ht (ft)}}\\ &= \sqrt{1.5 \times 5{,}000} & \text{or} \quad &= 1.22\sqrt{5{,}000}\\ &= \sqrt{7{,}500} & &= 1.22 \times 71\\ &= 87\ \text{(NM)} & &= 87\ \text{(NM)}\end{aligned}$$

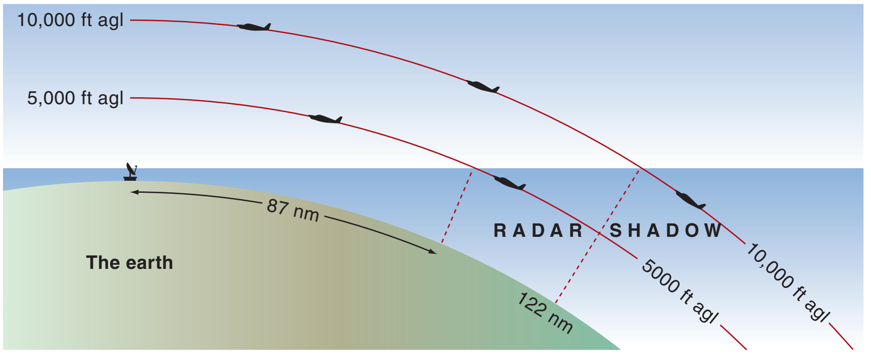


Figure 16-9 Example 16-1.

Example 16-2

At 10,000 feet AGL over flat terrain with no obstructions, an aircraft will be detected out to approximately 122 NM.

$$
\begin{aligned}
\text{Radar range (NM)} &= \sqrt{1.5\ \text{ht (ft)}} & &= 1.22\sqrt{\text{ht (ft)}} \\
&= \sqrt{1.5 \times 10{,}000} & \text{or} \quad &= 1.22\sqrt{10{,}000} \\
&= \sqrt{15{,}000} & &= 1.22 \times 100 \\
&= 122\ \text{(NM)} & &= 122\ \text{(NM)}
\end{aligned}
$$

Note. These are expected ranges under ideal conditions; in reality, the range of a radar may be significantly less than this, and it may experience blind spots and radar shadows.

Radar range may be increased if the radar antenna is sited at a high elevation, both to raise it above nearby obstacles that would cause shadows, and to allow it to see further around the curvature of the earth. Hence radar dishes are often sited on the tops of hills and buildings.

Another technical design feature (apart from the positioning of the radar dish) that determines the range of a radar is the interval existing between pulse transmissions to allow the transmitter to act as a receiver. The greater the time interval, the greater the range from which echoes can be received, prior to the next transmission. The number of separate pulses transmitted in one second is known as the *pulse repetition rate* (PRR) or *pulse repetition frequency* (PRF). A radar with a low PRR has a greater detection range than a radar with a high PRR.

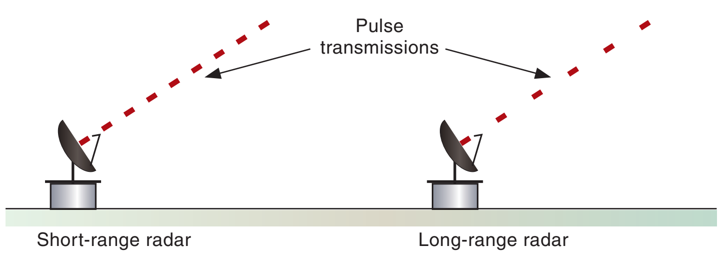


Figure 16-10
Long-range radar has a lower pulse repetition rate and must rotate more slowly.

Bearing Measurement by Radar

The bearing (direction) of reflecting objects from a radar site is determined by slowly rotating the dish antenna, a typical rate being between two and ten revolutions per minute.

As it rotates, a narrow beam of multiple radar pulses is directed around the horizon, with any reflected signals being received almost instantaneously along each bearing that is scanned. The angle of the antenna relative to north at the moment a return is received will provide the bearing (or azimuth) of the object.

Both the bearing and the range of an object can therefore be determined by radar, so that its position can be precisely pinpointed, and the *returns* displayed as *blips* (echoes or sometimes called skin paints) on a suitable screen.

Primary Surveillance Radar

Radar that makes use of reflected radio energy is known as *primary radar,* and it is used for a number of purposes in aviation including:

- *surveillance radar,* to provide an overview of a wide area, and used in *air route surveillance radar* (ARSR) and *airport surveillance radar* (ASR), and also used for ASR instrument approaches; and
- *precision approach radar* (PAR), used for extremely accurate azimuth and slope guidance on final approach to land.

Surveillance radar is designed to give a radar controller an overview of the area of responsibility. It does not transmit pulses in all directions simultaneously, but rather as a beam, which is slowly rotated. For an aircraft to be detected, the beam must be directed roughly toward it.

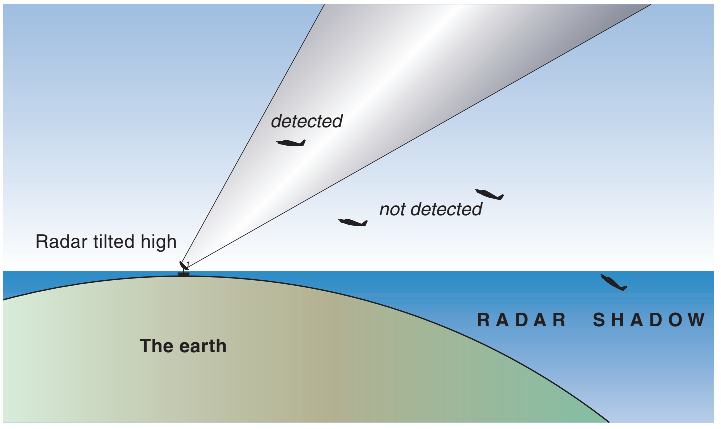


Figure 16-11
To be detected, aircraft must be within the radar transmitter's beam.

If the radar controller has the radar tilted up, then it may miss lower aircraft at a distance; conversely, nearby high aircraft may not be detected if the tilt is down.

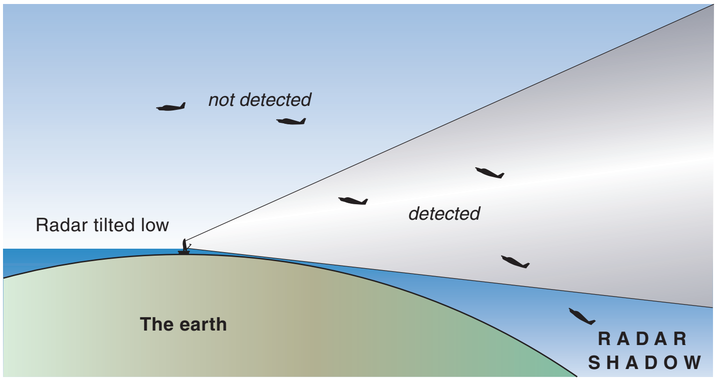


Figure 16-12
Radar tilted low cannot detect high targets.

The Radar Screen

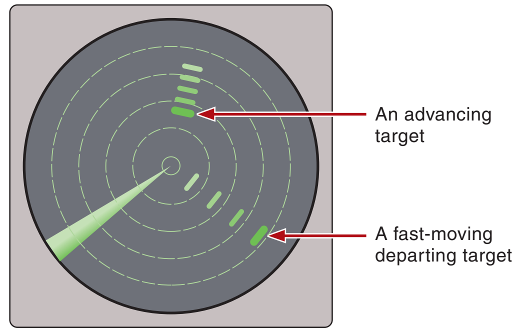


Figure 16-13 A radar screen (scope).

Most radar screens are simply cathode ray tubes (CRTs) that resemble circular television screens. Using the same principle as television, a beam of electrons is directed at the fluorescent coating of the CRT to provide a radar picture. Radar controllers generally have circular displays showing the position of the radar antenna in the center, with range marks to aid in estimating distance. The radar screen is also known as a *plan position indicator* (PPI).

The actual radar dish may be located away from the position of the radar controller, possibly on a nearby hill or tower. As the radar antenna rotates slowly, the small electron beam in the controller's CRT also rotates, leaving a faint line or trace on the screen in a direction aligned with the direction of the antenna at that moment. Any radar return signal along that same bearing appears as a *blip* or *paint* at the appropriate spot on the screen.

The direction of north is indicated on the screen, allowing the controller to estimate the bearing, or azimuth, of each target. Concentric range marks assist in the estimation of target distance. The paint of the target remains visible for some seconds after the small trace line has moved on, and will still be visible, but fading, as its next paint occurs in the following revolution. This fading trail of blips allows the controller to determine the motion of the target in terms of direction and speed.

In areas of high traffic density, the radar responsibility may be divided between various controllers, each with their own screen and radio communications frequency, and will go under such names as *Approach Control, Center,* and *Departure Control*.

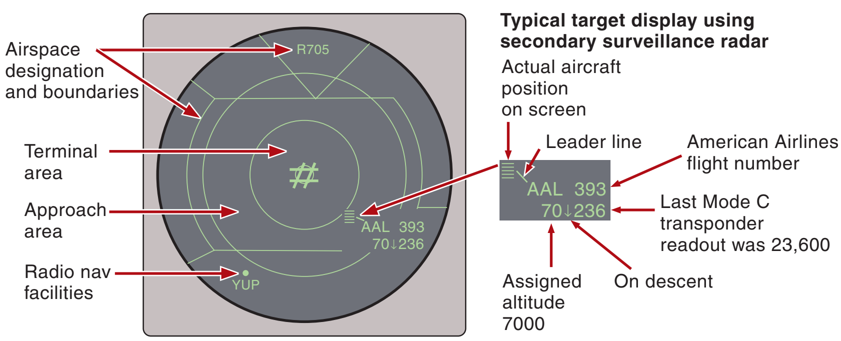


Figure 16-14 A typical ATC radar screen.

In addition to the range marks, various symbols and lines may be superimposed on an ATC radar screen, using a video overlay, so that it effectively becomes an electronic map of the scanned area.

The video image for a terminal area radar typically shows:

- the location of both primary and satellite airports, common flight paths to them, NAVAIDs (VORs, compass locators), and significant obstructions;
- airways, and extended runway centerlines; and
- the controlled airspace structure, and boundaries of any special use airspace (such as Prohibited and Restricted Areas).

Some Disadvantages of Primary Radar

While a big advantage of primary radar is that no special equipment is required in the aircraft, it does have some operational disadvantages including:

- *clutter,* caused by returns reflected from precipitation, ground obstacles and buildings or mountains (this principle is used for weather radar and ground mapping radar;
- *variation* in the size and intensity of radar returns, according to the reflectivity of different aircraft (for instance, a Cessna 172 is harder to plot than a Boeing 747); and
- *shadows* or blind spots, from screening by high terrain features or areas of heavy precipitation.

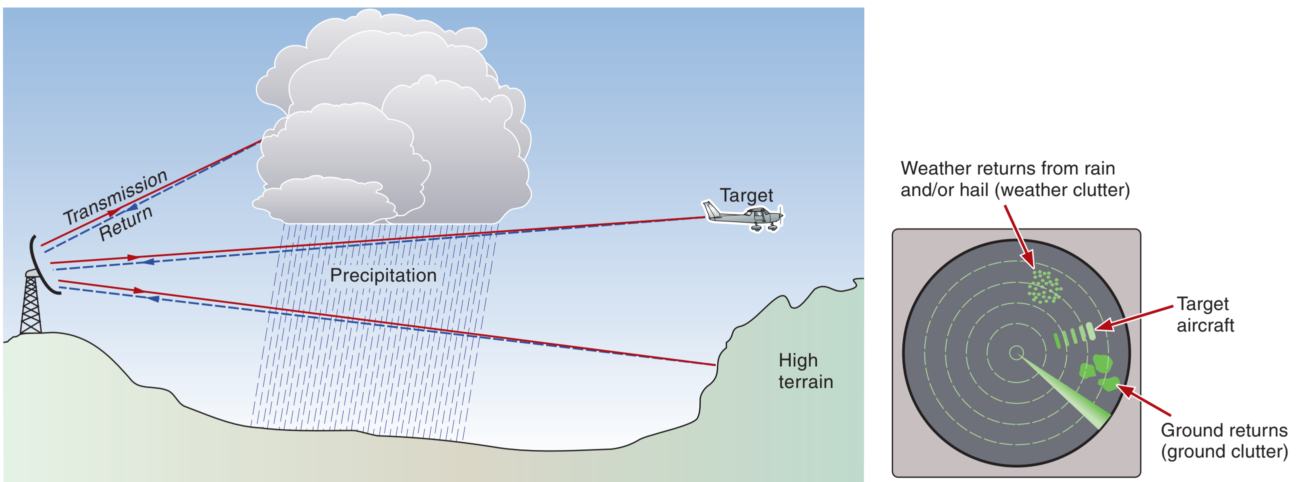


Figure 16-15 Primary Surveillance Radar is subject to clutter.

The radio energy in the reflected signal received at the radar dish may be quite small, depending on the strength of the original transmission, how good a reflector the target is, its distance from the radar antenna, and so on. A radar that is sensitive enough to pick up weak returns from targets may also pick up returns from terrain and precipitation, leading to ground clutter and weather clutter on the screen. During periods of heavy rain, primary radar may be significantly degraded.

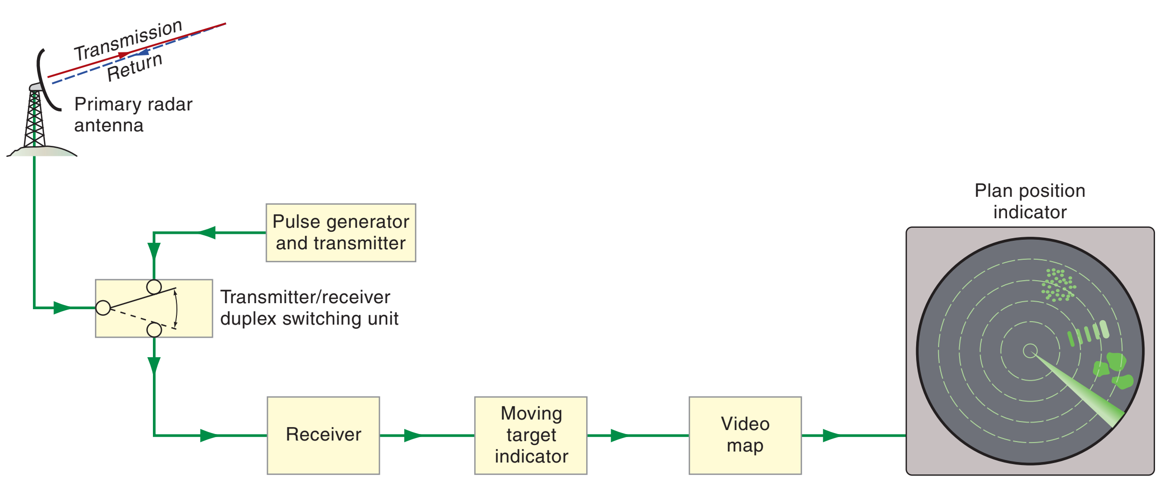


Figure 16-16 Diagrammatic layout of a primary radar system.

Some radars incorporate an electronic sifting device known as a *moving target indicator* (MTI) that only allows signals from moving targets to be shown on the screen, in an attempt to eliminate clutter from stationary objects.

On screens relying solely on primary radar returns, it will often be difficult for a controller to identify and track a particular aircraft, especially when there are other aircraft returns in close proximity, or in the presence of clutter caused by weather or terrain. The aircraft may have to execute a significant turn, for instance, in order for the controller to establish positive identification, a time-wasting and tedious process at best.

Secondary Surveillance Radar (SSR) or Air Traffic Control Radar Beacon System (ATCRBS)

Secondary surveillance radar overcomes most of the limitations of primary radar simply by ensuring that a conspicuous, high-energy return pulse is produced by any aircraft that is equipped with a *transponder*.

Primary radar detects radar energy passively reflected from a target and displays it as a blip, or fading series of blips, on a screen; this is similar to seeing an aircraft reflected in the beam of a searchlight at night.

Secondary radar is much more than this, and involves an active response by the aircraft every time it is interrogated by a ground-based radar. It is as if each time a searchlight strikes a target, the target is triggered to light itself up very brightly in response, rather than just passively reflect some of the light energy transmitted from the ground site. Secondary radar actually consists of two sets of radar "talking" to each other.

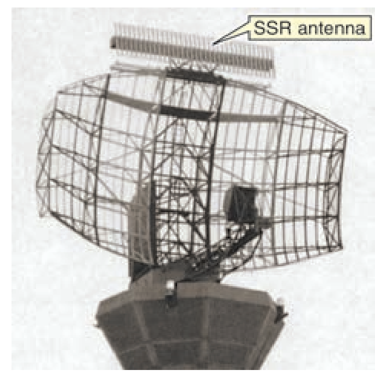


Figure 16-17
SSR antenna on top of radar head.

The strength of the reflected signals received by a primary radar system is usually only a tiny fraction of the energy of the original pulse transmissions. Consequently, primary radars need powerful transmitters and large antennas.

As only a small amount of radio energy transmitted from the ground is required to trigger a response from an airborne SSR transponder, the ground-based secondary radar transmitter and antenna systems tend to be quite compact in comparison. In fact, the typical long, narrow SSR antenna is small enough to be mounted above the larger primary radar dish at many radar ground sites.

The SSR ground equipment consists of:

- an interrogator that provides a coded signal asking a transponder to respond;
- a highly directional rotating radar antenna that transmits the coded interrogation signal, then receives any responding signals, and passes them back to the interrogator; and
- a decoder, which accepts the signals from the interrogator, decodes them and displays the information on a radar screen.

The SSR airborne equipment consists of a transponder carried in each individual aircraft. The original interrogation pulses transmitted from the ground station trigger an automatic response from the aircraft's transponder. It transmits strong coded reply pulses, which are then received back at the ground station. These reply pulses are much, much stronger than the simple reflected signals used in primary radar. Even a very weak interrogation pulse received at the aircraft will trigger a strong response from the transponder.

The secondary responding pulse sent by a transponder not only enhances the basic positional information available to a controller, but can also carry coded information that will help distinguish that aircraft from all others on the same radar screen.

Depending on the type, or *mode*, of the transponder, and the *code* selected on it by the pilot (as requested by ATC), it can convey additional information such as:

- the specific identity of an aircraft;
- its altitude (if Mode C has been selected by the pilot);
- any abnormal situation affecting the aircraft, such as radio failure, distress, emergency, etc.

Other significant advantages of SSR systems include:

- they are not degraded to the same extent as primary radar by weather or ground clutter;
- they present targets of the same size and intensity to the controller, regardless of the relative reflectivity of individual aircraft; and
- they minimize blind spots.

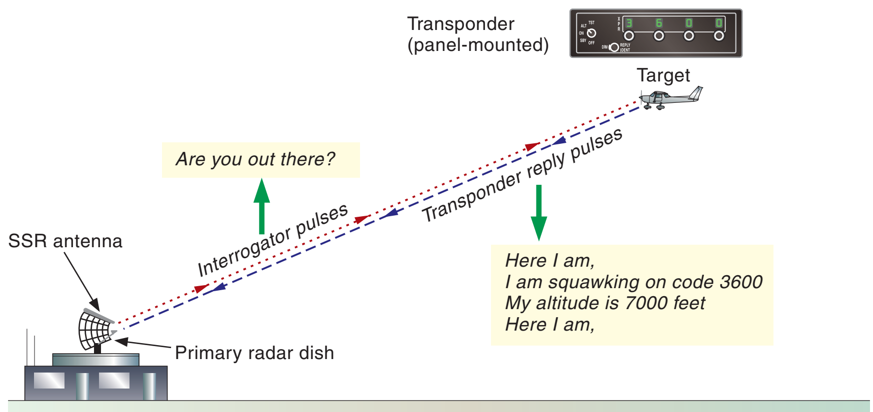


Figure 16-18 SSR is two radars talking to each other.

Radar Screens and SSR

In the United States, secondary surveillance radar is referred to as the *air traffic control radar beacon system* (ATCRBS). The role of the SSR transponder is becoming more and more crucial, not only within the busy terminal areas, but also in those areas of the ATC en route environment beyond the effective coverage of primary radar, where SSR is the only source of position information available.

On the radar screens used by most controllers, information from both primary and secondary radars is combined on the one display. In many cases, these "broadband" radar screens are actually synthetic radar displays, showing radar position symbols that are generated by automated computer processing of primary and secondary radar signals, sometimes from widely separated radar sites.

Different symbols are used to indicate whether the position information and track "history" for a particular aircraft have been derived from primary, secondary, or combined radar sources. Associated with each symbol will be other information regarding the aircraft concerned, which may include its identity, level, destination and groundspeed. This information may be obtained either directly from the coded SSR signals sent by the aircraft, from calculations by the radar's digital processor, or from manual entries made by the controller himself into the ATC computer.

We recommend that you visit an ATC radar facility, either a terminal approach/departure facility or an en route center, to see the system in action from the air traffic controller's point of view. Understanding the task, and how it interacts with yours as pilot-in-command, will lead to greater professionalism.

Traffic Awareness and Collision Avoidance Systems

There are several devices now available to alert pilots of potentially conflicting traffic and the risk of collision. They work on one of two principles:

- active; and
- passive.

They use the same principle as SSR. The aircraft carries a device that receives other airborne transponders. The active systems do not rely on ground radar to trigger those airborne transponders. The aircraft carries its own interrogator. Passive systems rely on the SSR to trigger a response, and they therefore only work within ground radar coverage. In the U.S. where there is extensive radar coverage, the simple and more economical passive systems work very well.

Remember: *large, fast aircraft cannot see you on their TCAS systems unless your transponder is ON and operating correctly.*

Active Systems

Airline-type airplanes carry a *traffic alert and collision avoidance system* (TCAS). In some cases, carriage of this equipment is mandatory. TCAS is an active system: it transmits a pulse that elicits a response from transponder-equipped aircraft within a particular area of interest—a limited range and altitude band.

Within this group, there is a further categorization:

- those that simply provide a warning and relative position of traffic (TCAS I)—called *traffic advisories* (TA); and
- those that also indicate pilot action to be taken to avoid collision, e.g. climb or descend (TCAS II). These avoidance actions are called *resolution advisories* (RA).

Both are required to actively interrogate other aircraft in order to allow TCAS to accurately measure the range of proximate aircraft and to make TCAS operation independent of ground facilities. Such independence is necessary in oceanic and other non-radar airspace.

Several acronyms associated with collision avoidance systems:

TCAS *is the generic name for the active traffic alerting and collision avoidance svystems*

TCAD *Traffic and Collision Alerting Device is the name used by Ryan Aeronautics for their passive GA system*

TPAS *describes the TrafficScope Traffic Proximity Alert System*

TCAS I Systems

TCAS I systems are the least complex of TCAS equipment, since they are only required to provide traffic advisories, i.e. they do not need to give any resolution advisories. *Traffic advisories* (TA) simply show the presence of other aircraft. *Resolution advisories* (RA) suggest action to be taken to avoid confliction. TCAS I systems do not require a Mode S transponder.

The display to the pilot is in a plan view which shows the relative position of target aircraft together with symbology that gives an altitude differential relative to the host aircraft (i.e. above or below) and a vertical trend. Figure 16-19 shows a typical TCAS I display which may be provided on a separate TCAS CRT display or on an existing radar display tube.

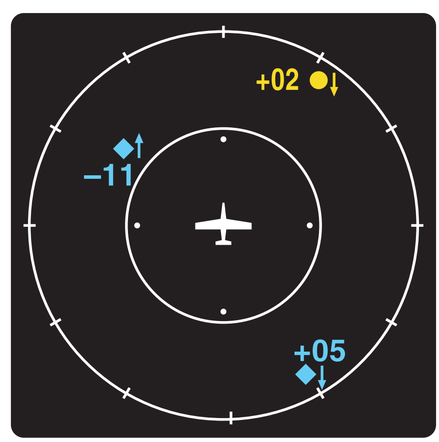


Figure 16-19 TCAS I display.

> **Note.** In figure 16-19, the numerals against the target display show height above or below host aircraft in hundreds of feet. The arrow indicates vertical trend. Different symbol shapes can be used to show varying levels of urgency.

Specifications for TCAS I require provision of a TA when an intruder aircraft comes within 30 seconds of the host aircraft. However, TCAS I also provides display of target aircraft outside the thirty-second time frame. Most systems use a "cylinder" or "barrel" of airspace 4 NM in radius and 1,200 feet above and below the host aircraft to display *proximate advisories* (PA), and they use different symbology to show aircraft outside that box.

TCAS II Systems

The main differences of a TCAS II system are:

- installation of a Mode-S transponder;
- provision of vertical resolution advisories; and
- a forty-five-second shield (rather than the thirty-second shield for TCAS I).

Use of Mode-S Transponder

A new type of transponder, known as Mode S, will become increasingly common. This new system is also referred to as the *discrete address beacon system* and promises to reduce both controller and pilot workloads, as well as reduce the congestion on normal radio communication frequencies.

In addition to the altitude information provided by the Mode C stem, Mode S transponders automatically transmit an aircraft's registration and type whenever it is interrogated by ground-based radar. This eliminates the need for the controller to manually enter the identification of each aircraft into the ATC computer and means that a pilot does not have to select a discrete code. This improvement is significant enough on its own, but fully optioned Mode S installation will provide further benefits.

By a process known as select addressing, it will also be possible for ATC to transmit other information, such as weather reports, ATIS, and clearances to a specific aircraft, which can then be displayed on a suitable screen or printer inside the cockpit. This promises to decrease the volume of radio transmissions considerably.

The Mode-S transponder provides the two-way data link which allows TCAS II equipped aircraft to coordinate their RAs.

This data link may also be used to seek stale data from other aircraft to aid in accurate determination of the level of threat. The calculations to support RAs are performed in the TCAS-II unit.

__ADS-B__ With this revolutionary traffic management system, aircraft are fitted with Mode S transponders which transmit position and tracking data from the GPS, as well as identity and altitude. Ground stations use this data to manage flight progress and separation. Ultimately it will replace many ground radar stations. In the next stage, cockpit TCAS displays will show aircraft tracks and altitudes on the aircraft's integrated EFIS/TCAS screen.

__TIS-B__ As a supplement to ATS-B, TIS-B will provide an integration of data input from sources that don't have the GPS/Mode S data link. this is particularly valuable for airport surface movement control where the surface radar information can be integrated.

Figure 16-20
Digital TCAD display.

Figure 16-21
Pictorial TCAD display.

Passive Systems (TCAD, TPAS and ATD)

There are a number of proprietary passive systems that rely on transponder pulses being triggered by a ground radar interrogator. Given that limitation, they are very effective.

The advantage of the passive systems is that they do not require a radar transmitter and so are easier and more economical to install. Some simply plug in and are ready to operate with their own internal microprocessor and antenna. Most systems give either a simple LED screen with a profile view of the relative altitude and distance to the other traffic. They generally operate in a close or far mode and show the closest target. Some show the three most threatening targets. Some have a warning light or lights which illuminate as traffic gets closer, and some have an audio warning, such as a voice, "traffic, traffic."

The more complex systems have multiple antennas mounted on top and underneath the aircraft and may display a plan view of the aircraft with multiple targets. Some even have a complex call-out of traffic: "Traffic, twelve o'clock, high, one mile!"

TAS *describes a Traffic Advisory System which may have audio warning*

ATD *is used as a product designator by Monroy for their alerting system*

ADS-B *automatic dependent surveillance broadcast*

FIS-B *flight information service broadcast*

Conclusion

Most near misses and mid-air collisions occur during clear weather in close proximity to an airfield. Thus visual lookout is not good enough to keep safe separation. You need to know where to look and if another aircraft penetrate your visual shield. Ground radar is valuable, but for the complete safety net of SSR and transponders to work, all aircraft need to have the transponder *on*, and all pilots need to know where to look for traffic. For this reason, all of the alerting devices are useful. I know of several near misses that could have been disastrous—the pilots were saved by their TCAD or TCAS alert.

Automatic Dependant Surveillance – Broadcast

The incoming system that will incorporate many technologies, including GPS and collision avoidance, is the Automatic Dependant Surveillance–Broadcast (ADS-B). ADS-B has both ground components and in-air components. On the ground ADS-B will eventually replace radar installations across the United States.

The major drawback of conventional radar is that there is a delay in position reporting as the antenna "dish" turns. When the radar antenna revolves quickly it is able to update the position of aircraft in motion more often, but the range of the radar is cut down. A fast moving antenna (approximately 10 RPM) is used at a busy airport terminal where it is important to keep updated on aircraft as they converge on the airport. A slower moving antenna (approximately 2 RPM) has slower updates but has greater range. The greater range is possible because turning the antenna slowly allows the pulse to go out and back while the antenna is still facing the target. Slow moving antennas are used at Air Route Traffic Control Centers to increase the range of radar coverage, but it's a trade-off. Fast moving antenna updates aircraft position better, but does not "see" very far. Slow moving antenna can see farther, but the position of the aircraft is updated less often. ADS-B solves this problem.

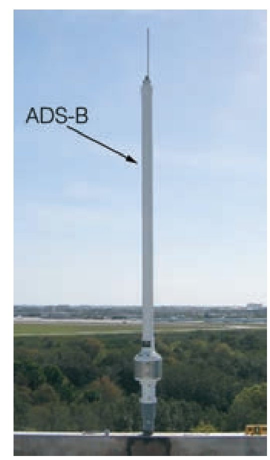


Figure 16-22
ADS-B Ground Based Transceiver (GBT) antenna.

ADS-B does not use a rotating antenna (see figure 16-22). Instead ADS-B uses a stationary antenna that sends out pulses in every direction approximately once every second. The pulse expands out in every direction like ripple in a pond when a pebble is dropped in. This means that aircraft positions are constantly updated with virtually no delay.

In the air ADS-B will provide collision avoidance information from plane to plane as illustrated in figure 16-23. In order to receive information using ADS-B from another airplane, the other airplane also must have ADS-B equipment. During the time of transition, many airplanes will not have ADS-B equipment, so to supplement ADS-B a system called the Traffic Information Service–Broadcast (TIS-B) is also used.

TIS-B takes information from the conventional radar screen and transmits it to ADS-B equipped aircraft. This means that even aircraft that do not have ADS-B equipment will appear on a collision avoidance screen in the cockpit. None of these collision avoidance devices relieves the pilot from the responsibility to "see and avoid" other traffic as all avoidance devices are considered advisory and pilots still need to look out the airplane windows frequently.

Another feature of ADS-B is called Flight Information Services–Broadcast (FIS-B). This feature has great potential for enhancing a pilot's situational awareness. FIS-B is an uplink from ground based ADS-B antennas to the airplane. Through FIS-B real time weather information can be brought up to the airplane. A pilot can read current METARS and TAFs while enroute. Most importantly it is possible to uplink current graphical NEXRAD weather radar pictures. Before this capability, pilots had to contact Flight Watch or a flight service station and have someone describe the weather radar picture. Now that picture is in the cockpit. NOTAMS and Temporary Flight Restrictions can be graphically presented over the top of electronic charts so that pilots always know what areas to avoid. The system also has downlink capabilities that transfer that information to the ground. In the future, every airplane could send down in-flight weather information to be analyzed in real time.

Information on actual (not forecast) wind direction and velocity, freezing levels, turbulence and more would be constantly sent to the ground to build an enhanced comprehensive and current weather picture. It will be an electronic PIREP. Engine information can also be down linked. This gives technicians on the ground the capability of viewing individual cylinder temperatures, EGTs, and also enables them to monitor engine systems to break-in engines more efficiently and detect problems early.

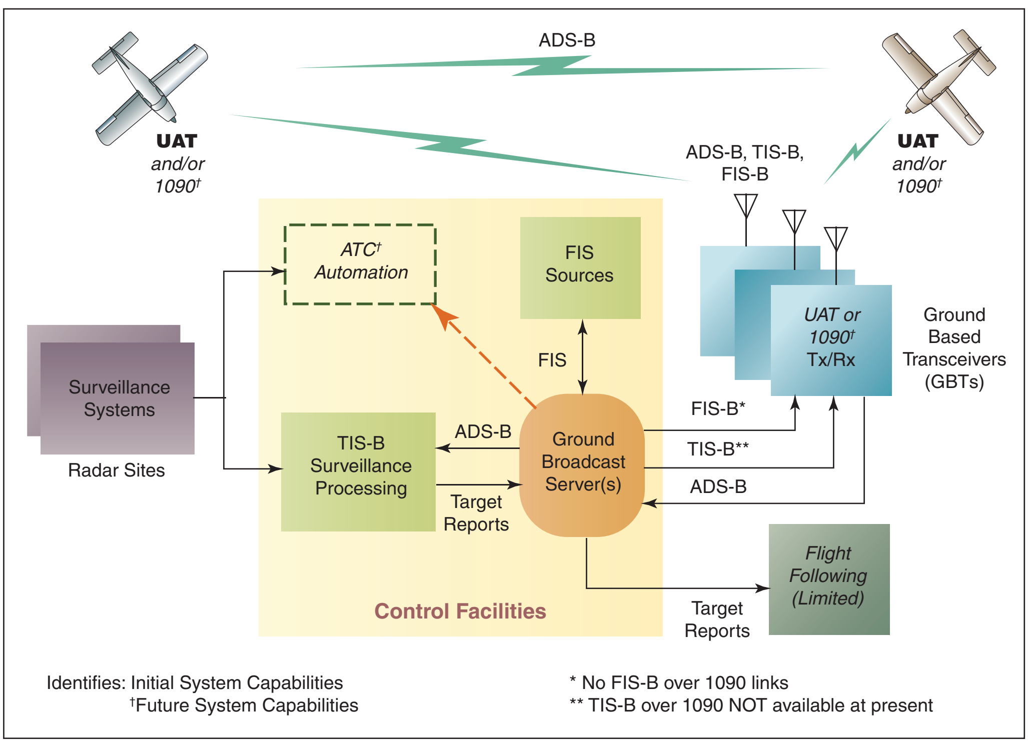


Figure 16-23 ADS-B, TIS-B, and FIS-B: broadcast services architecture.

Weather Detection and Avoidance

Weather alerting devices also use active and passive modes to detect and classify significant weather. The active systems use a radar transmitter/receiver. The passive systems detect electrical charges and discharges in the atmosphere (lightning).

These two types of systems for detection and avoidance of hazardous weather are quite different in their principles of operation. They are:

- weather radar; and
- stormscopes.

Weather Radar

One of the problems of radar was the presence of clutter due to precipitation and ground returns. This weakness has been developed into very useful weather detection and ground mapping facilities. Radar sensitivity to weather returns is a function of the wavelength of the pulses (the operating frequency). If the wavelength is close to the size of the target, the radar echo is maximized. Weather radars are tuned to detect particles and water droplets. However, radar may not see through intense nearby cells to show further cells beyond. There are shadow areas.

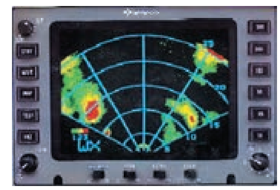


Figure 16-24
Weather radar picture.

Although weather radars are used primarily for airborne weather detection, ranging, and analysis, they may also be used in a ground mapping mode. The major components of a typical system are:

- radar antenna;
- receiver/transmitter unit;
- control panel; and
- display unit.

Figure 16-25
Combined weather radar ground map display.

The radar returns are displayed separately or superimposed on an *multi function display* (MFD) over the navigation and waypoint information. Thus the pilot receives a total picture of position track and possible heavy weather. Color coding is used to classify the seriousness of the weather (the size of the droplets and particles). The more active the cell, the larger the droplets. Also, a storm is most violent just before releasing the suspended rain and hail, perhaps before there is visible lightning; however, there are likely to be internal electrical discharges which will show on a stormscope.

Weather radar systems operate in the C and X bands, with power outputs in the order of 125W. The maximum range of modern radars is about 300 NM. The antenna is normally stabilized using attitude signals from one of the vertical gyros or inertial references (to avoid clutter from ground returns during turns).

The antenna sweeps (scans) the pencil-shaped radar beam about 60° either side of the nose and can be tilted up and down to about ±15°. Radar returns, or *echoes*, are processed to provide range and azimuth data, which is then displayed in the cockpit.

Airborne weather radar installed in sophisticated aircraft is a type of primary radar that can detect water drops. It cannot detect air currents, turbulence, windshear, hail, or the fact that instrument-flying conditions exist, but it can warn you of the possibility of these phenomena, since they are associated with cumulonimbus clouds, which do contain large water drops—a case of guilt by association.

Large water drops reflect the radar beam transmitted from the airplane, and this reflected signal is shown on the radarscope in the cockpit as a radar echo. The radar display can be either monochrome or color, depending on the equipment installed. Color weather radar displays are extremely effective in portraying the weather, with a number of strong colors representing the intensity of the returns—usually graded

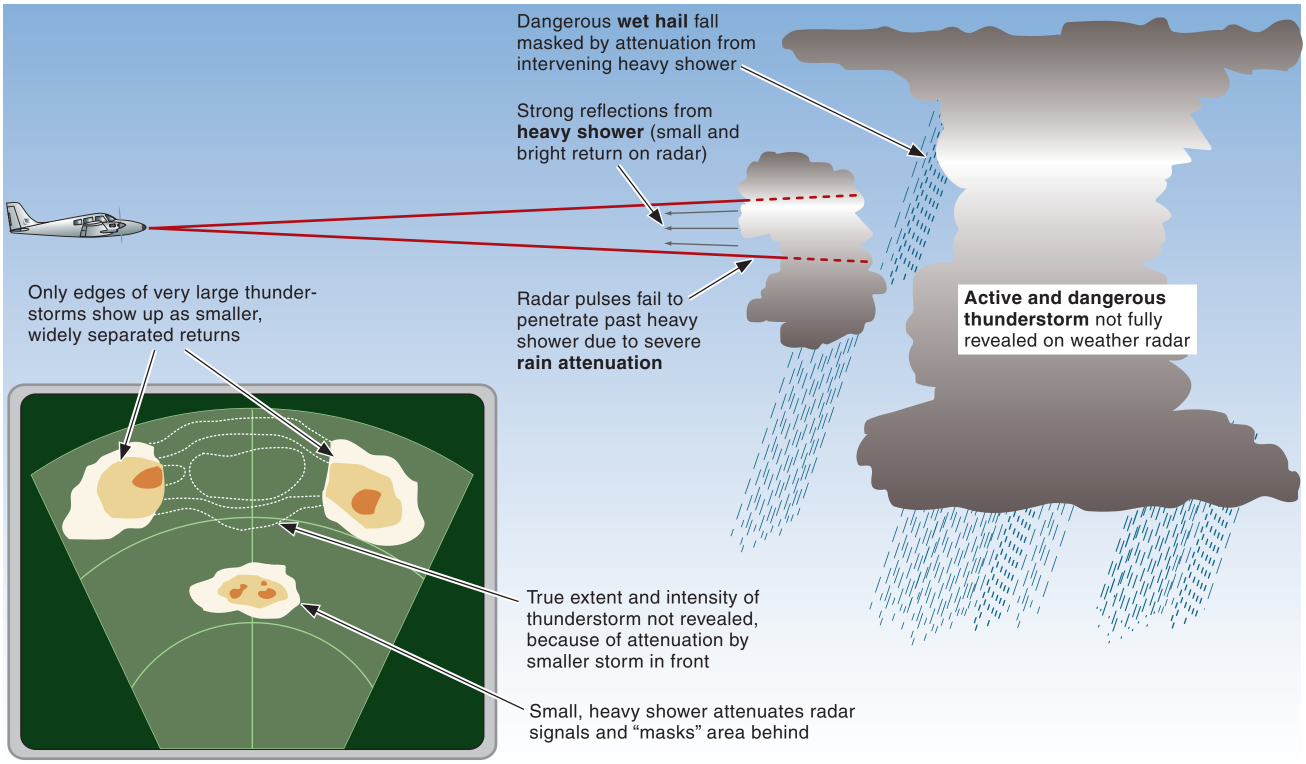


Figure 16-26 Storm cells appearing as echoes on a weather radarscope.

from *green* for light rain, through *yellow* and *red*, to *magenta* for severe rain showers. Monochrome displays rely on "gray-scales" to display gradations of echo intensity.

Not all storm cells containing large drops of water will be detected initially, since nearer cells may mask the presence of more distant cells. An extremely strong storm may also show up as a "hole" in the radar picture.

Any storm cells strong enough to cause a radar echo should be avoided by at least 20 miles. To achieve this separation between two storm cells, they must be at least 40 miles apart. If not you should consider flying to one side of the pair of cells.

While strong windshear, turbulence and/or a microburst cannot be detected directly by most weather radar, you should suspect their presence if there is a weather radar return from an overlying cumulonimbus cloud.

Radar is complex and works only as well as the operator. Pilots who use airborne weather radar are encouraged to take time to thoroughly learn to interpret their particular system.

In addition to the simple, reflected energy mode, which is a function of droplet size and density, there is a more sophisticated turbulence detection mode. The returned signal is not only measured by elapsed time and energy, but the spectrum of the very slight changes in frequency is also measured (called the *doppler effect* or *doppler shift*). This subtle change indicates the movement of the water droplets: those cells that show the most variance in droplet velocity indicate the greatest turbulence—brilliant technology.

Stormscopes and Strikefinders

Some aircraft have *stormscope* or *strikefinder* displays, which show the location of lightning. This equipment shows clusters of lightning strikes on a CRT screen as clusters of dots or plus signs (+). Since the lightning is always associated with thunderstorms in the mature (most dangerous) stage, avoiding the lightning allows pilots to avoid the thunderstorms. This equipment does not suffer from "masking" or "shadows," as does weather radar, and is somewhat easier to use. *Stormscopes* and *Strikefinders* are more likely to be found in light aircraft than weather radar because of their relatively simple installations, light weight and generally lower cost.

Figure 16-27
Stormscope clock code display.

Unlike radar, the stormscope principle does not rely on a transmitted signal and therefore is not limited by the need to bounce an echo back to the receiver. The aircraft installation is easier as a radome is not needed. The stormscope system is a passive detector of cells of electrical energy. It also shows cells that are hidden behind other cells, where radar may only echo the nearest. However, the principle relies on electrical discharges and so may not show heavy weather cells until they become active thunderstorms. Heavy precipitation, turbulence or icing may not show.

The stormscope system consists of:

- antennas;
- processor; and
- control/display unit.

Figure 16-28
360 degree picture.

Displays

Like weather radar, the display of storm cells can be on a discreet instrument or on the EFIS (electronic flight instrument system). Typically, the display can be a simple clock-code display, which is color-coded to show the most active storm cells. More complex systems can show patterns similar to weather radar displays or can even be integrated with weather radar data on a multi-function display. Stormscopes can also show a 360° plan view.

Summary

Weather radar and stormscopes work on different principles. Each has advantages and each has limitations. For an airplane that is operated regularly in marginal weather, there is a strong argument to have both systems fitted.

Review 16

Radar & ADS-B

1. The process of separating aircraft and positioning them by ATC passing them headings to steer is known as what?
2. If a radar service is not available, ATC will separate aircraft using procedures based on their estimated positions and known altitudes. This is known as:
   a. nonradar separation.
   b. procedural separation.
   c. standby separation.
3. Primary surveillance radar can detect aircraft, even if they carry no airborne equipment. What must an aircraft carry in order to transmit responding signals for secondary surveillance radar (SSR) to detect on the ground?
4. What is secondary surveillance radar known as in the United States?
5. In providing a radar traffic information service, ATC reports the position of a possibly conflicting aircraft as "two o'clock northbound." What does "two o'clock" refer to?
6. Is ATC radar approved for approach control service able to be used for course guidance to the final approach course?
7. Is ATC radar approved for approach control service able to be used for ASR approaches?
8. Is ATC radar approved for approach control service able to be used for the monitoring of nonradar approaches?
9. Is the radar ground equipment for a PAR approach the same as for an ASR approach?
10. What is the altitude-reporting capability of a transponder called?
11. When ATC requests you to "squawk ident," what should you do?
12. What are the standard transponder codes for the following:
    a. an emergency?
    b. a radio failure?
    c. a VFR airplane?
13. Where are FAA radar locations found?
14. How is the availability of radar at a particular airport indicated on FAA approach charts?
15. How is the availability of radar at a particular airport indicated on Jeppesen instrument approach charts?
16. An approach to a runway under the guidance of a radar controller who passes tracking instructions and recommended altitudes is known as what sort of approach?
17. What approximate rate of descent in fpm is required to achieve a 3° glide slope, which is 300 feet per NM, if the groundspeed of the airplane is the following:
    a. 60 knots?
    b. 90 knots?
18. What is the approximate range of any VHF signals for an aircraft at the following altitudes above the level of a ground station:
    a. 6,000 feet?
    b. 2,000 feet?
    c. 2,500 feet?
19. During an ASR approach, the controller provides headings to align the airplane with the extended centerline of the runway and what 3 additional items without request?
20. Must a particular surveillance approach have been previously authorized and established by the FAA for a particular runway for it to be available? Must it have an approach chart and/or published minimums?
21. During a no-gyro approach, and prior to being handed off to the final approach controller, at what rate should all turns be made unless otherwise advised? What is the case for after being handed off to the final approach controller?

Answers are given on page 778.

The VOR 17

The VOR is a very high frequency (VHF) NAVAID that is extensively used in instrument flying. Its full name is the *very high frequency omni-directional radio range*, commonly abbreviated to the VOR, VHF omni range, or omni.

Each VOR ground station transmits on a specific VHF frequency between 108.00 and 117.95 megahertz (MHz), which is immediately below the frequency range used for VHF communications. A separate VHF-NAV radio is required for navigation purposes, but is usually combined with the VHF-COM in a NAV/COM set.

The VOR has been largely supplanted by GPS in the real world of IFR, and the FAA plans to begin phasing out VOR within the next 5 to 10 years. Although VOR remains an important element of navigating the IFR environment, it is no longer the primary NAVAID.

Figure 17-1 VOR display and NAV/COM controller.

The VOR was developed in the U.S. during the late 1940s and was adopted by the International Civil Aviation Organization (ICAO) as the standard short-range radio navigation aid in 1960. When introduced, it offered an immediate improvement over previously existing aids such as the ADF/NDB combination, most of which operated in lower frequency bands than the VOR and suffered significant limitations such as night effect, mountain reflections and interference from electrical storms.

Principal advantages of the VOR over the NDB include:

- a reduced susceptibility to electrical and atmospheric interference (including thunderstorms);
- the elimination of night effect, since VHF signals are line-of-sight and not reflected by the ionosphere (as are NDB signals in the low and medium frequency band); and
- VOR is more accurate than NDBs.

The reliability and accuracy of VOR signals allow the VOR to be used with confidence in any weather conditions, by day or by night, for purposes such as:

- orientation and position fixing (where am I?);
- tracking to or from a VOR ground station;
- holding (for delaying action or maneuvering); and
- instrument approaches to land.

The Main Use of the VOR is for Tracking

Many VORs are paired with DME. Selection of the VOR on the NAV/COM also selects the paired DME, thereby providing both tracking and distance information.

The VOR can be used by a pilot to indicate the desired course and the angular deviation from that course.

For a desired course of MC 015, the pilot would expect to steer a heading of MH 015, plus or minus a wind correction angle (WCA). By selecting an omni bearing of 015 under the course index of the VOR indicator, the pilot can obtain tracking information as shown in figure 17-2.

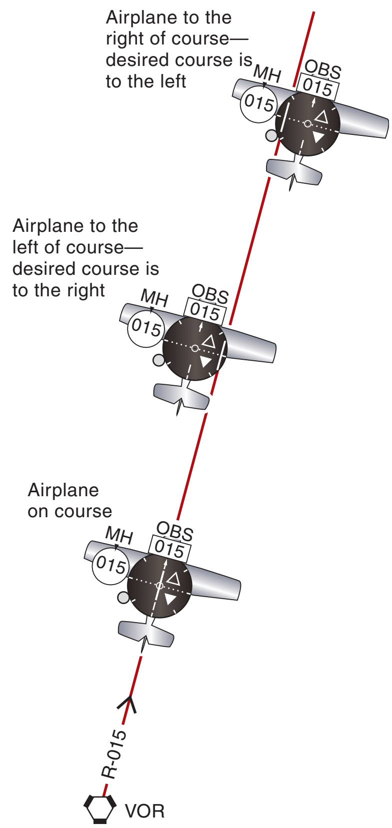


Figure 17-2
The VOR is used to indicate course (track).

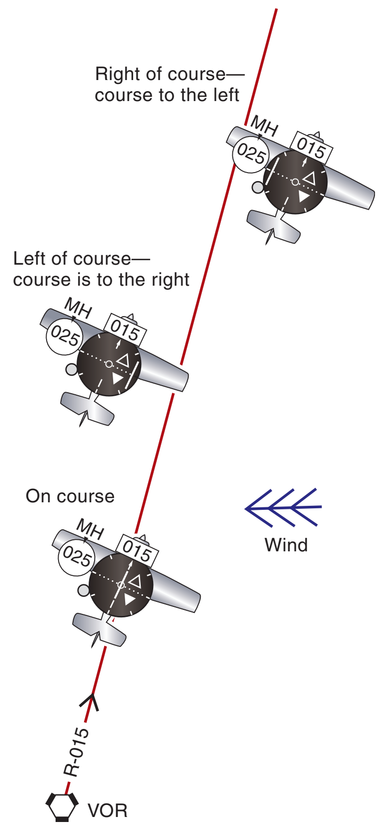


Figure 17-3
The VOR indicator is not related to heading but position relative to selected course.

The VOR cockpit display is not heading sensitive, which means that the display will not change as a result of the airplane changing heading. The case illustrated in figure 17-3 shows the same situation as figure 17-2, except that a wind correction angle (WCA) of 10° right is being used by the pilot to counteract a wind from the right, and so the airplane's magnetic heading is now MH 025 (rather than the previous MH 015).

Note that:

- the VOR indication depends on the angular deviation of the airplane relative to the selected course;
- it's the position of the airplane not just angular deviation—heading is not involved; and
- the VOR indication will not change with any heading change of the airplane.

VOR Radials

As its name *omni* suggests, a VOR ground transmitter radiates signals in all directions. Its most important feature, however, is that the signal in any particular direction differs slightly from its neighbors. These individual directional signals can be thought of as courses or position lines radiating out from the VOR ground station, in much the same way as spokes from the hub of a wheel.

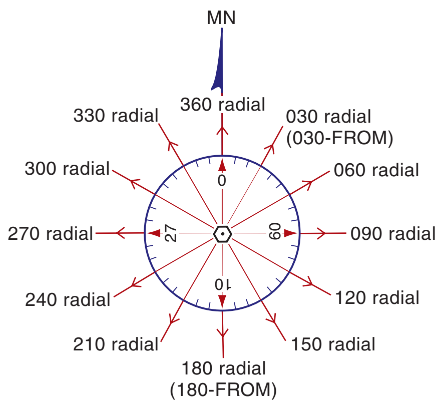


Figure 17-4
A radial is a magnetic bearing outbound *from* a VOR ground station.

By convention, 360 different tracks away from the VOR are used, each separated from the next by 1°, and each with its direction related to magnetic north. Each of these 360 VOR courses or position lines is called a *radial*. The 075 radial may be written R-075. A radial is the magnetic bearing outbound from a VOR.

An airplane tracking outbound on the 060 radial will diverge from an airplane tracking outbound on the 090 radial. Conversely, if they both reverse direction and track inbound on the 060 radial (240-TO the VOR) and the 090 radial (270-TO), their tracks will converge.

When a VOR is operating normally, the radials are transmitted to an accuracy of ±2° or better.

Figure 17-5
A VOR ground station.

Figure 17-6
VOR antennas.

How the VOR Works

The VOR ground station transmits two VHF radio signals:

1. the *reference phase* signal, which is omni-directional (the same in all directions); and
2. the *variable phase* signal, which rotates uniformly at a rate of 1,800 rpm, with its phase varying at a constant rate throughout the 360°.

The antenna of the VOR airborne receiver picks up the signals, whose *phase difference* (the difference between the wave peaks) is measured, this difference depending on the bearing of the airplane from the ground station. In this manner, the VOR can determine the magnetic bearing of the airplane from the VOR ground station.

The two signals transmitted by the VOR ground station are:

- in-phase on magnetic north, which is the reference for VOR signals;
- 90° out of phase at magnetic east 090°M;
- 180° out of phase at magnetic south 180°M;
- 270° out of phase at magnetic west 270°M; and
- 360° out of phase (back in-phase) at magnetic north 360°M, or 000°M.

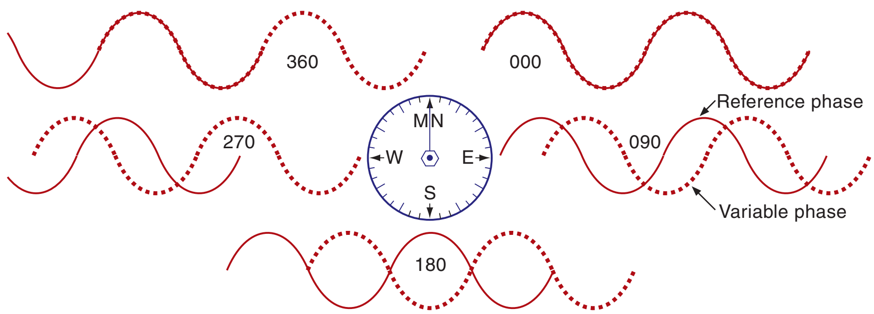


Figure 17-7
The VOR transmits two VHF signals with a phrase difference between them.

Every 10 seconds or so a Morse code identifier signal (or *ident*) is transmitted, modulated at 1,020 Hz, allowing the pilot to positively identify the VOR. The coded identifier for the Redmond VOR is RDM (*dit-dah-dit dah-dit-dit dah-dah*). Any associated DME will have a coded identifier broadcast about every 30 seconds, modulated at 1,350 Hz, about one DME ident at a higher pitch tone for every three or four VOR idents.

Some VORs may also carry a message such as a relevant ATIS, hazardous inflight weather advisory service (HIWAS), or automated weather observing system (AWOS).

Some VORs may also carry voice transmissions either identifying them (for example, "Linden VOR," alternating with the coded identifier), or carrying a message such as a relevant *automatic terminal information service* (ATIS), HIWAS, or AWOS.

The voice identifier of the VOR must have the word VOR or VORTAC stated after its name for the VOR to be considered identified.

If the VOR ground station is undergoing maintenance, the coded identifier is not transmitted, but it is possible that navigation signals will still be received. Sometimes a coded *test* signal (*dah dit dit-dit-dit dah*) is transmitted. Do not use these aids for navigation. No NAVAID signal should be used until positive identification is made.

VOR Distance

The VOR is a very high frequency aid operating in the frequency band 108.0 to 117.95 MHz. It allows high quality "line-of-sight" reception because there is relatively little interference from atmospheric noise in this band. Reception may be affected by the terrain surrounding the ground station, the height of the VOR beacon, the altitude of the airplane and its distance from the station.

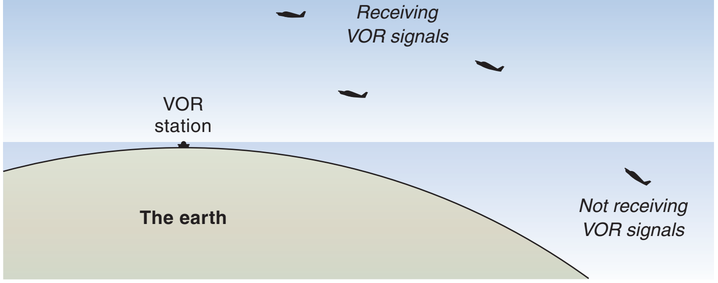


Figure 17-8 VHF line-of-sight signals.

The approximate maximum range of a VHF signal is given by the formula (which is printed here for your convenience):

$$\text{VHF Range} = \sqrt{1.5 \times \text{altitude (ft)}}$$

Example 17-1

$$\begin{aligned}\text{At 7,000 feet, approximate VHF Range:} &= \sqrt{1.5 \times 7{,}000}\\ &= \sqrt{10{,}000}\\ &= 100 \text{ NM}\end{aligned}$$

Different VORs may operate on the same frequency, but they will be well separated geographically so that there is no interference between their VHF line-of-sight signals. The higher the airplane's altitude, however, the greater the possibility of interference.

Standard Service Volumes

There are prescribed standard service volumes for three classes of VORs (High Altitude—H, Low Altitude—L, and Terminal—T) which define the reception limits usable at various altitudes. The transmitting power of each VOR is designed to achieve its specified volume.

Use standard service volumes when planning an off-airway route (off-airway routes must be flown only in radar contact, and when in radar contact standard service volumes can be exceeded). Standard service volume limitations do not apply to published IFR routes or procedures. For example, if planning an off-airway flight 17,000 feet above the level of a high altitude VOR ground station, the signal is officially usable out to

Use standard service volumes when planning routes that are not on Federal Airways.

100 NM. For complete VOR coverage along the route, the H-class VOR ground stations should be within 200 NM of each other, so that their signals overlap and the airplane will always be within range (100 NM at that altitude) of a VOR.

The class of a VOR is specified in the Airport/Facility Directory (A/FD), and also any restrictions on its use, such as unreliability between certain radials. Within its Directory Legend the A/FD also contains a table of altitudes versus distances. These are related to the standard service volumes and will help you when planning off-airway routes. The class of a VOR, other than H, is also specified in the NAVAID box on FAA En route Charts.

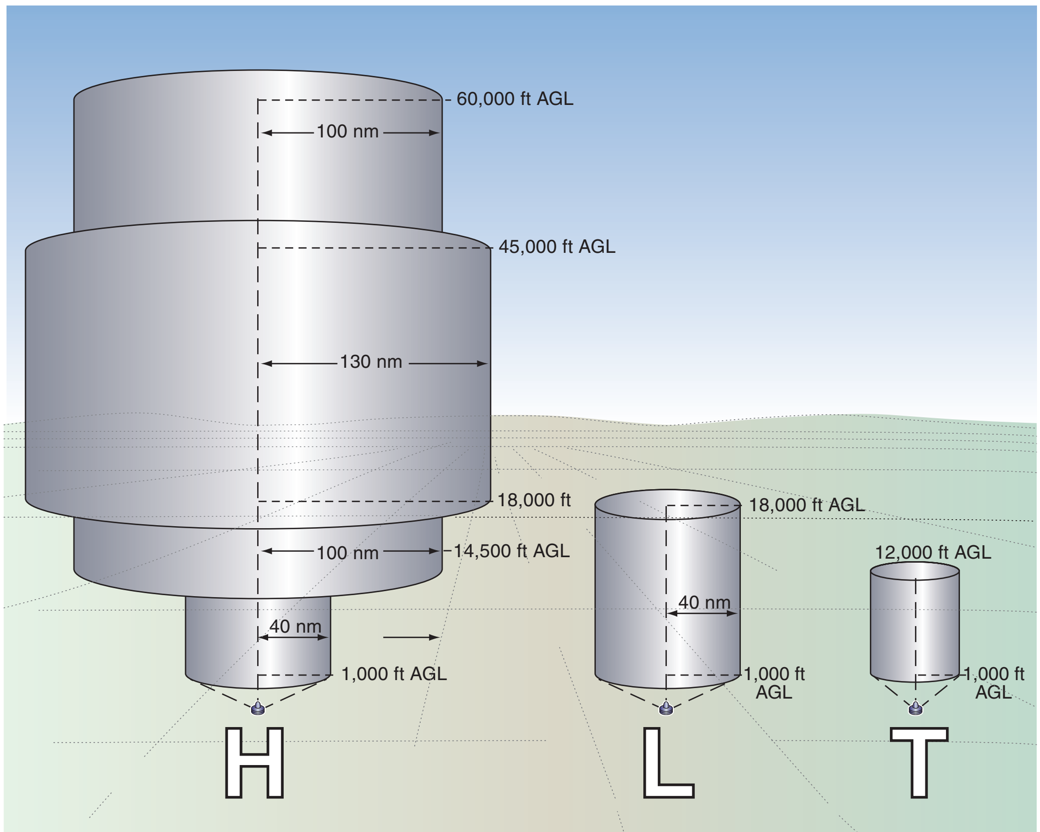


Figure 17-9 Standard service volumes.

Minimum En Route IFR Altitude (MEA)

The MEA is the lowest published altitude between NAVAID fixes that:

- meets obstacle clearance requirements between those fixes; and
- assures acceptable navigational signal coverage between those fixes.

Thus the MEA may be higher than the safe altitude to ensure continuous NAVAID reception.

Minimum Obstruction Clearance Altitude (MOCA)

The MOCA is the lowest published altitude between NAVAID fixes that:

- meets obstacle clearance requirements between those fixes; but
- assures acceptable navigational signal coverage only within 22 NM (25 SM) of a VOR.

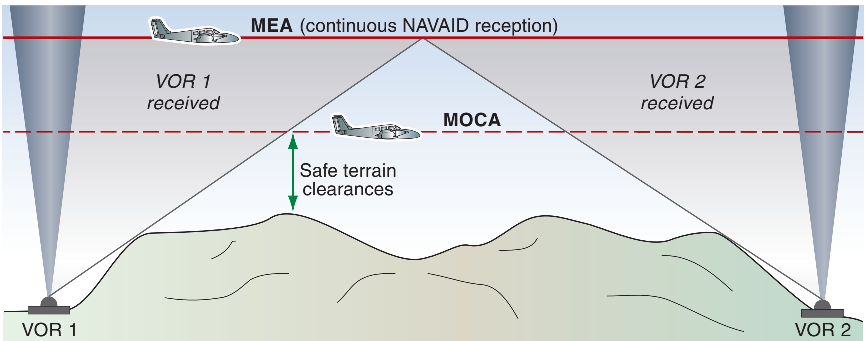


Figure 17-10 MEA and MOCA.

Therefore, in certain terrain, the MOCA may provide safe clearance but may not ensure continuous signal coverage. These gaps are depicted on the en route charts. The MOCA may be lower than the MEA, but of course can never be higher. For example, the route between two fixes may be labeled with an MEA of 6,000, and a MOCA of 5,000 (written as "*5000" on FAA charts and "5000T" on Jeppesen charts).

VOR Changeover Point (COP)

It is usual, when tracking en route from one VOR to another, to select the next VOR when the airplane is approximately halfway between them, unless a *designated changeover point* is specified on the low altitude chart. Selecting the next VOR at the changeover point will mean the stronger signal is being used.

Change VORs at the specified changeover point, otherwise at the approximate mid-point between them, or at the point where the airway changes direction. This occurs at some intersections, so watch for this. Certain intersections have a specified *minimum reception altitude* (MRA) published on charts, this being the minimum altitude at which this intersection can be identified; at altitudes lower than the MRA, navigational coverage is not assured.

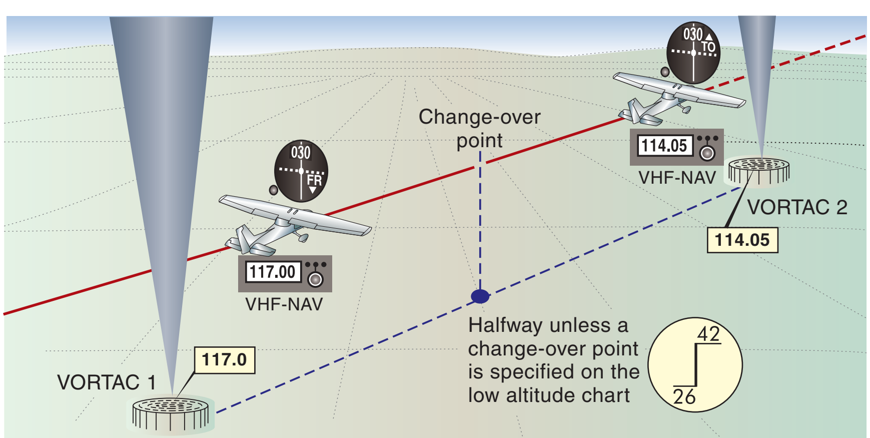


Figure 17-11 Tracking between two VORs.

VORs on Aeronautical Charts

Most aeronautical charts show the position, frequency and Morse code *ident* of each VOR ground station. Information on a particular VOR may be found in the A/FD, and any changes in this information will be referred to in NOTAMs (to which a pilot should refer prior to flight). You should take time to read the Directory Legend at the front of the A/FD regarding Radio Aids to Navigation.

A VOR ground station may be represented in various ways on a chart, the common forms are shown in figure 17-12. Since magnetic north is the reference direction for VOR radials, a magnetic north arrowhead usually emanates from the VOR symbol, with a compass rose heavily marked each 30° and the radials shown in 10° intervals. This is generally adequate for in-flight estimation of an off-airway course to an accuracy of ±2°, however, when flight planning prior to flight, it is advisable to be more accurate than ±2°.

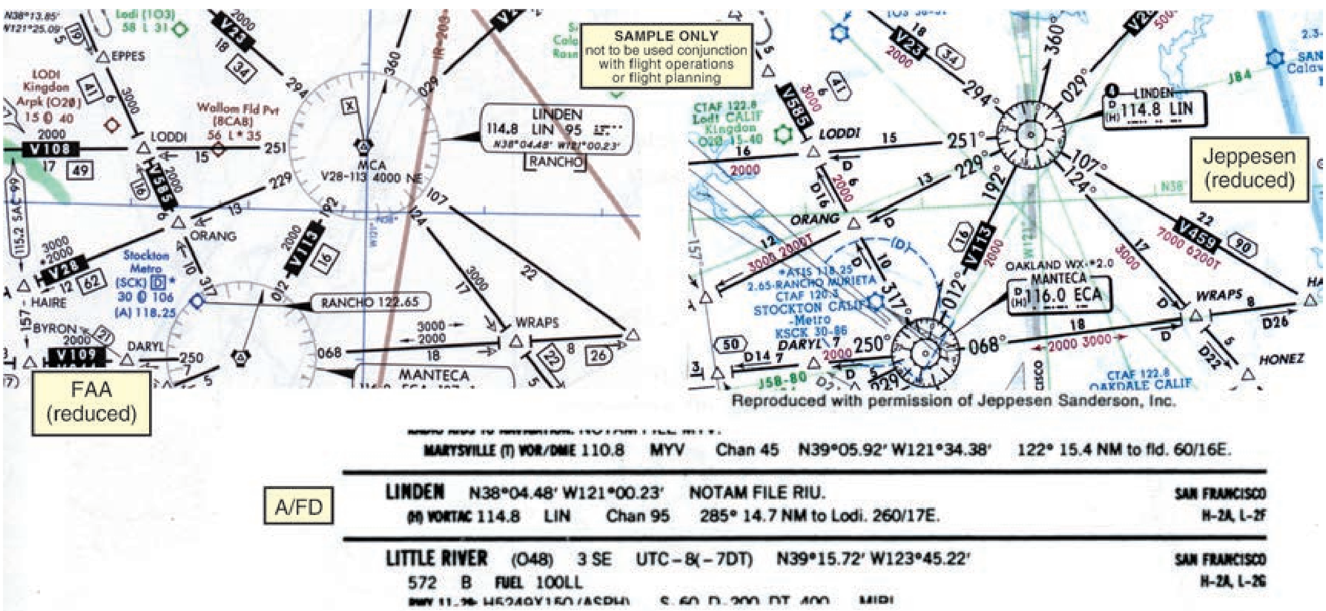


Figure 17-12 A VOR and its radials represented on various charts, and in the A/FD.

Most routes are published on the en route charts as airways, with the courses marked in degrees *magnetic*, thereby making it easy for the pilot to plan without having to use a protractor or plotter. If, for some reason, the pilot measures the course in true using a protractor, then variation needs to be applied to convert to magnetic ("Variation west, magnetic best" or "East is least, west is best").

The *Victor airways* between VORs shown on the low-altitude en route charts are marked at either end with the radial out of that VOR. These radials are not always exact reciprocals of each other, especially on east-west tracks, because:

- great circles (which the airways are) cross the north-south meridians of longitude at different angles; and
- magnetic variation (also called declination) changes slightly across the country (and this affects the calculation of the magnetic course, which a radial is, from the true course).

There are two sets of en route charts available—those published by *Jeppesen*, and those published by the FAA's National Aeronautical Charting Office (NACO).

VOR/DME, TACAN and VORTAC

Most civil VORs have an associated DME, providing both azimuth and distance information, and are known as VOR/DMEs. The VOR operates in the VHF range, but the DME, even though automatically selected along with the VOR selection, operates in the UHF range. The military has developed a different navigation system, called TACAN (Tactical Air Navigation system), which operates in the UHF band, and also provides both azimuth and distance information. It requires special airborne equipment (installed only in military aircraft) for the azimuth information to be received, however civil aircraft can receive the TACAN distance information using the DME. When a TACAN ground station has been integrated with a VOR/DME ground station, the combined facility is known as a VORTAC. The end result for a civil pilot using a VORTAC is the same as using a VOR/DME—both VOR and DME information are available.

On Jeppesen en route charts, a small letter D in the VOR box indicates that DME is also available when the VOR frequency is selected. On FAA en route charts, a (channel) number after the NAVAID three-letter ident (SEA 115 at Seattle), indicates DME is automatically available when the VOR frequency is selected. Underlined NAVAID frequencies on FAA charts means no voice is transmitted.

The VOR Cockpit Instrument

There are various types of VOR cockpit displays, however they are all reasonably similar in terms of operation. The VOR cockpit display, or VOR indicator, or omni bearing indicator (OBI), displays the omni bearing selected by the pilot on the course card using the *omni bearing selector* (OBS), a small knob that is geared to the card. The omni bearing selector is also known as the course selector.

The CDI indicates angular deviation from the selected course.

Each "dot" on the CDI equals 2 degrees course deviation.

A full-scale deflection of the VOR at 5 dots indicates a course deviation of 10 degrees or more.

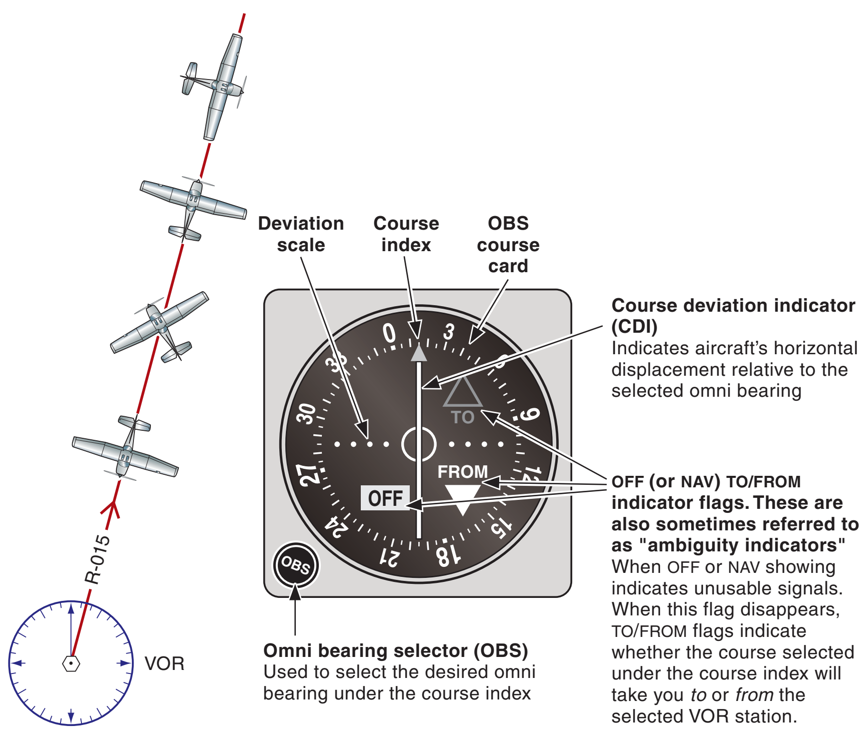


Figure 17-13 The VOR cockpit display (OBI) for airplanes on the 015 radial.

If the airplane is on the selected radial, then the VOR needle, known as the *course deviation indicator* (CDI), is centered. If the airplane is not on the selected course, then the CDI will not be centered.

Whether the selected course would take the airplane *to* or *from* the VOR ground station is indicated by the TO/FROM flag, removing any ambiguity.

The VOR is only to be used for navigation if:

- the red OFF warning flag is hidden from view;
- the correct Morse code or voice *ident* is heard; and
- the CDI is not moving erratically.

The red OFF flag showing indicates that the signal strength received is not adequate to operate the airborne VOR equipment, which may be the case if the airplane is too far from the VOR ground facility, too low for line-of-sight reception, or directly overhead where there is no signal. Also, it will show OFF if the equipment is switched off.

Course Deviation

Deviation "dots" on the CDI match up with the 1-in-60 rule: 1 NM off-course in 60 NM = 1° course error, therefore 2° NM off-course in 60 NM = 2° course error, or 1 dot on the VOR.

The course deviation indicator (or CDI) in the VOR cockpit instrument indicates off-course deviation in terms of angular deviation from the selected course. At all times, the reference when using the VOR is the selected course under the course index. (This is a totally different principle to that of the ADF needle which simply points at an NDB ground station and indicates its relative bearing.)

The amount of angular deviation from the selected course is referred to in terms of dots, there being 5 dots either side of the central position. The inner dot on both sides is often represented by a circle passing through them. Each dot is equivalent to 2 degrees course deviation.

- If the airplane is on the selected course, the CDI is centered.
- If the airplane is 2° off the selected course, the CDI is displaced 1 dot from the center (on the circumference of the inner circle).
- If the airplane is 4° off the selected course, the CDI is displaced 2 dots.
- If the airplane is 10° or more off the selected course, the CDI is fully deflected at 5 dots.

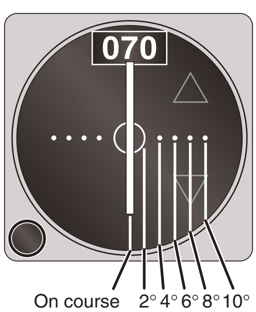


Figure 17-14 Course deviation in 2° increments.

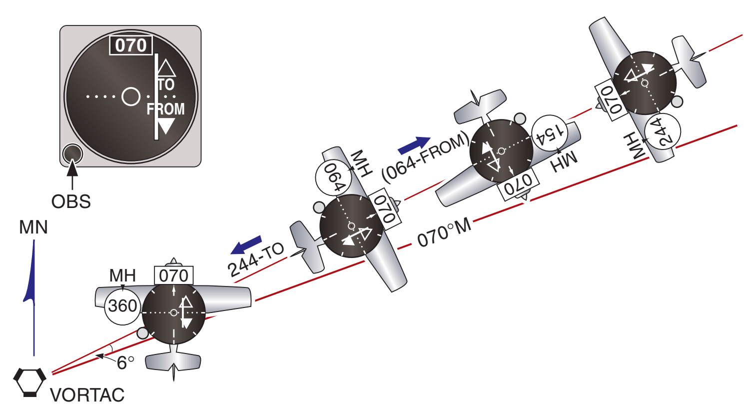


Figure 17-15 Each of these airplanes is displaced 6° from the 070 radial.

Since the CDI indicates angular deviation, the actual distance off-course for a given CDI indication will be smaller the closer the airplane is to the ground station. In a manner of speaking, airplanes tracking inbound are funneled in toward the VOR ground station.

At 1 NM distance from the VOR ground facility, a one-dot deviation from the selected course is a lateral deviation of approximately 200 feet, so:

- at 1 NM, one dot on the VOR indicator = 200 feet laterally;
- at 2 NM, one dot on the VOR indicator = 2 × 200 = 400 feet;
- at 30 NM, one dot on the VOR indicator = 30 × 200 = 6,000 feet = 1 NM;
- at 60 NM, one dot on the VOR indicator = 60 × 200 = 12,000 feet = 2 NM.

The CDI position will not change as the airplane changes heading only as it changes position relative to the selected course.

TO or FROM

The 090 radial, which is a magnetic bearing of 090 away *from* the station, is the same position line as 270 to the station. If an airplane is on this position line, then the CDI will be centered when either 090 or 270 is selected with the OBS. Any ambiguity in the pilot's mind regarding the position of the airplane relative to the VOR ground station is resolved with the TO/FROM indicator.

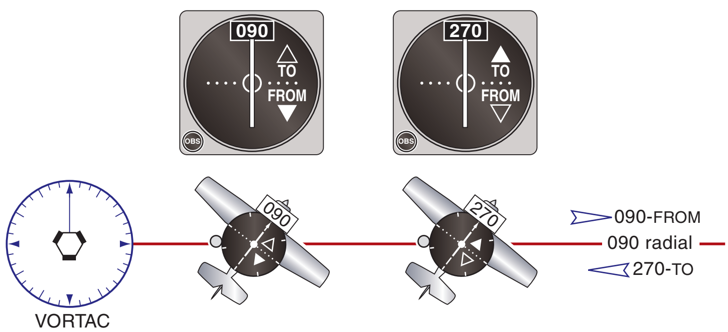


Figure 17-16 Using the TO/FROM flag.

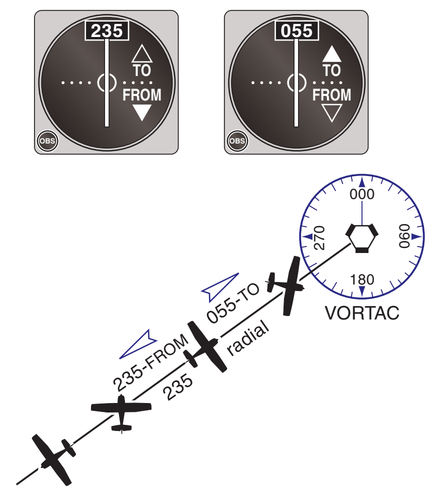


Figure 17-17
Indications that the airplane is on the 235 radial.

The TO or FROM flags or arrows indicate to the pilot whether the selected omni bearing will take the airplane *to* the VOR ground station, or away *from* it. In the case shown in figure 17-16, the pilot can center the CDI by selecting either 090 or 270 (which are reciprocals) with the OBS. A course of 090 would take the airplane *from* the VOR, whereas a course of 270 would lead it *to* the VOR.

Note. In this manual, the active direction is indicated by the white arrow, triangle.

Example 17-2

Figure 17-17 illustrates two indications on the VOR cockpit display informing the pilot that the airplane is on the 235 radial. The 235 radial is either:

- 235-FROM the VOR; or
- 055-TO the VOR.

So, with the CDI centered, the VOR cockpit display could indicate either 235-FROM or 055-TO.

At all times, the reference when using the VOR indicator is the course selected under the course index. The selected course determines CDI deflection and whether the TO or the FROM flag shows.

The VOR Display Is Not Heading Sensitive

The VOR indicates the position of the airplane with respect to the selected VOR course, and the actual VOR display in the cockpit will be the same regardless of the airplane's heading. If the airplane could turn in a circle on-the-spot, the VOR indications would remain the same, and the CDI would not move. Each of the airplanes in figure 17-18 will have the same VOR display, provided the same course is set under the course index with the OBS.

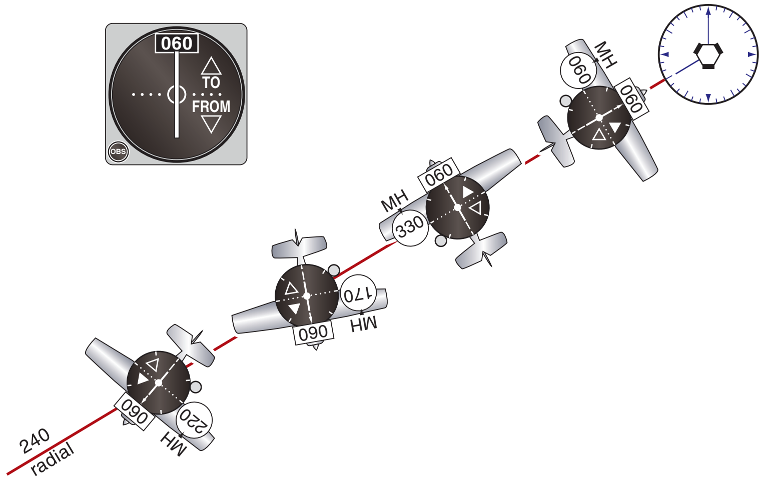


Figure 17-18 The VOR cockpit display is not heading sensitive.

Different Presentations of the Omni Bearing Indicator

There are various presentations of VOR cockpit information. In all cases, full-scale deflection is 10° either side of the selected omni bearing (a total arc of 20°), with five dots either side of center. In many VOR cockpit displays the two inner dots are joined by the circumference of a circle. The dots may be actual dots on some indicators, or they may be tick marks or hash marks.

The course deviation indicator (CDI) may also differ between instruments. On some displays, the whole CDI moves laterally (rectilinear movement); on others, the CDI hinges at the top and swings. Similarly, the means of displaying the selected omni bearing may differ between instruments. It may be shown under a course index, or it may be shown in a window. In some equipment, the TO and the FROM flags may be displayed in the one window, in others they may have separate windows.

In instruments where the VOR cockpit display also doubles as the ILS (instrument landing system) display, which is the usual case, vertical dots may be marked to indicate glide slope deviation (using a second needle which lies horizontal, or is hinged horizontally, so that it can move up or down). When being used for the VOR (and not the ILS), the glide slope needle may be biased out of view, and there may be a red GS warning flag showing.

Preparing the OBI for Use

Prior to using the VOR, a pilot must:

- ensure that the VOR has been checked as suitable for IFR flight (see The VOR Receiver Check below);
- ensure electrical power is available, and switch the NAV/COM on;
- select the desired frequency (as found on the en route charts or in the A/FD);
- identify the VOR (the coded identifier is specified on the charts); and
- check that the OFF flag is not showing (the signal is usable, otherwise the OFF flag would be visible).

The VOR Receiver Check

It is required that, for a pilot to use the VOR for IFR flight, the VOR equipment of that aircraft either:

- is maintained, checked and inspected under an approved procedure; or
- has been operationally checked within the preceding 30 days as specified below, and is within the limits of the permissible indicated bearing error.

Figure 17-19 Logbook with VOR check.

There are five ways in which the VOR receiver may be checked for accuracy prior to IFR flight. The regulations require this check to be logged or for there to be other records, but this doesn't necessarily need to be carried in the airplane.

1. VOT

FAA VOR test facility, or a radiated test signal from an appropriately rated radio repair station (usually on 108.0 MHz). These are test signals which allow the VOR to be tested for accuracy on the ground. To use the VOT service:

a. Tune the VOT frequency (found in the Airport/Facility Directory or on the A/G Communications panel of the Enroute Low Altitude Chart). The VOT radiates the 360 radial (360-FROM) in all directions.

b. Center the CDI by turning the OBS; the omni bearing indicator (OBI) should read 360-FROM or 180-TO, with an acceptable accuracy of ±4° (356-FROM to 004-FROM, or 176-TO to 184-TO is acceptable). Should the VOR operate an RMI, its needle should point to 180°±4° with any OBI setting, between 176° and 184° is acceptable.

2. FAA Certified Ground Checkpoint

(Specified in the A/FD). This is a certified radial that should be received at specific points on the airport surface.

a. Position the airplane on the ground checkpoint at the airport.

b. Tune the VOR and select the designated radial with the OBS. The CDI must be within ±4° of the radial, with the FROM flag showing (since it is a radial), for the accuracy of the VOR receiver to be acceptable.

3. FAA Certified Airborne Checkpoint

(Specified in the A/FD). This is a certified radial that should be received over specific landmarks while airborne in the immediate vicinity of the airport.

a. Tune the VOR and select the designated radial with the OBS.

b. Visually position the airplane over the landmark, and center the CDI with the OBS. The course reading on the OBI must be within ±6° of the designated radial for the accuracy of the VOR receiver to be acceptable.

4. Dual System VOR Check

If a dual system VOR (units independent of each other except for the antenna) is installed in the aircraft, one system may be checked against the other.

a. Tune both systems to the same VOR ground facility and center the CDI on each indicator using the OBS.

b. The maximum permissible variation between the two indicated bearings is 4°, and this applies to tests carried out both on the ground and in the air.

5. Course Sensitivity Check

This is not a required check.

a. Center the CDI and note the indicated bearing.

b. Turn the OBS until the CDI lies over the last (5th) dot which, ideally, indicates a bearing difference of 10°. Between 10° and 12° is acceptable sensitivity.

Orientation Using the VOR

Orientation

Using the VOR to Obtain a Position Line

Orientation means "to determine an airplane's approximate position." The first step in orientation is to establish a position line along which the airplane is known to be at a particular moment.

To obtain a position line using the VOR:

- rotate the OBS (omni bearing selector) until the CDI (course deviation indicator) is centered; and
- note whether the TO or FROM flag is showing.

Example 17-3

A pilot rotates the OBS until the CDI is centered, which occurs with 334 under the course index and the TO flag showing. Illustrate the situation. Could another reading be obtained with the CDI centered?

In this location, the CDI will be centered with either 334-TO or 154-FROM.

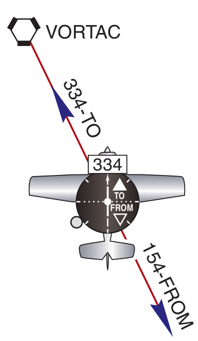


Figure 17-20 Example 17-3: on the 154 radial.

Using Two Position Lines to Fix Position

One position line alone does not allow a pilot to positively fix the position of the airplane; it only provides a line somewhere along which the airplane lies. It requires two or more position lines to positively fix the position of an airplane.

To be of any real value for position fixing, the two position lines need to cut, or intersect, at an angle of at least 45°; any cut less than this decreases the accuracy of the fix. Position lines can be provided by any convenient NAVAIDs, including VORs, NDBs and DMEs. Positions defined on charts by this means are known as *intersections.*

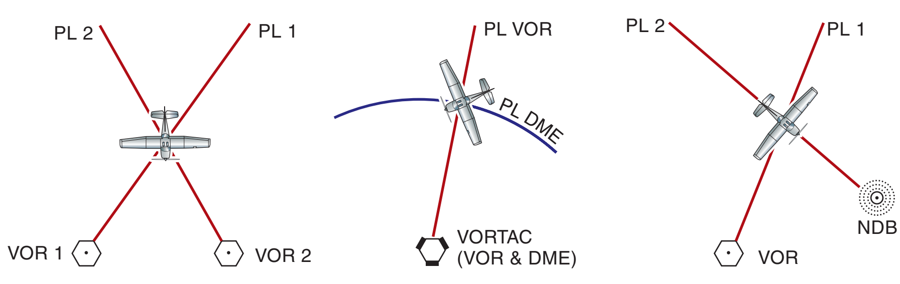


Figure 17-21 Fixing position requires two position lines with a good intersection.

Fixing Position Using Two VORs

Most IFR airplanes are fitted with two independent NAV/COM systems, enabling two different VORs to be tuned at the same time. Two position lines from two different VOR ground stations can then be obtained simultaneously. In an airplane with only one NAV/COM set, a pilot can, if he or she so desires, obtain two position lines using the one NAV/COM by retuning it from one VOR to another—a bit tedious, and an increased workload, but still satisfactory.

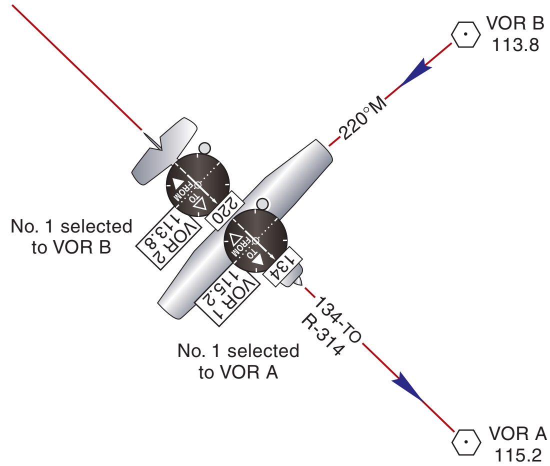


Figure 17-22 Fixing position using two VORs.

Example 17-4

An airplane fitted with two NAV/COMs is tracking MC 134-TO to VOR-A. The pilot obtains these indications:

- *VOR 1:* VOR-A 115.2 is selected, the *tracking* VOR, and the CDI centers with 134-TO.
- *VOR 2:* VOR-B 113.8 is selected, the *crossing* VOR, and the CDI centers with 220-FROM.

The two VOR position lines intersect at a good angle, and the pilot has a fairly positive indication of where the airplane is. The pilot has a VOR/VOR *fix*. Often an intersection of two radials from two VORs is used to define a position on the route, and such a position is known as an intersection. These intersections are clearly marked on the en route charts by triangles, with a five-letter name such as CISSI, GLADD, MUSKS, RADEX and ADOBE.

Fixing Position Using a VOR and a DME

A common form of en route position fixing between aids is the VOR/DME fix, based on a ground station where the DME (distance measuring equipment) is co-located with the VOR ground station. This is also the case with a VORTAC.

The VOR can provide a straight position line showing the radial that the airplane is on (CDI centered), and the DME can provide a circular position line showing the distance that the airplane is from the ground station. The intersection of the lines is the position of the airplane.

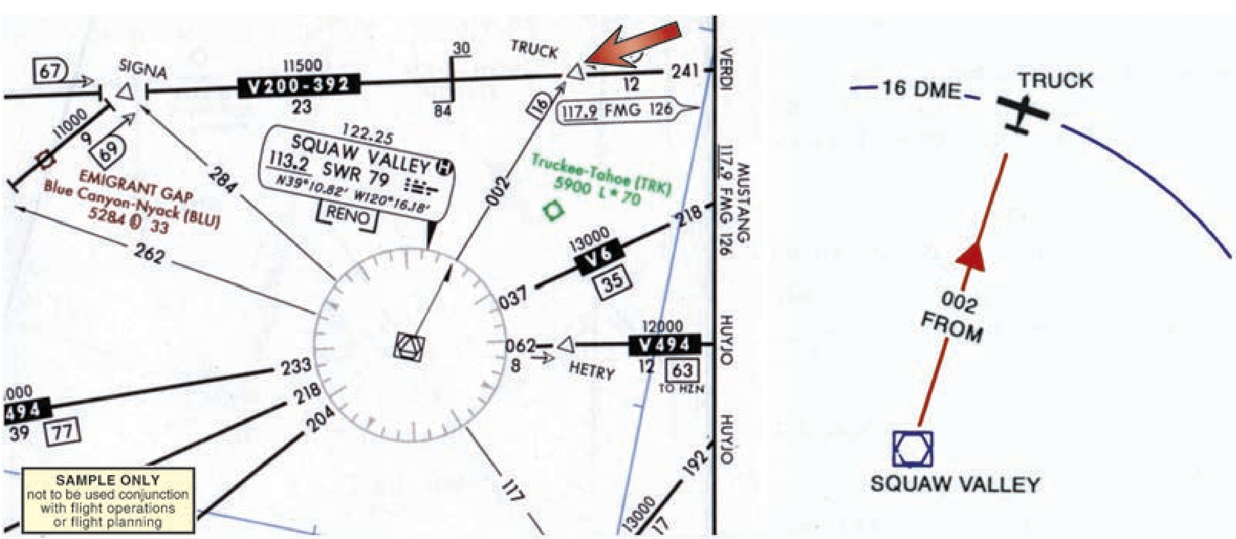


Figure 17-23 Fixing position at TRUCK using a co-located VOR and DME.

Example 17-5

An airplane tracking north from Squaw Valley (SWR 113.2) has the cockpit indications of SWR VOR 002-FROM, and SWR DME 16 NM. Where is the airplane?

As the en route chart extract in figure 17-23 shows, the airplane is at the TRUCK position, an in-flight position determined purely by NAVAIDs.

Fixing Position Over a VOR

As an airplane approaches a VOR, the CDI will become more and more sensitive as the ±10° funnel either side of course becomes narrower and narrower.

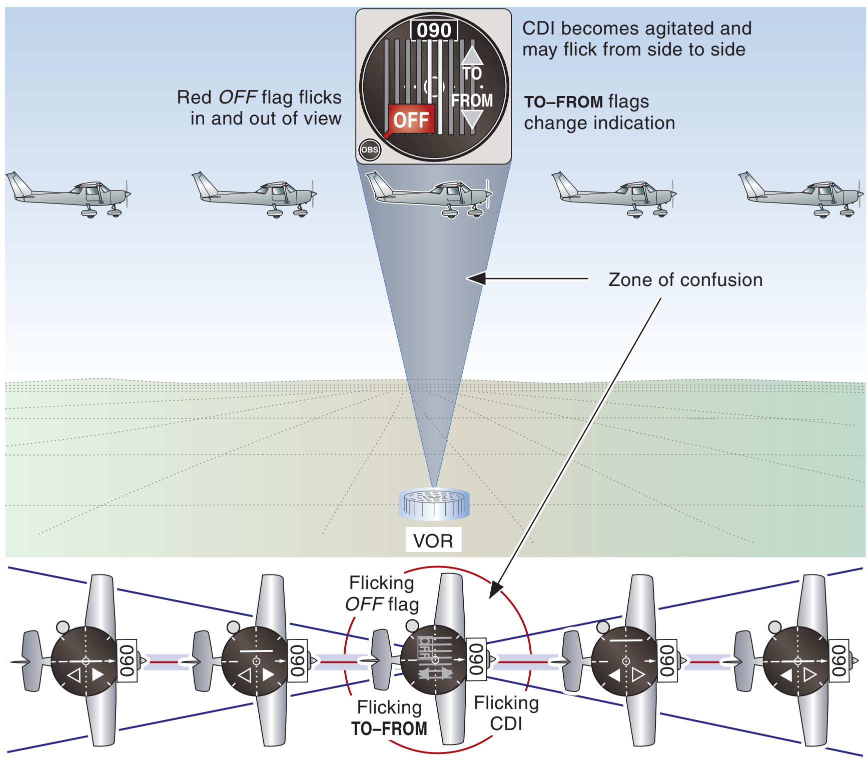


Figure 17-24 Fixing position over a VOR.

As the airplane passes through the *zone of confusion* over the VOR ground station, the CDI may flick from side to side, before settling down again as the airplane moves away from the VOR. The flag will also change from TO to FROM (or vice versa), and the red OFF flag may flicker in and out of view because of the unusable signal. The zone of confusion can extend in an arc of 70° over the station, so it may take a minute or so for the airplane to pass through it before the CDI and the FROM flag settle down, and the OFF flag totally disappears.

VOR *station passage* is indicated by the first positive complete reversal of the TO/FROM flag.

Fixing Position Passing Abeam a VOR

A common means of checking flight progress is to note the time passing *abeam* (to one side of) a nearby VOR ground station. The most straightforward procedure is to:

- select and identify the VOR; and
- under the course index, set the radial perpendicular (at 90°) to your course.

Example 17-6

An airplane is tracking MC 350, and will pass approximately 20 nautical miles abeam a VOR ground station out to its right. The VOR radial perpendicular to course is the 260 radial, and so 260 should be set with the OBS.

The CDI will be fully deflected to one side if the airplane is well away from the abeam position, and will gradually move from full deflection one side to full deflection on the other side as the airplane passes through the ±10° arc either side of the selected radial. The airplane is at the abeam position when the CDI is centered.

It is suggested that you set the radial (the bearing *from*) the off-course VOR on the OBI, in which case the CDI will be on the same side as the VOR until you have passed the radial. In figure 17-25, the VOR is off-course to the right, and before passing abeam the ground station, the CDI will be out to the right. It will center to indicate the abeam position, and then move to the other side.

The abeam position can also be identified by setting the bearing *to* the VOR under the course index (rather than radial *from* the VOR), in which case the movement of the CDI will be from the opposite side. It is better practice to standardize on one method, and we suggest setting the radial *from*.

The 1-in-60 rule, frequently used in navigation, states that 1 NM off-course in 60 NM subtends an angle of 1°. In rough terms, this means that the airplane, as it flies at right angles through the 10° from when the CDI first starts to move to when it is centered, will travel approximately 10 NM abeam the VOR when it is located 60 DME from the VOR ground station (or 5 NM at 30 DME). At say GS 120 knots (2 NM/minute), passing through a 10° arc abeam the VOR will take 5 minutes at 60 DME, or 2.5 minutes at 30 DME.

In a no-wind situation, you can estimate the time it would take to fly directly to the station by measuring the time for a bearing change as you fly abeam the station, and using the simple expression:

$$\text{Minutes to the station} = \frac{\text{seconds between bearings}}{\text{degrees of bearing change}}$$

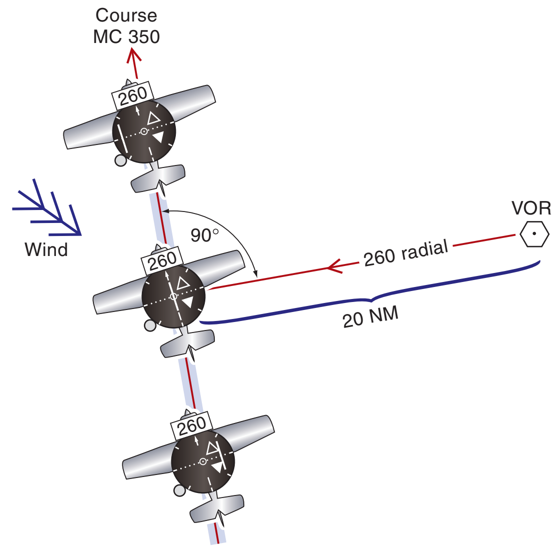


Figure 17-25 Passing abeam a VOR.

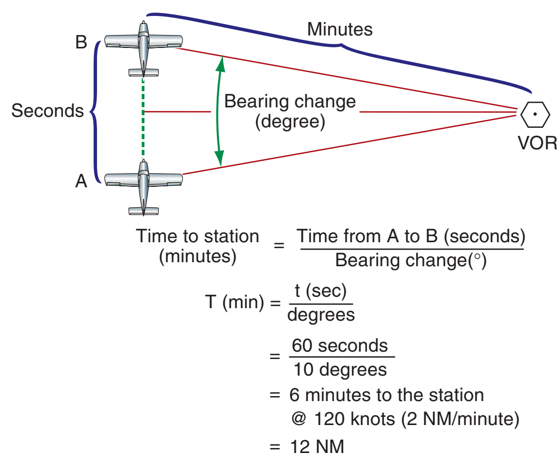


Figure 17-26 Principle of bearing change triangle.

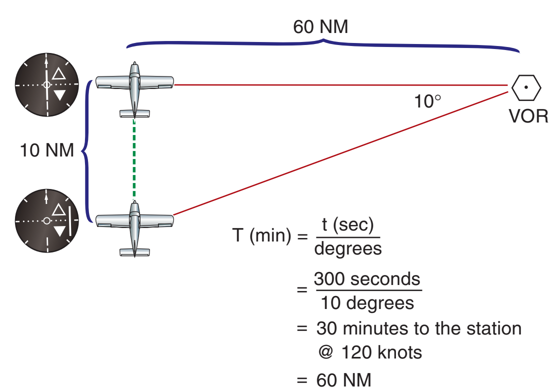


Figure 17-27 Sample calculation.

Example 17-7

A 10° bearing change abeam a VOR takes 5 minutes. By turning and flying direct to the VOR, the time required to reach the station is:

$$\text{Minutes to VOR} = \frac{300 \text{ seconds}}{10°} = 30 \text{ minutes}$$

At a groundspeed of 120 knots (2 NM/minute), this would mean that you are: $2 \times 30 = 60$ NM from the station.

Crossing a Known Radial from an Off-Course VOR

It is a simple procedure to identify passing a known radial from an off-course VOR and, indeed, many intersections are based on this.

Example 17-8

(Refer to figure 17-28.) LODDI intersection en route on Victor airway V-108 west of Linden VORTAC on the Linden 251 radial, intersecting with the 317 radial of the Manteca VORTAC.

In an airplane fitted with two NAV/COMs, it would be normal procedure to track using NAV-1 on Linden, and check LODDI intersection with NAV-2 on Manteca. Selecting the radial on NAV-2 (rather than the bearing *to* the VOR), the CDI will be deflected to the same side of the NAV indicator as the VOR ground station until the airplane passes the radial.

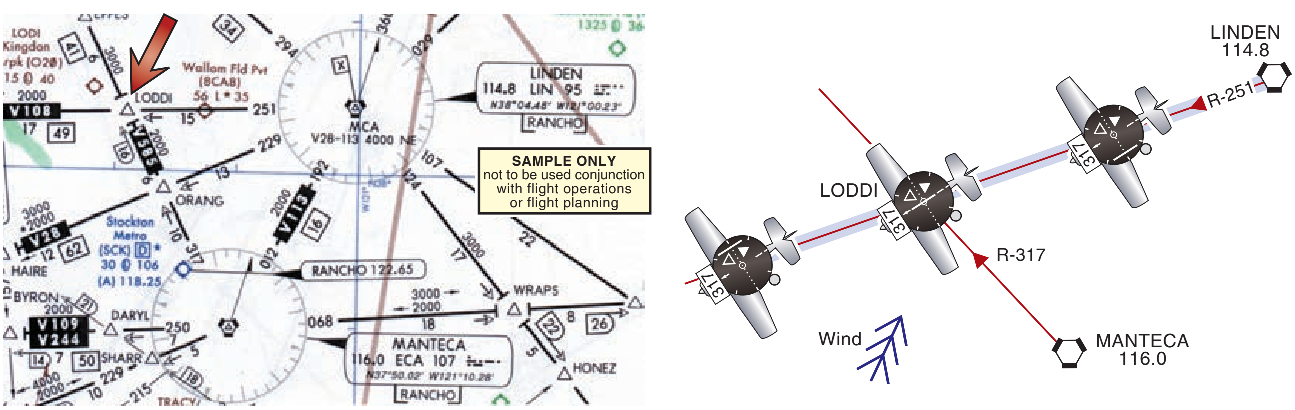


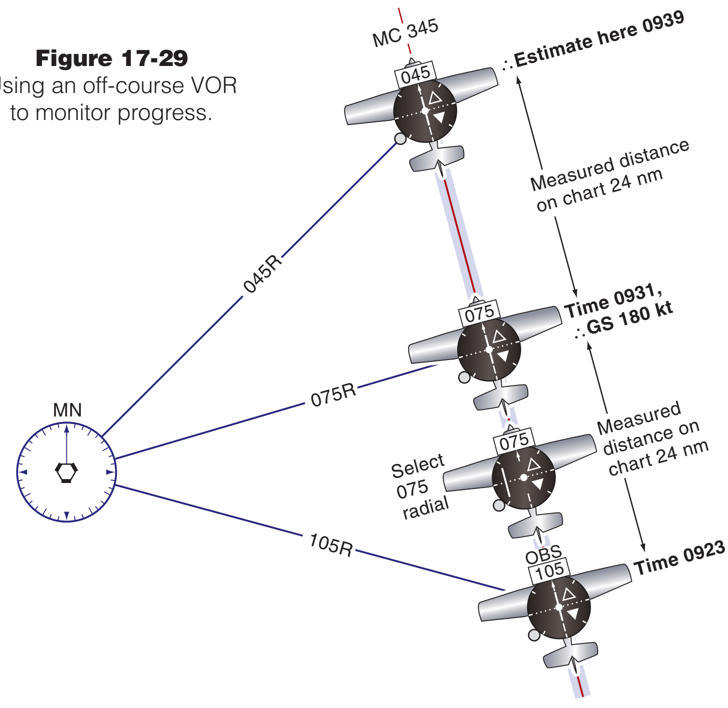
Figure 17-28 Crossing a known radial.

With only one NAV/COM, normal procedure would be to leave it on the main tracking aid (Linden) until almost at LODDI intersection (say 3 minutes before ETA), and then select MANTECA VORTAC and the 317 radial. Having identified the LODDI intersection (on crossing this radial), the NAV/COM can then be re-selected to the tracking aid (Linden and later the aid ahead).

If a 1:500,000 Sectional chart is being used (rather than an IFR en route chart), you can construct your own checkpoints along the planned course using nearby off-course VORs.

In figure 17-29, the pilot has chosen to check position crossing the 105, 075 and 045 radials from an *off-course* VOR. By measuring the distance between these planned fixes en route and noting the time of reaching them, the pilot can calculate the groundspeed and revise estimates for positions further along the planned course.

Figure 17-29
Using an off-course VOR to monitor progress.



Orientation Without Altering the OBI

It is possible, without altering the omni bearing selector, to determine which quadrant the airplane is in with respect to the selected course.

In figure 17-31, the selected omni bearing is 340.

- The CDI is deflected left, which indicates that, when looking in direction 340, the airplane is out to the right (of the line 340–160); and
- The FROM flag indicates that tracking 340 would take the airplane from the VOR ground station. The airplane is ahead of the line 250–070 when looking in the direction 340.

This puts the airplane in the quadrant:

- away from the CDI; and
- away from the TO/FROM flag.

So it is between the 340 and 070 radials (omni bearings from the VOR ground station). See figure 17-30.

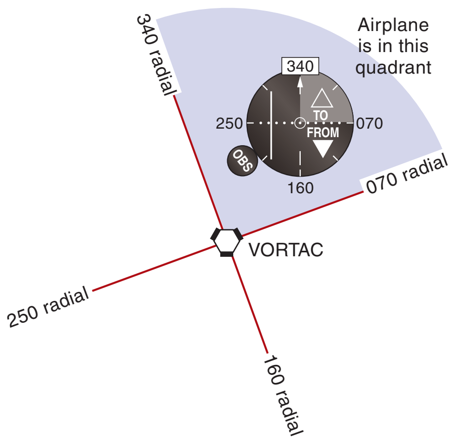


Figure 17-30
The airplane is in the quadrant away from the CDI and TO/FROM flag.

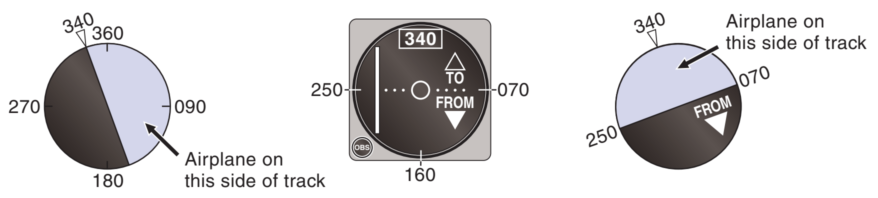


Figure 17-31 Using the CDI and the TO/FROM flag for orientation without moving the omni bearing selector.

Note. Remember, no information is available from the VOR cockpit display regarding airplane heading. Heading information in degrees magnetic must be obtained from the heading indicator.

Example 17-9

With 085 under the course index, the VOR indicator shows CDI deflected right with the TO flag showing. Position the airplane with respect to the VOR. This method is just a quick means of determining the approximate position of the airplane with respect to the VOR ground station.

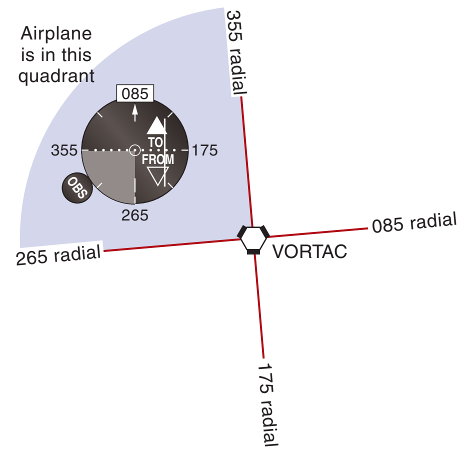


Figure 17-32
The airplane is between the 355 and 265 radials.

Tracking Using the VOR

Tracking to a VOR

To track to a VOR:
- *select* the VOR frequency;
- *identify* the station (Morse code ident as shown on the chart, or voice ident with VOR stated after the name);
- *check* that the red OFF warning flag is not displayed; and
- *select* the omni bearing of the desired course with the OBS.

Orient the airplane with respect to the desired course, and then take up a suitable *intercept heading* using the heading indicator (aligned with the magnetic compass). If the airplane is heading approximately in the direction of the desired course, the center circle will represent the airplane, and the CDI the desired course; to intercept course in this case, the pilot would turn toward the CDI.

This is using the VOR indicator as a *command instrument,* commanding the pilot to turn toward the CDI to regain course. Be aware, however, that this only applies when the airplane's heading is in roughly the same direction as the selected omni bearing.

On intercepting the course, the pilot should steer a reasonable heading to maintain the course, allowing a suitable wind correction angle to counter any wind effect. Remaining on course is indicated by the CDI remaining centered.

Example 17-10

In figure 17-33, with the desired course 030 set under the course index, the CDI is out to the right.

Since the airplane's initial heading agrees approximately with the course of 030, the pilot concludes that the course is out to the right of the airplane. The CDI out to the right commands the pilot to turn right to regain track and center the CDI.

The pilot has taken up a heading of MH 050 to intercept a course of 030-TO the VOR, which will give the pilot a 20° intercept. This shallow intercept is satisfactory if the airplane is close to the course.

If the airplane is well away from the course, then a 60° or 90° intercept might be more appropriate. This would be MH 090 or MH 120.

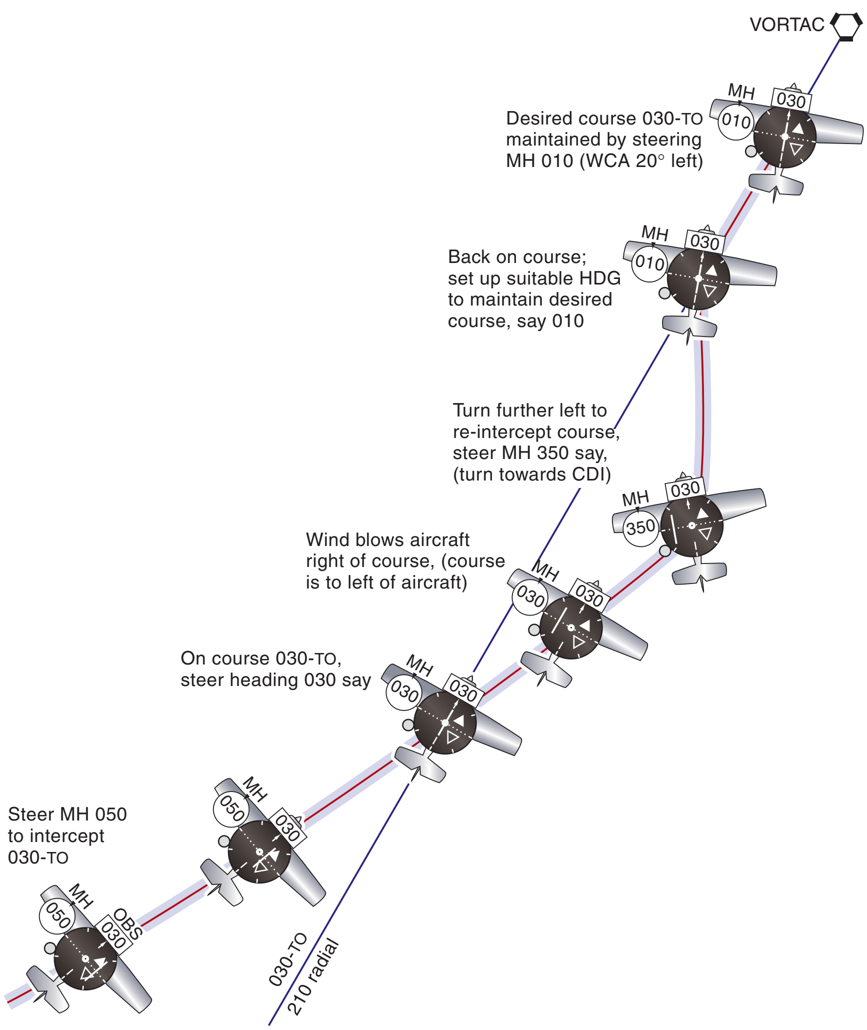


Figure 17-33 Using the CDI as a command instrument (by following its commands).

Determining Wind Correction Angle when Tracking on the VOR

When tracking inbound on 360-TO a VOR with 360 set under the course index, MH 360 will allow the airplane to maintain course provided there is no crosswind component. If, however, there is a westerly wind blowing, then the airplane will be blown to the right of course unless a wind correction angle (WCA) is applied and the airplane steered on a heading slightly into wind. This is MH 352 in figure 17-35.

If, on the other hand, there is an easterly wind blowing, the airplane will be blown left of course, unless a wind correction angle is applied and the airplane steered on a heading slightly into wind, such as MH 005 in figure 17-35.

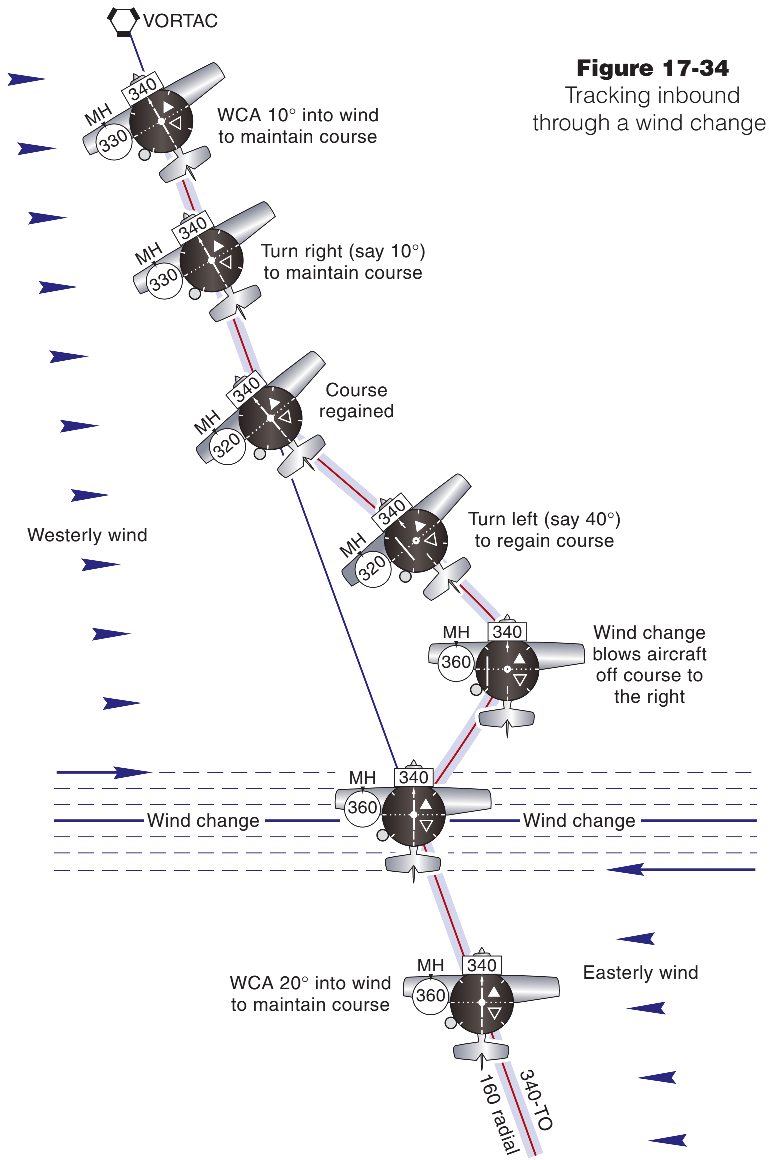


Figure 17-34
Tracking inbound
through a wind change.

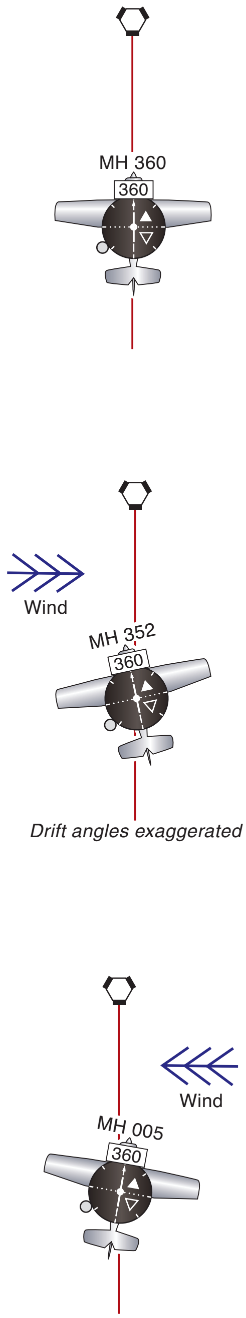


Figure 17-35
Tracking inbound and
allowing for drift.

Just how great the WCA needs to be is determined in flight by trial and error (preflight calculations using the flight computer may suggest a starting figure for WCA). If the chosen WCA is not correct, and the airplane gradually departs from course causing the CDI to move from its central position, the heading should be altered to regain the course (CDI centered) and a new magnetic heading flown with an improved estimate of WCA. This process of achieving a suitable WCA by trial and error is known as *bracketing*.

In the real world the wind frequently changes in both strength and direction, and so the magnetic heading required to maintain course will also change from time to time. This becomes obvious by gradual movements of the CDI away from its central position, which the pilot will notice in regular scan of the navigation instruments, and which the pilot will correct by changes in magnetic heading using the heading indicator.

Tracking From a VOR

To track *from* a VOR (assuming the VOR has not already been selected and identified):

- *select* the VOR frequency;
- *identify* the station (Morse code ident or voice ident);
- *check* that the red OFF warning flag is not displayed; and
- select the *omni bearing* of the desired course with the OBS.

Orient the airplane with respect to the course, and then take up a suitable intercept heading using the heading indicator (aligned with the magnetic compass). If the airplane is heading approximately in the direction of the course, the center circle will represent the airplane, and the CDI will represent the course.

To intercept course in this case, the pilot would turn toward the CDI. This is using the CDI as a command instrument, commanding the pilot to turn toward the CDI to regain course. Be aware, however, that this only applies when the heading is roughly in the same direction as the selected omni bearing. On intercepting course, the pilot steers a suitable heading to maintain it, keeping in mind the wind direction and strength. If the course is maintained, the CDI will remain centered.

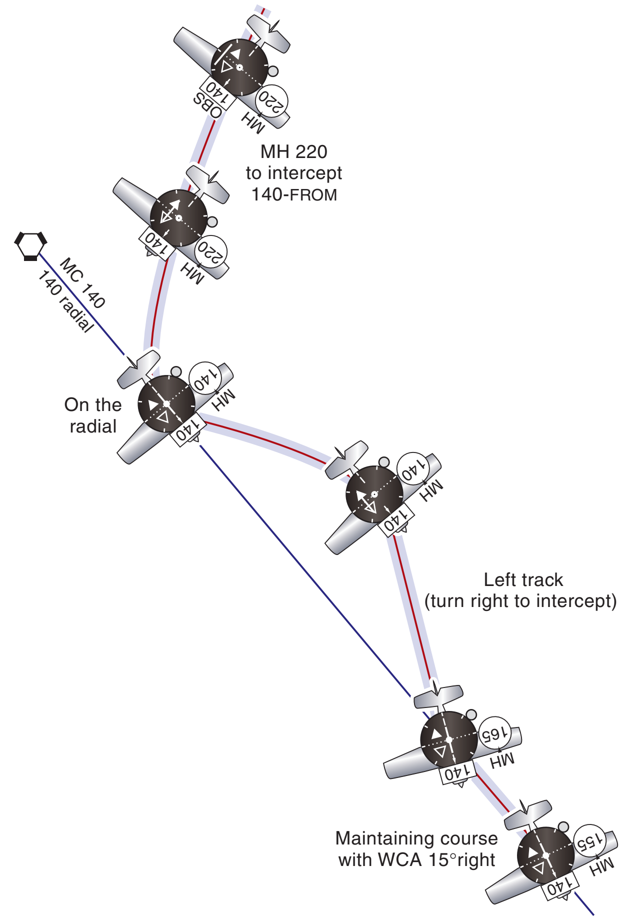


Figure 17-36
Using the CDI as a command instrument (example 17-11).

Example 17-11

In figure 17-36, with the course 140 set with the omni bearing selector (OBS), the CDI is out to the right. Since the airplane's initial heading agrees approximately with the course of 140, the pilot concludes that the course is out to the right of the airplane (or, in this case, straight ahead and to the right).

The pilot steers MH 220 to intercept a course of 140-FROM the VOR, which will give an 80° intercept. This is satisfactory if the airplane is well away from the course. If the airplane is close to course, then a 60° or 30° intercept might be more suitable which, in this case, would be MH 200 or MH 170.

Using the CDI as a Command Instrument

With the course set on the OBI, and the airplane headed at least roughly in the same direction as the selected course, the CDI will act as a command instrument. By flying toward the deflected CDI, the pilot can center it, and thereby regain course.

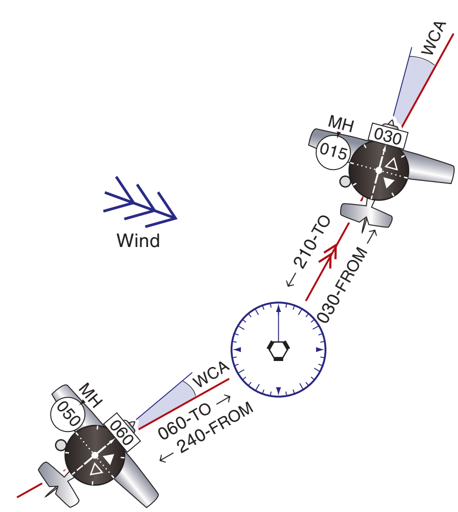


Figure 17-37
Use the CDI as a command instrument.

For example:

- tracking 060-TO the VOR, set 060 under the course index;
- tracking 030-FROM the VOR, set 030 under the course index.

A minor complication arises when the airplane is steered on a heading approximating the reciprocal of the course selected on the OBI. Under these circumstances, the CDI is *not* a command instrument. This situation is called *reverse sensing.*

Example 17-12

Suppose a pilot has been tracking 140-FROM a VOR, with 140 selected on the OBI and by steering MH 140. The airplane has drifted left of course, and so the CDI will be deflected to the right of center. Examine figure 17-38—to regain the 140-FROM course, the pilot must turn toward the needle, in this case to the right. Heading and OBI selection are similar, so it is used as a command instrument.

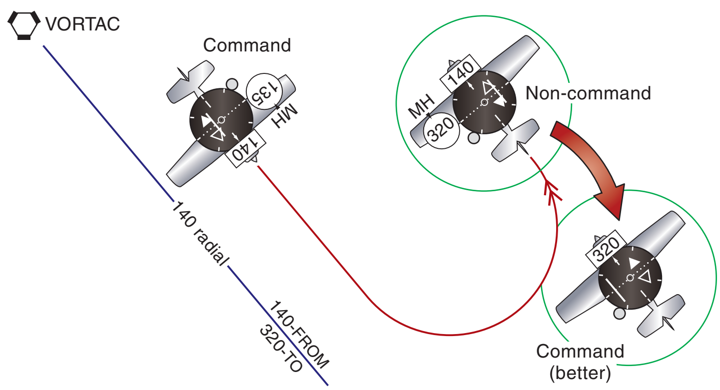


Figure 17-38
For ease of operation, use the CDI as a command instrument.

Suppose now that the pilot wants to return to the VOR ground station on the reciprocal course, which is 320-TO the VOR, and so turns through approximately 180° to MH 320 without altering the 140 set under the course index. The VOR indicator, because it is not heading sensitive, indicates exactly as it did before the turn, with the CDI out to the right of center.

To regain course on this reciprocal heading, the pilot would turn, not toward the CDI, but away from it. Turning toward the CDI on this reciprocal heading to the selected course would take the pilot further away from the selected course and the VOR is no longer a command instrument. This inconvenience can be easily removed, and the OBI returned to being a command instrument, by setting the new course under the course index of MC 320, which approximates the heading being flown. The immediate effect will be for the TO flag to appear, replacing the FROM flag, and the CDI to swing across to the other side. The CDI will now be out to the left, and a turn toward it will bring the airplane back toward the selected course. The VOR indicator is once again a command instrument, easier to understand, and easier to fly.

To keep the VOR indicator as a command instrument when flying on a VOR (so that the pilot can regain course by flying toward the CDI), set the OBI to the course to be flown. A good example of this is a procedure turn (teardrop) that is used in some instrument approaches to reverse direction:

- outbound on 160-FROM, where the pilot should set 160 with the OBS; and
- inbound on 325-TO, where the pilot should set 325 with the OBS.

The 15° between the 2 minute outbound leg in still air and the inbound leg of the descent allows sufficient arc for a standard-rate turn or less to align the airplane nicely for the final descent inbound to the VOR.

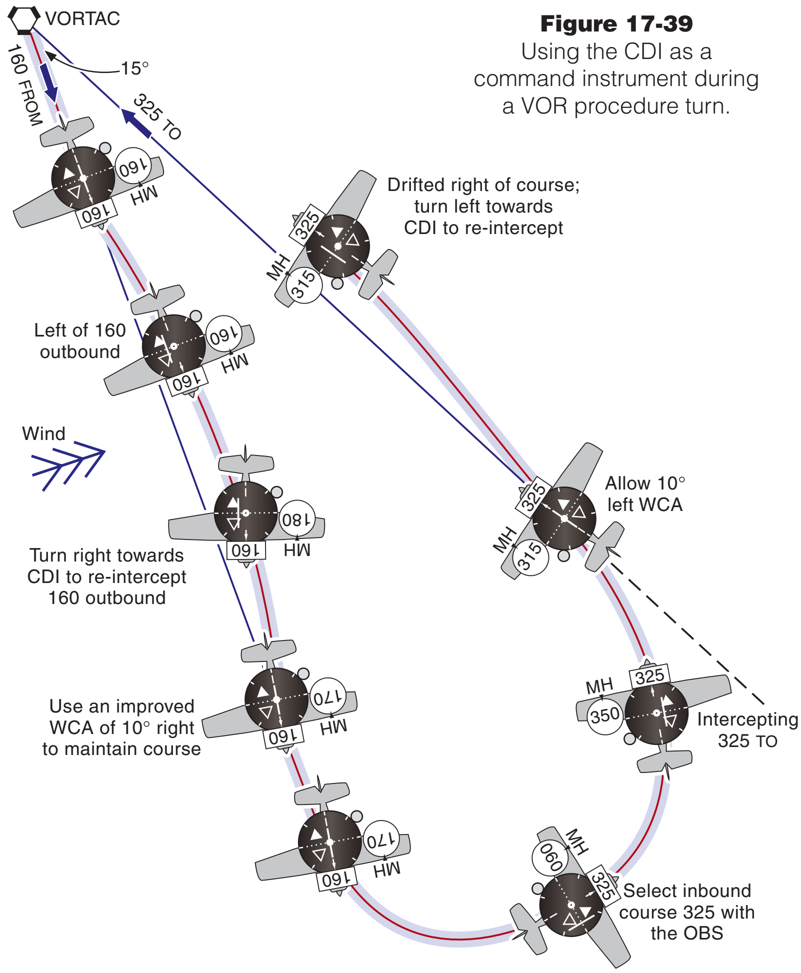


Figure 17-39 Using the CDI as a command instrument during a VOR procedure turn.

Slow aircraft doing a standard-rate turn have a smaller turning radius than fast aircraft (for which the approach plates are designed), and so may tend to undershoot the inbound track (unless there is a strong tailwind in the turn). To avoid undershooting the inbound leg, the airplane should be rolled out of the standard-rate base turn to a suitable heading to allow for a reasonable intercept of the inbound leg (say a 60°, 45° or 30° intercept).

A lot depends on the actual wind strength and direction at the time. For instance, a strong tailwind during the turn will cause the airplane to intercept the inbound leg more quickly than in no-wind or headwind conditions.

Note. The instrument landing system (ILS) uses the same cockpit instrument as the VOR. Whereas the pilot can select any VOR course, there is only one ILS course. The main points to consider are:

- when flying inbound on the ILS course (known as the localizer), the cockpit display is a command instrument (fly toward the CDI to center it and regain course); but
- when back-tracking from overhead the airport toward the ILS commencement point (flying outbound on the inbound localizer), sensing is reversed and the cockpit indicator is no longer a command instrument.

Intercepting a VOR Course

Visualizing Where You Are and Where You Want To Go

You need to know:
- Where am I?;
- Where do I want to go?; and
- How do I get there?

The easiest method of orienting the airplane using the VOR is to rotate the OBS until the CDI centers. This can occur on one of two headings (reciprocals of each other); choose the one with the omni bearing that most resembles the airplane's magnetic heading. If the airplane is heading toward the VOR ground station, then the TO flag will show; if it is heading away from the VOR, then the FROM flag will show.

Select the desired course in degrees magnetic with the OBS. Determine which way to turn to intercept the course, then steer a suitable intercept heading.

Intercepting an Outbound Course

The VOR is just as useful tracking away from a VOR ground station as tracking toward it, and it is much easier to use than the NDB/ADF combination.

Example 17-13

An airplane is tracking inbound on the 170 radial to a VOR (350-TO). ATC instructs the pilot to take up a heading to intercept the 090 radial outbound (090-FROM).

Orientation is not a problem in this example since the pilot already knows where he or she is (the usual situation). The better method tracking inbound on the 170 radial is to have 350 set under the course index, since the airplane is tracking 350-TO the VOR. This ensures that the VOR indicator is a command instrument (fly toward the CDI needle to regain course). The pilot visualizes the situation:
- tracking northward toward the VOR;
- the course, 090-FROM, lying ahead to the right.

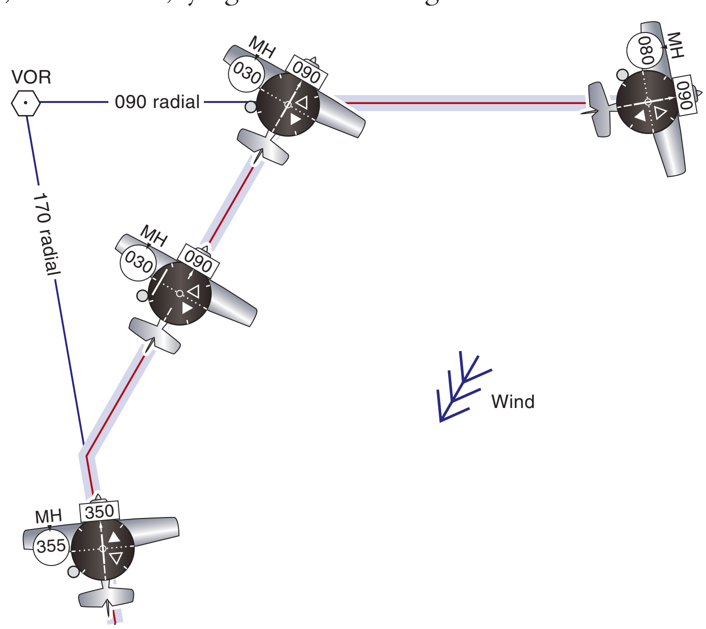


Figure 17-40 Intercepting a course outbound from a VOR.

To intercept the 090-FROM course, the pilot:

- sets 090 under the course index;
- takes up a suitable intercept heading (MH 030 for a 60° intercept); and
- maintains MH 030 until the CDI moves from full-scale deflection toward the center. Depending on your distance from the station, the needle will move at different rates. With experience, you will "lead" the needle by reducing the intercept angle as the needle closes to center.

Intercepting an Inbound Course

Example 17-14

ATC instructs a pilot to track inbound on the 010 radial to a particular VOR. The pilot:

- selects and identifies the VOR; then
- orients himself with respect to the VOR (perhaps by centering the CDI suitably);
- sets the desired course under the course index; inbound on the 010 radial, 190-TO; and determines the relative position of this course;
- takes up a suitable intercept heading, and waits for the CDI to center.

In figure 17-41:

- the CDI centers on 050-FROM (it would also center on 230-TO);
- the pilot has chosen a 90° intercept, steering MH 280 to intercept 190-TO; and as the CDI starts to move (within 10° of the selected course), the pilot leads in to smoothly join course, and allows a wind correction angle of 5° to counter a wind from the east.

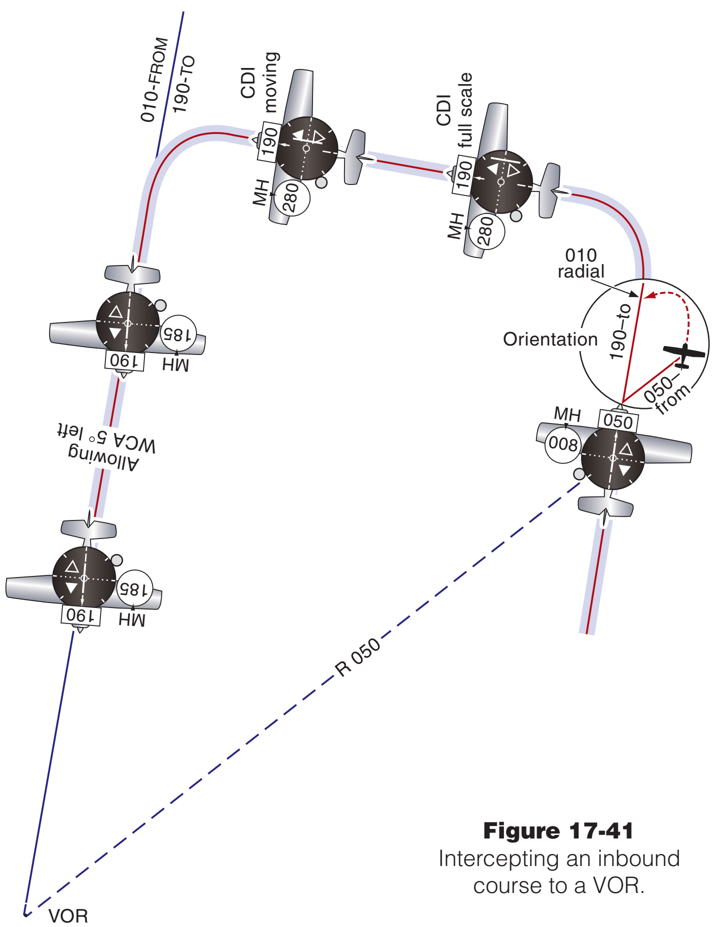


Figure 17-41
Intercepting an inbound course to a VOR.

Other VOR Presentations

There are various presentations of the VOR cockpit indicator with which a pilot should be familiar. In some aircraft, it is also possible to use an RMI needle to point to the VOR ground station as if it were an NDB. (The tail of the RMI needle shows the radial the airplane is on.) This can, on occasions, be quite useful.

The Radio Magnetic Indicator (RMI)

The radio magnetic indicator (RMI) combines a remote indicating compass and a relative bearing indicator into the one instrument. The RMI is a remote indicating compass with one or two ADF/VOR needles, but without a CDI.

The RMI compass card is continually being aligned so that it indicates magnetic heading, and the RMI needles point at the ground stations to which they are tuned. These ground stations, on many RMIs, may be either an NDB or a VOR, the selection of either ADF or VOR being made with small switches at the base of the RMI.

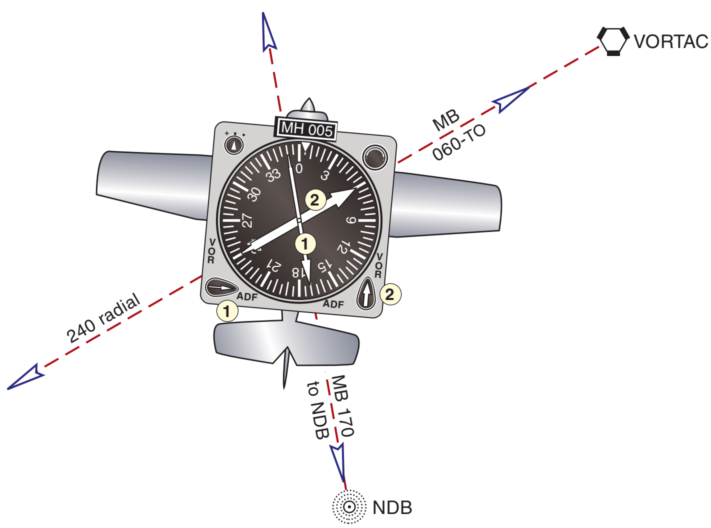


Figure 17-42
RMI needle 1 indicating NDB; RMI needle 2 indicating VOR.

In figure 17-42, the pilot has selected RMI needle 1 to the ADF, hence:

- the head of needle 1 indicates magnetic bearing *to* the NDB; and
- the tail of needle 1 indicates magnetic bearing *from* the NDB.

RMI needle 2 has been selected to the VOR, hence:

- the head of needle 2 indicates magnetic bearing *to* the VOR; and
- the tail of needle 2 indicates magnetic bearing *from* the VOR (radial).

Using the RMI with one needle selected to a VOR allows the VOR to be used as if it were an NDB for orientation and tracking purposes.

Orientation with VOR Selected to One Needle on the RMI

This makes orientation with the VOR easy, and it does not involve altering the OBI (omni bearing indicator). In figure 17-43, RMI needle 2 indicates that the magnetic bearing *to* the VOR is MB 043 (so the airplane is on the 223 radial).

Note that there is no need to alter the OBI to determine this, as would be necessary if an RMI were not installed. Without an RMI, the pilot would have had to alter the OBI until the CDI centered at either 043-TO or 223-FROM.

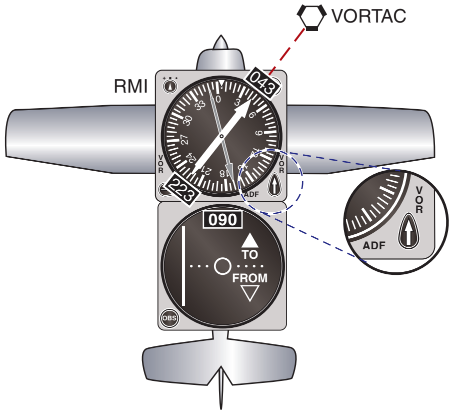


Figure 17-43
The RMI indicates 043 to the VOR.

Intercepting a Course with the RMI Selected to a VOR

If the pilot wishes to intercept the 090 inbound course to the VOR, then he or she would (since the pilot has already oriented the airplane using the RMI):

- set 090 under the course index with the OBS (already done); and
- take up a suitable intercept heading.

If the pilot is uncertain of orientation, he or she can use the ADF technique of imagining (figure 17-44):

- the airplane on the tail of the needle in its current situation; and
- the airplane on the tail of the needle where he or she wants to go (090-TO).

On MH 010, it would be an 80° intercept. If the pilot wanted a 60° intercept, he or she would turn to MH 030. Tracking on MH 030, the RMI needle will gradually fall toward 090. Once the airplane is within 10° of the selected course on the VOR cockpit display, the CDI will start to move.

At this stage, the pilot could shift attention to the VOR indicator, and turn in to track on 090-TO. In this case, the pilot is tracking in on 090-TO, allowing a wind correction angle of 5° left to counteract the wind from the north by steering MH 085.

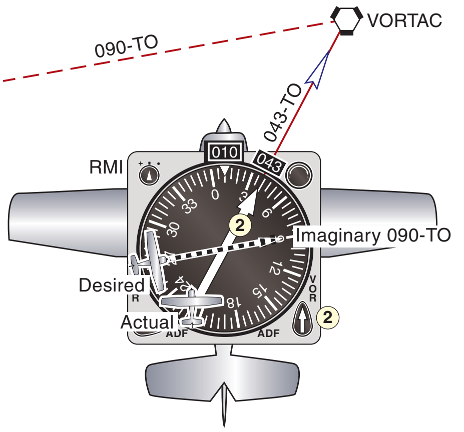


Figure 17-44
Determining "where to go?" using the RMI.

The Horizontal Situation Indicator (HSI)

The HSI is a remote indicating compass with a VOR indicator superimposed on it. It provides an easily understood pictorial display and is one of the most popular navigation instruments ever devised. It shows the magnetic heading and the position of the airplane relative to the selected course. Figure 17-45 shows the airplane on MH 175, about to intercept 205-TO the VOR.

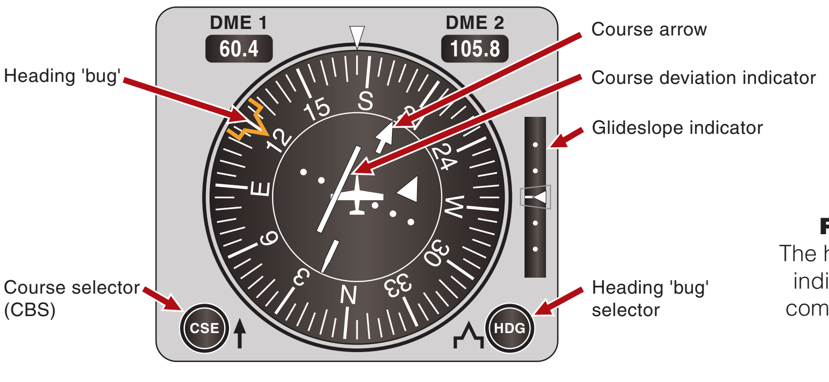


Figure 17-45
The horizontal situation indicator is always a command instrument.

An outstanding benefit of the HSI over the traditional VOR indicator is that the HSI is always a command instrument. If the airplane turns, the remote indicating compass card turns, carrying the VOR display with it, and so the HSI will always show the pilot a CDI deflection toward the selected course. In figure 17-45, the selected course is out to the left. If the airplane turns 180°, to MH 355, the HSI will show the selected course 205 out to the right of the airplane, which it actually is. There is no reverse sensing with an HSI.

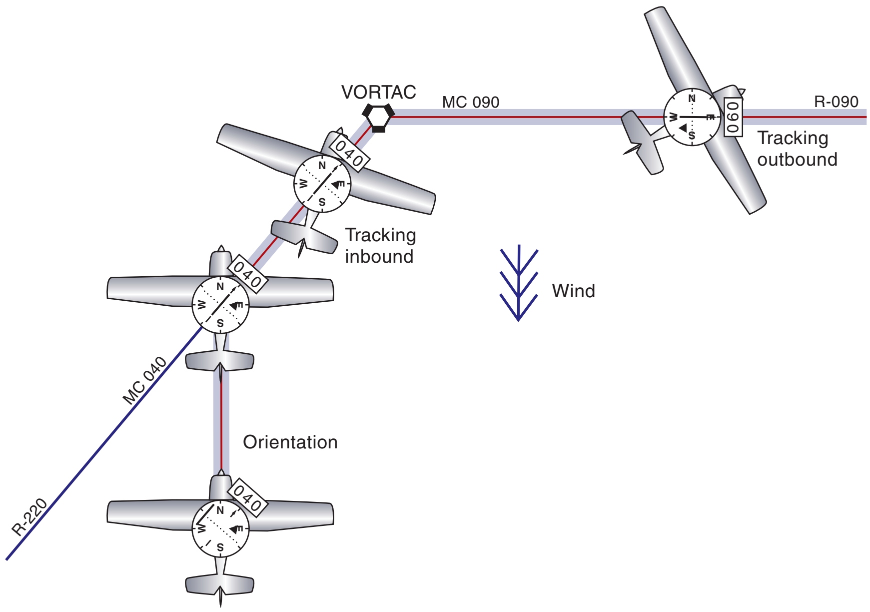


Figure 17-46 Tracking using an HSI.

Review 17

The VOR

1. What does VOR stand for?
2. What frequency does the VOR operate on?
3. What are many VORs coupled with?
4. An airplane at 3,000 feet MSL should be able to receive a VOR situated at sea level out to what range?
5. What is a VOR radial?
6. You are instructed by ATC to track outbound on the 070 radial from a VOR. What is the most suitable heading?
7. You are instructed to track inbound on the 050 radial. What is the most suitable heading?
8. How is a particular VOR identified?
9. What accuracy (±°) should a VOR ground station transmit to?
10. What radio set is used to select a VOR?
11. What is the needle in the VOR cockpit display known as?
12. Any one of 360 tracks may be selected on the VOR cockpit display using what?
13. Where can the position of the VOR receiver checkpoint(s) be found?
14. How many degrees displacement from the selected course are indicated by the following deviations of the CDI on the VOR cockpit display:
    - **a.** A 1 dot deviation?
    - **b.** A 2 dot deviation?
    - **c.** A 3 dot deviation?
    - **d.** A 4 dot deviation?
    - **e.** A 5 dot deviation?
15. If the CDI is centered with 090 set on the OBI, and the FROM flag is showing, what radial is the airplane on?
16. If the CDI is centred with 090 set on the OBI, and the TO flag is showing, what radial is the airplane on?
17. If the CDI is 2 dots right with 090 set on the OBI, and the TO flag is showing, what radial is the airplane on?
18. If the CDI is 1 dot left with 090 set on the OBI, and the FROM flag is showing, what radial is the airplane on?
19. You are flying MH 080, with the OBI selected to 080, CDI needle showing 2 dots right, and the FROM flag showing. Desired course is the 080 radial outbound. Is the desired course out to your left or right?
20. You are flying MH 300, with the OBI selected to 300, the CDI needle showing 3 dots left, and the TO flag showing. Desired course is 300°M to the VOR. Is the desired course out to your left or right?
21. You are flying MH 300, with the OBI selected to 300, the CDI needle showing 3 dots left, and the TO flag showing. If the airplane is now turned to the reciprocal heading of MH 120, would the indications in the VOR cockpit display change in any way (assuming the OBI is left unaltered)?
22. Refer to figure 17-47. Specify which of the airplanes on the left could have the VOR indications given on the right.

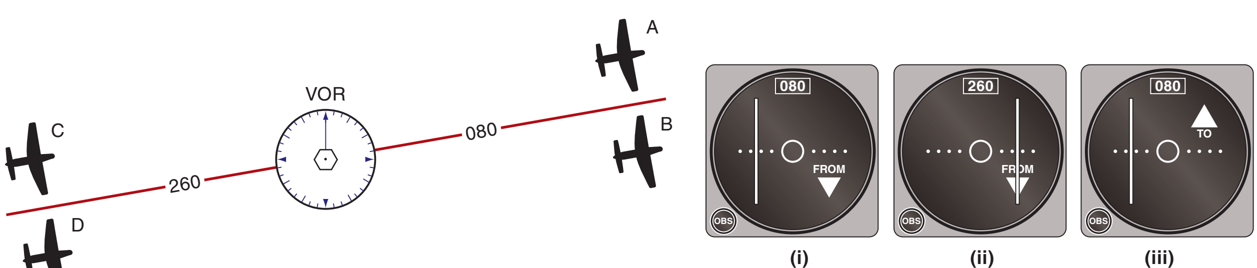
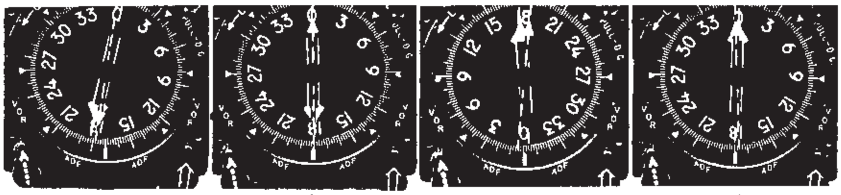


Figure 17-47 Question 22.

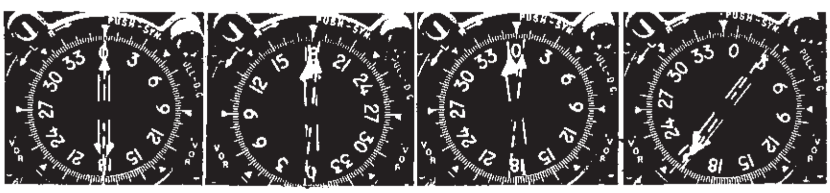
23. Refer to figure 17-48. When checking a dual VOR system by use of a VOT, which illustration indicates that the VORs are satisfactory?



a b c d

Figure 17-48
Question 23.

24. Refer to figure 17-49. Which is an acceptable operational check of dual VORs using one system against the other?



a b c d

Figure 17-49
Question 24.

25. When making an airborne VOR check, what is the maximum allowable tolerance between the two indicators of a dual VOR system (units independent of each other except the antenna)?

26. You are completing a VOR receiver check with the airplane located on the designated checkpoint on the airport. What do you set on the OBI? How many degrees of the radial must the CDI be within? What should the flag show?

27. The A/FD specifies an airborne checkpoint as overhead Lafayette (Louisiana) Regional Airport rotating beacon at altitude 1,000 feet, azimuth and distance from LFT VORTAC 340°/25 NM. What are the acceptable VOR indications to meet the requirements for an airborne receiver check of ±6°?

28. Where can the VOT frequency for a particular airport can be found?

29. When testing your two VOR receivers using a VOT, are readings of 176-TO and 003-FROM acceptable?

30. Describe two ways in which a VOR can be positively identified.

31. Should a pilot use a VOR for navigation if that VOR cannot be identified?

32. If a VOR is undergoing maintenance, is its identification removed? Will it still transmit navigation signals?

33. How often is a VOR identification signal transmitted?

34. If a single coded identification from a VORTAC is received only once approximately every 30 seconds, can the VOR be used for navigation? Can the DME be used for navigation?

35. For an airplane flying at the MOCA, for what distance from the VOR is acceptable navigational signal coverage assured?

36. A particular intersection is defined by intersecting radials from two different VORs and is labeled with MRA 6,000. How many NAV/COM sets do you require to identify when you are at the intersection. What is the significance of "MRA 6000?"

37. A 10° bearing change abeam a VOR takes 4 minutes and 30 seconds. If you turn and fly to the VOR, how long will it take, and what is the approximate distance (assume GS 180 knots)?

38. What angular deviation does full-scale deflection of the CDI represent?

39. At 17,000 feet above the level of a H-class VORTAC in the contiguous United States, what will its range be?

40. To use two H-class VORTACs to define a direct route off an established airway at 17,000 feet, how far apart should they be situated?

41. VOR station passage is indicated by:
 a. the first full-scale deflection of the CDI.
 b. the first movement of the CDI as the airplane enters the zone of confusion.
 c. the moment the TO/FROM indicator becomes blank.
 d. the first positive, complete reversal of the TO/FROM indicator.

42. To check the sensitivity of a VOR receiver, changing the OBI to move the CDI from the center to the last dot on either side should cause what bearing change?

43. What angular deviation from a VOR course is represented by a half-scale deviation of a CDI?

44. At 60 NM, a half-scale deflection of the CDI with a VOR tuned represents what distance from the course centerline?

45. At 30 NM, a half-scale deflection of the CDI with a VOR tuned represents what distance from the course centerline?

46. If the VOR shows a three dot deflection at 30 NM from the station, how far is the airplane displaced from the radial?

47. After overflying a VOR ground station, you select the desired radial and fly a heading estimated to keep you on that course. What is indicated if there is a steady half-scale deflection of the CDI as you fly some miles away from the station?

48. What does an RMI combine the functions of?

49. What does the HSI combine the functions of?

50. Refer to figure 17-50. In which direction is the aircraft located in relation to the VORTAC?

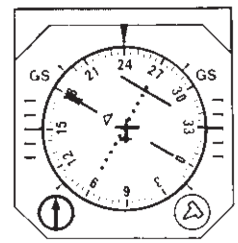


Figure 17-50
Question 50.

51. Refer to figure 17-51.
 a. What is the No. 1 NAV?
 b. What is the No. 2 NAV?
 c. What is the lateral displacement from the course selected on NAV-1?
 d. No. 1 NAV indicates that the aircraft is on which radial?
 e. Which OBI selection on the No. 1 NAV would center the CDI and change the ambiguity indication to a TO?
 f. What is the angular displacement from the desired radial on the No. 2 NAV?
 g. Which OBI selection on the No. 2 NAV would center the CDI?
 h. Which OBI selection on the No. 2 NAV would center the CDI and change the ambiguity indication to a TO?

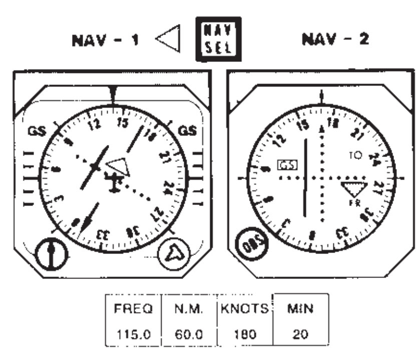


Figure 17-51
Question 51.

Refer to figures 17-52 and 17-53 for questions 52 to 57.

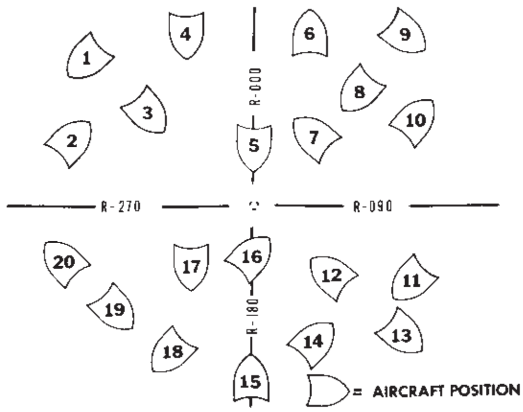


Figure 17-52 Aircraft position.

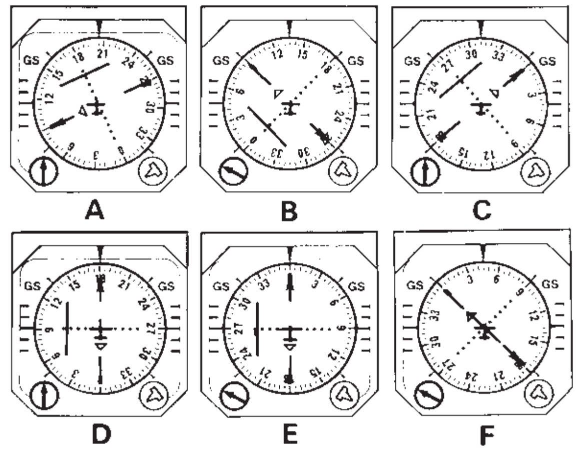


Figure 17-53 HSI presentations.

52. HSI presentation D corresponds to aircraft position:
a. 4.
b. 5.
c. 15.
d. 17.

53. HSI presentation E corresponds to aircraft position:
a. 5.
b. 6.
c. 15.
d. 17.

54. HSI presentation F corresponds to aircraft position:
a. 2.
b. 10.
c. 14.
d. 16.

55. HSI presentation A corresponds to aircraft position:
a. 1.
b. 8.
c. 11.
d. 18.

56. HSI presentation B corresponds to aircraft position:
a. 3.
b. 9.
c. 13.
d. 19.

57. HSI presentation C corresponds to aircraft position:
a. 6.
b. 7.
c. 12.
d. 20.

Answers are given on page 778.

Airspace 18

United States airspace is organized into six classes (A, B, C, D, E and G), in line with the International Civil Aviation Organization (ICAO) airspace classification system. Airspace Classes A through E are allocated to controlled airspace where Class A is the most restrictive and Class E the least restrictive. Uncontrolled airspace is Class G. Class F, although available in the ICAO system, has not been allocated in the United States. The airspace classification system links various parameters to each class, including:

- entry requirements (for example, radio contact for all aircraft in Class C airspace; ATC clearance for IFR flights in controlled airspace, and so on);
- minimum pilot qualifications;
- two-way communication and transponder equipment requirements;
- VFR weather minimums (where VFR is available); and
- aircraft separation, conflict resolution and traffic advisory services.

Airspace features	Class A Airspace	Class B Airspace	Class C Airspace	Class D Airspace	Class E Airspace	Class G Airspace
Flight Operations Permitted	IFR	IFR and VFR	IFR and VFR	IFR and VFR	IFR and VFR	IFR and VFR
Entry Prerequisites	ATC clearance	ATC clearance	IFR clearance/ VFR radio contact	IFR clearance/ VFR radio contact	Clearance/radio for IFR	None
Minimum Pilot Qualifications	Instrument Rating	Private Plot Certificate/ *endorsed student	Student Certificate	Student Certificate	Student Certificate	Student Certificate
Two-Way Radio Communications	Yes	Yes	Yes	Yes	IFR	No
VFR Minimum Visibility	not applicable	3 statue miles	3 statue miles	3 statue miles	**3 statue miles	***1 statue miles
Aircraft Separation	All	All	IFR, SVFR and rwy operations	IFR, SVFR and rwy operations	IFR, SVFR	None
Conflict Resol'n (collision avoidance)	not applicable	not applicable	Between IFR and VFR flights	No	No	No
Traffic Advisories	not applicable	not applicable	Yes	Workload permitting	Workload permitting	Workload permitting
Safety Advisories	Yes	Yes	Yes	Yes	Yes	Yes

*Operations at some class B airports requires a minimum of a Private Pilot Certificate—see Part 91 of the regulations

**Visibility and cloud clearance requirements increase above 10,000 feet MSL.

***Visibility and cloud clearance requirements decrease below 1,200 feet AGL; increase above 10,000 feet MSL, and at night—see Part 91 of the regulations or the AIM.

Table 18-1 Summary of the United States airspace classification system.

Subdivision of Airspace

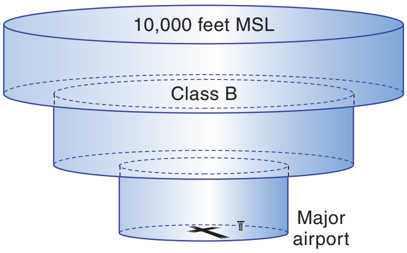


Figure 18-1 Class B airspace.

Class A Airspace

Class A airspace generally extends from 18,000 feet MSL up to and including FL600. Class A airspace is only available to aircraft operating on an IFR flight plan.

Class B Airspace

Class B airspace generally extends from the surface to 10,000 feet MSL surrounding the nation's major airports. The configuration of each Class B airspace is individually tailored and consists of a surface area with two or more larger radius layers above. Class B airspace is shown on sectional charts with a *thick blue solid line*.

To fly within Class B airspace the *minimum pilot qualification* is a private pilot certificate or an endorsed student pilot certificate for Class B airspace at a specific airport (see Part 61 of the regulations). The minimum required *airplane equipment* includes a two-way radio communication and a 4096-code transponder with Mode C capability (altitude reporting). IFR aircraft are required to carry VOR or TACAN equipment. VFR requirements are 3 SM visibility and clear of clouds.

- Class B airspace *operating rules* include:
- ATC clearance must be obtained before entering or departing the airspace;
- fly on published VFR transition routes found on the back of VFR terminal area charts; and
- contact ATC at geographical fixes shown on the sectional charts by small flags to obtain a clearance prior to entering Class B airspace.

If possible avoid Class B airspace by using VFR corridors, Terminal Area VFR Routes, or by flying above or below the Class B airspace.

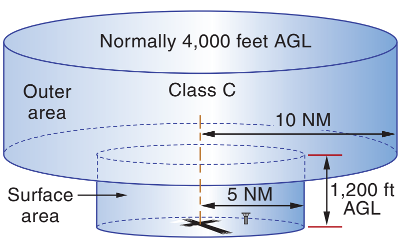


Figure 18-2 Class C airspace.

Class C Airspace

Class C airspace generally extends from the surface to 4,000 feet AGL around a busy airport which has:

- an operational control tower;
- a radar approach control; and
- a certain number of IFR operations or passenger enplanements.

Class C airspace areas are depicted by *solid magenta lines* on sectional charts. The configuration of each Class C airspace is individually tailored, usually with two tiers. The vertical limits of Class C airspace are indicated with the circle and are expressed in hundreds of feet MSL. The upper limit is shown above the straight line and the bottom limit (which may be SFC for surface area altitude) beneath the line. For example, refer to sectional chart excerpt no. 1 (page 329) and the Class C airspace around Mobile Regional Airport. The limits in the surface area are "$\frac{42}{\text{SFC}}$" which means that Class C airspace extends from the surface to 4,200 feet MSL. The limits for the outer area are 42/15 which means that the C Class airspace extends from 1,500 to 4,200 feet MSL.

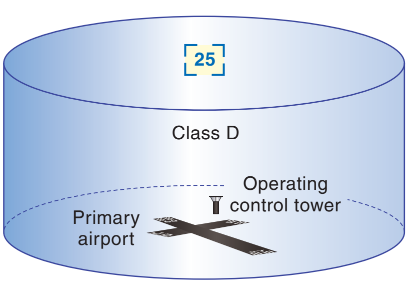


Figure 18-3 Class D airspace.

To fly in Class C airspace no specific *pilot certification* is required and the minimum *airplane equipment* includes two-way communication and a 4096 transponder with Mode C (altitude reporting). Class C *operating rules* require the establishment of two-way radio communications with approach control before entering Class C airspace. In addition, unless otherwise authorized or required by ATC, airplanes below 2,500 feet AGL and within 4 NM of the primary airport must not exceed an indicated airspeed of 200 knots. Class C radar services are usually provided beyond Class C airspace out to 20 NM from the primary airport. The minimum *VFR weather requirements* for Class C airspace are shown in figure 18-4.

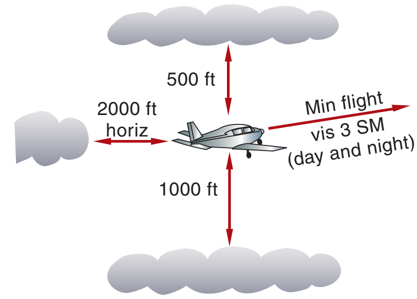


Figure 18-4 VFR requirements.

Class D Airspace

Class D airspace surrounds airports which have an operational control tower but are not associated with Class B or C airspace. Class D airspace generally extends from the surface to 2,500 feet AGL and is cylindrical in shape, plus extensions up to 2 NM necessary to include instrument approach and departure paths. On sectional charts Class D airspace is shown as a dashed or *segmented blue line*, with a blue segmented box showing the top of the Class D airspace in hundreds of feet MSL. For example on Sectional Excerpt No. 3 (page 332), Napa County is surrounded by Class D airspace with an upper limit of 2,500 feet MSL.

No specific *pilot certification* is required to fly in Class D airspace, and the minimum *airplane equipment* is an operational two-way radio. Class D *operating rules* include establishing two-way radio contact before entering Class D airspace and maintaining two-way radio contact while in Class D airspace. In addition, airplanes within 4 NM of the primary airport in the Class D airspace and at or below 2,500 feet AGL must not exceed 200 KIAS. The VFR minimums are the same as those for Class C airspace. When the control tower is not operating, the Class D airspace reverts to Class E.

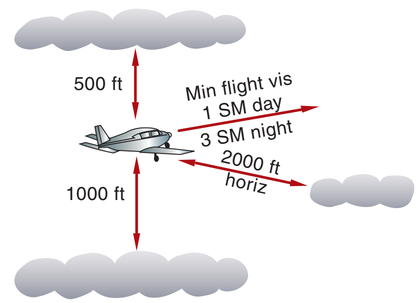


Figure 18-5
VFR minimum requirements
below 10,000 feet MSL,
but above 1,200 feet AGL by day.

Class E Airspace

Class E airspace is controlled airspace that is not Class A, B, C or D. Class E airspace includes airspace around airports without control towers, airspace used to transit between terminal or en route environments, Federal Airways including Victor airways (see Note 3), plus unallocated airspace over the United States from 14,500 feet MSL up to Class A airspace beginning at 18,000 feet MSL, or any overlying Class B, C or D airspace. Class E airspace lower limits are:

- the surface around airports marked by *segmented magenta lines*;
- 700 feet AGL in areas marked by *light magenta shading*;
- 1,200 feet AGL in areas marked by *light blue shading*;
- as depicted numerically by a *blue staggered line*; and
- 14,500 feet MSL if none of the others apply.

To fly in Class E airspace, no specific pilot certification is required and there are no specific equipment or operating requirements. The minimum VFR requirements are the same as for Class C and D if operating

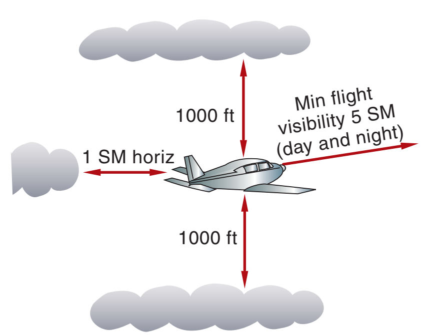


Figure 18-6
VFR minimum requirements
above 10,000 feet MSL.

below 10,000 feet MSL. At or above 10,000 feet MSL, VFR conditions are increased to flight visibility 5 SM, with 1,000 feet vertical separation from clouds and 1 SM horizontal separation from clouds. An ATC clearance is required to fly IFR in Class E airspace.

Class G Airspace

Class G airspace is the remaining airspace other than special use or restricted airspace. The minimum VFR requirements in Class G airspace depend on day or night and altitude above the surface. At or below 1,200 feet AGL by day, the minimum visibility is 1 statute mile (SM) and the airplane must remain clear of clouds. By day above 1,200 feet AGL but below 10,000 feet MSL, the minimum visibility is 1 SM and the airplane must remain at least 2,000 feet horizontally from, 500 feet below and 1,000 feet above clouds. For night VFR minimums, see Part 91. You do not need an ATC clearance to fly IFR in Class G airspace. Refer to Part 71 of the regulations for more detail on the airspace classes. Also, airspeed rules are contained in Part 91 (see Chapter 3).

Terminal Radar Service Areas

Some airports offer optional radar advisory services in airspace known as *Terminal Radar Service Areas* (TRSAs). The primary airport of a TRSA is Class D. The boundaries are marked on sectionals with thick dark-gray lines. Pilots can choose whether or not to participate with ATC by squawking 1200 or an ATC assigned code while flying in TRSA airspace. There are very few TRSAs.

Victor Airways

Victor Airways are low-altitude federal airways connecting VORs along specified radials and are for use by both IFR and VFR aircraft. They are shown on sectionals by straight blue lines containing the airway designator and its magnetic direction (e.g. V31-348°). Any *intersections* fixed by NAVAIDs are indicated by fine blue arrows directed toward the relevant facilities. Victor airways are normally 8 NM wide and extend vertically from 1,200 feet AGL up to but not including 18,000 feet MSL. Unusually high floors will be marked. You should normally cruise at an appropriate altitude along Victor airways. For VFR aircraft, "odds+500 feet" on easterly routes, and "evens+500 feet" on westerly routes.

Special Use Airspace

Special use airspace is not allocated a class. It consists of that airspace within which certain activities must be confined because of their nature such as military aerobatic training or missile firing. Special use airspace is shown on aeronautical charts (except for controlled firing areas where activity ceases when aircraft are spotted in the area either visually or by radar). Prohibited, Restricted and Warning Areas are outlined on sectionals by *blue lines with hachuring*.

Prohibited Areas contain airspace within which the flight of aircraft is prohibited for national security or other reasons. *Restricted Areas* contain airspace within which the flight of aircraft is subject to restrictions, but is not totally prohibited, because of hazards such as artillery firing, aerial gunnery or guided missiles. Penetrating Restricted Areas without authorization from the using or controlling authority may be extremely hazardous. *Warning Areas* are similar to restricted areas, except that they are beyond the 3-mile limit from the United States coastline and are therefore in international airspace. *Military Operations Areas* (MOAs) consist of airspace of defined vertical and lateral limits established to separate military training activities (usually involving aerobatic or abrupt flight maneuvers) from civil Instrument Flight Rules (IFR) traffic. Any FSS within 100 miles of the MOA should be able to advise if it is active or not and, if it is active, you should contact the controlling agency for traffic advisories. VFR pilots should exercise extreme caution when flying in an active MOA. *MOAs* are outlined on sectionals by *magenta lines with hachuring*. *Alert Areas* depicted on sectional charts by *blue boxes* show airspace within which there may be a lot of pilot training or unusual aerial activity.

Other Airspace

Military Training Routes

Military Training Routes (MTRs) are for military low-altitude high-speed training and may be flown by military aircraft either under the Instrument Flight Rules (indicated on the chart by IR), or under the Visual Flight Rules (VR). Military training routes are depicted with a *thin gray line*:

- MTRs at or below 1,500 feet AGL (with no segment above 1,500 feet AGL) are identified by 4-digit numbers, for instance, IR 1006, and VR 1007;
- MTRs above 1,500 feet AGL (with some segments possibly below 1,500 feet AGL) are identified by 3-digit numbers, for instance, IR 008, and VR 009; and
- alternate IR/VR military training routes are identified normally, but with a final letter suffix, such as IR 008A, or VR 009B.

Temporary Flight Restrictions (TFRs)

Airspace not defined on a chart may be activated by NOTAM (Notice to Airmen) and may temporarily restrict access or require special procedures. Such airspace is activated to allow activities such as fire fighting or disaster relief, where the operational aircraft must have free access, but access is denied to sightseeing aircraft that may impair operations. TFRs may be activated to prevent aircraft being exposed to hazards, such as volcanic ash, dense smoke, or high traffic density of a temporary nature.

TFRs may also be activated for purposes such as disaster relief, and temporarily prohibited for space flights, presidential flights, and so on.

Airport Advisory Areas

Airport Advisory Areas exist within 10 statute miles of any airport where a control tower is not operating but where a FSS provides an advisory service to arriving and departing aircraft. It is not mandatory to participate in the airport advisory service program, but it is strongly recommended.

Airspace			Flight Visibility	Distance from Clouds
Class A			N/A	Not applicable
Class B			3 SM	Clear of clouds
Class C			3 SM	500 ft below, 1,000 ft above, 2,000 ft horizontal.
Class D			3 SM	500 ft below, 1,000 ft above, 2,000 ft horizontal.
Class E	less than 10,000 ft MSL		3 SM	500 ft below, 1,000 ft above, 2,000 ft horizontal.
	at or above 10,000 ft MSL		5 SM	1,000 ft below, 1,000 ft above, 1 SM horizontal.
Class G	1,200 ft or less above the surface (regardless of MSL or altitude)	Day, except as provided in Part 91	1 SM	Clear of clouds
		Night, except as provided in Part 91	3 SM	500 ft below, 1,000 ft above, 2,000 ft horizontal.
	More than 1,200 ft above the surface but less than 10,000 ft MSL	Day	1 SM	500 ft below, 1,000 ft above, 2,000 ft horizontal.
		Night	3 SM	500 ft below, 1,000 ft above, 2,000 ft horizontal.
	More than 1,200 ft above the surface and at or above 10,000 ft MSL		5 SM	1,000 ft below, 1,000 ft above, 1 SM horizontal.

Table 18-2 Part 91 summary of basic VFR weather minimums.

Review 18
Airspace

1. How is Class B airspace indicated on Sectional charts?

2. What minimum pilot certification is required for operation within Class B airspace?

3. What are the VFR minimum weather requirements for Class B airspace?

4. How is Class C airspace indicated on sectional charts?

5. How far out does the outer area of Class C airspace typically extend?

6. What is minimum radio equipment required for operation within Class C airspace?

7. Who should you make radio contact with on the published frequency before entering Class C airspace?

8. What is the speed limit when below 2,500 feet AGL and within 4 NM of the primary airport in the Class C surface area?

9. What are the basic VFR minimum weather conditions in Class C airspace?

10. What class of airspace does Class D airspace around an airport with a control tower revert to when the tower is not operating?

11. What are the basic VFR weather minimums in Class D airspace?

12. What is the lower limit of Class E airspace?

13. On sectional charts, what lower limit in Class E airspace is indicated by:
a. magenta shading?
b. blue shading?

Refer to Sectional Chart Excerpt No. 4 (page 333) for questions 14 to 17.

14. What are the regulation visibility and cloud requirements to operate at Standpoint Airport below 700 feet AGL?

15. Identify the airspace over Sandpoint Airport that exists from the surface up to 14,500 feet MSL.

16. Identify the airspace over Coeur d'Alene airport that exists from the surface up to 14,500 feel MSL.

17. What type of military operations would you expect along IR314 crossing Lake Pend Oreille?

Refer to Sectional Chart Excerpt No. 3 (page 332) for questions or questions 18 to 22.

18. What class of airspace surrounds San Francisco International?

19. What is the elevation of San Jose International airport?

20. What is the meaning of the flag symbol shown at Crown Sterling Suites (area D)?

21. Within what distance of San Francisco International airport is a Mode C transponder required?

22. Is Special VFR (SVFR) flight permitted in the airspace surrounding San Francisco International airport? State how this is indicated on the chart.

23. What are the VFR minimums for flight in Class E airspace below 10,000 feet MSL, day or night?

24. What are the VFR minimums for flight in Class G airspace at 1,200 feet or less AGL (regardless of MSL altitude) by day?

25. What are the VFR minimums for flight in Class G airspace at or above 10,000 feet and more than 1,200 feet AGL (regardless of MSL altitude), day or night?

26. What are the VFR minimums for flight in Class G airspace more than 1,200 feet above the surface (regardless of MSL altitude) by night?

27. An airplane may be operated at night, in the traffic pattern of an airport in Class G airspace under what conditions?

28. How are military operations areas outlined on sectional charts?

29. What action should a pilot take when operating under VFR in a Military Operations Area (MOA)?

Answers are given on page 779.

Flight Planning 19

Flight Management

Cross-country flying is a significant step forward in your training. Up to this point, you have only been concerned with flying the aircraft. However, during cross-country flight, you will have to fly *and* navigate, which will significantly increase your workload. Careful preflight planning is paramount to safely managing the flight. Therefore, *flight management* applies to the preflight planning stage as well as to the actual flight.

Thorough preflight planning is paramount to flight safety.

Preflight planning includes preparing a detailed flight log, calculating weight and balance, filing a flight plan, obtaining a thorough weather briefing, securing the necessary aeronautical charts and airport data, and laying out your proposed route. The better the flight planning prior to flight, the easier the en route navigation!

Personal Navigation Equipment

A *flight case*, satchel, or nav bag that fits comfortably within reach in the cockpit should be used to hold your navigation equipment. A typical flight case should contain:

Keep the cockpit organized to reduce distractions.

- current aeronautical charts—typically Sectional Charts, together with Terminal Charts for nearby Class B airspace;
- a flight computer;
- a scale rule and protractor (or a plotter);
- pens and pencils;
- relevant documents (such as the Airport/Facility Directory and logbook for student pilots);
- spare flight log forms;
- a flashlight; and
- sunglasses.

Note. Also consider a kneeboard and some type of small electronic timer.

Weather and Operational Considerations

You should obtain *weather information* and *notices to airmen* (NOTAMs and TFRs) by the most convenient means available to you prior to your flight. Typically, this is accomplished via computer or by dialing 1-800-WX-BRIEF for the nearest flight service station.

Don't forget to check NOTAM and TFR information when obtaining a weather briefing.

```
BTL 08/013 BTL 13/31 CLSD WEF 0408301200
BTL 09/005 BTL 5/23 NE 1300 CLSD WEF 0409141700
BTL 09/008 BTL 23 ALS OTS TIL 0410082359
BTL 09/009 BTL 23 ILS OTS TIL 0410082359
BTL 09/011 BTL 5/23 CLSD 0200–1000 DLY TIL 0409221000
```

Figure 19-1 Typical NOTAM information.

```
METAR KFPR 261148Z 00000KT 10SM FEW020 BKN080 A2998
METAR KVRB 261150Z VRB03KT 10SM-SHRA FEW009 SCT035 BKN070 BKN200
22/21 A2999 RMK TSE35 MOV E SLP156 60087 70156 10250 20217 51017
METAR KSRQ 261150Z 05006KT 10SM SKC 25/24 A3001
current hourly report not available for SPG
METAR KSPG 261050Z 05010KT 10SM SCT150 26/25 A3001
TAF KVRB 261120Z 261212 VRB04KT P6SM
SCT025 BKN050 TEMPO 1213 3SM
TSRA
BKN025CB
FM1300 02007KT P6SM SCT030
TEMPO 1318 5SM SHRA BKN025
FM1800 03010KT P6SM SCT030
TEMPO 1820 BKN025
TAF KSRQ 261130Z 261212 06005KT P6SM SKC
FM1400 06008KT P6SM SCT030 SCT250
FM1900 05009KT P6SM SCT040
SCT250 PROB30 1923 3SM TSRA BKN025CB
FM0200 VRB03KT P6SM FEW020 SCT250
```

Figure 19-2 Some typical weather information.

Flight Service Stations can provide a standard, abbreviated, or outlook briefing.

Flight Service Stations (FSS) can provide three basic types of preflight briefing:

- a *standard briefing*—a full briefing including adverse conditions, VFR flight recommended or not, weather synopsis, current conditions, en route forecast, destination forecast, winds aloft, relevant NOTAMs, known ATC delays; or
- an *abbreviated briefing*—to supplement information you already have; or
- an *outlook briefing*—for advanced planning purposes (for a flight 6 or more hours from the time of briefing).

The Area Forecast will give cloud bases above mean sea level and the Aerodrome Forecast above ground level. From this information the most suitable cruising altitude can then be chosen. You should read and analyze the weather information so that you can make well-based judgments regarding your proposed flight, especially the "go/no-go" decision.

Analyze the weather reports and forecasts, weather charts, pilot weather reports, SIGMETs, AIRMETs, NOTAMs, windshear reports, and whatever other relevant information is available. Don't forget to walk outside and have a look at the sky yourself! It sounds like a lot, but the information will be presented to you in a logical manner—and the more practiced you become in planning a flight, the easier it will seem.

Make a sensible "go/no-go" decision based on your own personal weather minimums.

From this information, and from your knowledge of your own experience and capabilities, you can now make a firm, positive and confident "go/no-go" decision. This is a command decision, possibly the most important decision of the whole flight.

To help you make this critical decision objectively, establish your own personal weather minimums. For example: visibility 5 miles, ceiling 5000, wind < 15 KTS. If the weather at any point along your route exceeds, or is forecast to exceed, your personal minimums, *don't go*.

In addition, use your personal weather minimums while en route. If at any point the weather deteriorates below your personal minimums, consider an alternate course of action, such as making a 180 or landing at a different airport.

Preflight Planning

Start your planning by looking at the big picture. Select the route over which you want to fly. Note the nature of the terrain and the type of airspace along this route and to either side of it:

Use current charts, and check for terrain and airspace.

- *terrain*—check the height of any obstacles within (say) 10 miles either side of your proposed course; and
- *airspace*—check the route for:
  - different classes of airspace;
  - prohibited areas, restricted areas or warning areas; and
  - other airports.

Use the chart legend to decode chart information.

It may be best to avoid particularly high or rugged terrain (especially if you are flying a single-engine airplane), areas of dense air traffic, and areas of bad weather such as coastal fog, low clouds, and thunderstorms.

Choose turning points and prominent checkpoints which will be easily identified in flight, and which cannot be confused with other nearby ground features. Remember you are sitting on the left-hand side of the airplane. Select appropriate en route navigation aids, and note the communications facilities. Allow for necessary fuel stops. Mark the route on your sectional chart, and enter a few prominent checkpoints on the flight log.

It is not necessary to list every checkpoint on your flight log.

Note any suitable *alternate airports* available on or adjacent to the route, in case an unscheduled landing becomes necessary. Information on airports is available in the Airport Facility Directory (A/FD).

Consider highlighting suitable en route alternate airports.

Altitude

It is good airmanship to calculate a *safety altitude* that provides adequate clearance above terrain and obstacles. A quick means of determining the height of the highest obstacle or terrain is to use the *maximum elevation figure* (MEF) published for each latitude-longitude quadrangle on Sectional charts.

Terrain awareness is vital.

To be less restricted, you could instead find the highest terrain or obstacle within 5 NM or 10 NM either side of track. Then apply a safety buffer, say of 1,000 feet or whatever your flight instructor suggests, to obtain a safety altitude. Enter this figure on your flight log. This is not a requirement, but it provides a safe minimum altitude to fly at if, for instance, cloud forces you down.

Select a suitable *cruise altitude* for each leg and enter it in the flight log. Considerations should include:

- terrain;
- airspace restrictions;
- the cloud base; and
- VFR cruise altitudes.

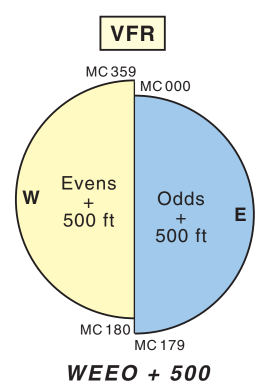


Figure 19-3
VFR cruise altitudes above 3,000 feet AGL.

The *VFR cruise altitudes,* when more than 3,000 feet above the surface, are:

- on a magnetic course 000° to 179° magnetic—*odd* thousands plus 500 (for example 3,500, 5,500, 7,500 feet MSL); and
- on a magnetic course 180° to 359° magnetic—*even* thousands plus 500 (for example 4,500, 6,500, 8,500 feet MSL).

Magnetic course is true course + or – variation.

Note. Cruise altitudes, as well as VOR radials, are based on *magnetic* course. A common mistake is to calculate VFR cruising altitudes based upon magnetic heading rather than magnetic course.

Courses and Distances

Estimating course and distance prior to actual measurement will avoid gross errors.

For each leg of the flight, mentally estimate the course direction and the distance in nautical miles before measuring it accurately (ensuring that you are using the correct scale). Insert the accurately measured figures on the flight log.

Measure true course against a meridian of longitude at the approximate midpoint of each leg. Add or subtract *magnetic variation* to the measured true course to find the magnetic course.

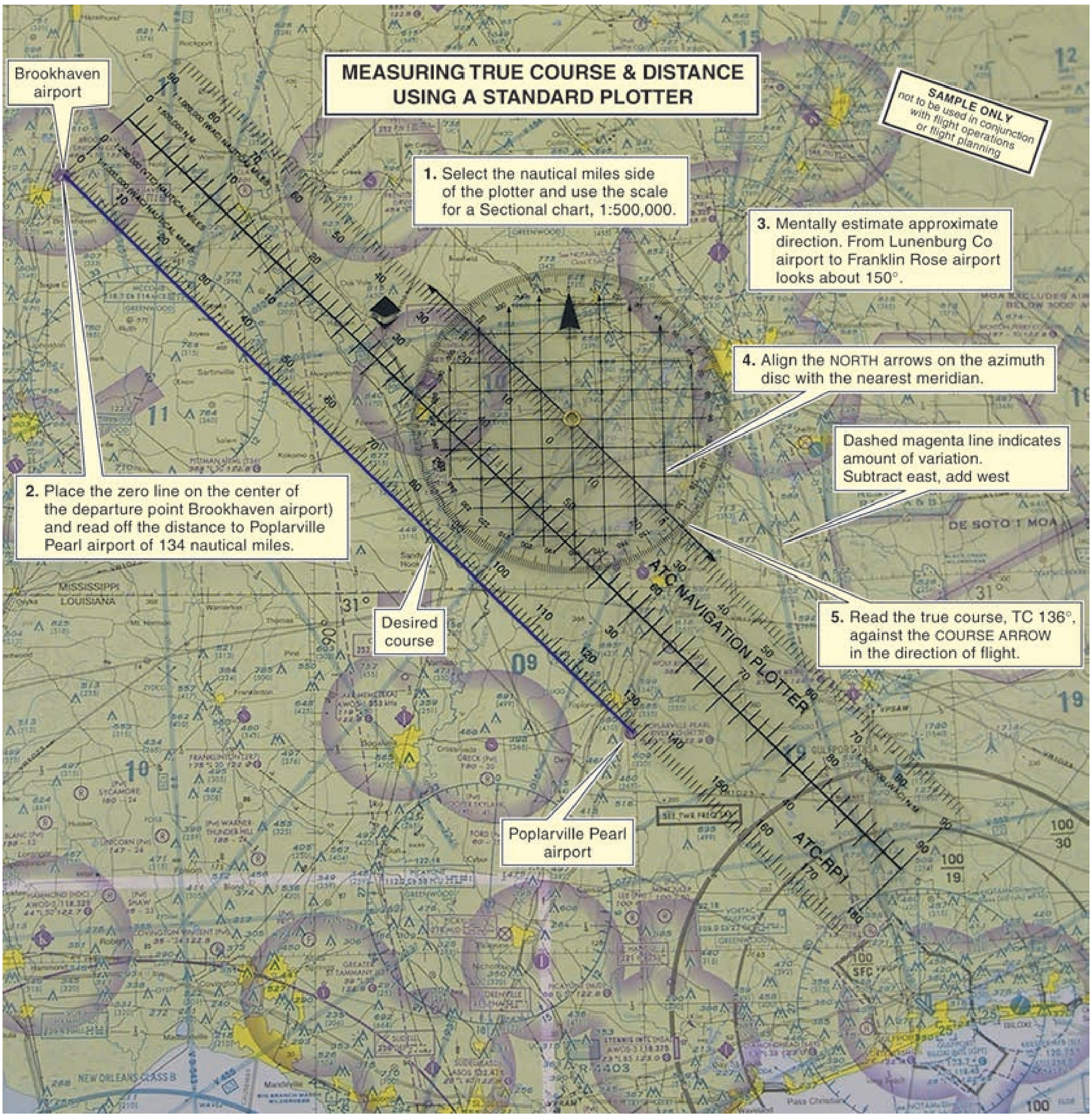


Figure 19-4 Measuring true course and distance on a standard plotter.

Distance Markers or Time Markers

To assist you in flight, it is suggested that each leg be subdivided using small marks placed at regular intervals along the course lines drawn on the chart. These may be:

- distance markers each 10 nautical miles (NM); or
- distance markers at the ¼, ½ and ¾ points; or
- time markers each 10 minutes; or
- time markers at the ¼, ½ and ¾ points.

Time markers have to wait until you have calculated groundspeeds and time intervals. Once in flight, these may vary from the flight planned values, unlike the distance markers. Engraving a pencil with 10 NM marks (in the correct scale for the chart) will help you estimating distances, particularly in flight.

Figure 19-5 A pencil engraved (by yourself) with 10 NM nicks is very useful.

Speed, Time, and Heading Calculations

Once the route has been selected and the courses and distances measured, the flight plan may be completed. Calculations of headings, groundspeeds, time intervals and fuel consumption must all be made.

Completing the Flight Log

Insert the forecast winds, the selected cruise altitude, and the TAS for each leg onto the flight log. Remember that for a given indicated airspeed, the true airspeed will be greater at higher altitudes and temperatures because of the decreased air density. Converting IAS to TAS is easily done on the calculator side of the computer, but most Pilot's Operating Handbooks directly provide cruise TAS information in the published cruise tables.

On the wind side of the flight computer, use the forecast wind to set up the triangle of velocities and calculate wind correction angle, heading and groundspeed for each leg.

> **Note.** It is most important when using the wind side of the computer that you work *completely* in degrees true (or *completely* in degrees magnetic).

Having measured the distance of each leg and calculated the expected groundspeed, determine the *estimated time interval* and insert it on the flight log. Then add all of the individual time intervals together and obtain the *total* time interval for the whole flight. Since climb to altitude will be at a lower airspeed (and higher fuel consumption) than cruising flight, some pilots add a climb allowance, say 2 minutes and 0.5 gallon, to the cruise-only figures calculated for the first leg. Check the POH for recommendations on fuel allowances for taxi and climb.

To check for gross errors, compare the total time en route with the total distance for the flight, considering the average GS expected. Also, confirm that you will arrive with adequate daylight remaining. You should plan to arrive with at least 30 minutes of daylight remaining. Ask your flight instructor for guidance. If diversion to an alternate airport is a possibility, then you should plan for a departure time that will allow you to fly to the destination airport, then to the alternate airport and still arrive well before the end of daylight.

Fuel Calculations

The fuel consumption for various power settings is published in the Pilot's Operating Handbook. These figures assume *correct leaning* of the fuel/air mixture when cruising at 75% maximum continuous power or less. Leaning the mixture can decrease fuel consumption by up to 20%. From the estimated time interval for the whole flight and the published fuel consumption rate, calculate the expected flight fuel.

Surprisingly, running out of fuel is a leading cause of accidents.

Reserve fuel should also be carried to allow for in-flight contingencies such as diversions, fuel consumption poorer than that published and unexpected headwinds en route. A *fixed reserve fuel* of 45 minutes by night and 30 minutes by day is required. This fixed reserve is only intended to be used in an emergency. Any fuel over and above the minimum fuel required is known as *margin fuel*. Insert the fuel calculations onto the flight log.

Weight and Balance

Do not exceed weight-and-balance limitations.

At this stage of flight planning, when the fuel required and the passenger and baggage load is known, it is appropriate to consider weight and balance. For a flight to be legal, the airplane must not exceed any weight limitation, and must be loaded so that the center of gravity (CG) lies within the approved range throughout the flight. Complete a load sheet (if necessary) to verify that the requirements are met. See Chapter 11 for more on weight and balance. Refer to figure 19-6.

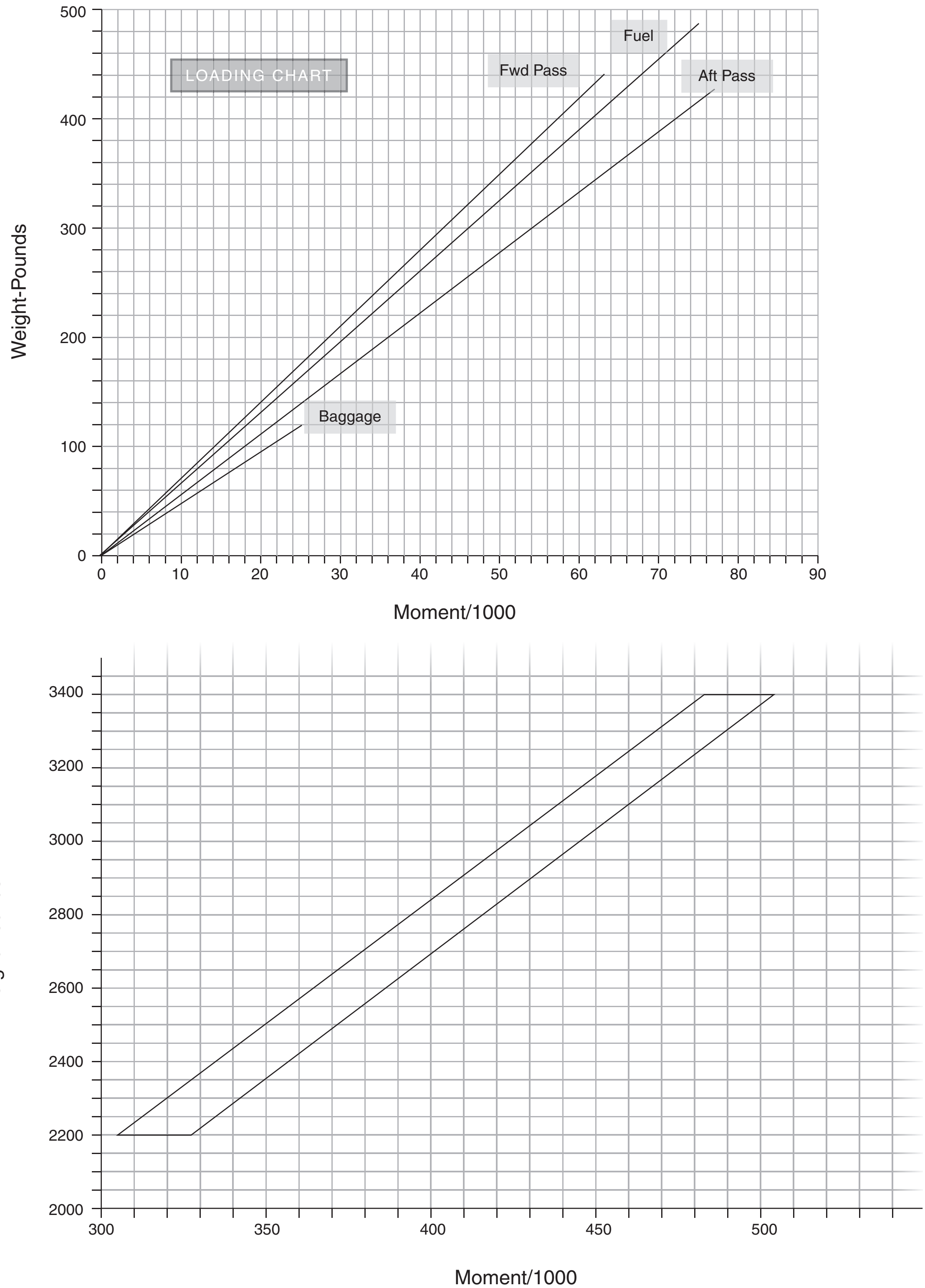


Figure 19-6 A typical load sheet.

Takeoff and Landing Performance

Having considered weight and balance, you will know the expected takeoff weight and landing weight of the airplane. If any doubt exists regarding the suitability of the departure, destination and alternate airports, then reference should be made to the takeoff and landing *performance charts* in the Pilot's Operating Handbook. The official source of *airport data* is the Airport/Facility Directory. *Weather data* (wind and temperature) affecting the performance can be obtained from the forecast. See Chapter 6 for more on takeoff and landing performance. Refer to figures 19-7 and 19-8.

Weight: 3400 lb.
Speed at Liftoff: 73 KIAS
Speeed over 50 ft. Obstacle: 78 KIAS
Flaps: 50%
Power: Takeoff
Runway: Dry, Paved, Level

Headwind: Subtract 10% for each 12 knots headwind.
Tailwind: Add 10% for each 2 knots tailwind upto 10 knots.
Runway Slope: Reference Notes.
Dry Grass: Add 20% to Ground Roll.
Wet Grass: Add 30% to Ground Roll.

PRESS ALT FT	DISTANCE FT	TEMPERATURE~ºC					ISA
		0	10	20	30	40	
SL	Grnd Roll	917	990	1067	1148	1229	1028
	50 ft.	1432	1539	1650	1764	1883	1594
1000	Grnd Roll	1011	1092	1176	1264	1355	1117
	50 ft.	1574	1691	1813	1939	2069	1728
2000	Grnd Roll	1118	1206	1299	1395	1496	1215
	50 ft.	1732	1861	1995	2133	2276	1874
3000	Grnd Roll	1234	1332	1435	1542	1653	1323
	50 ft.	1907	2049	2196	2349	2507	2035
4000	Grnd Roll	1365	1474	1588	1706	1829	1441
	50 ft.	2102	2259	2422	2590	2764	2212
5000	Grnd Roll	1512	1633	1758	1889	2025	1572
	50 ft.	2320	2493	2673	2858	3051	2407
6000	Grnd Roll	1676	1810	1950	2095	2245	1717
	50 ft.	2564	2755	2953	3159	3371	2622
7000	Grnd Roll	1861	2009	2164	2325	2492	1877
	50 ft.	2837	3048	3267	3494	3729	2858
8000	Grnd Roll	2068	2233	2405	2584	2770	2054
	50 ft.	3142	3376	3619	3871	4131	3122
9000	Grnd Roll	2302	2485	2677	2875	3082	2250
	50 ft.	3485	3744	4014	4293	4581	3412
10000	Grnd Roll	2564	2769	2982	3204	3434	2468
	50 ft.	3870	4158	4457	4767	5088	3733

Figure 19-7 Excerpt from a SR-22 takeoff performance chart.

Weight: 3400 lb. Speeed over 50 ft. Obstacle: 77 KIAS Flaps: 100% Power: Idle Runway: Dry, Paved, Level	Headwind: Subtract 10% for each 13 knots headwind. Tailwind: Add 10% for each 2 knots tailwind upto 10 knots. Runway Slope: Reference Notes. Dry Grass: Add 20% to Ground Roll. Wet Grass: Add 80% to Ground Roll.

PRESS ALT FT	DISTANCE FT	TEMPERATURE~°C					ISA
		0	10	20	30	40	
SL	Grnd Roll	1082	1121	1161	1200	1240	1141
	Total	2262	2316	2372	2428	2485	2344
1000	Grnd Roll	1122	1163	1204	1245	1286	1175
	Total	2317	2374	2433	2492	2551	2391
2000	Grnd Roll	1163	1206	1248	1291	1334	1210
	Total	2375	2436	2497	2558	2621	2441
3000	Grnd Roll	1207	1251	1295	1339	1384	1247
	Total	2437	2501	2565	2630	2696	2493
4000	Grnd Roll	1252	1298	1344	1390	1436	1285
	Total	2503	2569	2637	2705	2774	2548
5000	Grnd Roll	1300	1348	1395	1443	1490	1324
	Total	2572	2642	2713	2785	2857	2605
6000	Grnd Roll	1350	1399	1449	1498	1547	1365
	Total	2645	2719	2794	2869	2945	2665
7000	Grnd Roll	1402	1453	1504	1556	1607	1408
	Total	2723	2800	2879	2958	3038	2728
8000	Grnd Roll	1456	1509	1563	1616	1669	1452
	Total	2805	2887	2969	3052	3136	2794
9000	Grnd Roll	1513	1569	1824	1679	1735	1497
	Total	2892	2976	3064	3152	3240	2863
10000	Grnd Roll	1573	1630	1688	1746	1803	1545
	Total	2984	3074	3165	3257	3350	2936

Figure 19-8 Excerpt from a SR-22 landing performance chart.

En Route Performance

En route performance is an important consideration, especially in high-performance airplanes. The incorrect selection of power settings, cruise speed, and cruise altitudes can significantly affect the efficiency and economics of operating your airplane.

While you are required to extract only cruise performance data for the Private Pilot FAA Knowledge Exam, we recommend that, at some stage, you read through the commercial pilot sections of this chapter that include climb performance data, as well as different presentations of cruise performance data. The additional knowledge gained will lead to improved practical operation of your airplane.

Cruise Altitude and Power Setting

Choice of *cruise altitude* depends on:

- distance to destination;
- terrain;
- airplane gross weight;
- weather (visibility and cloud base);
- wind at various altitudes; and
- ATC and airspace requirements.

To level off at cruise altitude leave climb power set until the airplane has accelerated to the desired cruise speed in level flight. The power is then reduced to *cruise power*, and the mixture is *leaned* as recommended in the Pilot's Operating Handbook.

The cruise speed maintained is determned by the power set.

The cruise speed maintained is determined by the power set. Cruise power settings are usually specified as a percentage of *maximum continuous power* (MCP). Typical cruise figures are in the range of 55%–75% MCP (or 55–75% BHP, where BHP means brake horsepower). It is possible, of course, to set higher power for cruise, even 100% MCP as the name maximum continuous power implies, but the consequences will be very high fuel consumption and increased engine wear.

Lean the mixture for best fuel consumption.

After cruise power is set, you should lean the mixture according to the procedures in the Pilot's Operating Handbook. Most engine manufacturers recommend that you lean the mixture only when the power setting is 75% MCP or less—full rich is used at higher power settings. Usually you would lean for *best power,* so that there is a slight excess of fuel compared with the chemically correct mixture. This will give the best speed at that power setting, and the small amount of excess fuel will help cool the cylinders. Correct leaning procedure is important for long engine life.

From a performance point of view, the engine-propeller combination is most efficient at the altitude where the desired percentage power is obtained with the throttle fully open, known as the full-throttle altitude.

Indicated and Outside Air Temperature

As airspeed increases the IOAT will be slightly higher than the actual outside air temperature.

The temperature shown in the cockpit on the outside air temperature gauge is the *indicated outside air temperature* (IOAT). As airspeed increases, air moving past the outside-air-temperature probe will be compressed. When air is compressed, it warms, and this will cause a slight increase in the temperature detected and displayed in the cockpit.

The actual temperature of the outside air is called the *outside air temperature* (OAT) and also can be obtained from a weather forecast or report. When operating high-speed airplanes a correction factor can be applied to the IOAT to obtain OAT.

Although you will find both IOAT and OAT in performance tables and graphs, in the Private and Commercial Knowledge Exams, it is normal to find a simple reference to "temperature" in the question setting.

Presentation of Performance Data

Manufacturers present performance data in different ways, the most common being tables and graphs. The following examples are typical of the data for Cirrus airplanes.

75% POWER							Mixture = Best Power
Press Alt	Climb Fuel	Fuel Remaining For cruise	Airspeed	Fuel Flow	Endurance	Range	Specific Range ISA
FT	Gal	Gal	KTAS	GPH	Hours	NM	Nm/Gal
0	0.0	46.3	143	11.6	4.0	576	12.3
2000	0.6	45.7	147	11.6	4.0	594	12.6
4000	1.3	45.0	150	11.6	4.0	606	12.7
6000	2.0	44.3	152	11.6	4.0	617	12.7
8000	2.9	43.4	155	11.6	4.0	617	12.7
10000	3.8	42.5					
12000	5.0	41.3					
14000	6.8	39.5					

65% POWER							Mixture = Best Power
Press Alt	Climb Fuel	Fuel Remaining For cruise	Airspeed	Fuel Flow	Endurance	Range	Specific Range ISA
FT	Gal	Gal	KTAS	GPH	Hours	NM	Nm/Gal
0	0.0	46.3	137	10.5	4.4	608	13.0
2000	0.6	45.7	139	10.5	4.4	620	13.1
4000	1.3	45.0	141	10.5	4.4	628	13.2
6000	2.0	44.3	143	10.5	4.4	635	13.2
8000	2.9	43.4	145	10.5	4.4	645	13.3
10000	3.8	42.5	147	10.5	4.4	654	13.3
12000	5.0	41.3	150	10.5	4.4	666	13.4
14000	6.8	39.5					

Figure 19-9 Cruise performance graph for a Cirrus SR-22.

Cirrus SR-20 Performance Data

To use the table in figure 19-10, determine the pressure altitude of the cruise. The table reveals the airplane's endurance along with the range and specific range (nautical miles per gallon)

Cirrus DR-22 Performance Data

To use the table in figure 19-10, simply extract the figures. For instance at 4,000 feet pressure altitude at standard temperature (ISA of 7°C) and with Manifold Pressure set at 23.4", you would be cruising at 78% power and would achieve 172 knots true air speed (KTAS) with a fuel flow/consumption of 18.5 gph.

> **Note.** All performance graphs and tables will have various notes printed on them with details of the conditions that apply and information governing use of data. You should pay particular attention to these notes and be aware that they will be different for each graph or table.

2000 Feet Pressure Altitude										
		ISA -30ºC (-19ºC)			ISA (11ºC)			ISA + 30ºC (41ºC)		
RPM	MAP	PWR	KTAS	GPH	PWR	KTAS	GPH	PWR	KTAS	GPAH
2700	27.4	103%	186	24.6	98%	186	23.3	93%	181	22.0
2600	27.4	99%	183	23.5	94%	183	22.3	89%	178	21.5
2500	27.4	93%	179	22.1	88%	179	20.9	84%	174	20.8
2500	26.4	89%	176	21.1	84%	176	19.9	80%	171	20.2
2500	25.4	84%	173	20.0	80%	173	19.0	76%	168	19.5
2500	24.4	80%	170	19.0	76%	170	18.0	72%	165	18.8
2500	23.4	76%	167	18.0	72%	167	17.0	68%	162	18.1

4000 Feet Pressure Altitude										
		ISA -30ºC (-23ºC)			ISA (7ºC)			ISA + 30ºC (37ºC)		
RPM	MAP	PWR	KTAS	GPH	PWR	KTAS	GPH	PWR	KTAS	GPAH
2700	25.4	96%	185	22.9	91%	185	21.6	87%	180	20.8
2600	25.4	92%	182	21.9	87%	182	20.7	83%	177	20.6
2500	25.4	87%	178	20.6	82%	178	19.5	78%	173	29.9
2500	24.4	82%	175	19.5	78%	175	18.5	74%	170	19.2
2500	23.4	78%	172	18.5	74%	172	17.5	70%	167	18.5
2500	22.4	73%	169	17.4	69%	169	16.5	66%	163	17.7
2500	21.4	69%	165	16.4	65%	165	15.5	62%	159	16.9

Figure 19-10 Cruise performance table for a Cirrus SR-22.

Performance Data used for the Private Pilot Knowledge Exam

The table of *cruise power settings* used in the Private Pilot Knowledge Exam is shown in figure 19-11. It is based on an airplane gross weight of 2,800 pounds with 65% maximum continuous power set, or full throttle at higher altitudes. Enter this table on the left-hand side with *pressure altitude*, and *temperature* using either ISA deviation at the top of the table when planning, or with IOAT when in flight. Note that you will see that the IOAT values are slightly higher than the OAT. For instance at sea level, the ISA temperature is +15°C, whereas the IOAT for a TAS of 150 knots is +17°C. Now you can find:

- *power setting* to achieve 65% MCP in terms of *RPM* and *manifold pressure* (MP);
- fuel flow in gallons per hour (gph), with the expected fuel pressure gauge indication in pounds per square inch (psi); and
- *true airspeed* (TAS) in knots or miles per hour (MPH).

For example, at 4,000 feet pressure altitude with standard temperature (ISA), you can extract:

power setting 2,450 RPM, MP 20.7 in. Hg; fuel flow 11.5 gph (expected fuel pressure 6.6 psi); and TAS 156 knots (or 180 MPH).

CRUISE POWER SETTINGS

65% MAXIMUM CONTINUOUS POWER (OR FULL THROTTLE)
2800 POUNDS

PRESS ALT.	ISA −20 °C (−36 °F)									STANDARD DAY (ISA)									ISA +20 °C (+36 °F)								
	IOAT		ENGINE SPEED	MAN. PRESS	FUEL FLOW PER ENGINE		TAS		IOAT		ENGINE SPEED	MAN. PRESS	FUEL FLOW PER ENGINE		TAS		IOAT		ENGINE SPEED	MAN. PRESS	FUEL FLOW PER ENGINE		TAS	
FEET	°F	°C	RPM	IN HG	PSI	GPH	KTS	MPH	°F	°C	RPM	IN HG	PSI	GPH	KTS	MPH	°F	°C	RPM	IN HG	PSI	GPH	KTS	MPH
SL	27	-3	2450	20.7	6.6	11.5	147	169	63	17	2450	21.2	6.6	11.5	150	173	99	37	2450	21.8	6.6	11.5	153	176
2000	19	-7	2450	20.4	6.6	11.5	149	171	55	13	2450	21.0	6.6	11.5	153	176	91	33	2450	21.5	6.6	11.5	156	180
4000	12	-11	2450	20.1	6.6	11.5	152	175	48	9	2450	20.7	6.6	11.5	156	180	84	29	2450	21.3	6.6	11.5	159	183
6000	5	-15	2450	19.8	6.6	11.5	155	178	41	5	2450	20.4	6.6	11.5	158	182	79	26	2450	21.0	6.6	11.5	161	185
8000	-2	-19	2450	19.5	6.6	11.5	157	181	36	2	2450	20.2	6.6	11.5	161	185	72	22	2450	20.8	6.6	11.5	164	189
10000	-8	-22	2450	19.2	6.6	11.5	160	184	28	-2	2450	19.9	6.6	11.5	163	188	64	18	2450	20.3	6.5	11.4	186	191
12000	-15	-26	2450	18.8	6.4	11.3	162	186	21	-6	2450	18.8	6.1	10.9	163	188	57	14	2450	18.8	5.9	10.6	163	188
14000	-22	-30	2450	17.4	5.8	10.5	159	183	14	-10	2450	17.4	5.6	10.1	160	184	50	10	2450	17.4	5.4	9.8	160	184
16000	-29	-34	2450	16.1	5.3	9.7	156	180	7	-14	2450	16.1	5.1	9.4	156	180	43	6	2450	16.1	4.9	9.1	155	178

NOTES: 1. Full throttle manifold pressure settings are approximate.
2. Shaded area represents operation with full throttle.

Figure 19-11 Airplane power setting table used in the Private Knowledge Exam.

Interpolation

Often the figures you require lie somewhere between the tabulated figures, and so you must interpolate.

Example 19-1

Refer to figure 19-11. The IOAT at 6,000 ft is -5°C, what is the TAS? From table 19-1, you can see that at 6,000 ft, an IOAT of -15°C gives a TAS of 155 knots and +5° gives 158 knots. Since -5°C is halfway between -15 and +5°C, the TAS is:

Press alt	IOAT °C	TAS kt	IOAT °C	TAS kt
6,000	−15	155	+5	158

Table 19-1
Extract of table for interpolation

$$155 + \left(\frac{158 - 155}{2}\right) = 155 + 1.5 = 156.5 \text{ knots}$$

Fuel Consumption

Once the flight distance has been measured and the TAS and fuel flow found from the performance graph or chart, the fuel consumption for the flight can be calculated:

- first find the flight time by dividing the flight distance by the TAS. For example, to cover 240 nautical miles (NM) at 90 KTAS will take $^{240}/_{90}$ = 2.67 hours; and
- find the fuel consumption by multiplying the flight time by the fuel flow. For example, if the fuel flow was 6.6 gph over 2.67 hours the fuel consumption would be 6.6 × 2.67 = 17.6 gallons.

Note. These calculations can be done either on an electronic calculator or on a flight computer.

Example 19-2

Referring to figure 19-11 (page 461), what is the expected fuel consumption for a 420 NM flight in no-wind conditions at 65% MCP under the following conditions? Specify the power settings.

Pressure altitude	6,000 feet
Forecast temperature	-15°C
Wind	calm

First find which ISA column to use. ISA at 6,000 feet is [15 – (6 × 2)] = 3°C. Therefore –15°C is equivalent to ISA–18°C. This is closest to ISA–20°C, so we can extract:

- power setting: 2,450 RPM, MP 19.8 in. Hg;
- TAS 155 knots; and
- 11.5 gph.

1. Time calculation: Time = $\frac{\text{distance}}{\text{TAS}} = \frac{420}{155}$ = 2.71 hours

2. Fuel calculation: Fuel = time × fuel flow = 2.71 × 11.5 = 31.2 gallons.

Effect of Wind in Cruise

Normally during cruise, there is a wind that will affect the distance covered over the ground. If there is a headwind, the air in which the airplane is flying will be moving backward over the ground and therefore in a given time the ground distance covered, measured in nautical air miles (NM), will decrease. Conversely a tailwind will increase the ground distance covered in a given time. However the distance flown through the air, measured in nautical miles (NM), will remain the same.

Because the effect of wind will alter the time to cover a set ground distance, such as between two airports, it will also affect the amount of fuel required. A strong headwind will increase your flight time and fuel consumption, a hazardous situation if you had planned your fuel requirements without wind.

Example 19-3

Using the information in example 10-2, what will be the flight time and fuel consumption if there is now a 30-knot headwind?

1. $\text{Time} = \dfrac{\text{ground distance}}{\text{ground speed}} = \dfrac{420}{(\text{KTAS} - \text{headwind})} = \dfrac{420}{(155 - 30)} = 3.36 \text{ hours}$

2. Fuel = time × fuel flow = 3.36 × 11.5 = 38.7 gallons.

The Flight Plan Form

Fill out the flight plan form, and insert any relevant *emergency equipment* carried in the REMARKS section. In Block 3 of the flight plan form, the letter "U" indicates that you are equipped with a transponder with altitude encoding. In Block 7, you should insert your initial cruise altitude—other cruise altitudes may be requested from ATC en route. In Block 9, you should insert the final destination airport if no stopover at intermediate airports for more than 1 hour is anticipated. In Block 10, you should insert the amount of usable fuel on board expressed in time (total endurance)

AIRCRAFT EQUIPMENT SUFFIXES

	NO DME
/X	No transponder
/T	Transponder with no Mode C
/U	Transponder with Mode C
	DME
/D	No transponder
/B	Transponder with no Mode C
/A	Transponder with Mode C
	TACAN ONLY
/M	No transponder
/N	Transponder with no Mode C
/P	Transponder with Mode C
	AREA NAVIGATION (RNAV)
/Y	LORAN, VOR/DME, or INS with no transponder
/C	LORAN, VOR/DME, or INS, transponder with no Mode C
/I	LORAN, VOR/DME, or INS, transponder with Mode C
	ADVANCED RNAV WITH TRANSPONDER AND MODE C (If an aircraft is unable to operate with a transponder and/or Mode C, it will revert to the appropriate code listed above under Area Navigation.)
/E	Flight Management System (FMS) with en route, terminal, and approach capability.
/F	FMS with en route, terminal, and approach capability.
/G	Global Positioning System (GPS)/Global Navigation Satellite System (GNSS) equipped aircraft with en route and terminal capability
/R	Required Navigational Performance (Denotes capability to operate in RNP designated airspace and routes)
/W	Reduced Vertical Separation Minima (RVSM)
/Q	Required Navigation Performance (RNP) and Reduced Vertical Separation Minima (RVSM)

Figure 19-12 Special equipment suffixes for flight plan form.

U.S. Department of Transportation
Federal Aviation Administration

— FLIGHT PLANNER —

(INFORMATION THAT YOU ENTER ON THIS FORM IS FOR PILOT'S USE ONLY.)

SAMPLE ONLY
not to be used
in conjunction
with flight operations
or flight planning

PREFLIGHT				EN ROUTE					
DEPARTURE PT	ROUTE			ESTIMATED			ACTUAL		
CHECK POINTS	VIA	CRS	DIST	GS	ETE	ETA	GS	ATE	ATA
OGD	D→	190	41	89	:28				
SLC	V21	162	23	95	:15				
PVU	D→	157	39	97	:25				

	FUEL MANAGEMENT					
OFF						
ON						
TIME						

TIME EN ROUTE	
TOUCH-DOWN	
TAKE-OFF	
ATE	

FOLD ALONG THIS LINE

Form Approved: OMB No. 04-R0072

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
FLIGHT PLAN

CIVIL AIRCRAFT PILOTS. FAR Part 91 requires you file an IFR flight plan to operate under instrument flight rules in controlled airspace. Failure to file could result in a civil penalty not to exceed $1,000 for each violation (Section 901 of the Federal Aviation Act of 1958, as amended). Filing of a VFR flight plan is recommended as a good operating practice. See also Part 99 for requirements concerning DVFR flight plans.

1. TYPE	2. AIRCRAFT IDENTIFICATION	3. AIRCRAFT TYPE/ SPECIAL EQUIPMENT	4. TRUE AIRSPEED	5. DEPARTURE POINT	6. DEPARTURE TIME PROPOSED (Z)	ACTUAL (Z)	7. CRUISING ALTITUDE
✓ VFR / IFR / DVFR	N4608Q	Cirrus SR22/G	100 KTS	LGU	2030		10,500

8. ROUTE OF FLIGHT: DIRECT

9. DESTINATION (Name of airport and city)	10. EST. TIME ENROUTE HOURS	MINUTES	11. REMARKS
PVU	1	08	STUDENT PILOT

12. FUEL ON BOARD HOURS	MINUTES	13. ALTERNATE AIRPORT(S)	14. PILOT'S NAME, ADDRESS & TELEPHONE NUMBER & AIRCRAFT HOME BASE	15. NUMBER ABOARD
3	35		John J. Pilot, LOGAN, UT 801-555-1221	2

16. COLOR OF AIRCRAFT: WHITE/BLUE TRIM — CLOSE VFR FLIGHT PLAN WITH ________ FSS ON ARRIVAL

FAA Form 7233-1 (8-77)

CLEARANCES/RADIO FREQUENCIES:

LGU Unicom 122.8
FSS - Cedar City 122.1/115.7
SLC Apch for ARSA 121.1
PVU Unicom 122.8
FSS - Cedar City 122.1/116.6

INSTRUCTIONS FOR THE USE OF THIS FORM ARE CONTAINED IN THE FAA PAMPHLET "HOW TO OBTAIN A GOOD WEATHER BRIEFING" FAA-P-8740-30A

Figure 19-13 Flight log and flight plan.

Flight Notification

Prior to flight, contact the Flight Service Station (FSS) and file the flight plan.

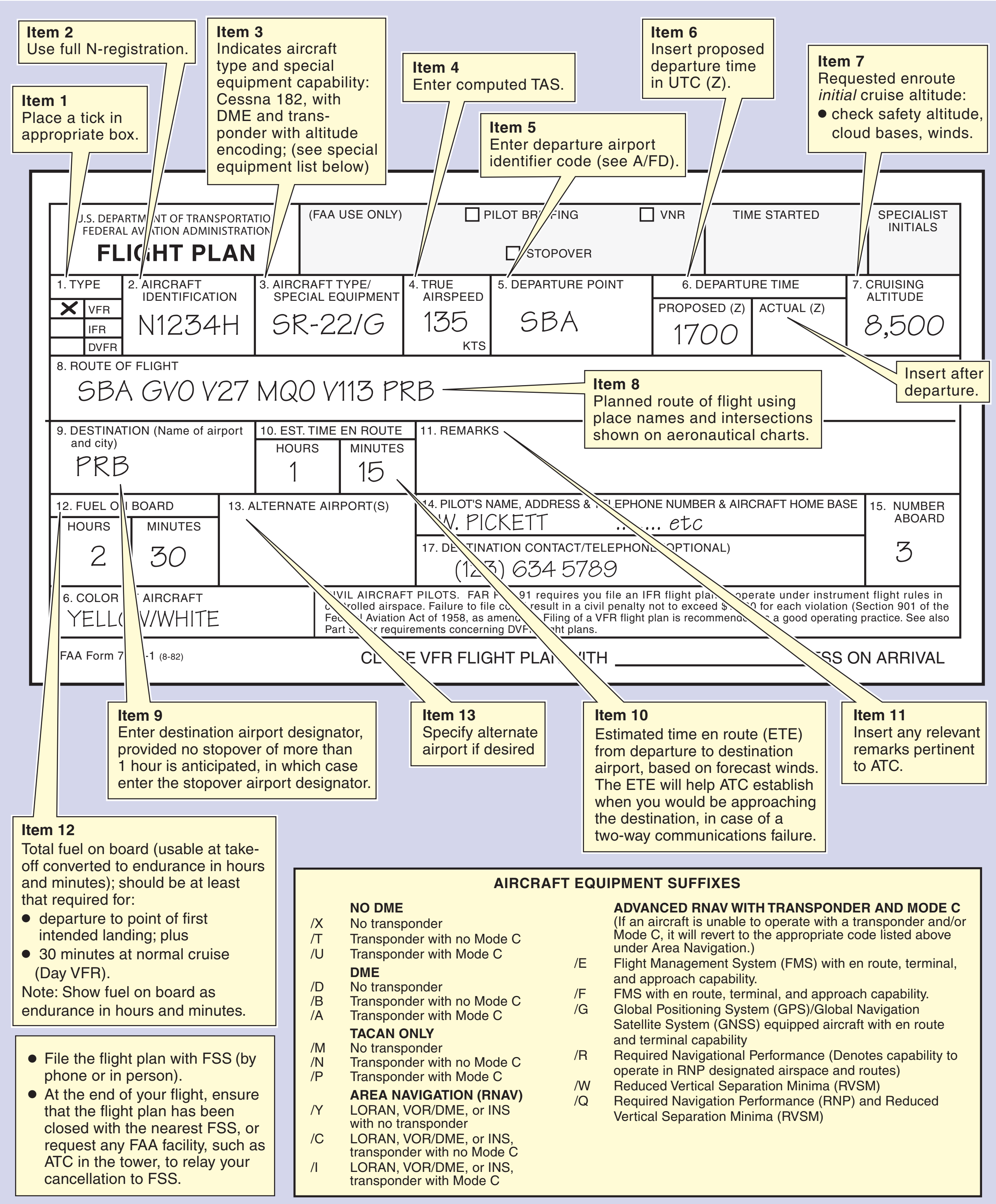


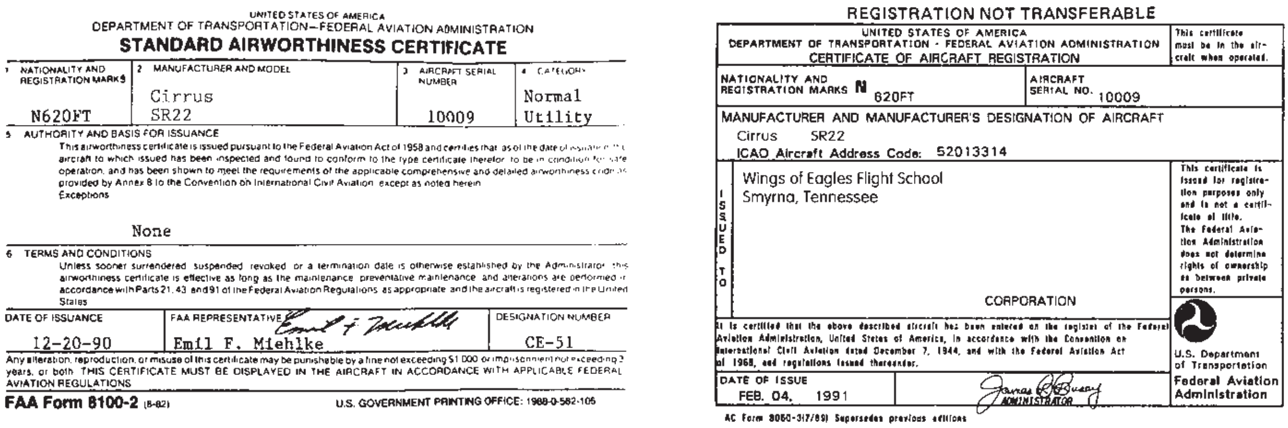
Figure 19-14 A typical VFR flight plan.

"AROW"
- *Airworthiness Certificate*
- *Registration Certificate*
- *Operating limitations (Flight Manual etc.)*
- *Weight-and-balance information*

Airplane Documentation and Preparation for Flight

You should check that the required documents are carried:
- "AROW"—for the airplane; and
- pilot certificate and medical certificate (and logbook with endorsements if you are a student pilot)—for yourself as pilot in command.

You must be familiar with these airplane documents, any equipment list, weight-and-balance data, maintenance requirements and appropriate records.



UNITED STATES OF AMERICA
DEPARTMENT OF TRANSPORTATION—FEDERAL AVIATION ADMINISTRATION
STANDARD AIRWORTHINESS CERTIFICATE

1 NATIONALITY AND REGISTRATION MARKS: N620FT
2 MANUFACTURER AND MODEL: Cirrus SR22
3 AIRCRAFT SERIAL NUMBER: 10009
4 CATEGORY: Normal Utility

5 AUTHORITY AND BASIS FOR ISSUANCE
This airworthiness certificate is issued pursuant to the Federal Aviation Act of 1958 and certifies that as of the date of issuance the aircraft to which issued has been inspected and found to conform to the type certificate therefor, to be in condition for safe operation, and has been shown to meet the requirements of the applicable comprehensive and detailed airworthiness code as provided by Annex 8 to the Convention on International Civil Aviation except as noted herein.
Exceptions
None

6 TERMS AND CONDITIONS
Unless sooner surrendered, suspended, revoked, or a termination date is otherwise established by the Administrator, this airworthiness certificate is effective as long as the maintenance, preventative maintenance, and alterations are performed in accordance with Parts 21, 43, and 91 of the Federal Aviation Regulations, as appropriate, and the aircraft is registered in the United States.

DATE OF ISSUANCE: 12-20-90
FAA REPRESENTATIVE: Emil F. Miehlke
DESIGNATION NUMBER: CE-51

Any alteration, reproduction, or misuse of this certificate may be punishable by a fine not exceeding $1,000 or imprisonment not exceeding 3 years, or both. THIS CERTIFICATE MUST BE DISPLAYED IN THE AIRCRAFT IN ACCORDANCE WITH APPLICABLE FEDERAL AVIATION REGULATIONS

FAA Form 8100-2 (8-82) U.S. GOVERNMENT PRINTING OFFICE: 1988-0-582-105

REGISTRATION NOT TRANSFERABLE

UNITED STATES OF AMERICA
DEPARTMENT OF TRANSPORTATION - FEDERAL AVIATION ADMINISTRATION
CERTIFICATE OF AIRCRAFT REGISTRATION

This certificate must be in the aircraft when operated.

NATIONALITY AND REGISTRATION MARKS N 620FT
AIRCRAFT SERIAL NO. 10009

MANUFACTURER AND MANUFACTURER'S DESIGNATION OF AIRCRAFT
Cirrus SR22
ICAO Aircraft Address Code: 52013314

ISSUED TO
Wings of Eagles Flight School
Smyrna, Tennessee
CORPORATION

This certificate is issued for registration purposes only and is not a certificate of title. The Federal Aviation Administration does not determine rights of ownership as between private persons.

It is certified that the above described aircraft has been entered on the register of the Federal Aviation Administration, United States of America, in accordance with the Convention on International Civil Aviation dated December 7, 1944, and with the Federal Aviation Act of 1958, and regulations issued thereunder.

DATE OF ISSUE FEB. 04, 1991
ADMINISTRATOR

U.S. Department of Transportation
Federal Aviation Administration

AC Form 8050-3(7/89) Supersedes previous editions

Figure 19-15 Examples of airworthiness and registration certificates.

Ensure that there is adequate fuel on board and complete your normal preflight duties, including the external (walk-around) inspection and internal inspection. Never hurry this aspect of the flight. It is most important that the preflight preparation is thorough and, even if you are running behind schedule because flight planning took longer than expected (a common reason), do not rush your normal preflight duties.

Complete as much flight planning as possible a day or more in advance of your planned flight.

Settle into the cockpit and place your navigation equipment and charts where they are readily accessible. Ensure that the charts are folded so that at least 20 NM either side of course is visible. Ensure that no metallic or magnetic objects (like headsets) are placed near the magnetic compass. Check on the comfort of your passengers (at this stage your flight instructor), and carry out any necessary briefing.

These final checks are worthwhile since, once the engine starts, the noise level will be higher, communication will be slightly more difficult, and you will be busier with the normal workload of manipulating the airplane.

Route Segment	Safety Altitude	Altitude	Temp °C	TAS	Course			Wind °T	Heading						Speed/Distance/Time			
					TC (ref long)	Var	MC (VOR)		WCA	TH	Var	MH	Dev	CH	GS	Dist	ETA ATE	ETA ATE
Peter Ck R																		
Dermott	2800	5500	+10	107	062	4E	058	270/30	–9	053	4E	049	+1	050	132	65	30	
Kelly	1300	5500	+10	107	177	3E	174	270/30	+12	189	3E	186	+2	188	105	47	25	
															TOTAL	112	55	

DEVIATION CARD

FOR					
N	30	60	E	120	150
STEER					
001	031	060	089	118	149
FOR					
S	210	240	W	300	330
STEER					
181	213	242	271	301	330

ON ☒ RADIOS ☐ NO

Base your selection of cruise altitude on Magnetic Course (also use it when selecting VOR radials

Calculate MH at flight-planning stage, and apply any deviation in flight (found on compass card in aircraft

Figure 19-16 Flight log for a flight from Peter Creek to Kelly, via Dermott.

Review 19

Flight Planning

1. When planning a VFR flight, what weather information should you study?
2. Where is detailed airport information found?
3. True or false? You should normally plan a VFR flight to cruise at least 500 feet AGL over open country.
4. What are the minimum altitudes for the following?
   - **a.** Flying above mountainous terrain.
   - **b.** Clearing wildlife refuges.
5. True or false? If planning to fly more than 3,000 feet AGL, you should you base your VFR cruise altitude on magnetic heading.
6. True or false? VOR radials are based on true north.
7. Cloud bases in Area Forecasts are given in:
   - **a.** feet MSL.
   - **b.** feet AGL.
8. Cloud bases in Terminal Aerodrome Forecasts are given in:
   - **a.** feet MSL.
   - **b.** feet AGL.
9. What are suitable cruise altitudes at or above your safety altitude of 4,300 feet MSL if the cloud bases are at 7,000 feet MSL and your planned magnetic course is:
   - **a.** MC 060.
   - **b.** MC 250.
   - **c.** MC 179.
   - **d.** MC 180.
10. How is fuel information specified on a flight plan form submitted to FSS?

Refer to figure 19-17 for questions 11 to 13.

11. If more than one cruising altitude is intended, which one should be entered in block 7 of the flight plan?
12. What information should be entered in block 9 for a VFR day flight?
13. What information should be entered in block 12 for a VFR day flight?
14. How should a VFR flight plan be closed at the completion of the flight at a controlled airport?

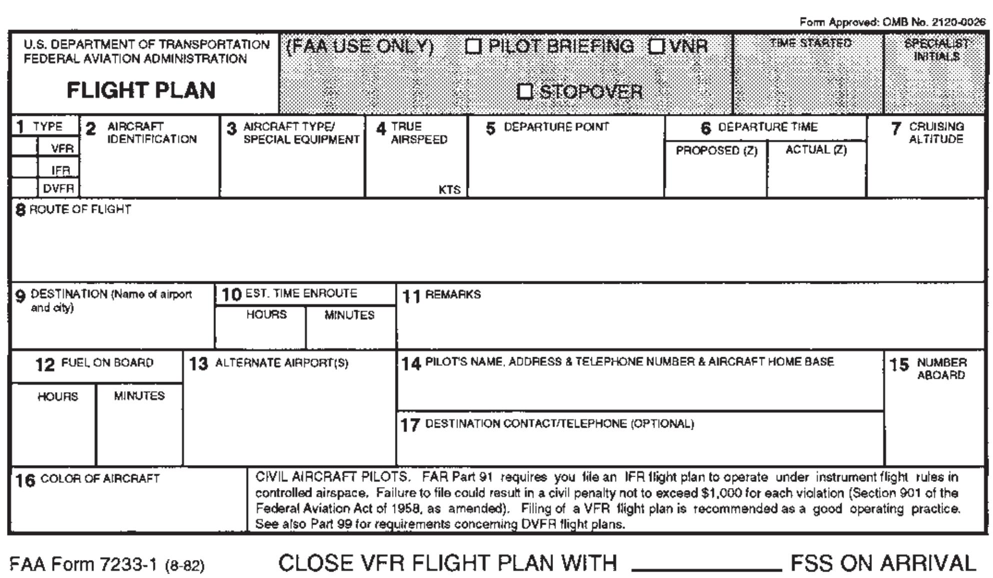

Form Approved: OMB No. 2120-0026
U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
FLIGHT PLAN
(FAA USE ONLY) ☐ PILOT BRIEFING ☐ VNR
☐ STOPOVER
TIME STARTED
SPECIALIST INITIALS
1 TYPE — VFR, IFR, DVFR
2 AIRCRAFT IDENTIFICATION
3 AIRCRAFT TYPE/ SPECIAL EQUIPMENT
4 TRUE AIRSPEED — KTS
5 DEPARTURE POINT
6 DEPARTURE TIME — PROPOSED (Z), ACTUAL (Z)
7 CRUISING ALTITUDE
8 ROUTE OF FLIGHT
9 DESTINATION (Name of airport and city)
10 EST. TIME ENROUTE — HOURS, MINUTES
11 REMARKS
12 FUEL ON BOARD — HOURS, MINUTES
13 ALTERNATE AIRPORT(S)
14 PILOT'S NAME, ADDRESS & TELEPHONE NUMBER & AIRCRAFT HOME BASE
15 NUMBER ABOARD
17 DESTINATION CONTACT/TELEPHONE (OPTIONAL)
16 COLOR OF AIRCRAFT
CIVIL AIRCRAFT PILOTS. FAR Part 91 requires you file an IFR flight plan to operate under instrument flight rules in controlled airspace. Failure to file could result in a civil penalty not to exceed $1,000 for each violation (Section 901 of the Federal Aviation Act of 1958, as amended). Filing of a VFR flight plan is recommended as a good operating practice. See also Part 99 for requirements concerning DVFR flight plans.
FAA Form 7233-1 (8-82)
CLOSE VFR FLIGHT PLAN WITH ____________ FSS ON ARRIVAL

Figure 19-17 Flight plan form.

Cruise Altitude and Power Setting

Refer to the cruise power setting table in figure 19-11 (page 461) for questions 15 to 24.

15. What true airspeed can you expect with 65% maximum continuous power at 8,000 feet pressure altitude with a temperature of 20°C below standard?

16. What true airspeed can you expect with 65% maximum continuous power at 9,500 feet pressure altitude with a temperature of ISA –20°C? Give your answer in knots and mph.

17. To achieve 65% maximum continuous power at 4,000 feet pressure altitude with 2,450 RPM set, what would be the manifold pressure, if the temperature was ISA –20°C?

18. Which of the following is the approximate manifold pressure setting with 2,450 RPM to achieve 65% maximum continuous power at 7,000 feet with a temperature of 36°F higher than standard:
a. 20.9 in. Hg.
b. 20.8 in. Hg.
c. 21.0 in. Hg.

19. You are cruising at 10,000 feet pressure altitude on a standard day (ISA temperatures) with 65% maximum continuous power.
a. What fuel flow in gph can you expect?
b. What true airspeed in knots would you expect to achieve?

20. You are cruising at 11,000 feet pressure altitude on a standard day (ISA temperatures) with 65% maximum continuous power.
a. What fuel flow in gph can you expect?
b. What true airspeed in knots would you expect to achieve?

21. Which of the following is the approximate true airspeed a pilot will expect with 65% maximum continuous power at 9,500 feet with a temperature of 36°F below standard?
a. 178 mph.
b. 181 mph.
c. 183 mph.

22. Given the following, what is the expected fuel consumption for a 500 NM flight?

Pressure altitude	4,000 feet
Temperature	+29°C
Manifold pressure	21.3 in. Hg
Wind	calm

23. Given the following, what is the expected fuel consumption for a 450 NM flight?

Pressure altitude	12,000 feet
IOAT	–6°C
Manifold pressure	18.8 in. Hg
Headwind	10 knots

24. Given the following, what is the expected fuel consumption for a 1,000 NM flight?

Pressure altitude	8,000 feet
Indicated temperature	–19°C
Manifold pressure	19.5 in. Hg
Wind	calm

Answers are given on page 780.

Instrument Flight

Introduction to Instrument Flight 20

Air travel becomes much more reliable when airplane operations are not restricted by poor weather or by darkness. Greater reliability can be achieved with a suitably equipped airplane and a pilot skilled in instrument flying.

The instrument-qualified pilot and the instrument-equipped airplane must be able to cope with flying in restricted visibility, such as in cloud, mist, smog, rain, snow, or at night, all of which may make the natural horizon and ground features difficult, or even impossible, to see.

As an instrument pilot, you must learn to trust what you see on the instruments. We generally use vision to orient ourselves with our surroundings, supported by other gravity-perceiving bodily senses, such as feel and balance. Even with the eyes closed, however, we can usually manage to sit, stand and walk on steady ground without losing control. This becomes much more difficult standing on the tray of an accelerating or turning truck, or even in an accelerating elevator.

In an airplane, which can accelerate in three dimensions, the task becomes almost impossible unless you have the use of your eyes.

The eyes must gather information from the external ground features, including the horizon; or, in poor visibility, they gather substitute information from the instruments.

Figure 20-1
Control and performance.

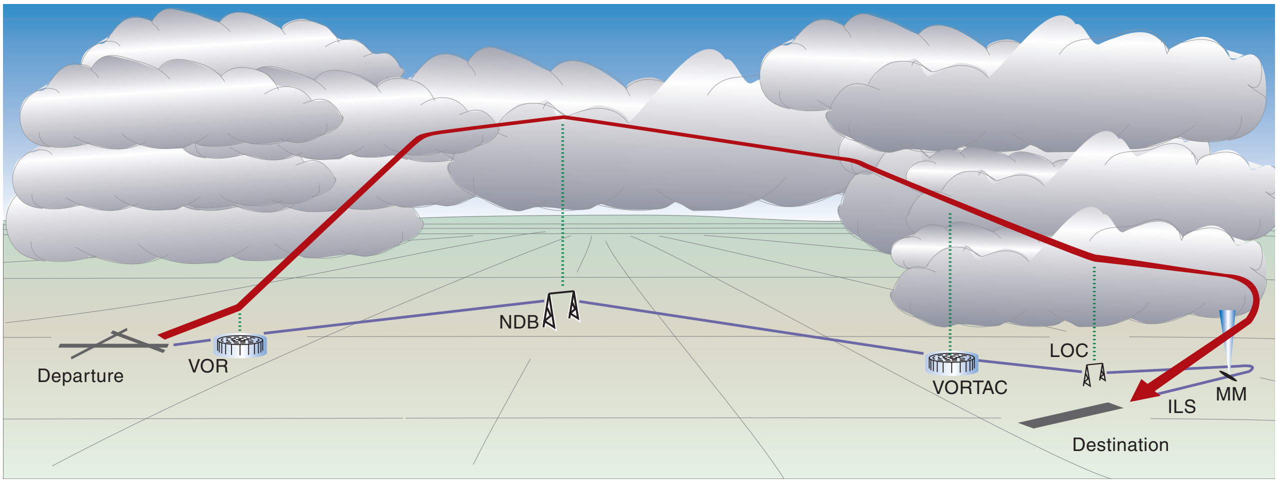


Figure 20-2 A typical flight on instruments.

A pilot's eyes are very important, and the starting point in your instrument training will be learning to use your eyes to derive information from the instruments in the most efficient way. You will learn various scan patterns that gather the most relevant data for your particular flight maneuver.

Figure 20-3 The eyes and the instruments.

The Three Fundamental Skills in Instrument Flying

The three fundamental skills in instrument flying are:

- *instrument cross-check* (also known as scanning the instruments);
- *instrument interpretation* (understanding their message); and
- *airplane control* (directing the airplane along the desired flight path).

The Cockpit and Radio

Make Yourself Comfortable in the Cockpit

Instrument flying is much easier if you are comfortable in the cockpit and know your airplane well. Adjust the seat position prior to flight to ensure that you can reach all of the controls easily, and so that you have the correct eye position. The view from the cockpit window must be familiar when you break out of the clouds at a low altitude, following a successful instrument approach, and see the rapidly approaching runway. A correct eye position will make the ensuing landing, possibly in poor visibility, so much easier.

A Good Communications System Is Essential

In instrument meteorological conditions (IMC), "see and be seen" does not apply. Communications equipment is essential.

Ensure that the radio communications equipment in the airplane is both adequate and fully serviceable. This is of great importance. One of your main responsibilities as an instrument pilot is to remain in communication with ATC. Under *instrument meteorological conditions* (IMC), you will not be able to see other aircraft, nor will they be able to see you, hence the visual safety rule of "see and be seen" will not apply.

The separation of aircraft in IMC is achieved by each pilot flying along a known route at a known altitude at known times, with ATC, in cooperation with the pilots, ensuring that there are no conflicting flight paths. Good communications are therefore essential. On the rare occasions when a radio or electrical system fails, special procedures laid down for pilots to follow will minimize risk.

During your instrument training, there will be a fair amount of talking in the cockpit. Your instructor will be explaining things to you, and offering words of encouragement as you perform the various maneuvers.

If this cockpit communication has to be done by shouting over the engine and air noise, as it was in days past, then a lot of totally unnecessary stress will be introduced into the cockpit. A good intercom system will make life a lot easier for you and for your instructor, and will save you time and money. Speak with your instructor about this.

Attitude Flying and Applied Instrument Flying

Attitude flying on instruments is an extension of visual flying.

The first step in becoming an instrument pilot is to become competent at *attitude flying* on the full panel containing the six basic flight instruments. The term attitude flying means using a combination of engine power and airplane attitude to achieve the required performance in terms of flight path and airspeed.

Attitude flying on instruments is an extension of visual flying, with your attention gradually shifting from external visual cues to the instrument indications in the cockpit, until you are able to fly accurately on instruments alone.

Partial panel attitude instrument flying, also known as limited panel, will be introduced fairly early in your training. For this exercise, the main control instrument, the attitude indicator, is assumed to have malfunctioned and is not available for use. The heading indicator, often powered from the same source as the AI, may also be unavailable.

Partial panel training will probably be practiced concurrently with full panel training, so that the exercise does not assume an importance out of proportion to its difficulty. You will perform the same basic flight maneuvers, but on a reduced number of instruments. The partial panel exercise will increase your instrument flying competence, as well as your confidence.

Figure 20-4 The full panel (left) and the partial panel (right).

An excessively high or low nose attitude, or an extreme bank angle, is known as an *unusual attitude*. Unusual attitudes should never occur inadvertently but can result from distractions or a visual illusion. Practice in recovering from them, however, will increase both your confidence and your overall proficiency. This exercise will be practiced on both a full panel and a partial panel.

After you have achieved a satisfactory standard in attitude flying, on both a full panel and a partial panel, your instrument flying skills will be applied to en route flights using navigation aids (NAVAIDs) and radar.

Procedural instrument flying (which means getting from one place to another) is based mainly on knowing where the airplane is in relation to a particular ground transmitter (known as orientation), and then accurately tracking *to* or *from* the ground station. Tracking is simply attitude flying, plus a wind correction angle to allow for drift.

Typical NAVAIDs used are the ADF, VOR, DME and ILS, as well as ground-based radar. In many ways, en route navigation is easier using the navigation instruments than it is by visual means. It is also more precise.

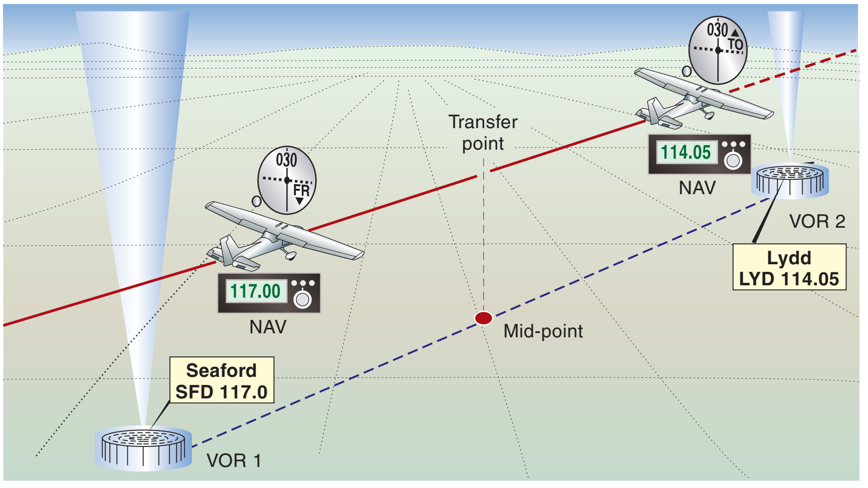


Figure 20-5 En route tracking on instruments.

Having navigated the airplane on instruments to a destination, you must consider your approach. If instrument conditions exist, an *instrument approach* must be made.

If you encounter visual conditions, you may continue with the instrument approach or, with ATC authorization, shorten the flight path by flying a visual approach or a contact approach. This allows you to proceed visually to a sighted runway.

Only published instrument approach procedures may be followed, with charts commonly used in the United States available from the FAA or Jeppesen. An instrument approach usually involves positioning the airplane over (or near) a ground station or a radio fix, and then using precise attitude flying to descend along the published flight path at a suitable airspeed.

If visual conditions are encountered on the instrument approach at or before a predetermined minimum altitude is reached, then the airplane may be maneuvered for a landing. If visual conditions are not met at or before this minimum altitude, perform a missed approach. The options are to climb away and position yourself for another approach, or to divert elsewhere.

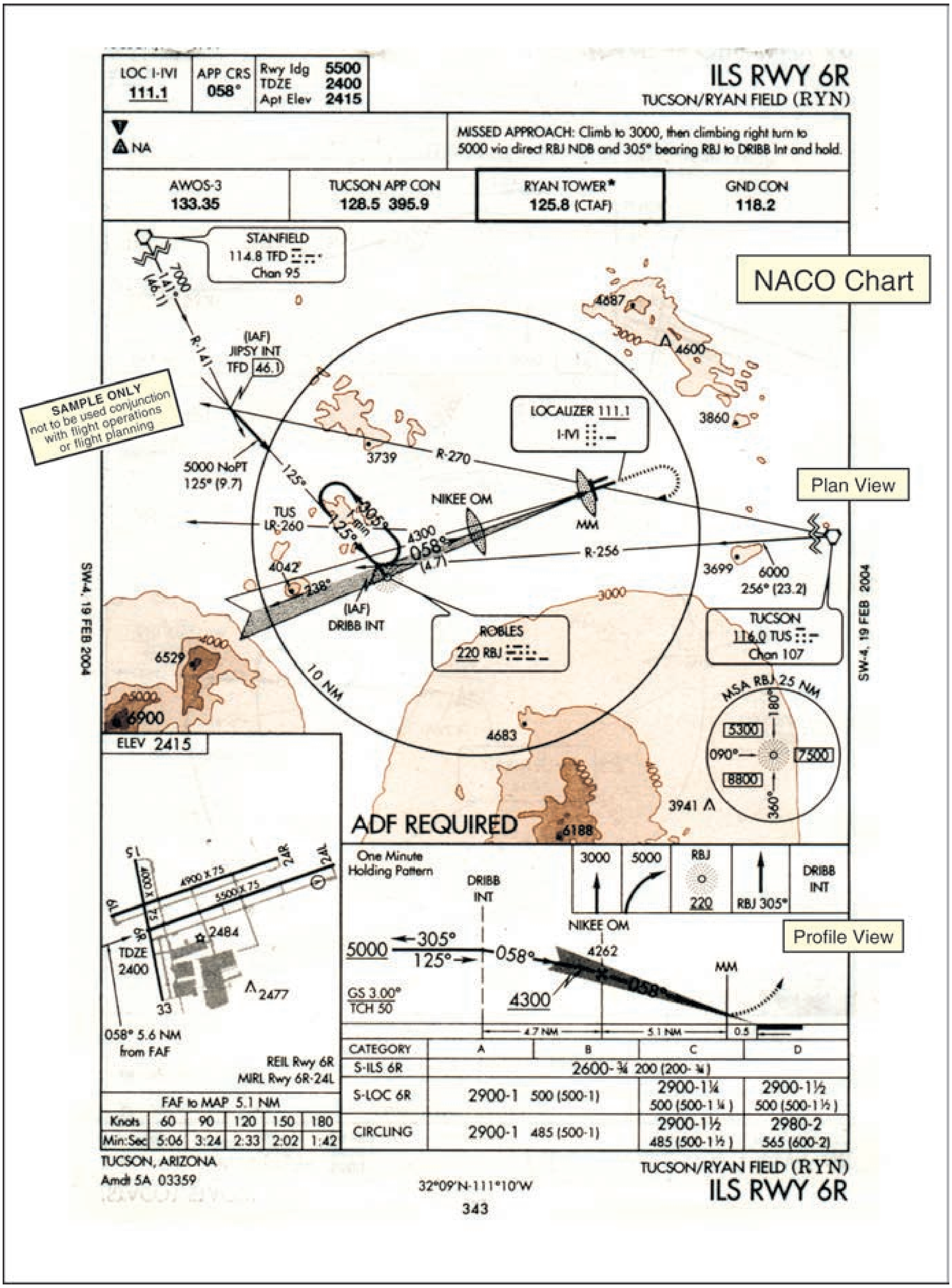


Figure 20-6 Plan and profile views of a precision instrument approach (NACO chart).

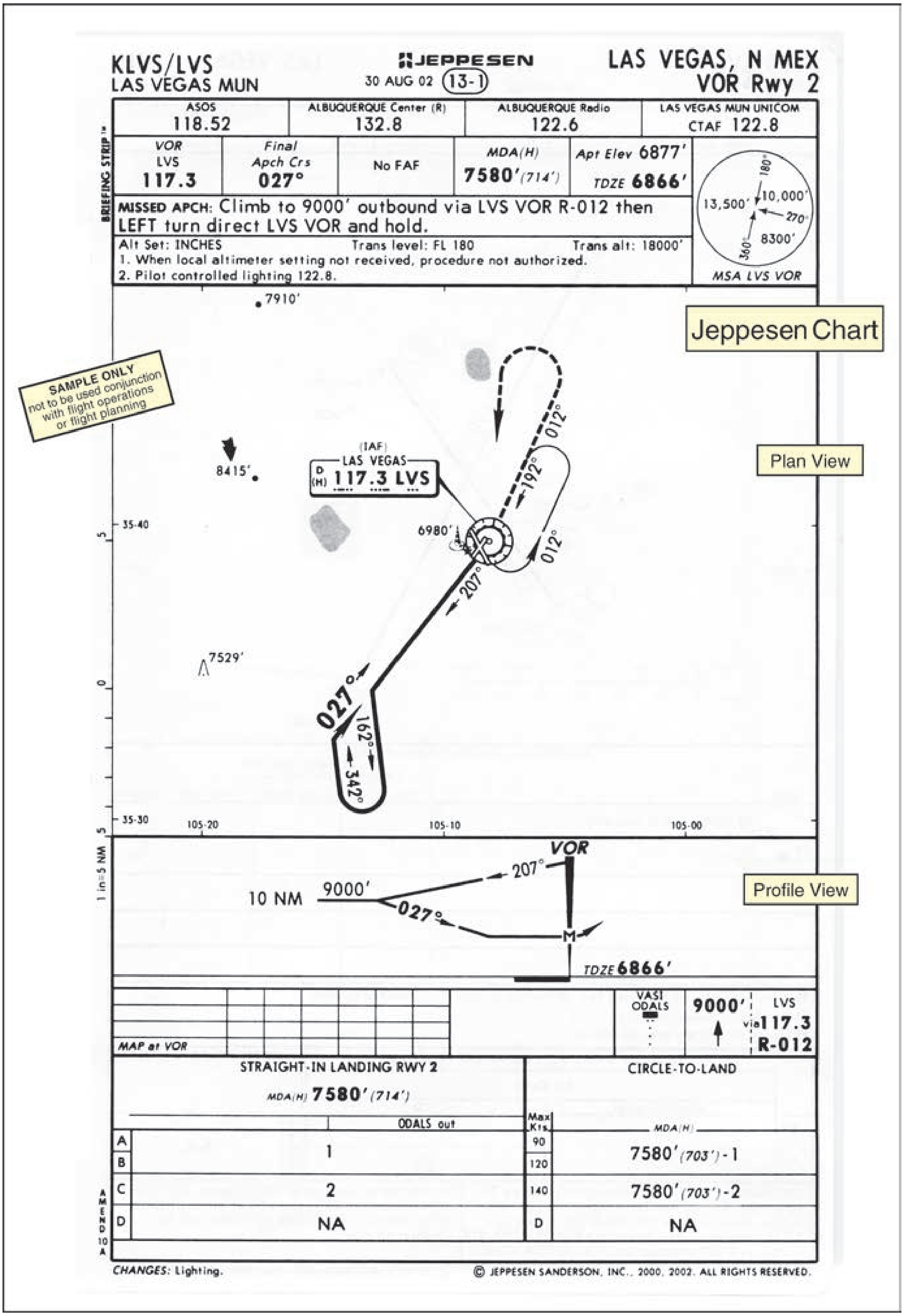


Figure 20-7 Plan and profile views of a nonprecision approach (Jeppesen Chart).

The Airplane and the Ground Trainer

Practice attitude instrument flying and procedures in a simulator or ground trainer first.

A simulator, ground trainer, or *personal computer aviation training device* (PCATD) is an extremely valuable training aid for practicing both attitude flying and instrument procedures. It is a great time-saver. It allows certain maneuvers (for instance, climbing turns at 5,000 feet) to be practiced without having to preflight check an actual airplane, then taxi out, wait in the queue, takeoff and climb for ten minutes, and so on. It is not dependent on weather—adverse weather conditions will not stop your practice. It allows easy conversation between student and instructor without the distraction of engine noise or radio calls. Time can be frozen, while the instructor discusses points of detail before the exercise continues.

Maneuvers can be repeated without delay and without interruption. Instrument procedures, such as an ILS approach to busy JFK International Airport in New York, can be practiced repeatedly in the simulator—a situation probably not possible in a real airplane because of the heavy traffic in the New York area. Also, procedures at any airport that you are about to visit for the first time, or that you might have to divert to, can be practiced beforehand—very useful, and a great confidence builder when you are about to proceed into unfamiliar territory.

The fact that most ground trainers do not move, and experience only the normal earth-bound 1g gravity force, is not really a disadvantage for instrument training, since one of the aims of this training is to develop the ability to interpret the instruments using your eyes, and to disregard the other senses.

The ground trainer is also less expensive to operate than an airplane. This, and the many other advantages, make it an extremely valuable aid. But, it is still not an airplane!

Figure 20-8 The PCATD (left) and the airplane (right).

Instrument flying in the airplane is the real thing! It is important psychologically to feel confident about your instrument flying ability in an actual airplane, so in-flight training is important. There will be more noise, more distractions, more duties and differing body sensations in the airplane. G-forces resulting from maneuvering will be experienced, as will turbulence, and these may serve to upset the inner senses. Despite the differences, however, the ground trainer can be used very successfully to prepare you for the real thing. Practice in it often to improve your instrument skills. Time in the real airplane can then be used more efficiently.

Attitude Instrument Flying

Power plus attitude equals performance.

The performance of an airplane in terms of flight path and airspeed is determined by a combination of the power set and the attitude selected. Airplane attitude has two aspects—pitch and bank, that is, nose position against the horizon, and bank angle. *Pitch attitude* is the angle between the longitudinal axis of the aircraft and the horizontal. *Bank attitude* is the angle between the lateral axis of the airplane and the horizontal.

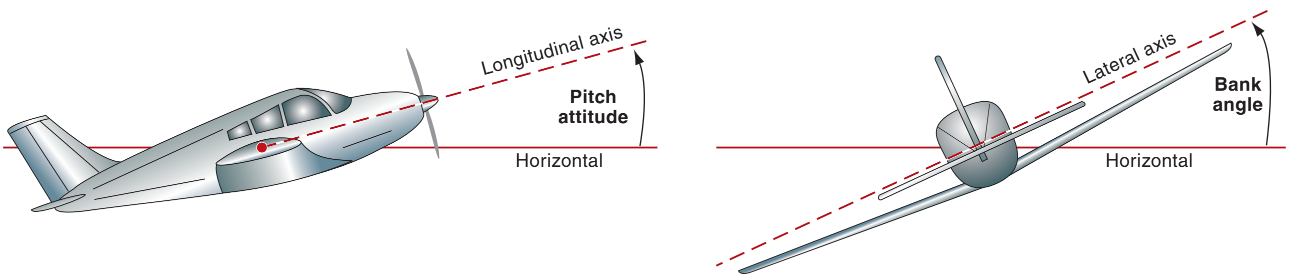


Figure 20-9 Pitch attitude (left) and bank attitude (right).

For a given airplane weight and configuration, a particular attitude combined with a particular power setting will always result in a similar flight path through the air, be it a straight-and-level flight path, a climb, a descent or a turn. Any change of power and/or attitude will result in a change of flight path and/or airspeed.

The pilot selects pitch attitude using the elevator. In visual conditions, you refer to the external natural horizon. At any time (in cloud, at night, or in visual conditions) you can select a specific pitch attitude with reference to the *attitude indicator* (AI) on the instrument panel. In visual flight, the pitch attitude can be estimated from the position of the natural horizon in the windshield. In instrument flight, pitch attitude is selected with reference to the AI, using the position of the center dot of the wing bars relative to the horizon bar. The center dot represents the nose of the airplane.

The pilot selects bank attitude (bank angle) using the ailerons. In visual conditions, you refer to the angle made by the external natural horizon in the windshield. On instruments, you select bank angle on the attitude indicator, either by estimating the angle between the wingbars of the miniature airplane and the horizon bar, or from the sky pointer (or bank pointer) position on a graduated scale at the top of the AI.

Figure 20-10
Slightly low pitch attitude and wings level.

Figure 20-11
Nose-high pitch attitude and right bank.

Most of your attention during flight, both visual and on instruments, is concerned with achieving and holding a suitable attitude. A very important skill to develop when flying on instruments, therefore, is to check the attitude indicator every few seconds. There are other tasks to be performed, and there are other instruments to look at as well, but the eyes should always return fairly quickly to the AI.

Check the attitude indicator every few seconds.

To achieve the desired performance (in terms of flight path and airspeed), you must not only place the airplane in a suitable attitude with the flight controls, you must also apply suitable power with the throttle. Just because the airplane has a high pitch attitude does not mean that it will climb—it requires climb power as well as climb attitude to do this. With less power, it may not climb at all. *Attitude flying* is the name given to this skill of controlling the airplane's flight path and airspeed with changes in attitude and power. The techniques used in attitude flying are the same whether flying visually or on instruments.

Pitch Attitude

The *pitch attitude* is the geometric relationship between the longitudinal axis of the airplane and horizontal. Pitch attitude refers to the airplane's inclination to the horizontal, and not to where the airplane is actually going. The *angle of attack*, however, is the angle between the wing chord and the relative airflow. The angle of attack, therefore, is closely related to flight path.

Pitch attitude is not angle of attack.

Pitch attitude and angle of attack are different, but they are related in the sense that if the pitch attitude is raised, then the angle of attack is increased. Conversely, if the pitch attitude is lowered, then the angle of attack is decreased.

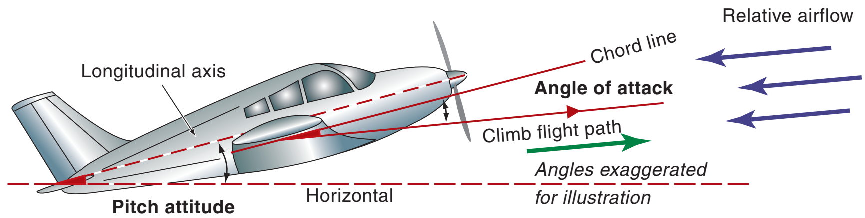


Figure 20-12 Pitch attitude and angle of attack are not the same.

An Airplane Flies Identically, In or Out of Clouds

The principles of flight do not change when an airplane enters clouds. The airplane will fly identically, and be controlled in the same way, both in clouds and in clear skies. The only difference in clouds is that the pilot loses reference to external visual cues, and must derive substitute information from the instrument panel.

When flying visually, you are already deriving a lot of information from the instruments. The exact altitude, for instance, cannot be determined from external features—you must look at the altimeter to positively know the altitude. Similarly, the precise heading is found on the heading indicator or the magnetic compass, and not by reference to external features. The precise airspeed can only be determined from the airspeed indicator. Also, to set a precise power, you must look (briefly) at the power indicator.

Coordination, in turns as well as in straight-and-level flight, is maintained precisely with reference to the coordination ball, in both visual and instrument flight, although the "seat of your pants" can also be a good guide.

The main change, it seems, when switching to instrument flying from visual flying, is to transfer attention from the natural horizon outside the cockpit to the horizon bar of the AI in the cockpit.

Instrument-rated pilots are no different from other pilots, except that they have acquired more knowledge, and can derive more information from the instrument panel. An altimeter can tell you more than just the current altitude—it also says something about the rate of change of altitude, and if the selected pitch attitude is correct for altitude to be maintained. Similarly, the heading indicator can provide heading information, but it also can tell you if the wings are banked. If the heading is changing and the ball is centered, then the wings must be banked.

The skill of instrument interpretation is not difficult, but it does take practice to acquire and maintain.

The skill of instrument interpretation (deriving all sorts of information from various instruments) will develop quickly during your instrument training. It is not difficult—it just takes practice. The airplane will fly exactly the same on instruments as when you are flying visually, and you will control it in the same way. The information required to do this is available on the instrument panel.

During instrument training, most maneuvers will be performed first in visual conditions, where the AI indications can be related to the appearance of the natural horizon in the windshield. After a satisfactory standard of visual flying is demonstrated, practice will occur in simulated instrument conditions—probably achieved by your instructor restricting your view of the outside world with a screen or hood.

The pilot's view, however, will remain unobstructed so that he or she can act as safety pilot, keeping a lookout for other aircraft, and monitoring the position of your airplane. You will concentrate on attitude flying using the instruments, interpreting their indications, and then responding with the controls. You should then be able to cope with actual instrument conditions.

A good understanding of each maneuver, and the ability to put it into practice in visual conditions, will speed up your instrument training. If you happen to be a little rusty, the first volume of this series—*Flight School*—contains detailed briefings for each visual maneuver.

Scanning the Instruments

Scanning the instruments with your eyes, interpreting their indications and applying this information is a vital skill to develop if you are to become a good instrument pilot.

Power is selected with the throttle, and can be checked (if required) on the power indicator. Pitch attitude and bank angle are selected using the control column, with frequent reference to the attitude indicator. With both correct power and attitude set, the airplane will perform as expected. The attitude indicator and the power indicator, because they are used when controlling the airplane, are known as the *control instruments*.

The actual performance of the airplane, once its power and attitude have been set, can be cross-checked on what are known as the *performance instruments*—the altimeter for altitude, the airspeed indicator for airspeed, the heading indicator for direction, and so on.

A valuable instrument, important in its own right, is the clock or timer. Time is extremely important in instrument flying.

The timer is used:

- in holding patterns (which, for example, may be racetrack patterns with legs of 1 or 2 minutes duration);
- in timed turns (a 180° change of heading at standard-rate of 3° per second taking 60 seconds); and
- to measure time after passing certain radio fixes during instrument approaches (at 90 knots groundspeed, for instance, it would take 2 minutes to travel the 3 NM from a particular fix to the published missed approach point).

Figure 20-13 ASA flight timer.

Another area on the instrument panel contains the navigation instruments, which indicate the position of the airplane relative to selected navigation facilities. These NAVAIDs will be considered in detail later in your training, but the main ones are:

- *VHF omni range* (VOR) *cockpit indicator*, which indicates the airplane's position relative to a selected course *to* or *from* the VOR ground station;
- *automatic direction finder* (ADF), which has a needle that points to a non-directional beacon (NDB); and
- *distance measuring equipment* (DME) or VORTAC, which indicates the slant distance in nautical miles to the selected ground station.

Instrument scanning is an art that will develop naturally during your training, especially when you know what to look for. The main scan to develop initially is that of the six basic flight instruments, concentrating on the AI and radiating out to the others as required. Then as you move on to en route instrument flying, the navigation instruments will be introduced. Having scanned the instruments, interpreted the message that they contain, built up a picture of where the airplane is and where it is going, you can now control it in a meaningful way.

Your main scan is across six basic instruments:
• ASI • AI • ALT
• TC • HI • VSI

Figure 20-14 Layout of a typical instrument panel.

Scanning the Instruments in a Glass Cockpit

The introduction of computer screens into the cockpit, sometimes referred to as "glass cockpits," has changed the look of the General Aviation flightdeck but not the function of the flight instruments. Both the traditional, round dial flight instruments and the glass instruments deliver the same information to the pilot, yet the presentation is different.

The traditional round dial placement of the instruments has been called the "six pack." Figure 20-17 is a photograph of the six basic instruments; much thought went into where these instruments should be placed for maximum efficiency. The Primary Flight Display (PDF) of a glass cockpit also has a "six pack" (see figure 20-18). Compare the traditional six pack in figure 20-17 with the PFD in figure 20-18.

On both panels the airplane attitude is displayed in the center. The round attitude gyro is top center in the most prominent position. The airplane's attitude is also displayed prominently on the PFD with an illustration of the horizon crossing the entire screen. The round airspeed indicator is located on the upper left of the six pack. The airspeed indicator is also on the left of the PFD (figure 20-19). The airspeed displayed on the PFD is a vertical "tape" that uses the proper color-codes. The round altimeter and vertical speed indicator are on the right side of the traditional panel and they are also on the right side of the PFD (figures 20-20 and 20-21). The round heading indicator is placed at the lower center of the six pack and likewise the electronic image of a round heading indicator is located at the lower center of the PFD. The six pack remains virtually intact whether the presentation is mechanical round dials or an electronic computer screen.

Controlling the Airplane

During instrument flight, the airplane is flown using the normal controls according to the "picture" displayed on the instrument panel. From this picture, you will, with practice, know what control movements (elevator, aileron, rudder and throttle) are required to either maintain the picture as it is, or to change it.

When maneuvering the airplane, a suitable control sequence to follow (the same as in visual flight) is:

1. *Visualize* the desired new flight path and airspeed.
2. *Select the attitude and the power required* to achieve the desired performance by moving the controls, and then checking when the airplane has achieved the estimated attitude on the AI.
3. *Hold the attitude* on the AI, allowing the airplane to settle down into its new performance, and allowing the pressure instruments that experience some lag to catch up.
4. *Make small adjustments* to attitude and power until the actual performance equals the desired performance.
5. *Trim* (which is vital, if you are to achieve accurate and comfortable instrument flight). Heavy loads can be trimmed off earlier in the sequence to assist in control, if desired, but remember that the function of trim is to relieve control loads on the pilot, and not to change aircraft attitude.

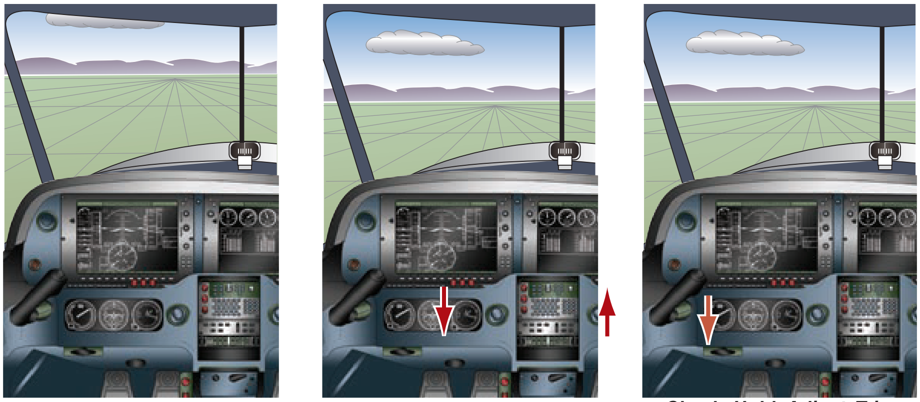


Figure 20-15 Control sequence.

Some helpful hints follow:

- Derive the required information from the relevant instrument—direction from the heading indicator, altitude from the altimeter, airspeed from the airspeed indicator.
- *Respond to deviations* from the desired flight path and/or airspeed. Use the AI as a control instrument, with power as required. For example, if you are 50 feet low on altitude, then increase the pitch attitude on the AI slightly and climb back up to altitude. Do not just accept steady deviations—it is just as easy to fly at 3,000 feet as it is to fly at 2,950 feet. A lot of instrument flying is in the mind and, in a sense, instrument flying is a test of character as well as of flying ability. Be as accurate as you can!
- *Do not over-control.* Avoid large, fast or jerky control movements, which will probably result in continuous corrections, over-corrections and then re-corrections. This can occur if attitude is changed without reference to the AI, or it might be caused by the airplane being out-of-trim, or possibly by a pilot who is fatigued or tense.
- *Do not be distracted* from a scan of the flight instruments for more than a few seconds at a time, even though other duties must be attended to, such as checklists, radio calls and navigational tasks.
- *Relax.* Easier said than done at the start, but it will come with experience.

Sensory Illusions

Most people live in a 1g situation most of the time, with their feet on the ground. 1g means the force of gravity. Some variations to 1g, however, do occur in everyday life—for instance, when driving an automobile. Accelerating an automobile, hard braking, or turning on a flat bend will all produce g-forces on the body different to the 1g of gravity alone. Passengers with their eyes closed could perhaps detect this by bodily feel or with their sense of balance.

A right turn on a flat road, for instance, could be detected by the feeling of being thrown to the left—but it might be more difficult to detect if the curve was perfectly banked for the particular speed. A straight road sloping to the left (and causing the passenger to lean to the left) might give the passenger the false impression that the automobile is turning right, even though it is in fact not turning at all.

The position sensing systems of the body, using nerves all over the body to transmit messages of feel and pressure to the brain, can be fooled in this and other ways.

Sensory illusions can lead you astray.

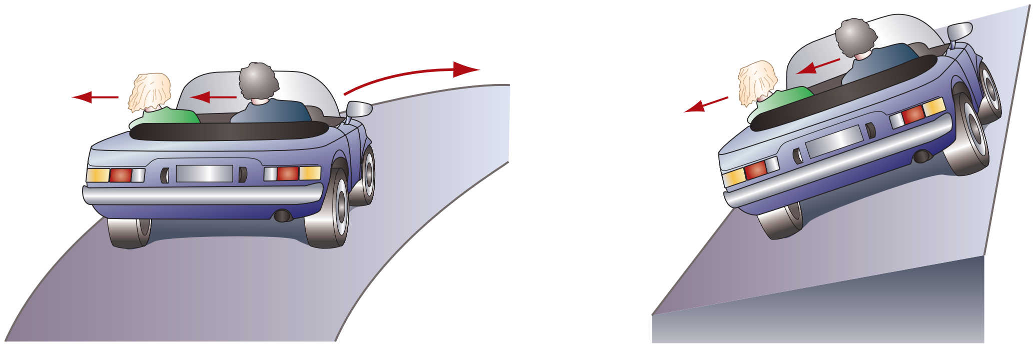


Figure 20-16 Turning right—or left leaning?

The organs within the inner ear, used for balance and to detect accelerations, can also be deceived. For instance, if you are sitting in an automobile traveling around a suitably banked curve, the sensing system in your ears falsely interprets the g-force holding you firmly and comfortably in the seat as a vertical force, as if you were moving straight ahead rather than in a banked turn.

The inner ear organs also have other limitations, one being that a constant velocity is not detected, nor is a gradual change in velocity. For instance, you are sitting in a train and notice another train on the next track moving past your window. Is it moving forward? Are you moving backward? Are you both moving forward but at different speeds? It is sometimes difficult to tell.

False impressions of motion can also be caused by unusual g-forces—for instance, by rapid head motion, or by lowering the head. If you happen to drop your pencil while instrument flying, don't just lower your eyes and lean down to look for it in one motion—take it carefully step by step to avoid any feeling of vertigo.

Believe only what your eyes tell you when flying on instruments.

Because an airplane moves in three dimensions, there is the possibility to accelerate and decelerate in three dimensions, and this can lead to more complicated illusions. Pulling up into a steep climb, for example, will hold you tightly in your seat, which is exactly the same feeling as in a steep turn. Banking the airplane and pulling it into a turn will increase the pressure on "the seat of your pants," which is a similar sensation

Figure 20-17 The flight instruments.

Figure 20-18 Cirrus/Avidyne PFD.

to suddenly entering a climb. As well as your muscles, the balance organs of your inner ear may be sending false signals to your brain. Rolling into and out of a turn may be interpreted as a climb or descent (or vice versa) by your bodily feel. With your eyes closed, it is sometimes difficult to say which maneuver it is.

A sudden change from a climb to straight-and-level flight or a descent may cause an illusion of tumbling backward. A sudden acceleration in straight-and-level flight, or during the takeoff roll, may cause an illusion of being in a nose-up attitude.

Decelerating while in a turn to the left may give a false impression of a turn to the right. Be aware that your sense of balance and bodily feel can lead you astray in an airplane, especially with rapidly changing g-forces in maneuvers such as this.

The one sense that can resolve most of these illusions is sight. If the automobile passenger could see out, or if the pilot had reference to the natural horizon and landmarks, then the confusion, and the risk of not knowing your attitude in space (i.e. the risk of *spatial disorientation*), would be easily dispelled. A false horizon seen by the eyes, however, can be misleading—such as what a pilot might see flying above a sloping cloud formation, or on a dark night with ground lights and stars spread in certain patterns, or when the natural horizon is obscured. Believe the flight instruments!

Unfortunately, in instrument flight you do not have reference to ground features, but you can still use your sense of sight to scan the instruments and obtain substitute information. Therefore, an important instruction to the budding instrument pilot is: "believe your eyes and what the instruments tell you."

It is good airmanship to avoid any situation in flight, or prior to flight, that will affect your vision. While in clouds at night, for instance, turn off the strobe light if it is bothering you. It could induce vertigo, a sense of dizziness or of whirling around, if sufficient of its flashing light is reflected into the cockpit. It is good practice to avoid strong white light, such as a flashlight, in the cockpit when night flying, so that the night adaptation of your eyes is not impaired. However, if flying in dark conditions with thunderstorms in the vicinity, turn the cockpit lights up bright to minimize the effects of nearby lightning flashes. If expecting to fly out of cloud tops and into bright sunlight, have your sunglasses handy. Protect your sight!

While sight is the most important sense, and must be protected at all costs, also make sure that you avoid anything that will affect your balance or position sensing systems.

Avoid alcohol, drugs (including smoking in the cockpit) and medication. Do not fly when ill or suffering with an upper respiratory infection (a cold). Do not fly when tired or fatigued. Do not fly with a cabin altitude higher than 10,000 feet MSL without using oxygen (or above 5,000 feet MSL at night). Avoid sudden head movements, and avoid lowering your head or turning around in the cockpit.

Despite all these don'ts, there is one very important do—*do* trust what your eyes tell you from the instruments.

The Instrument Rating Test

Detailed information of the standards required for you to obtain an instrument rating is included in 14 CFR (Part 61) and in a small publication entitled Practical Test Standards (PTS), published by the FAA and reprinted by ASA in both book form and digitized on CD-ROM. These standards change from time to time, so be sure that you are working from a current set of regulations and a current issue of the PTS book.

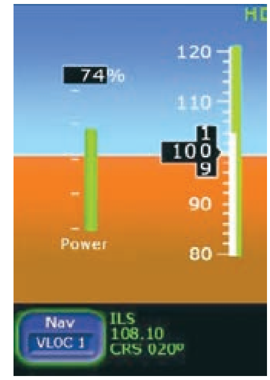


Figure 20-19
PFD airspeed indicator with color codes.

Figure 20-20
PFD altimeter.

Figure 20-21
PFD vertical speed indicator.

Review 20

Introduction to Instrument Flight

1. How can you avoid spatial disorientation when flying in IMC?
2. Flying visually in a clear, blue sky above a sloping cloud layer may not be as easy as it sounds. Why?
3. You are flying over a well-lit town situated on sloping ground. What sort of visual illusion could you experience?
4. How can you assist the adaptation of your eyes to darkness in the cockpit at night?
5. If you do not refer to your flight instruments, what sort of illusions or sensations can result from the following:
   - **a.** an abrupt change from climb to straight-and-level flight?
   - **b.** rapid acceleration during straight-and-level flight?
   - **c.** rapid acceleration during takeoff?
   - **d.** abrupt head movement?

Answers are given on page 780.

Instrument Departures 21

A pilot should not take off unless certain that conditions at the departure airport are suitable, and that conditions at the destination or alternate airport will allow a landing to be made. Operating in adverse weather can be safe only within certain limits. It is strongly recommended, therefore, that a careful decision to operate or not is made before every IFR flight, taking into account all the available relevant information.

Use all relevant information when making a sound Go/No-Go decision.

Weather at the Departure Airport

The *automatic terminal information service* (ATIS) provides a description of the current weather and non-control information at that airport. ATIS broadcasts are updated on receipt of any official weather, regardless of content change and reported values. If the weather is above ceiling/sky condition of 5,000 feet and the visibility 5 SM or more, it is possible that these items may not be included in the ATIS. You should listen to the ATIS prior to taxiing, and notify ATC on initial contact that you have received it.

The ATIS broadcast will be updated on receipt of any official weather regardless of content change or reported values.

Some airports have *automated weather observing systems* (ASOS or AWOS). Refer to the AIM and A/FD for details.

ATC often operates the *airport rotating beacon* in daylight hours to indicate a ground visibility of less than 3 SM and/or a ceiling less than 1,000 feet HAA.

Beware of standing water or slush on the runway, which may cause the tires to *hydroplane* by separating them from the runway surface. Surface friction is greatly reduced, causing directional control problems and greatly reduced braking capability. This is important, especially if you attempt to abort the takeoff, or if you return for a landing.

Takeoff Minimums

Published takeoff minimums (either standard minimums or specific minimums applicable to a particular runway or airport) apply to commercial operations only, and are intended to protect the traveling public. If you are pilot-in-command of a Part 91 operation (private, flight instructional or training operation), then you are not legally bound to comply with these published minimums, however they do provide good guidance as to whether you should take off or not.

Standard takeoff minimums are stated as *visibility only*, since normal climb-out performance after takeoff will keep the airplane above any obstructions in a normal obstacle-clear takeoff area. Standard takeoff minimums are:

- 1 statute mile visibility for airplanes with 1 or 2 engines;
- ½ statute mile visibility for airplanes with 3 or more engines.

If conditions are too poor for highly trained professional pilots in commercial aircraft, then they are probably too poor for you.

If the standard takeoff minimums apply to a particular runway, and are met, then, provided a climb gradient of 200 feet/NM or better can be achieved, you may make a normal IFR takeoff. You should climb straight ahead to at least 400 feet before turning to intercept the outbound course.

A climb gradient of 200 feet/NM will keep the airplane above any obstructions during the climb to the applicable *minimum en route altitude* (MEA). A gradient of 200 feet/NM is 1 in 30, or 2°. If you are confident that your airplane will achieve a rate of climb that will satisfy this gradient, then you may takeoff in low visibility, immediately enter clouds, and still be confident of clearing all obstacles.

- At groundspeed 60 kt, 200 feet/NM is achieved with a rate of climb of 200 fpm.
- At groundspeed 90 kt, 200 feet/NM is achieved with a rate of climb of 300 fpm.
- At groundspeed 120 kt, 200 feet/NM is achieved with a rate of climb of 400 fpm.

An *obstacle identification surface* (OIS) is projected from a point no higher than 35 feet above the departure end of the runway at a gradient of 1 in 40, which is 1.5° or 152 feet/NM. If no obstacles penetrate this OIS, then standard takeoff minimums apply (visibility 1 SM for 1- or 2-engined airplanes), a normal takeoff and climb can be made, and no special IFR procedures need to be published. If the airplane achieves a climb gradient of 200 feet/NM, then clearance above obstacles on the climb to the MEA will increase by at least 48 feet for each NM traveled (200 – 152).

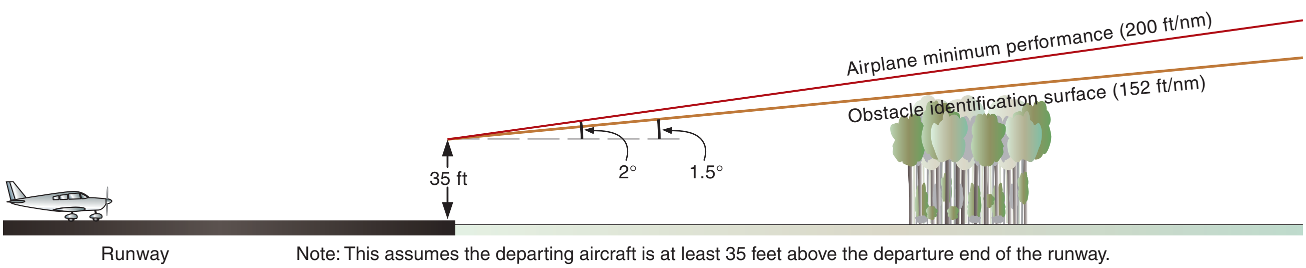


Figure 21-1 Obstacle clearance in the takeoff area.

Note. In figure 21-1, this assumes the departing aircraft is at least 35 feet above the departure end of the runway.

On some runways, an IFR takeoff may not be authorized because of obstacle clearance problems.

Obstacle Clearance Procedure

If there are obstacles that do penetrate this obstacle identification surface, then obstacle clearance procedures are specified, which may be either:

- *a steeper climb gradient* in excess of the standard 200 feet/NM, so that the airplane will clear the obstacles on a normal straight flight path, and the standard minimums still apply (visibility 1 SM for airplanes with 1 or 2 engines, and with no reference to a ceiling minimum); or
- takeoff minimums expanded to include a *cloud ceiling* as well as a visibility minimum, allowing a pilot to see and avoid the obstacle; or
- *a prescribed IFR departure procedure*, describing the flight path to be followed (turns, heading, altitudes) to avoid the obstructions; or
- a combination of the above.

Sometimes horizontal visibility along a runway is expressed in terms of runway visual range (RVR) in feet, measured by a transmissometer placed near the runway. If the minimums on the chart are prescribed as an RVR, but the transmissometer(s) is(are) inoperative, then you may convert the RVR minimum in feet to an equivalent visibility in statute miles, and apply that (1 SM = 5,000 feet; ½ SM = 2,400 feet).

If special takeoff minimums and/or special IFR departure procedures apply to an airport, then this is indicated on the instrument charts:

- NACO instrument charts have a symbolic "T" in an inverted black triangle, directing you to the front of the NACO booklet for details of IFR Takeoff Minimums and Departure Procedures; and
- *Jeppesen* instrument charts display *Takeoff and IFR Departure Procedures* on the front or rear face of the airport chart.

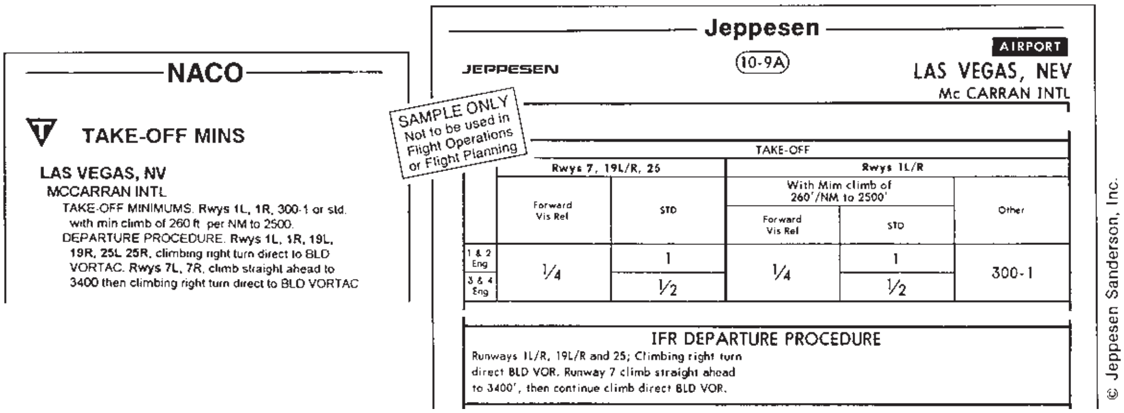


Figure 21-2 Nonstandard takeoff minimums and IFR departure procedure.

For Las Vegas Runway 1L or 1R, the standard takeoff minimums (visibility 1 SM for airplanes with 1 or 2 engines) only apply if you can achieve a climb gradient of 260 feet/NM or better to an altitude of 2,500 feet MSL. At a groundspeed of 90 knots, this would require a rate of climb of 390 fpm. If you cannot climb at this higher rate, then the takeoff minimums are increased to ceiling 300 feet/visibility 1 SM; the 300 feet ceiling requirement enabling the pilot climbing at only 200 feet/NM to visually avoid any obstacles below this level. Additionally, an IFR departure procedure applies to this runway, requiring a climbing right turn direct to the Boulder City VORTAC. This procedure *must* be flown, regardless of whatever minimums apply to the takeoff.

Prior to every IFR takeoff, you should carefully consider obstacle clearance and climb capability. In particular, beware of taking off in a tailwind—this means a higher groundspeed for the same airspeed, and consequently a flatter climb path over the ground. To achieve the same climb gradient as in still air, a higher rate of climb will therefore be required, and the airplane may not be capable of achieving this. In addition, a 5-knot tailwind on the ground may well increase to a 10-knot, or even 20- or 30-knot tailwind soon after takeoff, further penalizing the climb performance, this is known as an undershoot (or performance-decreasing) windshear/wind gradient. You should also plan your takeoff to avoid possible wake turbulence from a preceding heavy aircraft.

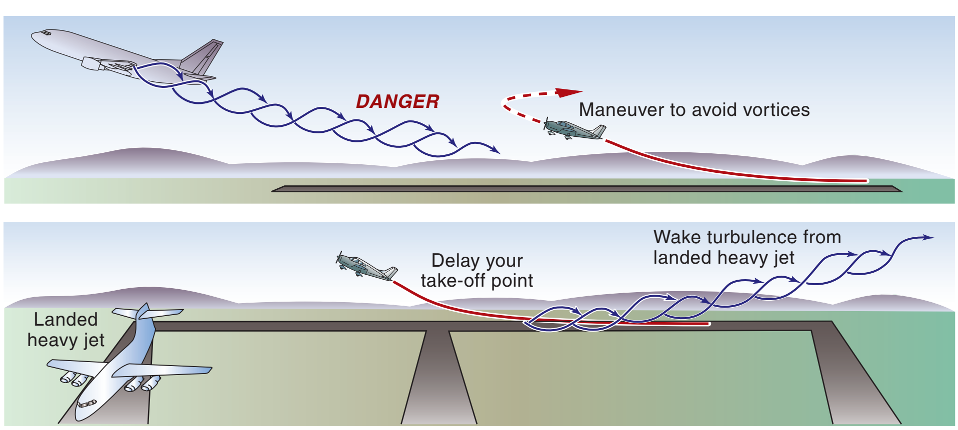


Figure 21-3 Avoid wake turbulence on your takeoff.

Setting Course

Most departures on an instrument flight involve maneuvering after takeoff to intercept the departure course to or from a particular navigation aid. It is good airmanship to have in mind the direction of turns necessary, and the approximate time required to intercept the course. If it is a complicated procedure, take time to review it before taxiing on to the runway.

The tower controller will normally inform you of the departure control frequency and, if appropriate, the transponder code, prior to takeoff. The transponder should not be operated until ready to start the takeoff roll, and you should not change to departure control until requested. Ensure that the current local altimeter setting is set in the pressure window for takeoff and departure so that the altimeter indicates vertical distance above mean sea level, and ensure that your heading indicator is aligned with the magnetic compass.

Standard takeoff and departure procedure is to climb straight ahead to at least 400 feet HAA before making any turns, and then to climb to the en route MEA at best rate of climb. Change from the tower frequency to departure control when requested. Any IFR departure procedure, standard departure procedure or other clearance specified by ATC, and accepted by you, should be followed. ATC should be notified if your rate of climb to cruising altitude is less than 500 fpm. For the last 1,000 feet of the climb to the cleared cruising altitude, the rate of climb should be reduced to between 500 and 1,500 fpm.

Figure 21-4 shows an airplane taking off and intercepting the 270 magnetic course outbound from an NDB positioned near the airport.

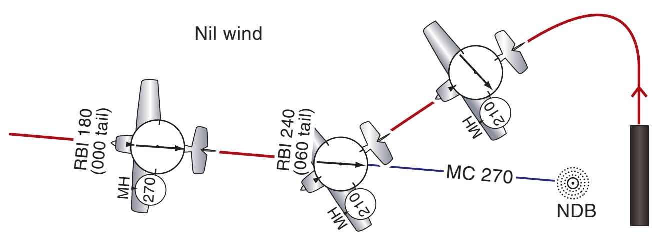


Figure 21-4 Intercepting the departure course using an NDB.

Figure 21-5 shows an airplane intercepting the 030-TO course to a VOR (the 210 radial), and then tracking outbound on the 090 radial.

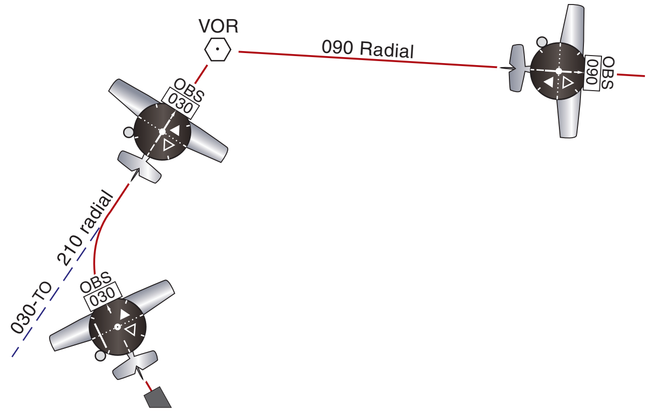


Figure 21-5 Intercepting departure course using a VOR.

Note. Many instrument departures are made in visual conditions (VMC), and you should take advantage of this to scan the sky for other aircraft to reduce the risk of a collision. Climb on the centerline of the airway and systematically focus on different segments of the sky for short intervals, occasionally making gentle banks left and right to clear the area under the nose.

Instrument Departure Procedures (DPs)

A DP is a published IFR departure procedure providing a standard route from the terminal to the appropriate en route structure. To accept a DP, you must have at least have it written down in the cockpit.

At many busy controlled airports, specific *instrument departure procedures* (DPs) (previously referred to as *standard instrument departures*, or SIDs) are published for the use of instrument-rated pilots. A DP is a published IFR departure procedure providing a standard route from the terminal to the appropriate en route structure. In some cases a DP may have an associated *transition*, which is a published procedure connecting the end of the DP to one of several en route structures.

DPs considerably simplify the issuance of departure clearances, allowing ATC to simply specify the DP by name without having to describe any further tracking details, since these are provided in diagrammatic and textual form on the pilot's DP charts. The clearance may include the basic DP name and number, plus a transition to the desired route. The departure control frequency, normally passed to a pilot with IFR departure clearance, may be omitted by ATC since it is published on the DP page.

To accept a DP, you must have at least a textual description of it available in the cockpit. An example of a DP, the STAAV-2 DP for Las Vegas, is shown in figure 21-6, on page 493. ATC may issue DPs without a specific pilot request. If you do not wish to accept a DP, then you should advise ATC, preferably by inserting "No DP" in the remarks section of the filed flight plan, otherwise verbally. (The same applies to STARs—Standard Terminal Arrival Routes.) This does not preclude ATC from reading to you the textual form of a DP as your clearance.

Instrument departure procedures (DPs) are designed to:
- separate departing traffic from arriving traffic;
- provide efficient interception of outbound course;
- avoid noise-sensitive areas near the airport;
- simplify the issuance of departure clearances; and
- reduce radio talk.

There are two basic forms of DPs:
- *pilot navigation DPs*, where the pilot is primarily responsible for navigation along the published DP route (as in the Las Vegas case in figure 21-6); and
- *vector DPs*, where ATC will provide radar vectors to a filed/assigned route or to a fix depicted on the DP.

Typical DPs issued by ATC as part of an IFR departure clearance are:

"..., STAAV-2 departure,...;"
"..., STAAV-2 departure, Beatty transition,...;"
"..., STAAV-2 departure, Beatty transition, cross STAAV at or below seven thousand,...."

ATC Clearances

To operate in controlled airspace under IFR, you are required to file an IFR flight plan and obtain a clearance.

An ATC clearance is an authorization by ATC for you to proceed under specified conditions within controlled airspace.

Always write down an ATC clearance, and read it back.

Clearances are normally issued for the altitude and route as filed (AF) by the pilot, however this is not always the case, depending upon traffic flow, congestion, etc. You should always write down any clearance issued to you by ATC (using clearance shorthand), and then read it back without error as a double-check.

Do not accept a clearance that causes you to break a rule or break your aircraft. Request an amended clearance instead.

You, as pilot-in-command, are ultimately responsible for the safety of your aircraft (14 CFR Part 91), so do not accept a clearance that would cause you to deviate from any rule or regulation or that would place the aircraft in jeopardy. Instead, request an amended clearance.

Pre-Taxi Clearance Procedures

If operating on an IFR flight plan, you should communicate with the control tower on the appropriate ground control or clearance delivery frequency, prior to starting engines, to receive engine-start time, taxi and/or clearance information. At certain airports, you may obtain your IFR clearance before taxiing by calling Clearance Delivery or Ground Control not more than 10 minutes prior to the proposed taxi time, otherwise request it prior to takeoff.

Sometimes the clearance is available immediately, and sometimes there is a delay. An ATC response of "Baron 1543 Foxtrot—clearance on request" or "Baron 1543 Foxtrot—stand by," means that your clearance is not yet available. When it is ready, they will advise you "Baron 1543 Foxtrot—clearance," which you may then receive at a convenient time. The clearance will contain:
- your identification;
- the clearance limit (often the destination airport, otherwise an en route fix);
- the departure procedure or DP to be followed;

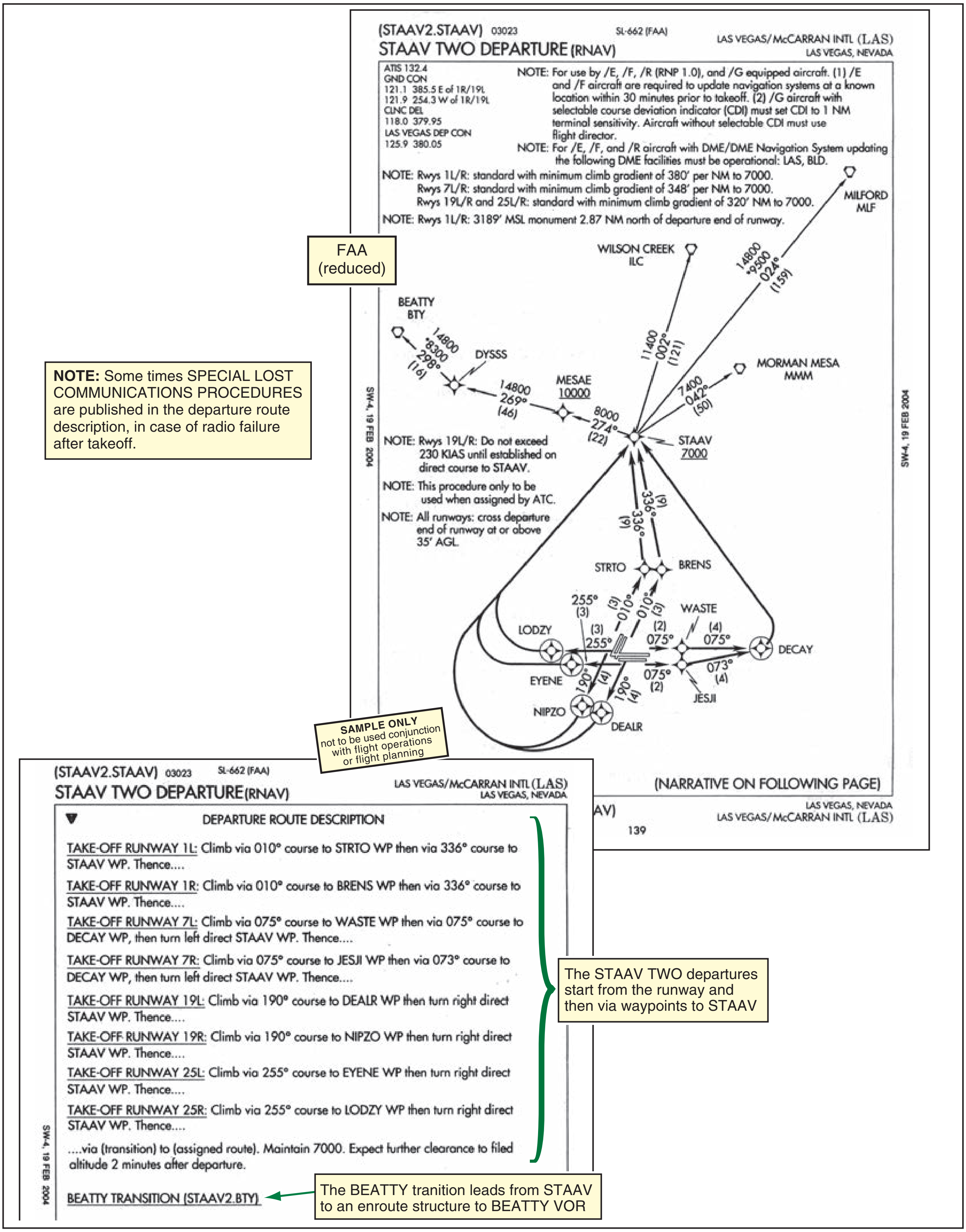


Figure 21-6 The STAAV departures for Las Vegas.

- altitude(s);
- any holding instructions;
- any other special information;
- radio frequency and transponder code information.

The route issued in the clearance, if it is the same as you filed in your IFR flight plan, may be abbreviated to "as filed," and you can write this down as AF. This is known as an *abbreviated clearance*, and it will always contain at least:
- the name of the destination airport or a fix (clearance limit);
- DP and transition, if appropriate; and
- altitude.

The clearance may contain a delay, such as "hold for release—expected delay 10 minutes," which you can write as "H-10." Develop a clearance shorthand to speed up the process of copying clearances. You must be fast and accurate.

A *clearance void* (CV) *time* stated in the clearance when departing from an airport not served by a control tower means that you must depart by the CV time for the clearance to remain valid. If you decide not to depart before the CV time, you should advise ATC of your intentions as soon as possible, but no later than 30 minutes past the clearance void time, to avoid unnecessary ATC action following a false assumption that you have departed.

An altitude assignment "maintain 6,000" instructs you to fly *at* that altitude. An altitude assignment "cruise 6,000" means that you can fly at any altitude from the minimum IFR altitude up to and including the altitude specified in the clearance, and you may alter your altitude within this layer of airspace without advising ATC. Most IFR clearances in the busy United States airspace are to "maintain" the specified altitude, rather than cruise within a layer.

Strict adherence to clearances by the pilot-in-command is essential to safety, so you must know the exact conditions of your clearance throughout the flight, even though it might be amended by ATC from time to time. IFR departure clearances should be copied, and then read back, as mutual pilot/controller verification of accuracy.

The items in an ATC clearance are issued in a predictable order, and you should develop a shorthand pattern of writing them down, as shown below:

Memory aid for IFR clearance format:

C learance limit
R oute (including DP, if any)
A ltitude
F requency
T ransponder code

Cleared to..........................
Via..
Climb to & maintain............ Expect................. minutes after departure
Instructions on departure..................................
Departure Frequency.................. Squawk........

This can be abbreviated to:

C....................
Via...
C & M............ E................. >dpt.
On dpt..................................
Dpt freq.................. Sqk........

With practice this reminder pattern can be dispensed with altogether.

The following IFR departure clearances were written down exactly as spoken by actual controllers, except for certain abbreviations in brackets that will help you practice your clearance shorthand. The term "cleared to" is used by ATC; the term "ATC clears..." is used by a flight service station (FSS) relaying an ATC clearance to you.

Example 21-1

Teterboro NJ (TEB) to Allentown PA (ABE).

> C-ABE
> TEB-2 RV LANNA V30 ETX DIR
> 6000/10
> 127.6 4317

King Air 280SC
cleared to Allentown airport
via Teterboro-2 departure
expect radar vectors to Lanna intersection
Victor-30 East Texas (ETX VORTAC)
direct
expect 6,000 10 minutes after departure
departure frequency will be 127.6
squawk 4317

Note. The Teterboro-2 departure off runway 19 (which you will read from your DP chart) is:

Maintain runway heading until leaving 800 feet, then turn right heading 280, maintain 1,500 feet until crossing the Patterson NDB 195 bearing (PNJ NDB), then climb and maintain 3,000 feet, then expect radar vectors to Lanna intersection.

Example 21-2

Teterboro NJ (TEB) to Fulton County GA (FTY).

> C-FTY
> TEB-2 RV LANNA J48 FML
> DIR AWS-7
> F430/10
> 127.6 4354

Gulfstream N1040
cleared to Fulton County Airport (FTY)
via Teterboro-2 departure (TEB-2)
expect radar vectors to Lanna intercept
then J-48 to Fort Mill (FML VORTAC)
direct Awson-7 arrival
expect FL 430 10 minutes into departure

departure frequency will be 127.6
squawk 4354

Example 21-3

Santa Barbara CA (SBA) to Paso Robles CA (PRB).

> C-PRB
> GVO V27 MQO DIR
> 6000 (H)
> 119.05 4576

Baron 4123G
cleared to Paso Robles airport (PRB)
via Gaviota (GVO VORTAC)
Victor-27 to Morro Bay (MQO VORTAC)
direct
climb and maintain 6,000
hold for release
departure frequency 119.05
squawk 4576

Example 21-4

Santa Barbara CA (SBA) to San Diego CA (SAN).

> C-SAN
> R-VTU V299 LAX
> V23 OCN DIR MZB SAN
> 6000 12,000/5
> CV 0045Z
> 119.05 4273

November 3456D
cleared to San Diego Lindbergh Field (SAN)
via radar vectors to Ventura (VTU VORTAC)
Victor-299 to Los Angeles (LAX VORTAC)
Victor-23 Oceanside (OCN VORTAC)
direct Mission Bay (MZB VORTAC)
San Diego Lindbergh Field
climb and maintain 6,000
expect 12,000 5 minutes after departure
you are released—clearance void if not off by 0045 Zulu
departure frequency 119.05
squawk 4273

Example 21-5

Rock Springs WY (RKS) to Denver International (DEN).

> C-DEN
> V4 LAR AF
> 17,000
> 119.25 6035

ATC clears Rocky Mountain Flight 2247
from Rock Springs airport to Denver airport
via Victor-4 Laramie (LAR VORTAC) then as filed
climb and maintain 17,000
contact Salt Lake Center on 119.25 after departure
squawk 6035

Example 21-6

Rock Springs WY (RKS) to Liberal KA (LBL).

> C-LBL
> V4 LAR AF
> 9000 VFR 17,000
> 119.25 6074

ATC clears Cessna 9478G
to Liberal airport from Rock Springs airport
via Victor-4 Laramie then as filed
climb VFR through 9,000 up to and maintain 17,000
contact Salt Lake Center on 119.25 after departure
squawk 6074

Example 21-7

El Paso TX (ELP) to Dallas Love Field TX (DAL).

> C-DAL
> RV V16 INK V15 DAL
> 11,000
> RWY HDG
> 119.7 4205

November 3812S
cleared to Dallas (DAL)
via radar vectors to join Victor-16 to Wink
(INK VORTAC)
Victor-15 to Dallas
maintain 11,000 on departure fly runway heading
departure frequency 119.7
squawk 4205

Example 21-8

Spokane WA (GEG) to Seattle WA (SEA).

Northwest 1289
cleared to Seattle
direct Ephrata (EPH VORTAC)
Jay-70 Seattle
climb to and maintain 12,000
expect FL 230 5 minutes after departure
hold for release—expect 15 minutes departures delay
departure frequency 124.3
squawk 4650

C-SEA
DIR EPH J70 SEA
12,000 F230/5 (H-15)
124.3 4650

Example 21-9

Spokane WA (GEG) to Yakima WA (YKM).

Cessna 541S
cleared to Yakima airport via Spokane-4 departure
Victor-2 Seattle
Victor-23 Battleground (BTG VORTAC)
Victor-448
climb to and maintain 12,000
departure frequency 124.3
squawk 4705

C-YKM
GEG-4 V2 SEA V23 BTG V448
12,000
124.3 4705

Review 21

Instrument Departures

Takeoff Minimums

1. What are standard takeoff minimums stated as?
2. What are the standard takeoff minimums for airplanes with 1 or 2 engines? What RVR is this equivalent to?
3. What does ATIS stand for?
4. How often is the ATIS updated?
5. What does the absence of sky condition and visibility on an ATIS broadcast imply in terms of ceiling and visibility?
6. What climb gradient is required for standard takeoff minimums?
7. If standard takeoff minimums apply, and you estimate your groundspeed will be 60 knots, what is the required rate of climb?
8. If standard takeoff minimums apply, and you estimate your groundspeed will be 90 knots, what is the required rate of climb?
9. To achieve the same climb gradient taking off with a tailwind, compared with no-wind or a headwind, will the rate of climb need to be higher, lower, or similar?
10. What does a "T" in an inverted black triangle mean on NACO charts?
11. What does a "T" in an inverted black triangle on NACO charts require you to do?
12. If standard takeoff minimums apply, what climb gradient is required for the airplane to remain well above the obstacle-clear surface?
13. If a nonstandard takeoff minimum climb gradient of 240 feet/NM applies, what rate of climb must you achieve if your groundspeed is 120 knots?

14. As well as a visibility requirement, nonstandard takeoff minimums may contain what other requirement, so that the pilot may see and avoid obstructions?
15. Do you need to scan the sky for other aircraft during an IFR departure in visual conditions?
16. During an IFR departure in visual conditions, where should you climb in relation to the airway?
17. How long after takeoff should you change from tower control frequency to departure control?
18. Which rate of climb should be used to climb to the assigned altitude? Should this rate be used for the entire climb?

DPs

19. If you do not have DP charts available, what should you insert in the remarks section of your flight plan?
20. To accept a DP, you must have with you in the cockpit at least:
    - **a.** a textual description.
    - **b.** a diagram.
    - **c.** a textual description and a diagram.
    - **d.** neither a textual description nor a diagram.
21. What are the two basic forms of standard instrument departure?
22. Can ATC issue you with a DP without you making a specific request?
23. What do preferred IFR routings beginning with a fix indicate?
24. Refer to figure 21-6 on page 493 (STAAV-2 DP for Las Vegas):
    - **a.** Can you accept the STAAV-2 DP if your DME is inoperative?
    - **b.** Where does the basic STAAV-2 DP begin and end?
    - **c.** Where does the BEATTY transition lead from? Where does it lead to?
    - **d.** What minimum climb gradient is required for the STAAV-2 DP on runway 7? What rate of climb would you need to achieve this at groundspeed 120 knots?
    - **e.** What is the minimum crossing altitude at STAAV?
    - **f.** What is the maximum altitude at which you may cross STAAV?
    - **g.** What is the Las Vegas departure frequency?
    - **h.** If you were to track southwest from Las Vegas, which waypoint would you use?
    - **i.** What is the distance from STAAV to BTY?
25. A particular DP requires a minimum climb rate of 210 feet per nautical mile. With an airspeed of 120 knots and a 20-knot tailwind, what is the required minimum rate of climb?
26. Are Special Lost Communications Procedures published on a DP departure route description in some cases?

ATC Clearances

27. What sort of clearance do the words "cleared as filed" indicate?
28. Which items are given in an abbreviated clearance?
29. If your clearance to depart an airport not served by a control tower contains a void time, and you do not make it off before this void time, what should you do?
30. If your clearance is to "maintain 7,000," must you fly at 7,000, or may you cruise below it?
31. If your clearance is to "cruise 7,000," must you fly at 7,000, or may you cruise below it?
32. With a clearance to "cruise at 6,000," must you advise ATC if you wish to descend to 5,000 feet?
33. With a clearance to "maintain 6,000," must you advise ATC if you wish to descend to 5,000 feet?

Answers are given on page 781.

Now return to the ATC clearances given in full in this chapter, and practice writing them in your own shorthand. Assume that they are being read by a controller at normal speaking rate.

En Route 22

The en route phase of flight follows your departure from one airport and lasts until your arrival at another. There are a number of tasks for the instrument pilot to perform en route, such as maintaining course, making the required radio reports, preparing for the descent, arrival and approach at the destination airport, and making the appropriate calculations in case a diversion to an alternate airport is necessary. Fuel is always an important consideration.

Radar Service

Normally you will change to departure frequency when instructed to by the tower after takeoff. Initial radar identification of your aircraft by a controller will be advised by the phrase "radar contact." Transponder Mode C (or S) should always be selected, unless otherwise requested, to provide ATC with altitude reporting. The controller will follow your flight on radar, until "radar contact lost" or "radar service terminated" is advised, or until you have been cleared for a visual approach with a preceding aircraft in sight, or until after you have landed. If the controller instructs you to "resume own navigation," then you are responsible for your own navigation even though *radar flight following* will continue.

En Route Clearances

Pilots of airborne aircraft, upon receiving a clearance or instruction from ATC, should read back the numbers (altitudes, altitude restrictions, radar vectors) and any data needing verification. Altitudes in charted procedures (DPs, STARs, IAPs) need not be read back unless they are specifically stated by the controller. It is your responsibility, as pilot-in-command, to accept the clearance, or to refuse it. Any changes of altitude should be made without delay, unless the clearance includes "at pilot discretion." You should change altitude at the optimum rate of climb or descent consistent with normal operation of the airplane until the last 1,000 feet which should be at 500-1,500 fpm. Advise ATC if you cannot achieve a 500 fpm climb/descent rate.

Operating on a composite VFR/IFR flight plan:

- If you are changing from VFR to IFR, you should close the VFR portion of your flight plan with FSS and request an ATC clearance, but remain in VMC until operating in accordance with the IFR clearance.
- If you are changing from IFR to VFR, you should close the IFR portion of the flight plan with ATC when overhead the IFR clearance-limit fix, and then contact the nearest FSS to activate the VFR portion of the flight plan.
- If you do not wish to change from IFR to VFR, but to continue IFR, advise ATC at least 5 minutes prior to reaching the IFR clearance-limit fix and request a further IFR clearance. Do not proceed IFR past the IFR clearance-limit fix until you have obtained the onward ATC clearance—hold in a published holding pattern at the fix, otherwise in a standard holding pattern on the radial or course to the fix.

Position Reports

ATC needs to know where aircraft are in the IFR environment, and this is achieved by:

- ATC radar, where possible, supported by limited reports from aircraft; or
- full position reports from aircraft in a nonradar environment.

A *full position report* contains:

- aircraft identification;
- position;
- time;
- altitude (specifying VFR-on-top if appropriate);
- type of flight plan (not necessary if in contact with Center or Approach);
- ETA and name of next reporting point;
- name only of the following reporting point; and
- pertinent remarks.

Example 22-1

Sacramento, Cessna 238 Sierra
Sacramento at two eight
Niner thousand
Manteca four seven
Following-point Panoche
Moderate turbulence.

Compulsory reporting points are shown on en route charts by solid triangles; on-request reporting points are shown by open triangles, requiring reports only when requested by ATC. When flying on a direct route and when requested, reports shall also be made over each fix defining the route.

In a radar environment, after having been informed of being in radar contact by ATC, you may discontinue position reports.

In a radar environment, after having been informed of being in radar contact by ATC, you may discontinue position reports. The words "radar contact" signify that you have been identified on the radar controller's display, and that radar flight-following will be provided until radar service is terminated or radar contact lost. You should use transponder Mode C (altitude reporting capability) at all times, unless ATC requests you not to. If ATC advise "radar contact lost" or "radar service terminated," you should resume normal position reporting.

Even in a radar environment, you should maintain a flight log, so that, in the event of loss of radar contact, you are able to continue with full position reporting.

Additional Compulsory Radio Reports

You should initiate the following radio reports without any specific request from ATC:

- at all times:
  - when vacating a previously assigned altitude for a newly assigned altitude;
  - when an altitude change will be made while operating VFR-on-top;
  - when unable to climb or descend at a rate of at least 500 fpm;
  - after initiating a missed approach;
  - if you change the TAS at cruising altitude by 5% or 10 knots (whichever is greater) from that filed in the flight plan;
  - the time and altitude upon reaching a holding fix or clearance limit;

  - when leaving any assigned holding fix or point;
  - any loss of navigation or communications capability in controlled airspace;
  - any information relating to the safety of flight; and
  - any unforecast weather, or any hazardous conditions encountered (forecast or not).
- when not in radar contact:
  - when leaving the final approach fix (FAF) inbound on a nonprecision approach (VOR/NDB/LOC/LDA/SDF/GPS);
  - when leaving the outer marker (OM), or fix used in lieu of the outer marker, inbound on a precision approach (ILS/MLS/PAR);
  - when an estimate previously submitted is in error by in excess of 3 minutes, and a revised estimate is required.

En Route Charts

It is essential that you can read IFR charts quickly and accurately, and this takes practice. Study your own charts, and become familiar with the legend. Each chart carries an enormous amount of vital information concerning NAVAIDs, airways, safe altitudes, airports, airspace, and communications. You have the choice of FAA National Aeronautical Charting Office (NACO) or *Jeppesen* charts—we consider both types here. The instrument rating FAA Knowledge examination is based on NACO low-altitude en route charts.

Airports

Airports are shown on the en route charts, accompanied by some basic information, such as elevation. NACO en route charts have Air-to-Ground Voice Communication panels that include tower hours of operation. More complete information on each airport and its facilities, such as control tower hours of operation, traffic pattern altitude (TPA), elevation, runway data, communications, navigation aids, instrument approach procedures (IAPs), and servicing facilities may be found in the *Airport/Facility Directory* (A/FD) booklet.

MT OLIVE MUNI (W40) 3 NE UTC – 5(– 4DT) N35°13.33′ W78°02.27′ **CHARLOTTE**
168 B S4 **FUEL** 100LL **L-20G, 27C**
RWY 05-23: H3697X75 (ASPH) S-20 MIRL **IAP**
RWY 05: VASI(V2L)—GA 3.0°TCH 23′. Ground. **RWY 23:** VASI(V2L)—GA 3.25° TCH 20′. Crops.
AIRPORT REMARKS: Attended 1300–2300Z‡. Parachute Jumping. Low level military activity near arpt.—5′ drainage ditch 100′ left of centerline of Rwy 05. Rwy 05 and 23 VASI out of svc indefinitely.
COMMUNICATIONS: CTAF/UNICOM 122.8
RALEIGH FSS (RDU) TF 1-800-WX-BRIEF. NOTAM FILE RDU.
® **SEYMOUR JOHNSON APP/DEP CON** 123.7
RADIO AIDS TO NAVIGATION: NOTAM FILE ISO.
KINSTON (L) VORTAC 109.6 ISO Chan 33 N35°22.26′ W77°33.50′ 254° 25.2 NM to fld. 70/05W.

Figure 22-1 A sample airport entry in the A/FD.

Navigation Aids

VORs and VORTACs are prominently displayed on the en route charts, as they form the basis of the airways. Civil pilots use the VOR for course guidance, and the DME function of the TACAN for distance information. Many VORs transmit HIWAS messages (hazardous in-flight weather advisory service). NDBs are also depicted if they provide an en route function or transmit HIWAS broadcasts.

Localizer front courses and/or back courses are only shown on NACO en route charts if, as well as providing approach guidance to an airport, they also serve an additional ATC function such as defining an intersection, and are therefore part of the en route structure. The same applies to LDAs and SDFs.

Routes

Airways, also known as *federal airways*, are controlled airspace established in the form of a corridor, the centerline of which is defined by navigation aids, usually VORTACs.

Below 18,000 feet MSL, the airways are known as VOR, or *Victor airways*, and are labeled with a "V" and their designated number, "V223." They exist down to 1,200 feet AGL (higher in some instances), and are depicted on the low altitude en route charts. Various information is shown along the airways, such as the magnetic course, distance, MEA and MOCA. All distances are in nautical miles, and all directions are in degrees magnetic.

Breaks in airways are shown at intersections (published fixes) by a triangle, and at mileage break points not coincident with an intersection by a small cross. DME distance to the relevant VORTAC is shown at intersections, if appropriate.

A segment of an airway common to more than one route carries the numbers of each of these routes, "V107-301," but you only need to indicate the number of the route you are using on your flight plan, "V301." Alternate airways are identified by their location with respect to the associated main airway, "V12W" is to the west of "V12."

From 18,000 feet MSL up to and including FL 600, the airspace is Class A. Flight in Class A airspace is IFR only, and the airways from 18,000 feet MSL up to and including FL 450, are known as *jet routes*. These are labeled with a "J" and their designated number, "J 84". The low altitude en route charts are not designed for flights above 18,000 feet MSL.

Minimum En Route IFR Altitude (MEA)

The MEA appears as a number, such as 9,500, along the airway, and is the lowest published altitude between fixes that assures:

- *acceptable navigation signal coverage* (but not necessarily 2-way communications coverage); and
- *meets obstacle clearance requirements between those fixes* (1,000 feet normally, 2,000 feet in designated mountainous areas) within ±4 NM of the route to be flown.

It is usual to maintain an IFR altitude at or above the MEA that is in accordance with the hemispherical rule (WEEO: West-evens; East-odds), according to your magnetic course. Occasionally, an MEA may be approved with a *gap* in navigation signal coverage, and this will be depicted on NACO charts with the words "MEA GAP," and on *Jeppesen* charts by a broken bar. Some routes have *directional MEAs*, the MEA depending on which direction you are traveling—the MEA flying toward high ground being higher than when flying in the opposite direction away from high ground.

A bar crossing an airway at an intersection indicates that there is a change of MEA. You do not have to commence a climb to a higher MEA until reaching the intersection where the MEA change occurs, unless a minimum crossing altitude (MCA) is specified.

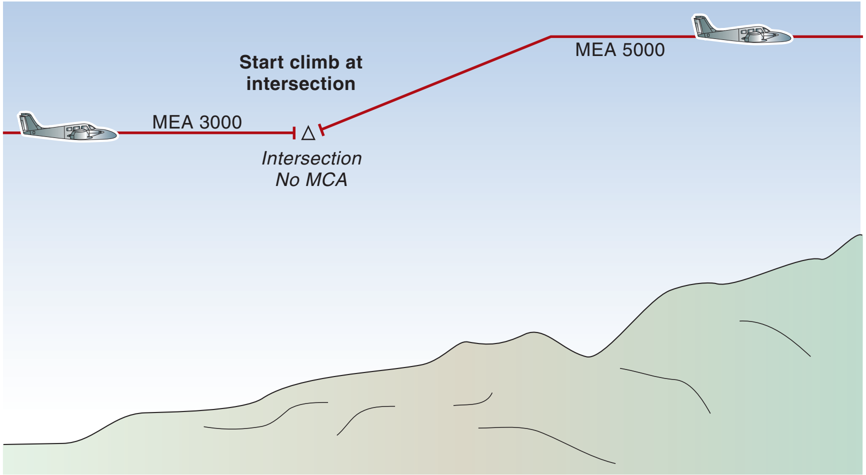


Figure 22-2 Approaching a higher MEA, with no MCA specified.

Minimum Crossing Altitude (MCA)

The MCA is the lowest altitude at certain fixes at which an aircraft may cross when proceeding in the direction of a higher MEA. The MCA is usually specified for obstacle clearance requirements, but it may also be specified to assure adequate reception of navigation signals so that you can identify the intersection. MCA is indicated by a "flagged X" on NACO charts, and as an airway number and altitude alongside the intersection on *Jeppesen* charts ("V-25 11000S" means MCA 11,000 feet MSL flying south on V-25).

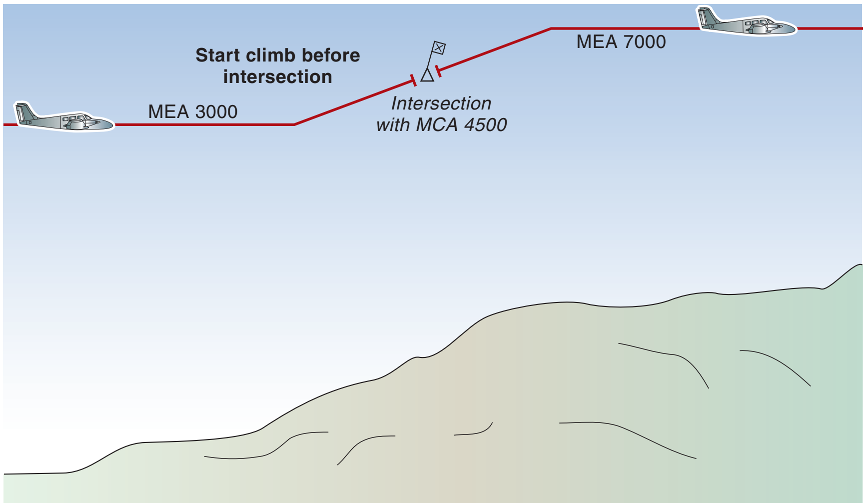


Figure 22-3 Approaching a higher MEA, with an MCA specified for the following course.

Minimum Obstruction Clearance Altitude (MOCA)

The MOCA is the lowest published altitude in effect between fixes on VOR airways, off-airway routes, or route segments which meets obstacle clearance requirements for the entire route segment, and which ensures acceptable navigation signal coverage only within 22 nautical miles (25 statute miles) of a VOR. The MOCA, if shown, is differentiated from the MEA by an asterisk on NACO charts (*2500) and a "T" on *Jeppesen* charts (2500T). If the MOCA is the same as the MEA, it is not shown.

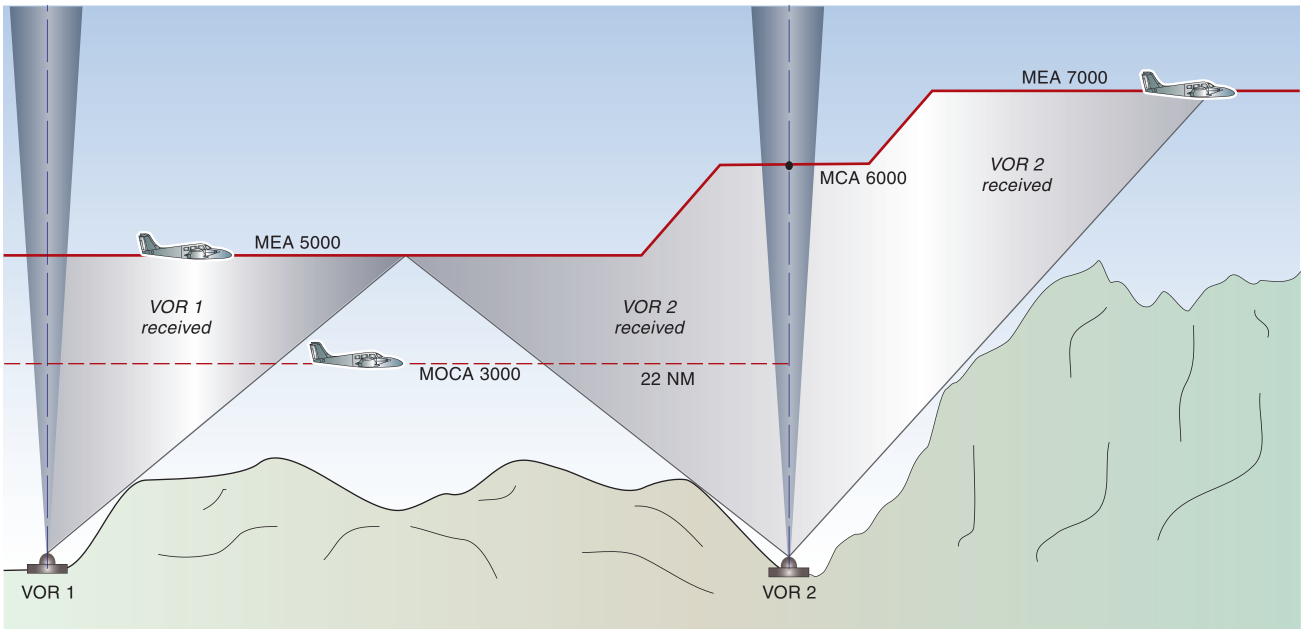


Figure 22-4 MEA, MOCA and MCA.

Minimum Reception Altitude (MRA)

The MRA is the lowest altitude at which an intersection can be determined. At altitudes lower than the MRA, navigation signal coverage is not assured, and you may not be able to identify the intersection. An MRA is indicated by a "flagged R" on NACO charts and by "MRA" on *Jeppesen* charts (MRA 9000).

Changeover Points (COPs)

A changeover point (COP) is the position en route between two adjacent navigation facilities where changeover in navigation guidance should occur from the ground station behind to the ground station ahead. If the COP is not at the midway point, then it will be shown on aeronautical charts with the appropriate DME distances. COPs are designed to prevent the loss of navigation guidance, to prevent frequency interference from other ground facilities, and to prevent use of different facilities by different aircraft that are operating in the same airspace. You should use COPs to the fullest extent.

Maximum Authorized Altitude (MAA)

The MAA is the highest usable altitude for an airspace structure or route segment at which adequate reception of navigation signals is assured. At altitudes above the MAA, there may be navigation signal interference from another station on the same frequency. It is rare to see an MAA on a chart.

Flying the Airways

You should fly along the centerline of airways, except to pass well clear of other traffic in VFR conditions, keeping in mind that the protected airspace of an airway is at least ±4 NM, making a corridor 8 NM wide. Maintain calculated IFR safe altitudes when flying IFR routes and procedures, since this is your only protection from obstacles and terrain that you may not see.

An airway corridor is 8 NM wide. Strive to fly in this protected airspace.

If climbing, cruising or descending outside of clouds, you should keep a good lookout, and make gentle banks periodically to assist you in detecting other traffic. When weather conditions permit, you are responsible to see-and-avoid, even if you are under radar control. The radar controller may advise you of nearby traffic using the clock-code based on the direction your radar blip is moving across the display (based on your track and not your heading). Therefore, their clock-code call may need to be adjusted for drift.

En Route Information

As you proceed toward your destination, you should stay aware of the current weather. The en route flight advisory service (EFAS) is probably the best source of information as you fly along. EFAS operates on frequency 122.0 MHz usually between the hours of 0600-2200 local time. To obtain the EFAS, call Flight Watch on 122.0 MHz with your aircraft identification and the name of the nearest VOR. FSSs that provide EFAS are listed in the A/FD and indicated on en route charts.

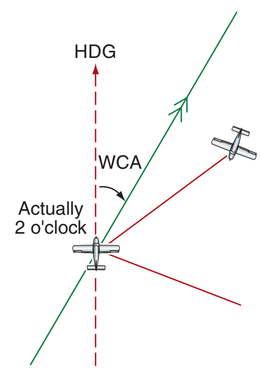


Figure 22-5
"Traffic, one o'clock high, 2 miles."

En Route information is also broadcast over selected VORs and NDBs, predominantly through the hazardous in-flight weather advisory service (HIWAS). This service provides a continuous broadcast of severe weather forecast alerts (AWW), SIGMETs, convective SIGMETs, center weather advisories, AIRMETs and urgent pilot reports (PIREPs).

At locations where HIWAS is not implemented, ARTCCs and terminal facilities will broadcast HIWAS information on all but emergency frequencies.

The availability of en route information broadcasts is shown on NACO charts by a white "H" in a black circle in the top right corner of the NAVAID data box for HIWAS broadcasts.

On *Jeppesen* en route charts, the weather service HIWAS is listed immediately above the NAVAID identifier box.

Note. Underlining of the frequency in the NAVAID data box on NACO en route charts indicates that no voice is transmitted on that frequency.

High-Altitude Flying and Oxygen

You must use oxygen for all of the time that you are above a cabin altitude of 14,000 feet, and for the time in excess of 30 minutes above 12,500 feet up to and including 14,000 feet. The onset of *hypoxia*, a lack of oxygen, is gradual and insidious. You may not even be aware of it—you might feel euphoric and think that you are the world's greatest pilot, when in reality your performance is dreadful.

You may not recognize the symptoms of hypoxia before your reactions are affected, so use oxygen at high cabin altitudes!

Note. Hypoxia is different from hyperventilation which is a result of too much air being breathed into the lungs. If you suspect hyperventilation, breathe at a slower rate than normal. If you suspect hypoxia, use oxygen.

VFR-On-Top

An "on top" clearance requires VFR conditions at altitude.

If you are operating on an IFR clearance, and suitable conditions exist, you may "request VFR-on-top" in lieu of an assigned IFR altitude. A clearance to operate VFR-on-top will not be initiated by ATC; it must be initiated by the pilot. It allows you to climb through cloud layers, if necessary, to reach the VFR conditions on top of clouds, or to stay in VFR conditions below clouds.

You must fly at a VFR altitude based on magnetic course (*WEEO plus 5: West evens+5; East odds+5*); comply with VFR visibility and distance-from-cloud criteria; and comply with IFR requirements such as MEAs, position reporting and adherence to ATC clearances. With a VFR-on-top clearance, you are still on an IFR flight plan, but ATC is no longer responsible for your separation from other IFR aircraft. You must see and avoid other traffic. A VFR-on-top clearance is not available in Class A airspace.

> **Note.** Under certain circumstances, it is possible to get a short-range IFR clearance to VFR conditions over the top. This is most frequently used at coastal airports to climb up through a cloud layer, then cancel IFR and proceed VFR once on top of the layer. This is often a tower en route clearance (TEC), and may not require even the filing of a flight plan.

DME Failure

If VOR equipment is required, then DME is also required for you to file FL 240 or above. If the DME fails at or above FL 240, then you should notify ATC immediately, and continue operations at and above FL 240 until the next airport of intended landing at which repairs or replacement can be made.

En Route Diversions

As you proceed toward your destination, you should stay aware of the suitability of en route airports in case you have to make an unexpected diversion. You may be able to obtain the current weather at these airports from:

- automatic terminal information service (ATIS);
- airport automated weather observation systems (ASOS or AWOS).

Failing that, the en route flight advisory service (EFAS) on 122.0 MHz can provide airport weather information on request.

Diversion to an Alternate Airport

If the weather is bad at your destination airport, you may decide to hold in the vicinity in the hope that it will improve, making an approach and landing possible. You should carefully consider the amount of fuel that you have available for holding, after allowing for:

- flight from the holding point to the destination airport, with an approach followed by a possible missed approach and climb-out;
- diversion to the alternate airport with an approach and landing; plus
- 45 minutes reserve.

Note. At the flight planning stage you will have considered the alternate minimums at your proposed alternate airport. Once you arrive there, however, you may fly the approach to the usual landing minimums, which are lower. Alternate minimums are for planning purposes only.

"Minimum Fuel"

If your fuel state is such that you cannot accept any undue delay at your destination, you should advise ATC: "minimum fuel." This is not declaration of a fuel emergency, but an advisory message to ATC that you may have to declare an emergency and receive priority if there is any undue delay.

Canceling an IFR Flight Plan

If operating on an IFR flight plan to an airport with a functioning control tower, the flight plan is automatically closed upon landing. You do not need to request the cancellation. If operating on an IFR flight plan to an airport with no functioning control tower, however, you must initiate the cancellation.

If conditions at the destination airport are IFR, you should wait until after landing before closing your IFR plan, which you can do by radio or telephone to any FSS or ATC facility (but do not forget, as this will increase the workload on FSS/ATC, who will try to trace you).

You may cancel an IFR flight plan in flight only if you are operating in VFR conditions outside Class A airspace, by advising the controller "cancel my IFR flight plan." You should then take action to change to the appropriate air/ground frequency, VFR transponder code, and VFR altitude. ATC separation and information services will be discontinued, including radar services where applicable. Request VFR radar advisory service, if desired.

Note. Decent weather conditions at your destination may tempt you to close your IFR flight plan early. You must make sure that ceilings are at least 1,000 feet and visibility is 3 miles to legally close an IFR flight plan in controlled airspace.

Review 22
En Route

Radar Service

1. Should you normally have Mode C selected?
2. IFR clearance consists of a DP to follow radar vectors and intercept a Victor airway. As you approach the airway on an intercept heading, you are advised "resume own navigation." Is radar flight-following terminated? When should you turn to intercept the airway?

En Route Clearances

3. Should you read back any altitude ATC assigns you when airborne?
4. Should you read back any heading ATC assigns you when airborne?
5. Should you read back any speed restriction ATC assigns you when airborne?
6. What term is used by ATC to indicate that your aircraft has been radar identified and that radar flight-following will be provided?
7. If ATC issues an instruction or a clearance, some aspect of which is not clear to you, what should you do?
8. If you are instructed to climb from your current altitude 6,000 feet MSL to 13,000 feet MSL, you should climb:
   a. at 500 fpm throughout.
   b. at the optimum rate of climb throughout.
   c. at the optimum rate of climb, reducing to 1,000 fpm for the last 500 feet.
   d. at the optimum rate of climb, reducing to 500–1,500 fpm for the last 1,000 feet.
9. If you are instructed to descend from your current altitude 16,000 feet MSL to 13,000 feet MSL, you should descend:
   a. at 500 fpm throughout.
   b. at the optimum rate throughout.
   c. at the optimum rate, reducing to 500–1,500 fpm for the last 1,000 feet.
   d. at the optimum rate, reducing to 1,000 fpm for the last 500 feet.
10. You are operating on a composite flight plan. What radio calls would you make to change from VFR to IFR?

Radio Reports

11. Is full position reporting normally required in a radar environment?
12. Is full position reporting normally required in a nonradar environment?
13. How are compulsory reporting points in a non-radar environment shown on en route charts?
14. If your estimate at the next fix, not advised to ATC because you are in a radar environment, is in error by more than 3 minutes, must you advise ATC?
15. If your estimate at the next fix, in a nonradar environment, is in error by more than 3 minutes, must you advise ATC?
16. Must you report if unable to climb or descend at 500 fpm or better?
17. Are you required to report when vacating a previously assigned altitude for a newly assigned altitude?
18. If you filed 115 knots, are you required to report if you alter cruising TAS to 120 knots?
19. If you filed 115 knots, are you required to report if you alter cruising TAS to 130 knots?
20. What are you required to report upon reaching an assigned holding fix?
21. Are you required to report leaving an assigned holding fix?
22. Are you required to report over fixes you have selected, and filed, to define a direct route?
23. When should Mode C be selected for an IFR flight?
24. Are you required to report the failure of your only NAV radio?

25. Are you required to report the failure of your no. 1 NAV, which has ILS capability, if your no. 2 NAV, without ILS capability, remains serviceable?

26. You fly into unexpected moderate turbulence and reduce speed from cruise speed 145 KIAS to maneuvering speed VA 110 KIAS while attempting to maintain a level flight attitude. What, if anything, should you report to ATC?

27. You cross ETX VORTAC at 0432 Zulu, and pass a full position report with an estimate of 0458 Zulu at the next compulsory reporting point at 60 DME ETX. You pass 20 DME ETX at 0442 Zulu. What action, if any, should you take in a nonradar environment?

28. Are you required to report at the FAF inbound on a nonprecision approach in a nonradar environment?

29. Are you required to report at the FAF inbound on a nonprecision approach in a radar environment?

30. Are you required to report at the outer marker inbound on a precision approach in a nonradar environment?

31. Are you required to report at the outer marker inbound on a precision approach in a radar environment?

32. Are you required to report after commencing a missed approach?

Flying the Airways

33. How much protected airspace is there either side of an airway?

34. Is it your responsibility to see and avoid other traffic when operating on an IFR flight plan, but not in clouds?

35. The radar controller advises "traffic 2 o'clock." You are holding 20° correction for a crosswind from the right. Where should you look for traffic?

36. How is availability of HIWAS en route weather broadcasts at a NAVAID facility indicated on FAA en route charts? How is this indicated on Jeppesen en route charts?

37. What does underlining of the NAVAID frequency in the data box on an FAA en route chart indicate?

38. Who should you contact for access to a weather specialist at a Flight Service Station? What frequency should you use? What information do you need to give?

39. Are Flight Service Stations that provide the en route flight advisory service listed in the appropriate Airport/Facility Directory?

High Altitude Flying and Oxygen

40. What is a lack of oxygen known as? Are symptoms of this easy to recognize before your reactions are affected? How do you combat this?

41. What is too much air being breathed into the lungs known as? How is this remedied?

42. You are cruising at 15,000 feet MSL in an unpressurized airplane. What are the oxygen requirements for the crew and passengers?

VFR-On-Top

43. Can ATC authorize VFR-on-top operations to an IFR flight without a specific request from the pilot to operate in VFR conditions?

44. Does a clearance to operate IFR to VFR-on-top allow you to climb through cloud layers to reach the VFR conditions on top?

45. What words should an instrumented-rated pilot use to request an ATC clearance to climb through a cloud layer, or an area of reduced visibility, and then to continue the flight VFR, but still remain on an IFR plan?

46. May you operate on a VFR-on-top clearance below a cloud layer?

47. Must a VFR-on-top cruising altitude comply with VFR weather minimums?

48. Must a VFR-on-top cruising altitude comply with the appropriate VFR altitude?

49. Must a VFR-on-top cruising altitude also meet the minimum IFR altitude?

50. The VFR-on-top cruising altitude is based on:
a. true course.
b. magnetic course.
c. magnetic heading.

51. When flying VFR-on-top, do you use VFR or IFR cruising altitudes?

52. An appropriate VFR-on-top cruising altitude on magnetic course MC 170 is:
a. 6,000 feet MSL.
b. 6,500 feet MSL.
c. 7,000 feet MSL.
d. 7,500 feet MSL.

53. An appropriate VFR-on-top cruising altitude on magnetic course MC 190 is:
a. 6,000 feet MSL.
b. 6,500 feet MSL.
c. 7,000 feet MSL.
d. 7,500 feet MSL.

54. An appropriate VFR-on-top cruising altitude on MC 180 is:
a. 6,000 feet MSL.
b. 6,500 feet MSL.
c. 7,000 feet MSL.
d. 7,500 feet MSL.

55. When operating VFR-on-top, do VFR, IFR, or both VFR and IFR rules apply?

56. Are VFR-on-top operations prohibited in Class A airspace?

57. You are cruising IFR on MC 340. What is your correct altitude? After you request "to VFR-on-top," ATC assign you a VFR-on-top clearance at the next higher suitable altitude. What is this altitude?

58. Can you cruise VFR-on-top on MC 097 at FL195?

59. Are VFR-on-top operations permitted in Class D airspace?

60. Are VFR-on-top operations permitted in Class B airspace?

61. Are VFR-on-top operations permitted in controlled airspace?

62. Are radio reports from an airplane on an ATC VFR-on-top clearance the same reports that are required for any IFR flight?

63. Do VFR-on-top flights need to be above or below the MEA?

64. Which class of airspace do VFR-on-top flights need to be below?

DME Failure

65. The appropriate course of action if your DME fails is:
a. landing immediately.
b. continuing to the nearest airport where repairs can be made.
c. continuing to the next airport of intended landing where repairs can be made.

66. Do you need to advise ATC if your DME fails while maintaining FL 240 or above?

67. Do you need to descend to a lower altitude if your DME fails while maintaining FL 240?

En Route Diversions

68. What does EFAS stands for?

69. What frequency does the EFAS usually operate on?

70. What are the EFAS's hours of operation?

71. The weather at your destination is below minimums, but improving. You decide to hold at a VOR 20 NM away. How would you calculate how much fuel is available for holding?

72. If you are unable to accept any undue delay at the destination because of your fuel state, how should you advise ATC? Is this a declaration of an emergency?

Radio Communications Failure

73. While operating on an IFR clearance, you experience 2-way radio communications failure. You are in VFR conditions. What should you squawk? What should your plan of action be?

74. You are operating on an IFR flight plan in IFR conditions when you experience two-way radio communications failure shortly after takeoff. What should you squawk? Should you follow the route as cleared? If you have been assigned 3,000 feet and advised to expect 9,000 feet, with a route segment MEA of 4,000 feet, what altitude should climb to and maintain?

Canceling an IFR Flight Plan

75. Do you need to initiate the closure of your IFR flight plan after landing at an airport with no functioning control tower?

76. Is your IFR flight plan automatically closed after landing at an airport with a functioning control tower?

77. Under what circumstances can you close an IFR flight plan prior to completing the flight?

En Route Charts (a)

78. What do the letters MEA stand for?

79. Does the MEA between two fixes meet obstacle clearance requirements between the two fixes?

80. Does the MEA between two fixes guarantee adequate navigation signal coverage between the two fixes?

81. Does the MEA between two fixes guarantee two-way radio communications when flying between the two fixes?

82. Does the MEA between two fixes guarantee radar coverage between the two fixes?

83. Does the MEA between two fixes guarantee DME reception between the two fixes?

84. Does the MEA between two fixes guarantee reception of more than one navigation signal at all points between the two fixes?

85. What is MOCA an abbreviation for?

86. Does the MOCA between two fixes meet obstacle clearance requirements between the two fixes?

87. Does the MOCA between two fixes guarantee adequate navigation signal coverage between the two fixes?

88. What distance from the VOR is an acceptable navigation signal coverage at the MOCA assured to?

89. Is the MOCA higher than the MEA?

90. Reception of signals from an off-airway facility when flying at the MEA may be inadequate to identify a fix or intersection. What is the minimum altitude at which the reception will be adequate known as?

91. You are cruising at the MEA of 7,000 feet MSL and have 30 NM to reach a radio fix beyond which the MEA is 8,500 feet MSL. If no MCA is specified, what is the lowest altitude at which you may cross the fix? The airplane is capable of a 500 fpm climb. When should this be initiated at the latest?

92. In the case of operations within a designated mountainous area, where no other minimum altitude is specified, what is the lowest altitude above the highest obstacle that an aircraft under IFR may be operated? What horizontal distance from the course flown is this within?

93. Does the MEA assure acceptable navigation signal coverage? Does it meet obstruction clearance requirements?

94. If no COP is shown on an en route chart for an airway between two VORTACs, where would you change VOR frequencies?

95. If the COP is not at the midway point between two VORs, how is it shown on the en route charts?

96. What is a waypoint?

97. Are Victor airways depicted on en route low-altitude charts?

98. Where does Class A airspace begin? Is it depicted on en route low-altitude charts?

99. What is the maximum speed below 10,000 feet MSL?

100. What is the maximum speed within 4 NM of the primary airport of a Class C airspace area?

101. Is special-use airspace depicted on en route low-altitude charts?

102. Which class of airspace includes extensions to Class D airspace which accommodate an instrument approach, and which extend more than 2 NM from the Class D core area?

103. Where do transition area extensions commence when associated with an airport with an instrument approach procedure in a Class D airspace area?

104. Where do transition areas associated with the airways route structure commence? Where do they extend up to?

105. What sort of airspace lies beneath a transition area and down to the surface?
106. What areas are established to separate certain military activities from IFR traffic?
107. What class of airspace is represented by unshaded white areas on FAA low-altitude en route charts?
108. Is ATC responsible for the control of air traffic in Class G airspace?
109. When is a mode-C equipped transponder required?
110. When is DME required to plan for flight?
111. How many stepped tiers does Class C airspace usually have? Where does Class C airspace extend upward to?
112. How is Class D airspace at an airport indicated? What altitude does Class D airspace usually extend upward to?
113. What is the minimum equipment required for flight within Class B airspace?
114. You are inbound and close your IFR flight plan 10 miles from your destination, which is a Class D towered airport. When should you be in contact with the control tower?
115. If the control tower is not operating, but there is an FSS at the airport, what sort of service will you receive?
116. Where can hours of operation of a control tower be found?
117. Can the time difference between local time and UTC at a particular airport be found in the A/FD?

En Route Charts (b)

Refer to figure 22-6 (page 513) for questions 122 to 142.

118. Are LDA approaches indicated on en route charts?
119. What communications frequencies are normally available at all FSSs but are not shown above the Air/Ground communication boxes on FAA en route charts?
120. What does HIWAS stand for?
121. What do the areas shaded light brown on FAA low altitude en route charts denote?
122. Where is the VOR changeover point when flying east on V306 from Daisetta to Lake Charles?
123. What is the appropriate FSS to communicate with in the Lake Charles area?
124. On which frequencies can you receive De Ridder FSS during the day in the Lake Charles area?
125. What is the appropriate FSS to communicate with over the Daisetta VOR?
126. Can you talk to, and receive messages from, Montgomery County FSS on 122.1 in the Daisetta area?
127. How can you receive messages from Montgomery County FSS in reply to a call you have made on 122.1 in the Daisetta area?
128. What frequencies can you receive Montgomery County FSS on during the day in the Daisetta area?
129. What does the striped area around the Houston Class B airspace indicate?
130. At Jefferson County airport, why is the back course of the localizer depicted, but not the front course?
131. What airspace exists at Jefferson County airport?
132. Where is the VOR changeover point when flying southwest from Jefferson County along V20 to Hobby?
133. Where is the VOR changeover point when flying from Jefferson County along V20 to Hobby?
134. What is the MEA flying northwest from Jefferson County to Daisetta along V574?
135. What is the MEA flying north from Jefferson County to SILBE intersection along V569?
136. What is the MEA flying north from SILBE intersection along V569? Is adequate obstruction clearance assured at this altitude? Is adequate navigation signal coverage assured at this altitude?
137. What is the meaning of the symbol: "*1800" flying north from SILBE intersection along V569? Is adequate obstruction clearance assured at this altitude? Is adequate navigation signal coverage assured at this altitude?
138. What are the ARTCC frequencies in the Jefferson County and the Lake Charles areas?

139. On what frequency is an en route flight advisory service, EFAS, available in the Jefferson County to Lake Charles area?

140. Which frequency is the HIWAS available on in the area near Jefferson County airport? Which radio would you select for this?

141. What available lighting is indicated on the chart at Lake Charles Regional airport?

142. What is the responsible ARTCC unit and frequency in the Lake Charles area?

Answers are given on page 781.

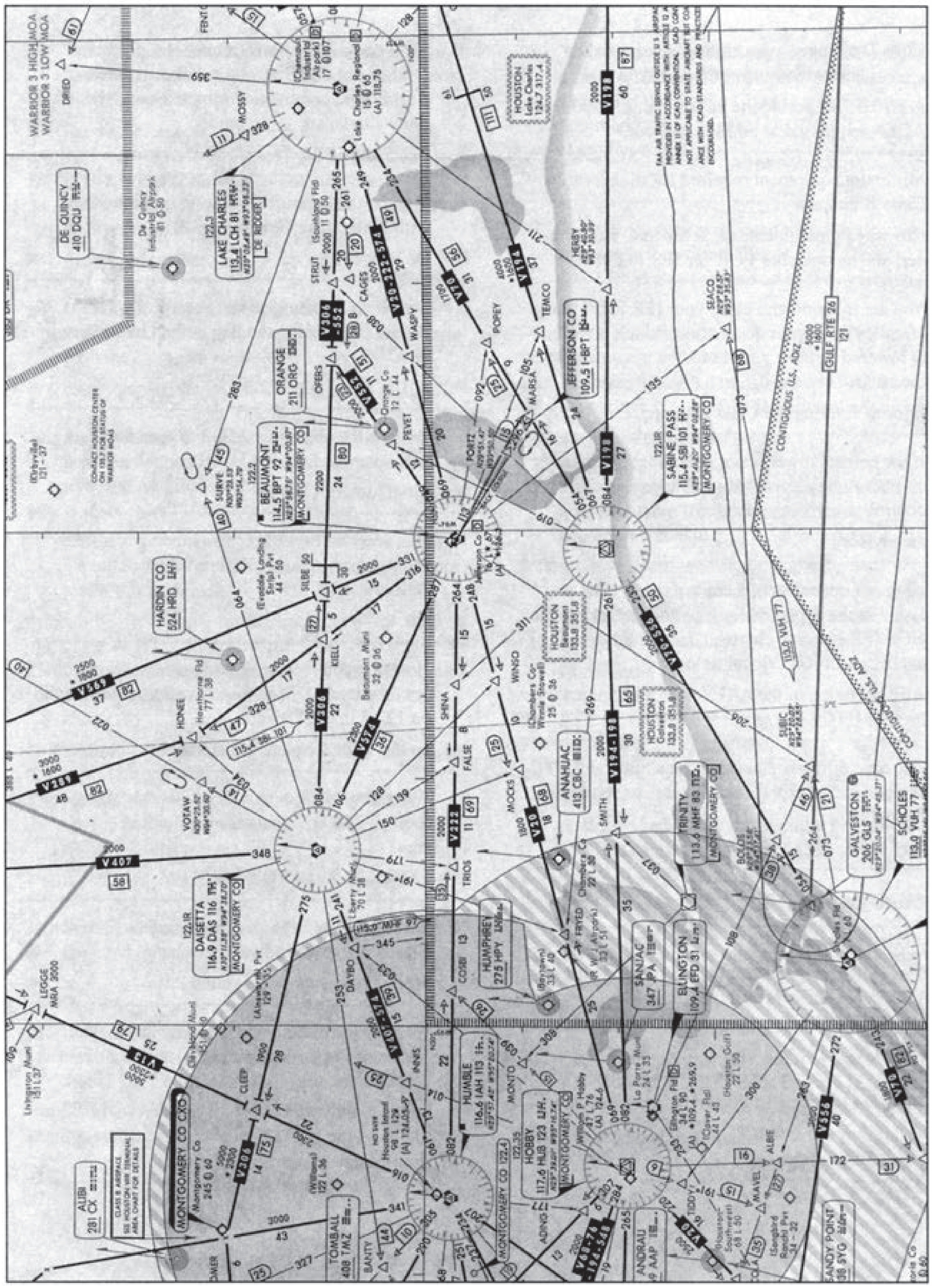


Figure 22-6 L-17 FAA low-altitude en route chart—excerpt of Galveston, Texas area (reduced in size).

Instrument Approaches 23

Arrivals

Plan your arrival long before you reach your destination.

Arrival planning should begin early in the cruise, so that your descent and arrival in the terminal area is at the correct speed and altitude, with you in a relaxed, but alert, condition. Appropriate charts should be close at hand.

Before beginning a descent, you must consider conditions at the planned destination airport to determine if an approach is desirable. Thunderstorms over the airport, reported windshear, contaminated runways or a crosswind well above the maximum for your airplane might encourage you to divert from cruise altitude to the alternate. Standing water or slush on a runway will cause poor or nonexistent braking, and possibly *hydroplaning*, where the tire does not contact the runway, but glides along the water/slush surface. Do not land in hydroplaning conditions.

To calculate a descent point, you may work backward from the approach and landing. Start by obtaining the airport information—automatic terminal information service (ATIS) or an automated weather observing system (AWOS or ASOS) at the airport. To begin an ILS at 3,000 feet some 10 NM the other side of the airport adds distance to your route, and so your descent may be delayed compared with descent for a straight-in approach from an en route segment.

You should start descent promptly following a descent clearance unless it is qualified by "at pilot discretion." The normal descent procedure is to maintain the optimum descent rate, reducing it to 500–1,500 fpm for the last 1,000 feet. If you are flying an unpressurized airplane, then 500 fpm throughout the whole descent is a reasonable rate that should not harm any eardrums. As an example of descent planning, losing 6,000 feet at 500 fpm takes 12 minutes which, if your groundspeed is 120 knots (2 NM per minute), will require 24 NM.

ATC requirements may, of course, lead to a descent different from that planned. ATC may require speed adjustments, which you should maintain as closely as possible, but certainly within ±10 knots, and also altitude and tracking adjustments. You may have to track using pilot navigation with NAVAIDs onto the final approach course, or you may receive radar vectors if the airport is in a radar environment. You may also have to hold, and perhaps become one aircraft in a series of timed approaches from a holding fix. Allow yourself some flexibility to cope with reasonable unexpected variations.

VFR practice approaches are just that, VFR. Do not accept headings or altitudes that will take you into IMC. Request amended instructions from ATC.

If making a VFR practice instrument approach and ATC assigns a heading or altitude that will take you into clouds, then avoid the clouds, remain VFR and advise ATC that the assigned altitude or heading will not permit VFR.

Standard Terminal Arrival Routes (STARs)

STARs are published in textual and diagrammatic form to simplify clearance delivery to IFR arrivals at some airports. A STAR is a published IFR arrival procedure that provides transition from the en route structure to a fix or waypoint in the terminal area leading into the instrument approach. ATC may issue a STAR without a specific pilot request; if you do not want a STAR, advise ATC, preferably by writing "No STAR" in the remarks section of your flight plan.

To accept a STAR, you must have at least a textual description in the cockpit.

To accept a STAR, you must have at least a textual description in the cockpit. If not, ATC may still issue you with an arrival clearance identical to the STAR, but they will have to read it out in full.

STARs are found alphabetically in a group at the front of the applicable FAA *Terminal Procedures* booklet, and are included with the other instrument charts for that particular airport in the *Jeppesen* airway manual. Shown here is the DINGO standard terminal arrival route at Tucson, Arizona, with the Gila Bend transition. It is written as "GBN.DINGO 5." The actual arrival begins overhead DINGO, with the Gila Bend transition providing the routing from the en route phase of the flight to DINGO. Flown properly, and with good pilot/controller cooperation, this STAR will lead you to the TUS Rwy 11 ILS at the ideal commencement altitude.

STARs are *not* approach clearances, so you must not descend below the last assigned altitude until you receive an approach clearance and are on a published segment for that approach.

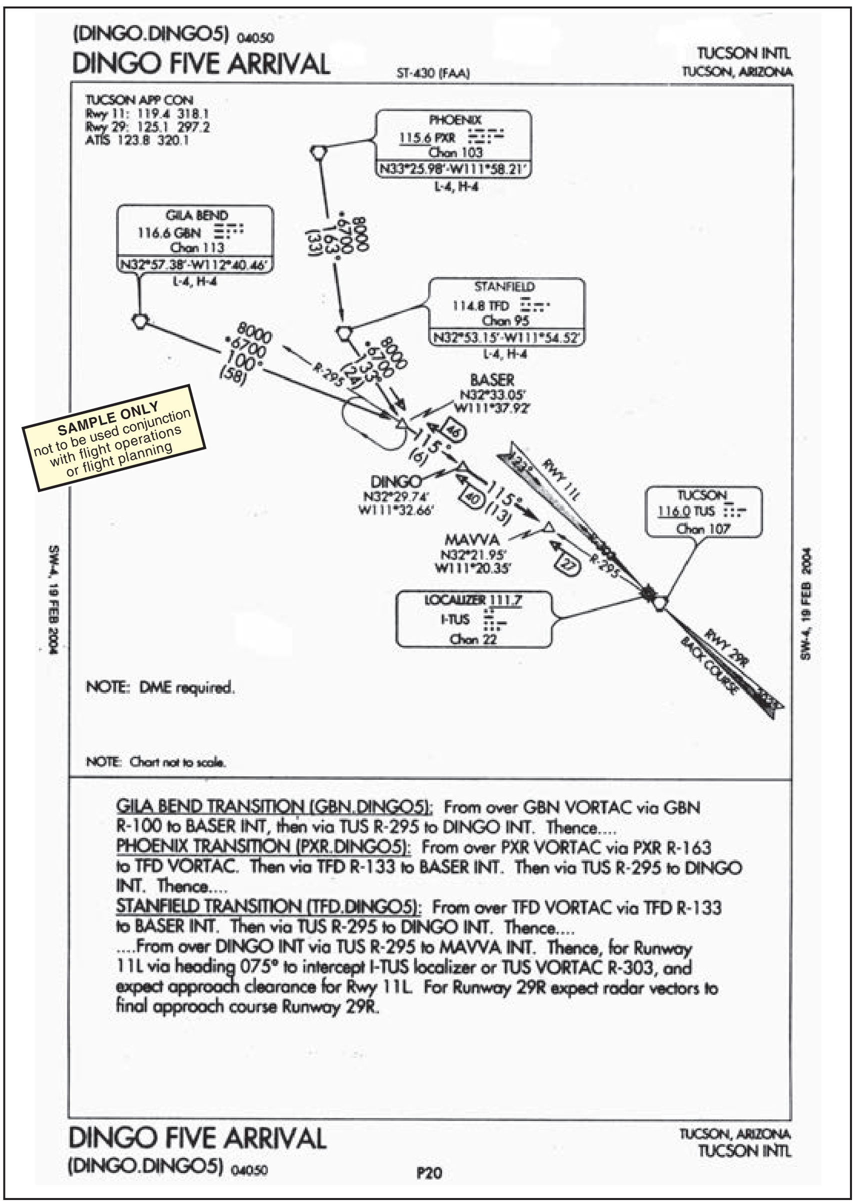


Figure 23-1 NACO chart for DINGO FOUR STAR at Tucson, Arizona, with the Gila Bend transition.

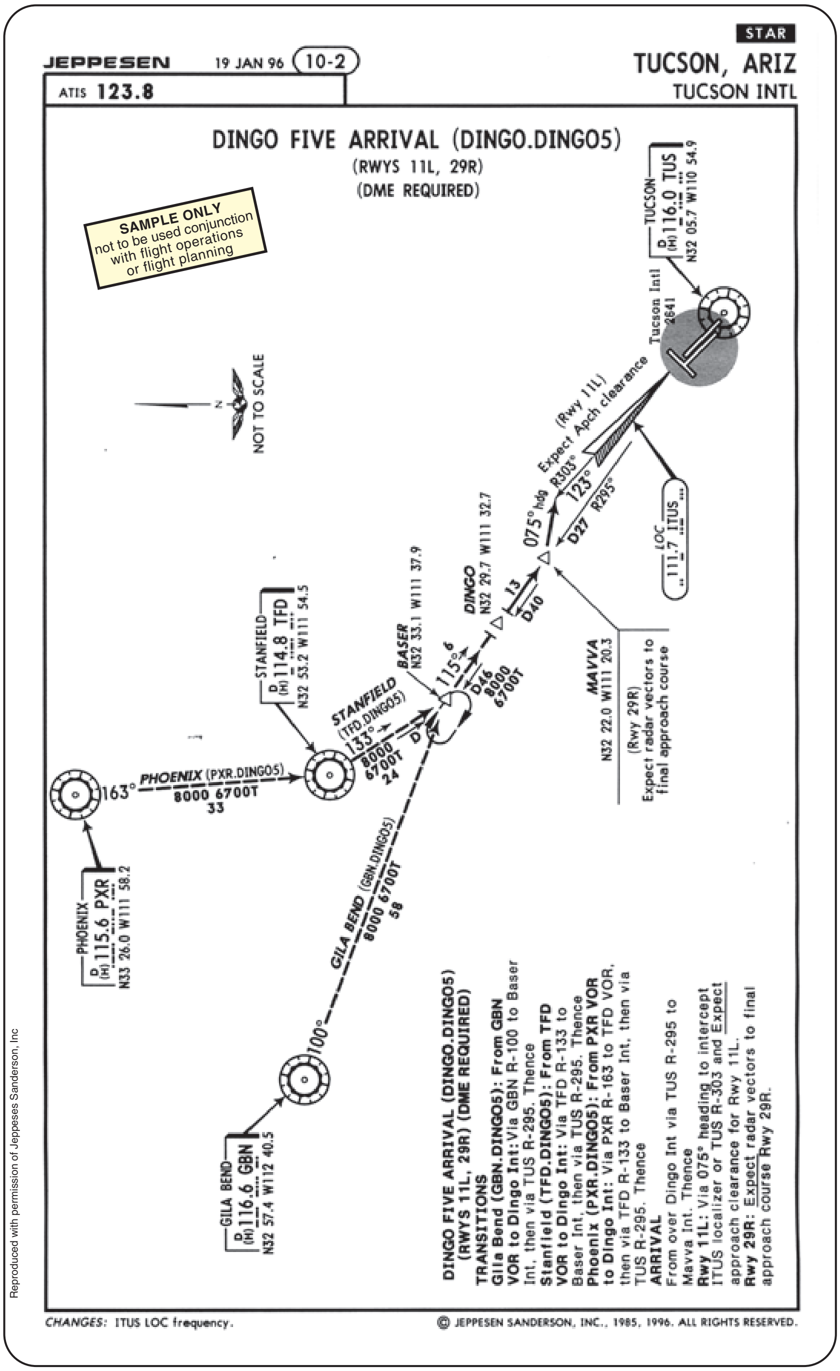


Figure 23-2 Jeppesen chart for DINGO FIVE STAR at Tucson, Arizona (reduced).

Vertical Navigation

Read back all altimeter settings for confirmation.

Correct vertical navigation is vital during instrument flight when terrain, obstacles and other airplanes may not be seen. Vertical navigation is based mainly on the indications of the altimeter, therefore the correct altimeter setting is most important. It is so important that each new subscale setting advised by ATC, and its location, should be read back by the pilot as confirmation. The datum for vertical navigation is mean sea level, and the correct altimeter setting in the pressure window causes the correct altitude MSL to be indicated.

The Instrument Approach

Having arrived in instrument conditions at the initial approach fix (IAF), the airplane is then in a position to commence the instrument approach. Delaying action, if necessary, can be taken by entering a holding pattern if cleared by ATC.

When an instrument approach is designed by an airplane performance specialist, the first consideration is the final approach course to the runway for a straight-in procedure, or to the airport for a circle-to-land procedure. The procedure is then designed backward from this desirable final approach course through a number of segments, with the aim of providing a suitable flight path between the en route phase of the flight and final approach. Generally, the fewer the turns and the less complicated the approach, the better it is for the pilot and for ATC.

The Segments of an Instrument Approach

The complete instrument approach procedure (IAP) may be divided into up to five separate segments that blend into each other. They are:

1. arrival segment, or feeder route;
2. initial approach segment;
3. intermediate approach segment;
4. final approach segment; and
5. missed approach segment.

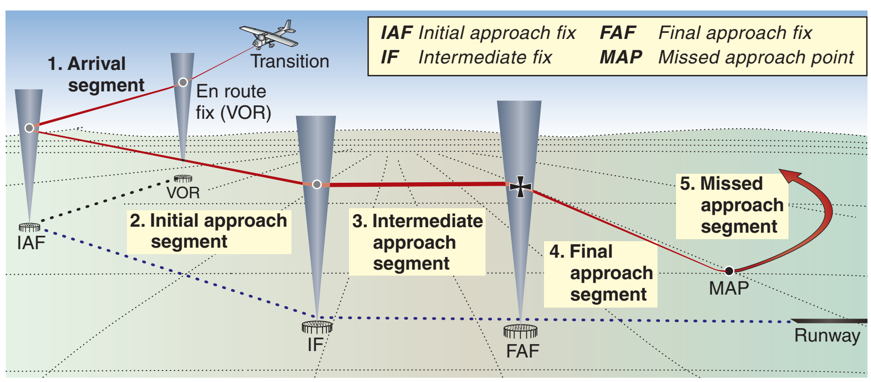


Figure 23-3 A simple and well-designed instrument approach.

1. The Arrival Segment

The feeder route, also known as the arrival segment, is the route followed from the en route phase of the flight to the initial approach fix (IAF). It usually starts at an en route fix and ends at the initial approach fix (IAF), often the first navigation facility associated with the procedure. The IAP chart will show the feeder route, if any, with its minimum altitude, course to be flown, and distance to the IAF (although this does not distinguish the feeder from the transition, which will also show minimum altitude, course to be flown, and distance to IAF). Transitions differ from feeder routes in that they are only associated with DP/STARs, are not shown on the IAP chart, and do not necessarily lead to the final approach course.

There may be a number of feeder routes into the one instrument approach procedure to cater for airplanes arriving from different directions, or there may be none. Many procedures do not require a feeder route—for instance, if the en route tracking ends at an initial approach fix (IAF). Both Jeppesen and NACO plates depict feeder routes with a bold course arrow.

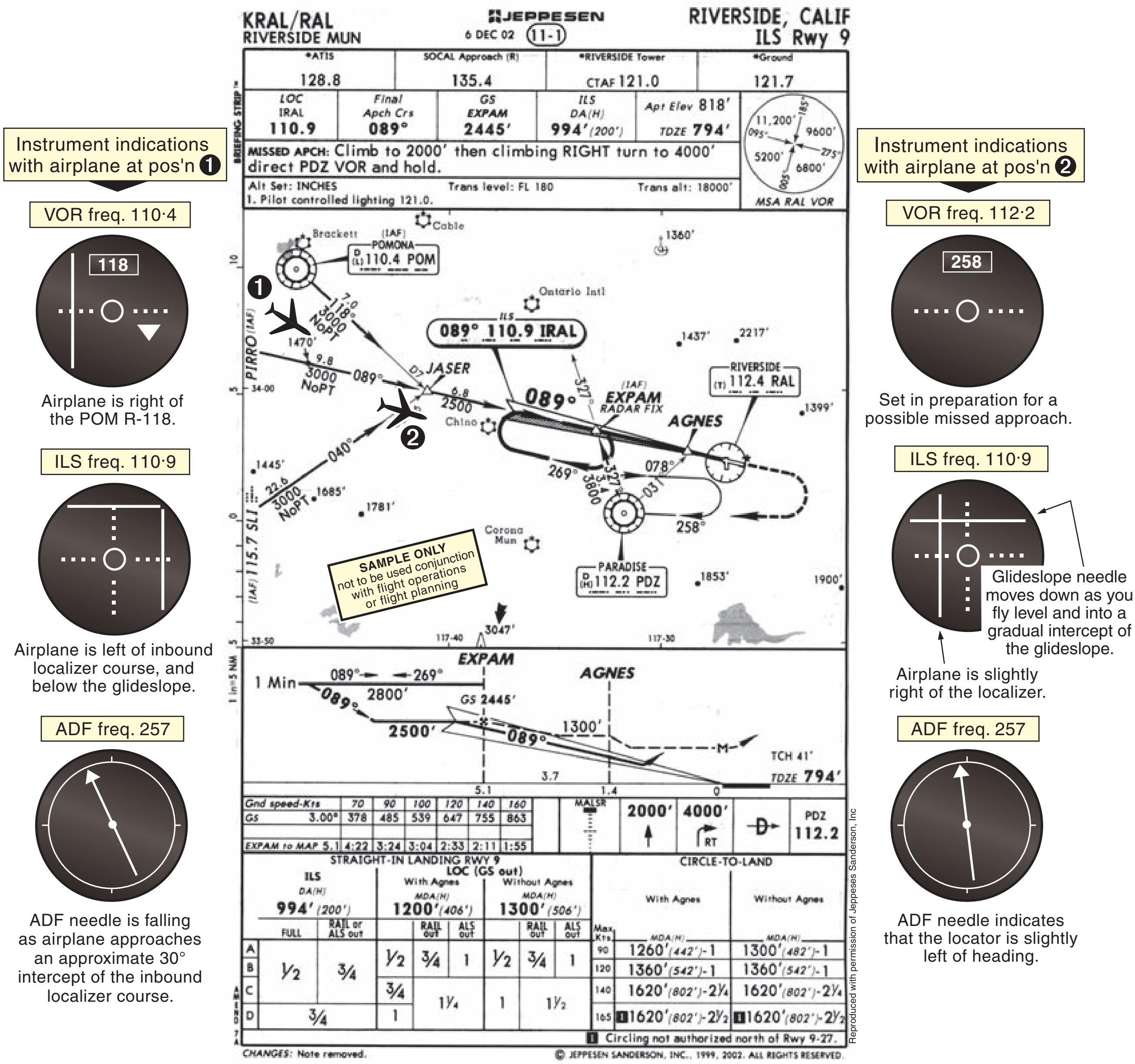


Figure 23-4 Riverside CA, ILS Rwy 9 (Jeppesen, reduced).

2. The Initial Approach Segment

In the initial approach segment, the airplane is maneuvered to enter the intermediate segment which aligns it, at least approximately, with the final approach course. The initial approach segment commences at the initial approach fix (IAF), and may consist of a particular course, radial, DME arc, procedure turn, holding pattern, radar vector, or any combination of these.

3. The Intermediate Approach Segment

The intermediate approach segment blends the initial approach segment and the final approach segment. It is the segment in which aircraft configuration, speed and positioning adjustments should be completed prior to entering the final approach segment, by which time all cockpit prelanding checks should normally be completed, with the airplane established in a suitable condition for landing. Your instructor will explain the procedures you are to use for your particular airplane.

The intermediate approach segment ends at the final approach fix (FAF), and may begin either:

- at a designated intermediate approach fix (such as an NDB or a locator outer marker—LOM); or
- on completion of a dead-reckoning course, a procedure turn, or a reversal turn in a racetrack pattern.

4. The Final Approach Segment

The final approach segment of a nonprecision approach (such as an NDB approach) begins at the final approach fix (FAF), and is the segment in which the alignment and descent for landing are accomplished. It ends at the missed approach point (MAP).

In some instrument approaches, the final approach fix is the same as the initial approach fix (the IAF may be the locator outer marker LOM when flying outbound, and the FAF is the same locator outer marker when flying inbound).

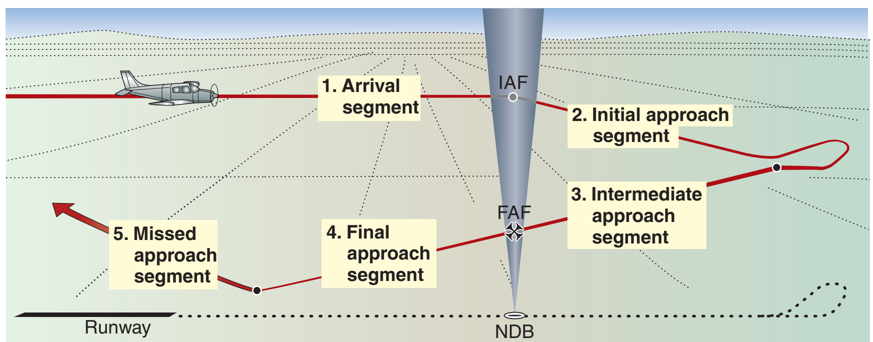


Figure 23-5 The five segments of a typical NDB approach.

Final approach may be made to a runway for a straight-in landing, or it may be made for a circling approach (visual maneuvering for at least a partial traffic pattern) to a runway with which the final approach of the instrument approach procedure is not aligned, provided of course that the pilot becomes visual at a suitable time. The final approach fix on nonprecision approaches should be crossed at or above the specified altitude before final descent is started. The FAF is marked on IAP charts with a Maltese cross or a lightning bolt symbol. The lightning bolt symbol (NACO) represents the glide-slope intercept altitude for a precision approach as well as the final approach fix. The Maltese cross represents the final approach fix for a nonprecision approach. If ATC directs a lower-than-published glide-slope intercept altitude, then the FAF is the resultant actual point of glide-slope intercept. Where no final approach fix is shown, final descent should not be commenced until the airplane is established within ±5° of the final approach course.

Step-down fixes, if published on the chart profile diagram, are limiting altitudes, and should be crossed at or above their minimum crossing altitudes.

The final approach segment for a precision approach starts at the final approach point (FAP), where the intermediate segment of the procedure intersects the glide path for the precision part of the ILS. The ILS approach is designed so that the airplane will intercept the glide slope from below, generally by flying level until the slope is intercepted, to avoid the possibility of following one of the false glide slopes that may exist at steep angles such as 12°.

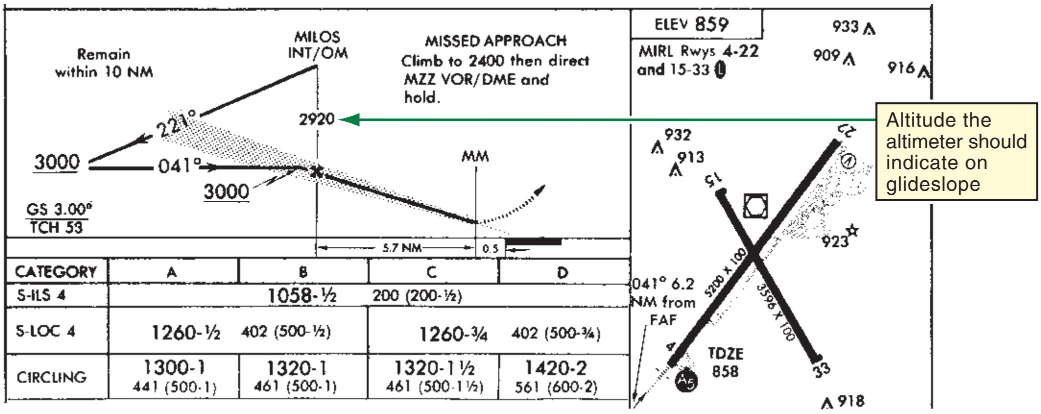


Figure 23-6 The final approach sesgment of an ILS.

Avoid false glide slopes! Intercept the glide slope on an ILS from below.

Final descent slope guidance on an ILS is provided by the electronic glide slope. Descent on the glide path should not be initiated by the pilot unless the airplane is on course (within half-scale deflection of the localizer). A fix or facility, usually the outer marker (OM) (but it could be a compass locator, a DME distance, or a radar fix), is provided to allow the pilot to verify the glide path/altitude relationship at one point on the precision approach. Pilots should check their altimeter reading against the published altitude when crossing the fix to verify:

a. if the altimeter setting is correct;
b. and the altimeter is reading correctly.

Timing should commence at the FAF to assist in determining arrival at the missed approach point for some nonprecision approaches.

It is most important that a pilot does not descend below the minimum permitted altitude for a particular approach unless the pilot has become visual, and can continue the approach to land visually with the runway environment and nearby ground features in view. The items that constitute runway environment such as the approach lights, are listed with the Part 91 discussion (Chapter 3).

5. The Missed Approach Segment

If the pilot has not become visual by a particular point or minimum altitude on final descent, then a missed approach must be made.

If the pilot has not become visual by a particular point or minimum altitude on final descent (in flight, visibility minimums are not met), then a missed approach must be made. For a *precision approach*, such as the ILS, the *missed approach point* is defined by the intersection of the glide path with the pilot's *decision height* (DH/DA), and therefore is not shown diagramatically on the charts. Unless visual, the pilot should begin the missed approach *immediately* when the DH/DA is reached.

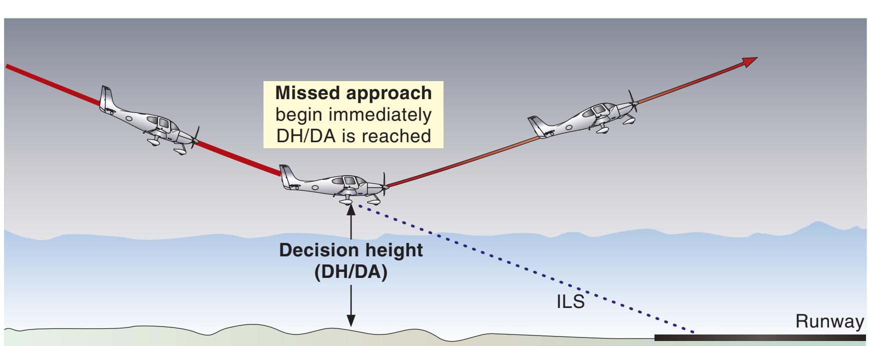


Figure 23-7 If not visual, commence the missed approach at DH/DA on a precision approach.

For a *nonprecision approach*, the *missed approach point* is defined by either a *fix*, *facility* or by *timing*, and is shown on both the plan and profile diagrams as a dotted line. The MDA(H) is shown in the table. It is also described in text. If a turn is specified in the missed approach procedure, then it should not be commenced until the airplane has passed the MAP and is established in the climb. It's a good idea to climb at least to circling minimums before starting any turns on the missed approach.

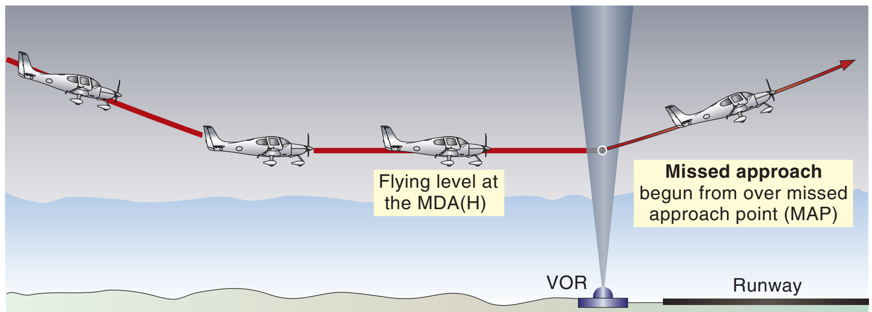


Figure 23-8 If not visual on a nonprecision approach, track in to the MAP at MDA.

If you want to execute an early missed approach before reaching the MAP, you may commence climbing at any time, but you should continue tracking to the MAP and then follow the prescribed missed approach course (unless otherwise directed by ATC).

The pilot may not descend below the calculated *minimum descent altitude* (MDA) on a nonprecision approach unless he or she becomes visual, however (unlike on a precision approach), the pilot may track in as far as the MAP at or above this level in the hope of becoming visual, before having to commence a missed approach. It is possible that the pilot may become visual in a position from which it is not possible to complete a straight-in landing safely, in which case some maneuvering to position the airplane will be necessary, known as a *circle-to-land* maneuver.

The missed approach segment is considered to be completed at an altitude sufficient to allow either:

- initiation of another instrument approach;
- return to a designated holding pattern; or
- resumption of en route flight to a diversion airport.

Once you've started your missed approach, advise ATC of your intentions.

Instrument Approach Charts

Instrument approach procedure (IAP) charts provide a graphic presentation to the pilot of:

- *holding procedures* (if required prior to commencing the instrument approach);
- *the instrument approach procedure*; and
- *the missed approach procedure*.

Instrument approach charts are designed to be readable in the cockpit, although some difficulty may be experienced in turbulence and/or poor light. A good approach briefing in cruise will minimize these problems once you've begun the approach. The actual instrument approach is shown in both plan and profile on the chart.

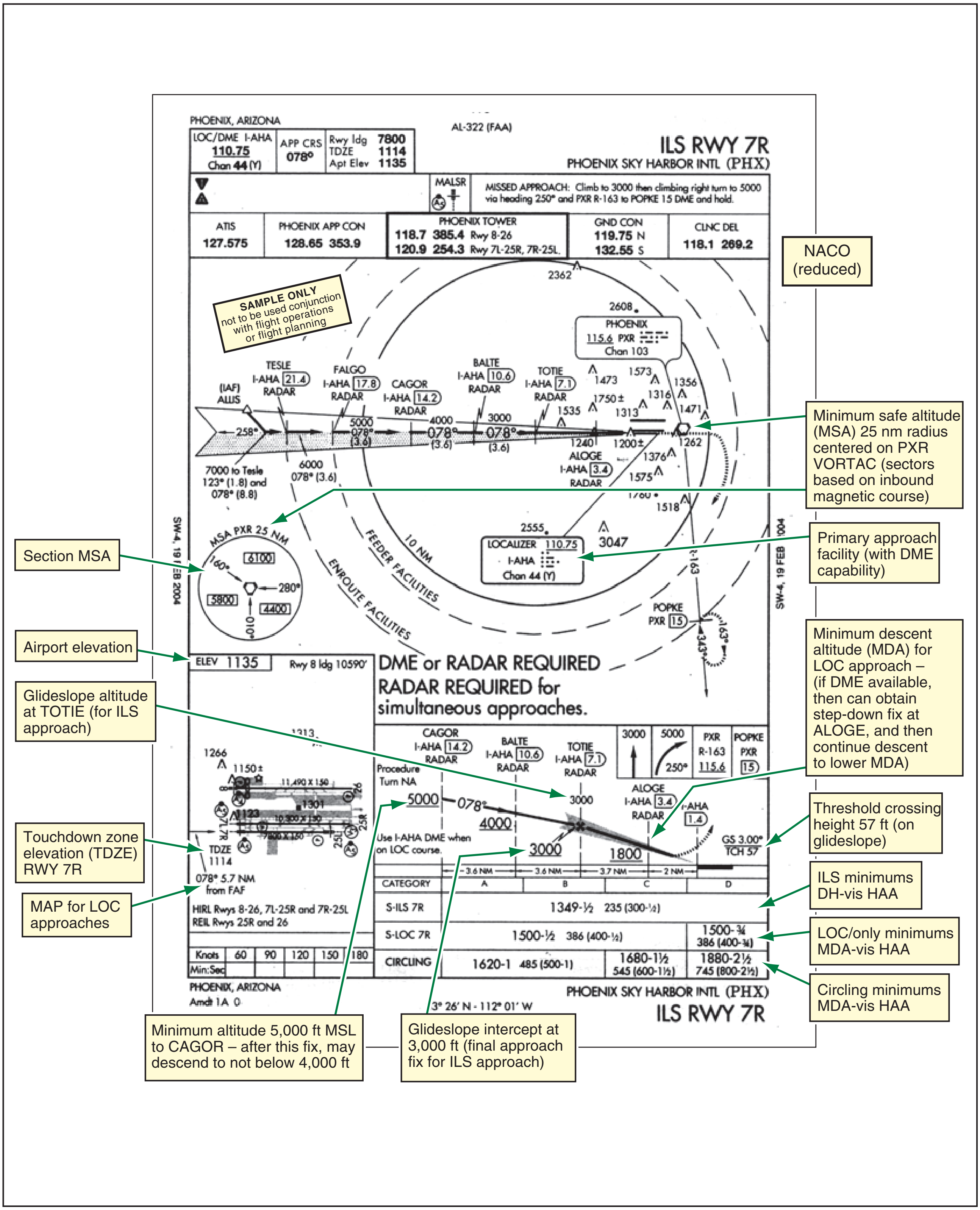


Figure 23-9 A typical instrument approach chart (ILS).

IAP charts are available for all airports where instrument approach procedures have been established and approved by the FAA. Charts acceptable to the FAA are those published by NACO (National Aeronautical Charting Office) and *Jeppesen*.

You must study carefully the actual instrument approach charts that you will be using, since presentation of the same instrument approach by the various publishers is not identical. The symbols and abbreviations used will also differ. We have used both NACO and *Jeppesen* charts as examples.

Update your approach charts at the designated intervals.

Only current instrument approach charts must be used! They are regularly revised, and amendments are made available every 56 days. Changes to the actual procedure, the appearance of significant new obstacles, such as buildings or masts in the approach or missed approach areas, changes to frequencies or the addition of new NAVAIDs relevant to that approach will require a current chart. Urgent amendments of a timely nature may be advised to pilots by NOTAM. Check currency of chart, and check the NOTAMs for any amendments.

The Elements of an Instrument Approach Chart

The information provided on an instrument approach chart includes:
- identification of the particular approach;
- a *plan* view of the approach and the missed approach;
- a *profile* view of the approach and the missed approach;
- holding procedures associated with the approach;
- full details of facilities associated with the instrument approach, missed approach and holding;
- necessary airport and topographical information (coastlines, lakes and rivers, relief, built-up areas, etc.) pertinent to the safe execution of the approach; and
- a landing chart, showing the runway layout.

Identification of an Instrument Approach Chart

An instrument approach chart is normally identified at the top by:
- the name of the airport;
- an abbreviation of the type of radio facility (further identified by the runway served in the case of a runway approach as against an airport approach); and
- additional information to distinguish between separate charts for the same airport.

"ILS DME Rwy 9" indicates that the approach requires both an ILS and a DME, whereas "ILS Rwy 27" indicates that DME is not required. If a letter follows the aid, such as VOR-A or VOR-B, it indicates that circling minimums only are published, either because the IAP is not aligned with the runway, or the descent gradient from the FAF to the touchdown zone straight-in is too steep.

Communications Frequencies

The relevant VHF communications frequencies, usually in the order in which a pilot will use them, are also listed near the top of the chart.

Plan View of the Instrument Approach

The plan view is a *conformal* projection that displays correct angular relationships. The scale is such that the approach charts are of a convenient small size for use in the cockpit, yet large enough to show the intermediate approach area as well as the final approach and missed approach areas. A scale of 5 NM to the inch is typical. A graduated scale line is shown down the left hand side of the *Jeppesen* charts.

A reference circle of 10 NM radius centered on a fix or facility on NACO charts (5 NM centered on the airport on *Jeppesen* charts) emphasizes to the pilot any obstructions or features close to the airport. Horizontal distances along the approach are measured in *nautical miles* to facilitate use of the DME which reads in NM, however remember that runway distances and runway visual range (RVR) are specified in *feet*, and visibility in *statute miles.*

The airport is clearly shown on the plan view, including the runway pattern and any other distinctive patterns perhaps formed by taxiways or aprons. Even though obstacle clearance is provided for in the design of the instrument approach, significant topographical and other data, although not part of the actual instrument approach, may be shown on the chart to assist the pilot when and if he or she becomes visual. It is handy, for instance, for a pilot to know the runway layout and the position of any nearby obstacles that the pilot can expect to see when and if he or she becomes visual on final approach.

The plan position of each of the NAVAIDs required for the procedure is shown, with frequencies, ident, and defined courses in *degrees magnetic.*

Main Procedure Course

The main procedure course is shown as a heavily printed full line with its magnetic direction and a directional arrow. Any procedure turn required to reverse direction is also clearly shown.

Missed Approach

The missed approach is shown as a dashed line with its magnetic direction and a directional arrow. The latest point at which the pilot may commence a missed approach according to the procedures is referred to as the missed approach point (MAP).

Holding Pattern

The *holding pattern*, which, strictly speaking, is not part of most approaches, is shown with magnetic direction and a directional arrow. Some approaches, however, use the racetrack pattern as part of an alternative intermediate segment, replacing a procedure turn. In these cases, the hold will be depicted in the same heavy black line as the main approach course.

Profile View

The profile view of the instrument approach is published directly beneath the plan view. The *main procedure course* is a solid line with a directional arrow and magnetic course. In the profile view, the angles shown are generally not correct, but exaggerated for display purposes.

Approach Slopes

Approach slopes are really quite gentle (a typical ILS glide slope, for instance, is only 3° to the horizontal, a gradient of 1 in 20). The profile view of any reversal or procedure turn is shown as a horizontal line, which may have associated altitude, distance or time requirements stated nearby.

Facilities

Relevant facilities (LOM, MM) are also shown in profile. The missed approach procedure is shown as a dotted line with a directional arrow, and with a written description nearby.

Vertical Distance

Vertical distances are shown in *feet MSL. Airport elevation* is the vertical distance (in feet MSL) of the highest point on the landing area of the airport, and is published on all instrument approach procedure (IAP) charts:

- on NACO charts as Elev near the airport diagram;
- on *Jeppesen* charts as Apt. Elev (airport elevation) at top-right, and as Apt. near the runway on the profile diagram.

Airport elevation is the reference level for cloud ceiling. For instance, a cloud ceiling of 800 feet at an airport, elevation 5,200 feet, would be encountered at altitude 6,000 feet MSL. Height above the airport elevation is written as HAA, and is used when specifying circling minimums and alternate minimums for an airport.

Touchdown Zone Elevation

Touchdown zone elevation (TDZE) is the highest elevation in the first 3,000 feet of the runway, and is shown near the runway on the IAP chart when straight-in landing minimums are authorized. Height above touchdown zone is abbreviated to HAT, and is used when straight-in minimums are published. In other words, 200 feet minimums are referenced to 200 feet above touchdown zone.

Threshold Crossing Height

Threshold crossing height (TCH) is the theoretical height above the runway threshold at which the aircraft's glide-slope antenna would be if the aircraft is flown precisely on the ILS/MLS glide slope.

> **Note.** TCH is not wheel height above the threshold—the wheels might be considerably lower.

The Minimum Safe Altitude Circle (MSA)

The MSA circle, which may be broken into sectors, indicates minimum safe altitudes that provide 1,000 feet obstruction clearance within 25 NM of the facility on which the MSA circle is based. These altitudes, while they guarantee obstruction clearance, do not guarantee reception of navigation or communication signals, and so are considered as *emergency* minimum altitudes for an IFR flight.

Approach Minimums

Approach minimums are a critical part of each instrument approach. The appropriate minimums to use depend on the qualifications and experience of the pilot, the performance category of the aircraft, the equipment carried in the aircraft, and the approach itself. The *performance category* of the aircraft is based on its maneuverability, which depends to a large extent on its airspeed. An airplane flying slowly is able to maneuver in less airspace than a fast airplane.

The categories are based on 1.3 × V_{S0}, where V_{S0} is the stall speed in the landing configuration at maximum landing weight. 1.3V_{S0} is a measure of maneuvering speed, and is the speed that would be used on approach (at least approximately, depending on actual weight and conditions).

Most general aviation airplanes fall into Categories A or B; *Boeing 757s* are in Category C, and *Boeing 767s* are in Category D.

1.3 V_{SO}	Performance Category
90 kt and below	A
91 kt to 120 kt	B
121 kt to 140 kt	C
141 kt to 165 kt	D
166 kt and above	E

Table 23-1
Aircraft performance categories.

You must know your airplane category before you can determine the approach minimums. If your airplane has V_{S0} = 50 knots, then $1.3V_{S0} = 1.3 \times 50 = 65$ knots, which places it in Category A. Another airplane, with V_{S0} = 70 knots ($1.3V_{S0} = 1.3 \times 70 = 91$) would be in Category B. The approach minimums consist of an altitude by which you must be visual, and a required visibility.

Once you are visual, the landing minimum is determined by visibility alone, which may be *runway visual range* (RVR) in feet or visibility in statute miles. RVR is measured by a *transmissometer* installed beside the runway—if this is inoperative, and the prescribed minimum is expressed in RVR, you may convert the RVR in feet to a comparable ground visibility in statute miles (using tables published in the IAP booklets, or by using RVR 2,400 feet = ½ SM, RVR 5,000 feet = 1 SM). Minimums are raised if:

- you approach at a higher speed than for your normal category—then you must use the minimums for the higher category; or
- components are inoperative (MM not available). See the front of the NACO IAP booklet, and on the *Jeppesen* IAP charts, to see what penalties apply.

If more than one component is inoperable, use the highest adjustment that applies. The minimums (in order of meeting them on the approach) can be thought of as:

- circle-to-land minimums, for other than straight-in landings;
- straight-in nonprecision minimums (localizer only if the ILS glide slope is not available);
- straight-in precision minimums (ILS);
- landing minimums (RVR or visibility only).

Note. The *alternate minimums*, which are used for flight planning purposes to determine if you may file that airport as an alternate, are higher minimums than the approach minimums and are not found on the approach charts, but at the front of the NACO IAP booklet. They are on the *Jeppesen* airport charts.

Some nonprecision approaches have a *visual descent point* (VDP) from which normal descent from the minimum descent altitude (MDA) may be commenced, provided the runway environment is clearly visible.

For certain instrument approaches, there may be a *sidestep maneuver*, where you fly an ILS approach to one runway (say ILS Rwy 25R), but are cleared to land on another parallel runway (25L) that is within 1,200 feet laterally. You can only sidestep to land if the maneuver was part of your original approach clearance. For example, "cleared to ILS 16R approach, sidestep to 16L." The sidestep minimum is based on nonprecision criteria and may be higher than the minimum for a straight-in approach to the initial runway, but lower than the circle-to-land minimums. You should perform the sidestep maneuver as soon as you have the landing runway environment in view.

Timing to the Missed Approach Point

For a *nonprecision* approach where the approach aid is well away from the airport and acts as the final approach fix (FAF), a small table at the bottom of the chart shows the time from the final approach fix to the missed approach point (MAP). On ILS charts, this information is useful in situations where the electronic glide slope is not available, and a nonprecision localizer approach has to be made.

Always start timing at the FAF, even on an ILS approach. If the glide slope fails after the FAF, you can still proceed with a nonprecision localizer approach and recognize the MAP.

Figures 23-10, 23-11 and 23-12 show typical instrument approach charts.

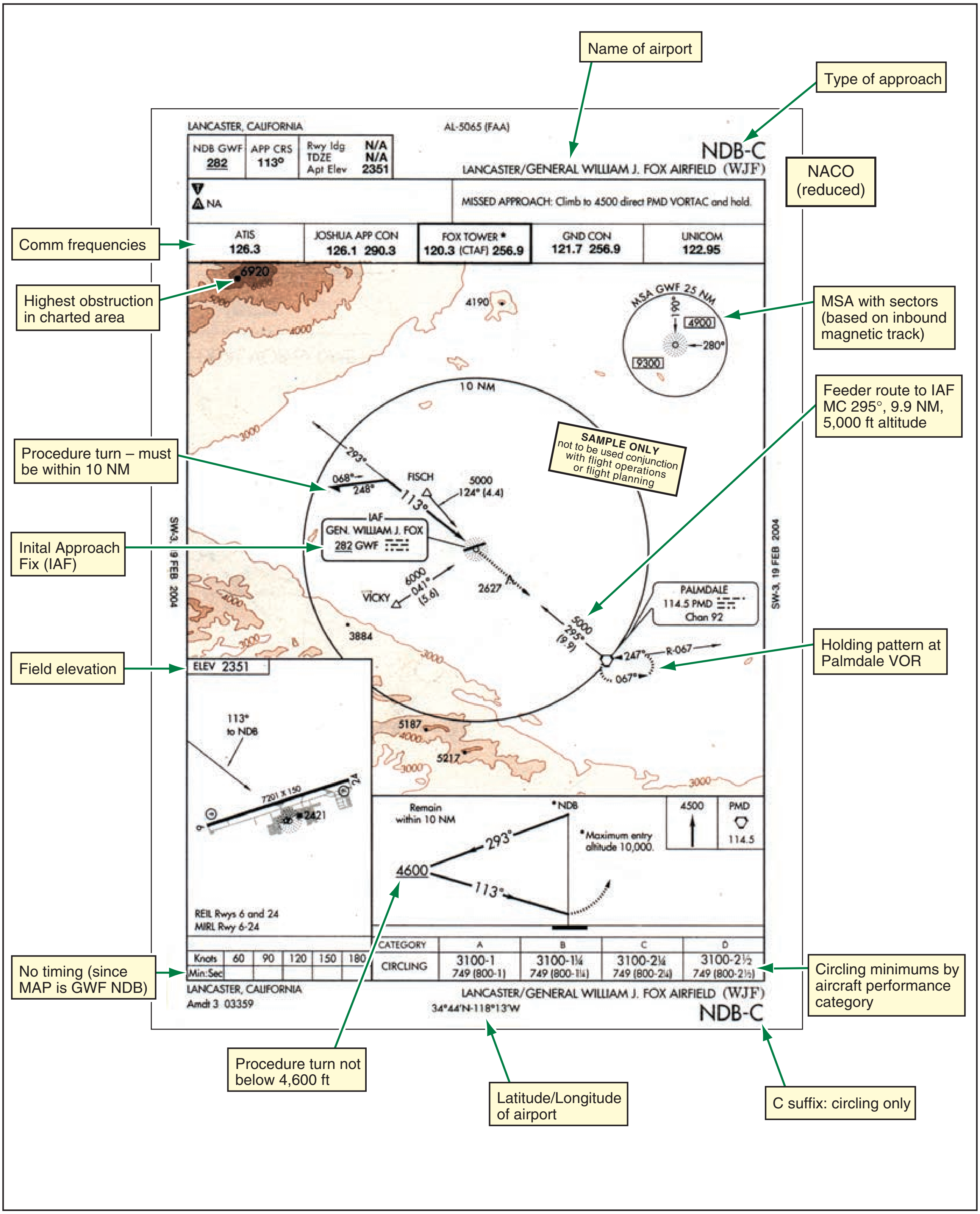


Figure 23-10 Tracking aid at airport—Lancaster NDB-C (NACO).

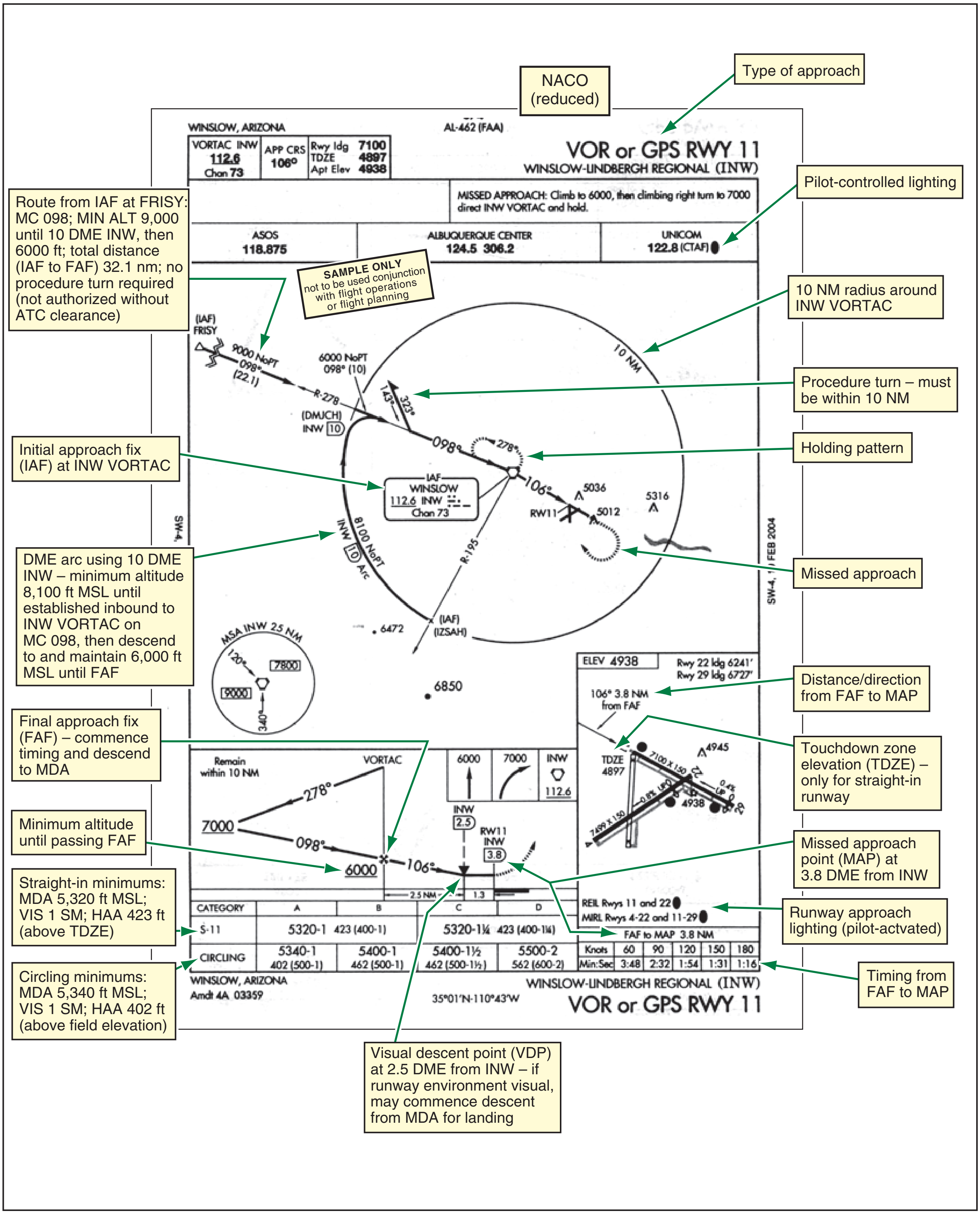


Figure 23-11 An off-airport tracking aid—Winslow VOR Rwy 11 (NACO).

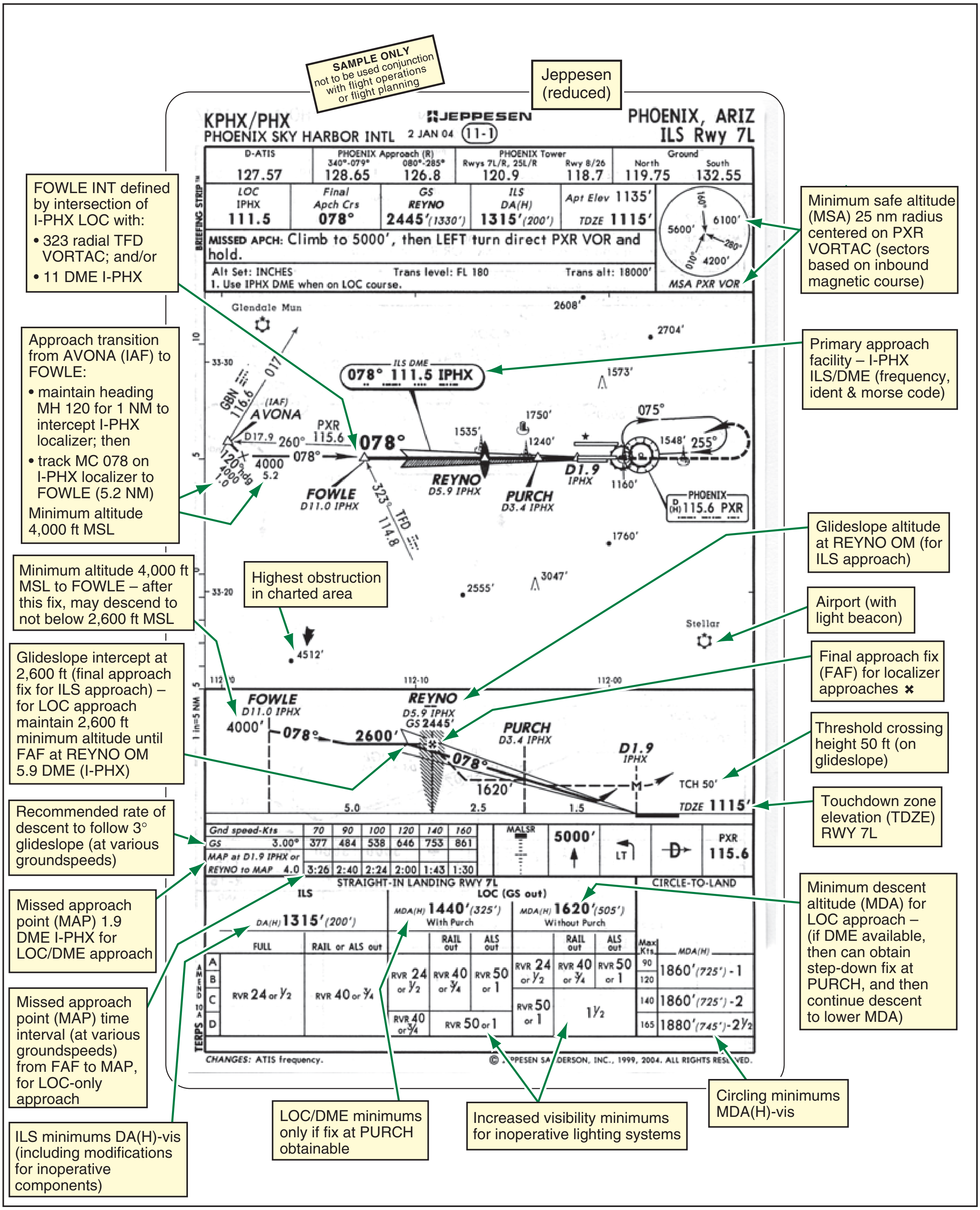


Figure 23-12 Phoenix ILS Rwy 8R (Jeppesen, reduced).

General Comments on Instrument Approaches

Given the choice, a precision approach is preferred over a nonprecision approach. The best approach, however, may be the one that allows a straight-in approach into the wind.

It is most important that the cockpit be well organized prior to starting an instrument approach, since the workload during the approach will be high. The instrument approach procedures to be used, including the missed approach, should be reviewed en route, preferably well before the airport is approached and even prior to commencing descent from cruise altitude.

You must also consider:

- runway surface conditions (dry, wet, standing water, slush, ice);
- crosswind;
- airplane performance (landing distance required).

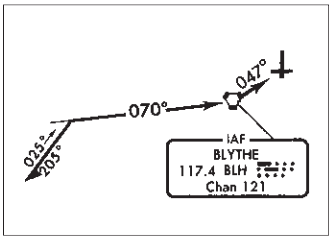
Given a choice of instrument approaches to an airport or to a particular runway, a pilot will generally opt for a precision approach, such as an ILS, over a nonprecision approach. As well as making it easier to fly an accurate final descent, the glide-slope guidance of a precision approach will permit a lower minimum altitude, possibly making the difference between becoming visual or having to make a missed approach.

The charts required should be arranged in order, consideration of minimums completed, and intended action in the case of a missed approach determined (diversion, return for a second approach, etc.). Fuel on board is an important consideration, especially if a diversion to an alternate becomes necessary.

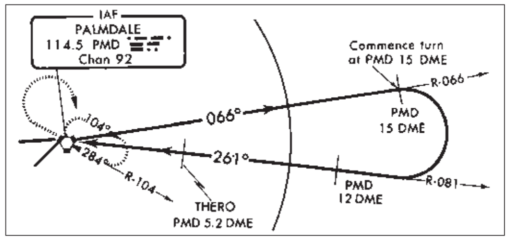
The navigation aids required for the approach should be set up as early as convenient, although some delays may be necessary. For instance, the NAV/COM may need to remain selected to a VOR for en route tracking prior to the start of an ILS approach. Make use of every available means of navigation to assist you in forming a picture of exactly where the airplane is. Do not leave the NAV/COM, ADF or DME idle if they can be tuned to useful aids, even if those aids are not part of the published procedure.

Ensure that the altimeter setting is correct for precise vertical navigation. If a high speed has been used on the cruise and descent, it may be appropriate to slow the airplane to a more suitable maneuvering speed before reaching the initial approach fix, and to complete any necessary cockpit checks at that time.

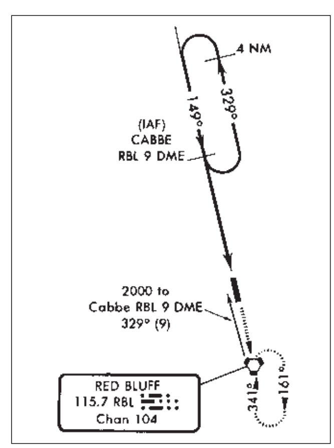
If the instrument approach uses the same facility for the initial approach fix (IAF) and the final approach fix (FAF), the pilot will track outbound from the IAF, reverse course by making a procedure turn inbound, and then track to the final approach fix. Some instrument approaches are designed so that a teardrop turn (rather than a procedure turn) is used to align the airplane on the final approach course (see figure 23-13). Others use a holding pattern.



Procedure turn



Base turn



Holding pattern and reversal turn

Figure 23-13 Aligning the airplane on final approach course.

Under *radar control*, a pilot may be radar vectored directly to the final approach course of any instrument approach, and cleared to descend to suitable altitudes by ATC, so that a smooth intercept of final approach may be made. If *feeder routes* are published for the particular approach, then the pilot will possibly be routed by ATC via one of these routes. Sometimes it is possible to track via a DME arc from the en route phase to intercept the final approach course. In all of these cases, reversal turns may be avoided.

The *minimum altitude* at which the pilot may fly in any particular segment using pilot NAV will be shown on the chart, although ATC may assign a higher level. Do not leave the last assigned level unless you have been cleared for the approach, and do not intercept final approach off a radar vector unless you have been cleared for the approach (you may give the controller a reminder that you are about to cross the final approach course). The radar controller will be using a *minimum vectoring altitude* (MVA) to provide you with adequate obstruction clearance (1,000 feet normally, 2,000 feet in mountainous areas), and at least 300 feet above the floor of controlled airspace to give you the protection of controlled airspace.

Establish your airspeed, altitude, and mental attitude for the approach during the intermediate segment.

During the *intermediate approach segment*, the airplane is being maneuvered to be positioned on final approach at a suitable altitude and airspeed. The actual configuration of the airplane (the position of flaps and landing gear) and the speed at which it should be flown at various stages in the approach will vary between airplane types, and clear instructions in this regard will be given to you by your instructor, and in the Pilot Operating Handbook. If you think that you will be far too high to start the approach, you can request a holding pattern or radar vectors in order to lose the excess altitude. If you are doing a visual practice instrument approach and look like you will be flying into actual instrument conditions, remain VFR and advise ATC.

During *final approach*, normal attitude flying techniques should be used, with constant reference to the flight instruments and regular reference to the navigation instruments. During an ILS, the glide slope should be maintained with small adjustments of pitch attitude on the attitude indicator using the elevator, and airspeed should be maintained on the ASI with power adjustments using the throttle. For a nonprecision approach, a suitable steady rate of descent should be set up.

For example, to lose 1,500 feet of altitude in 5 NM (300 feet per NM) at a groundspeed of 90 knots (1.5 NM per minute), a suitable rate of descent is $1.5 \times 300 = 450$ feet per minute.

When on final approach, the pilot should have clearly fixed in mind the *minimums*, and the *missed approach procedure*. If not visual with the runway environment in sight at the calculated minimum altitude:

- *DH/DA* for a *precision approach*—a missed approach should be commenced immediately; or
- *MDA* for a *nonprecision approach*—the airplane may continue tracking at MDA to the missed approach point (MAP) in the hope of becoming visual, but a missed approach must be commenced at or before the MAP if visual flight does not become possible. Early missed approach climbs are permitted, but tracking for the missed approach must be as published, unless otherwise authorized by ATC.

Approach lights, runway lights, runway markings, and features in the general runway environment are all visual references the pilot looks for before descending below DH/DA or MDA(H).

What is "Visual Reference" at the DH/DA or MDA(H)?

Visual reference is the minimum visual reference that a pilot should have in view before continuing the approach below the DH/DA or MDA(H). The visual segment should contain sufficient physical features (approach lights, runway lights, runway markings, and features in the general runway environment) to ensure that the position of the aircraft relative to the desired flight path can be positively ascertained. This then enables the pilot to make an informed judgment at DH/DA or MDA, and thereafter to maintain stable flight toward the runway. After becoming visual, the *landing minimum* is visibility alone (or RVR). The in-flight visibility must be at or above minimums in order to land or descend below DH/DA or MDA.

A precision approach such as an ILS will be aligned with the extended runway centerline and the electronic glide slope will provide an ideal slope to the touchdown zone. Therefore, if you have flown a stable ILS approach in clouds with localizer and glide-slope needles centered, you should be in a good position, when and if you become visual, to continue the stable approach without any dramatic alterations of heading or rate of descent (unless necessitated by windshear or turbulence).

The localizer allows you to track accurately along the extended runway centerline—so remember that, if a significant crosswind exists, you can expect to see the runway not directly straight ahead through the windshield, but slightly left or right depending on the wind direction. Do not make any large changes of heading immediately when you become visual—wait briefly to see if you already have the correct wind correction angle—likely to be the case if you have tracked accurately down the localizer. Of course, you may have to make some minor adjustments to heading to keep your flight path aligned with the extended runway centerline.

Nonprecision approaches using a VOR or an NDB, may or may not be aligned with the runway centerline—you can determine this from the approach charts—so you should prepare yourself and know where to look for the runway when and if you become visual. If not aligned with the centerline and/or if not on a suitable approach slope, when you become visual you should maneuver into a position so that you can fly a straight and stable last few hundred feet to the touchdown zone on the runway.

Even when you are out of the clouds and visual, you should always be prepared to make a *missed approach*:

- if you feel your approach is too unstable or too far out of alignment with the runway centerline; or
- if you are unable to maintain a safe rate of descent to the touchdown zone or to control the airspeed sufficiently well; or
- if the runway is obstructed.

Make use of any VASI to assist you in achieving the correct approach slope. If at the MDA on a nonprecision approach the VASI lights are all red (showing you well below slope) then fly level at the MDA until you are on slope, then proceed with the landing.

Keep in mind the runway, its length and surface conditions (wet, slushy, etc.) and the possibility of wake turbulence or low-level windshear. There is a lot to think about on approach but, with practice and experience, it becomes a lot easier. Always keep in mind: a good landing requires a good approach.

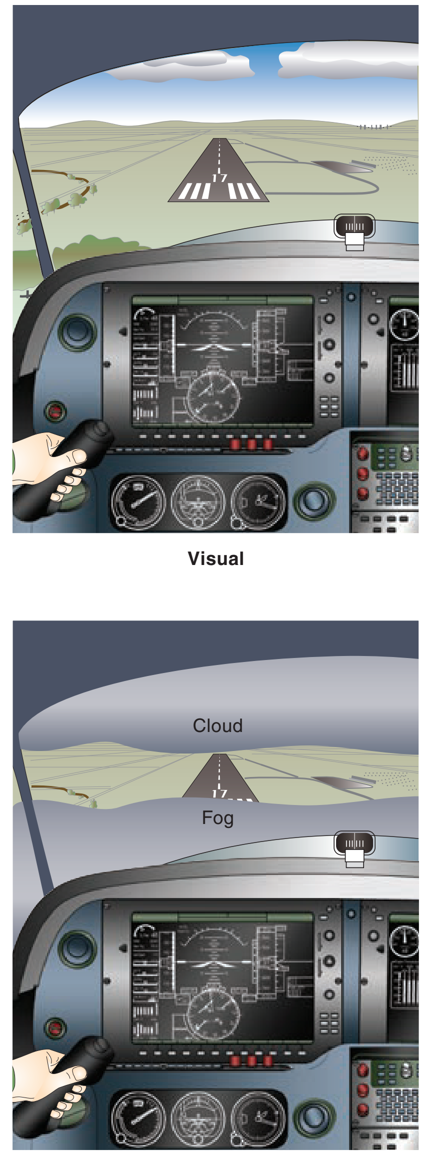


Figure 23-14 Visual, or not visual.

Visual Illusions on Approach

Be prepared for visual illusions. A narrower-than-usual or upsloping runway will give the impression that you are high on slope, leading some pilots to make a lower-than-normal approach. Haze creates the illusion that the runway is further away, and can lead some pilots into making a lower-than-normal approach.

Most runways are of standard width and on flat ground. On every approach, you should try to achieve the same flight path angle to the horizontal, and your eyes will become accustomed to this, allowing you to make consistently good approaches along an acceptable glide slope merely by keeping your view of the runway through the windshield in standard perspective.

Runway Slope

If you are approaching a sloping runway, however, the perspective will be different. A runway that slopes upward will look longer and you will feel that you are high on slope, when in fact you are right on slope. The tendency will be for you to fly lower and make a shallower approach. If you know that the runway does have an upslope, you can avoid this tendency.

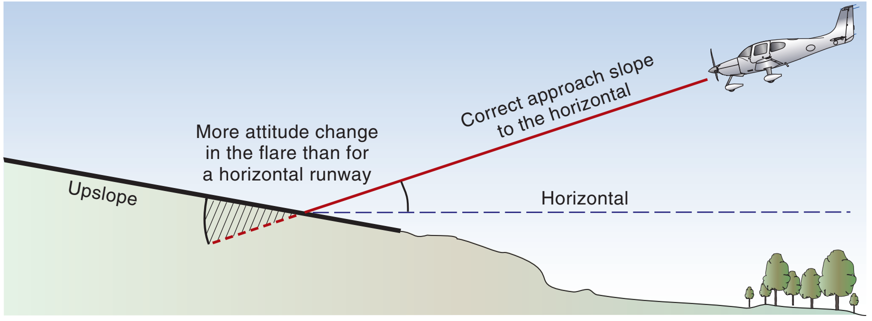


Figure 23-15 An upward sloping runway creates a "too-high" illusion.

A runway that slopes downward will look shorter and you will feel that you are low on slope, when in fact you are on slope. The tendency will be for you to go higher and make a steeper approach. If you know that the runway does have a downslope, you can avoid this tendency. If you know the slope of the runway, you can allow for it in your visual estimation of whether you are high or low on slope.

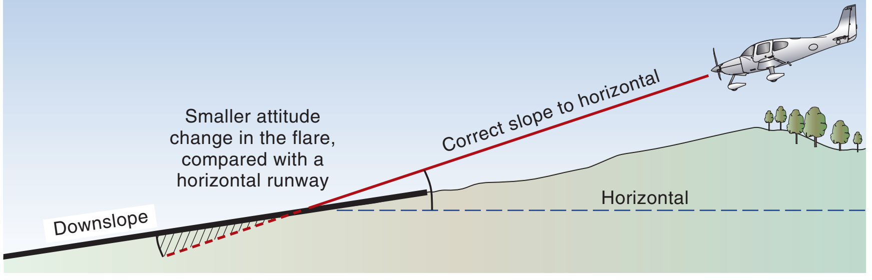


Figure 23-16 A downward sloping runway creates a "too-low" illusion.

Runway Size and Shape

A runway that is larger than usual will appear to be closer than it really is. Conversely, a runway that is smaller than usual will appear to be further away than it really is.

A wide runway, because of the angle at which you view it peripherally in the final stages of the approach and landing, will cause an illusion of being too low, and you may flare and hold-off too high as a result, leading to "dropping in" for a heavy landing. Conversely, a narrow runway will cause an illusion of being too high, and you may delay the flare and make contact with the runway earlier (and harder) than expected.

If you know that the runway is wider or narrower than what you are familiar with, then you can allow for this in your visual judgment of flare height and hold-off.

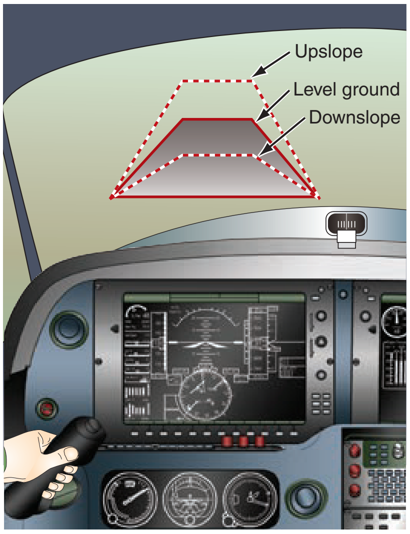


Figure 23-17 How runways of different slopes should appear at the same point on final.

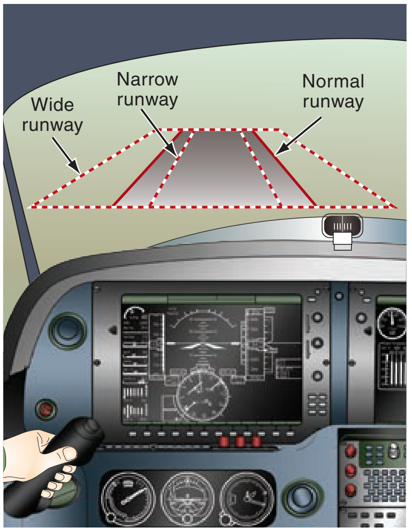


Figure 23-18 How runways of different widths should appear at the same point on final.

Poor Visibility

In hazy conditions, you may be closer to the runway than you appear to be, an illusion that may lead to an unnecessarily hard landing if you are not aware of the effect of haze on your vision. Heavy rain on the windshield—a frequent occurrence when flying IFR—can create a visual illusion that you are higher than you actually are, causing some pilots to fly a lower-than-normal approach. Using a VASI (visual approach slope indicator system), or referring to the electronic glide-slope needle if usable, can help a pilot maintain a suitable approach slope. Flying into fog or clouds on approach can create an illusion of pitching up, causing some pilots (who do not recognize this as an illusion by failing to check their instruments or the VASI) to pitch the nose down and steepen the flight path unnecessarily, sometimes quite abruptly!

If the runway is situated in featureless terrain, or is surrounded by water, snow, or darkened areas, then an illusion can be created that the airplane is higher than it actually is, causing a tendency to fly a lower-than-normal approach.

The Night Approach

A powered approach is preferable at night, rather than a glide approach, providing a normal well-controlled approach at normal speeds. In modern training aircraft, the powered approach is generally used by day also. Power gives the pilot more control, a lower rate of descent and, therefore, a less steep approach slope. The approach to the aiming point should be stable, using any available aids, such as the runway lighting and a VASI if available.

Using the runway edge lighting only, correct tracking and slope is achieved when the runway perspective is the same as in daylight. For correct tracking, the runway should appear symmetrical in the windshield. Guidance on achieving the correct approach slope is obtained from the apparent spacing between the runway edge lights.

If you are low on slope, the runway lights will appear to be closer together. If you are above slope, then the runway lights will appear to be further apart. Attention should also be paid to the airspeed indicator throughout the approach, to ensure that the correct airspeed is being maintained.

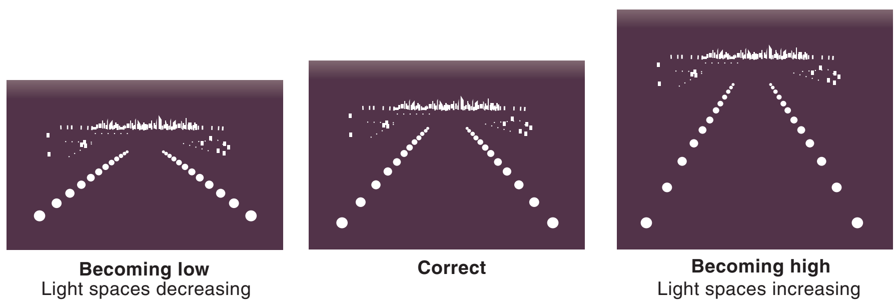


Figure 23-19 Perspectives on approach using runway edge lighting.

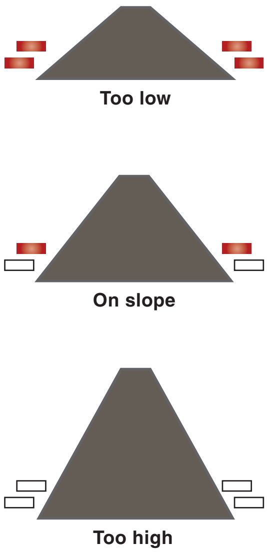


Figure 23-20 Perspectives on approach using a VASI.

A VASI will provide correct slope guidance day or night, but the perspective provided by runway edge lighting may be slightly misleading if you do not allow for any runway slope.

At night, you must be careful not to mistake a well-lit road for the runway, which may have less intense lighting than nearby roads. Lights of townships built on the side of a hill may provide a false horizon, so refer regularly to your flight instruments to avoid unwanted banking. Bright runway and approach lights, especially when surrounded by dark areas with little or no lighting, may create the illusion that you are closer to the runway than you really are, causing a tendency to fly a higher-than-normal approach.

You can take action to avoid being misled by these visual illusions by:

- Anticipating the possibility of visual illusions at unfamiliar airports, especially at night or in adverse weather conditions.
- Making a visual inspection of an unfamiliar airport before landing, if you feel it is needed and conditions permit.
- Use a VASI or electronic glide slope (ILS) for slope guidance on final approach, if they are available.
- Even when visual on an approach, regularly refer to your airspeed indicator and your altimeter, vertical speed indicator and glide-slope needle if you think it is useful.
- Pay special attention to the flight path and airspeed if you run the risk of being distracted by an abnormality, emergency or other non-normal activity.
- Maintain optimum proficiency in your approach, landing and missed approach procedures.

Review 23

Instrument Approaches

Arrivals

1. What does a clearance to descend to 4,000 feet at a pilot's discretion mean?

2. You are doing a VFR practice instrument approach and your clearance appears likely to take you into clouds. What should you do?

3. Approaching the airport, ATC requests you to reduce speed to 160 knots. What speed range should you remain within?

4. The radar controller advises "traffic at 2 o'clock, 5 miles, southbound." Wind is calm. Where should you look?

5. The radar controller advises "traffic at 2 o'clock, 5 miles, southbound." You are holding a 20° correction for a crosswind from the right. Where should you look?

6. The term "radar contact" signifies that your aircraft has been identified on the radar display. Will radar flight-following be provided? Are you required to give position reports?

7. What does STAR stand for?

8. What are STARs used for?

9. To accept a STAR, what sort of description of it do you need in the cockpit?

10. Can ATC issue a STAR without a specific request from the pilot?

11. If a STAR is not wanted, what should be written in the remarks section of a flight plan?

12. Refer to the Jeppesen DINGO-5 STAR chart on page 516:

- **a.** You are cleared for the DINGO-5 arrival via the Stanfield transition. Where does the actual arrival begin?
- **b.** Where does the Stanfield transition begin?
- **c.** Where does the Pheonix transition begin?
- **d.** Can you accept this clearance if you do not have an operational DME?
- **e.** How can you obtain the current weather conditions at Tucson International?

13. Does a STAR give you approval to commence an actual approach?

Instrument Approach Charts

14. An initial approach fix is represented on an instrument approach chart by which letters?

15. Is a procedure turn part of the initial approach segment?

16. What are aircraft approach categories based on?

17. What does a "T" in an inverted black triangle in the minimums section on an NACO instrument approach chart mean? Do you need to consult the alternate takeoff procedures?

18. What does the letter "A" in a black triangle in the minimums section of an NACO instrument approach chart indicate?

19. What do the letters "MSA" on an instrument approach chart mean?

20. What obstacle clearance does a published MSA provide?

21. Does the MSA assure acceptable navigation signal coverage within a 25 mile radius of the navigation facility?

22. When being radar vectored for an ILS approach, at what point may you start a descent from your last assigned altitude if cleared for the approach?

23. Your current radar vector is about to take you through the localizer. You have been cleared for the approach. What do you do?

24. Your current radar vector is about to take you through the localizer. You have not been cleared for the approach. What do you do?

25. If cleared for an approach over a waypoint labeled NoPT, should you commence final approach after making a procedure turn or without a procedure turn?

26. What are circle-to-land minimums based on?

27. If your aircraft has a published V_{S0} of 52 knots, what category will it be?

28. If your aircraft has a published V_{S0} of 77 knots, what category will it be?

29. When may a pilot make a straight-in landing if using an instrument approach procedure having only circling minimums?
30. The pilot of a Category B aircraft decides to circle-to-land at a speed 5 knots faster than the maximum speed for that category. Which category approach minimums should be used?
31. When the approach procedure involves a procedure turn, what is the maximum speed?
32. If a DME is inoperative, will its code tone be transmitted?
33. A DME has locked-on but no identifiable coded tone. Is it usable for navigation?
34. You are holding at an intersection and cannot determine the abeam position. When should timing on the outbound leg commence?

RVR

35. Minimums for an ILS approach, with all components operative, normally establish what visibility requirement?
36. RVR represents which of the following distances a pilot can see?
    - **a.** In-flight slant range at the minimum.
    - **b.** In-flight slant range crossing the threshold on glide slope.
    - **c.** Horizontal distance down the runway from the approach end of the runway.
37. The RVR is not available for a particular instrument approach. Can the published RVR minimum be converted from feet to miles and used as ground visibility minimum for the landing?
38. If the RVR equipment is inoperative for an instrument approach that specifies a minimum RVR 2,400, what should the visibility requirement be?

Sidestep Maneuver

39. You are cleared to execute a published sidestep maneuver for a specific approach and landing on the parallel runway. When should you commence this maneuver?

Missed Approaches

40. You commence an early missed approach prior to reaching the published MAP, which is a left turn from the MAP. After applying power and commencing a missed-approach climb, what should you do?
41. You become visual on an instrument approach before reaching the MAP, and commence a circle-to-land maneuver. During this maneuver, you lose visual reference. What should your actions be?

Equipment Requirements

42. What is the minimum aircraft navigation equipment needed to perform the following:
    - **a.** an ILS approach?
    - **b.** an ILS/DME approach?
    - **c.** a VOR approach?
    - **d.** an NDB approach?
    - **e.** an RNAV approach?
    - **f.** GPS approach?

Visual Illusions on Approach

43. When flying in haze, what sort of illusion could you experience?
44. To reduce the danger of spatial disorientation occurring when flying in poor visual conditions, what should you rely on?
45. Will a runway that is larger than usual appear to be further away or closer than it really is?
46. Will a runway that is smaller than usual appear to be further away or closer than it really is.
47. Will a narrow runway give the pilot on the correct approach slope an impression of being high or low on slope?
48. Will a wide runway give the pilot on the correct approach slope an impression of being high or low on slope?
49. You are on approach to land on an upsloping runway without slope guidance. Is the tendency to approach on a flight path that is too steep or too shallow?
50. You are on approach to land on a downsloping runway without slope guidance. Is the tendency to approach on a flight path that is too steep or too shallow?

Riverside ILS Rwy 9 Chart

Refer to figure 23-22 (page 540) for questions 51 to 83 and use Category A aircraft. These questions relate to the NACO chart. You may repeat the questions using the equivalent Jeppesen chart in figure 23-4 (page 519).

51. Approaching from the southwest, what is the MSA?

52. The ATIS at Riverside can be received on which frequency?

53. What is the Ontario approach control frequency?

54. What is the Riverside control tower frequency? Is it manned continuously?

55. What is the Ground control frequency?

56. Approaching from the southwest and planning to use SEAL BEACH as the IAF, what would be the appropriate NAVAID selections?

57. Approaching the localizer from the SEAL BEACH IAF, what is the minimum altitude?

58. Are DME indications available when the NAV/COM is selected to SLI VORTAC?

59. Are DME indications available when the NAV/COM is selected to the I-RAL localizer?

60. Once you have intercepted the localizer, what altitude may you descend to prior to EXPAM?

61. Where is the FAF?

62. What is the distance from SEAL BEACH to EXPAM?

63. Approaching EXPAM after following the feeder route from the SLI IAF, and cleared for the approach, are you required to enter the holding pattern?

64. What is the glide-slope angle? What is the TCH of the glide path?

65. What is the touchdown zone elevation on Rwy 9?

66. What is the decision height for a straight-in landing? Assume V_{S0} = 60 knots. What does $1.3V_{S0}$ give? This places the aircraft in which Category?

67. What is the visibility required to continue with the landing?

68. If the glide slope fails, and you have to make a localizer-only approach, what does the minimum become? How is the MAP recognized?

69. Will you need a second NAV/COM to identify the AGNES intercept while you are flying a localizer (no glide slope) approach? If you are able to identify the AGNES intercept, where may you cross AGNES? You may then descend to what MDA? What is the visibility required to land?

70. How can you fix your position at AGNES intercept?

71. After you have become visual with the runway in sight, the localizer fails. What are your actions?

72. The localizer fails before you have become visual. What are your actions?

73. Following a missed approach, what method is used to enter the holding pattern at PDZ?

74. Approaching Riverside from the southeast, you may reverse direction to join the localizer inbound. How?

75. You are holding at the LOM for an ILS approach, and ATC has advised you to expect clearance for the approach at time 0915. At 0907 you experience a two-way radio communications failure. What action, if any, should you take with your transponder? At what time would you begin your approach?

76. You approach JASER intercept from SLI at 3,000 feet MSL and slightly right of course. Sketch how your navigation instruments might appear on the instrument faces below.

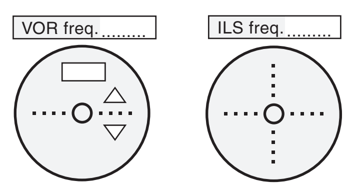


Figure 23-21 Question 76.

77. Is a DME required for this approach?

78. How many initial approach fixes are there for this approach?

79. When Riverside Tower is not operating, is the runway/approach lighting operating continuously or is it pilot-activated?

80. What radio equipment and frequency would you use to activate the lighting? What type of approach lighting is available on Rwy 9 at Riverside?

81. Due to excessive crosswind on Rwy 9, you have been cleared for an ILS Rwy 9 approach for a landing on Rwy 34. What minimums are applicable for this procedure?

82. What landing distance is available on Rwy 34?

83. Is Riverside Municipal airport equipped with its own radar?

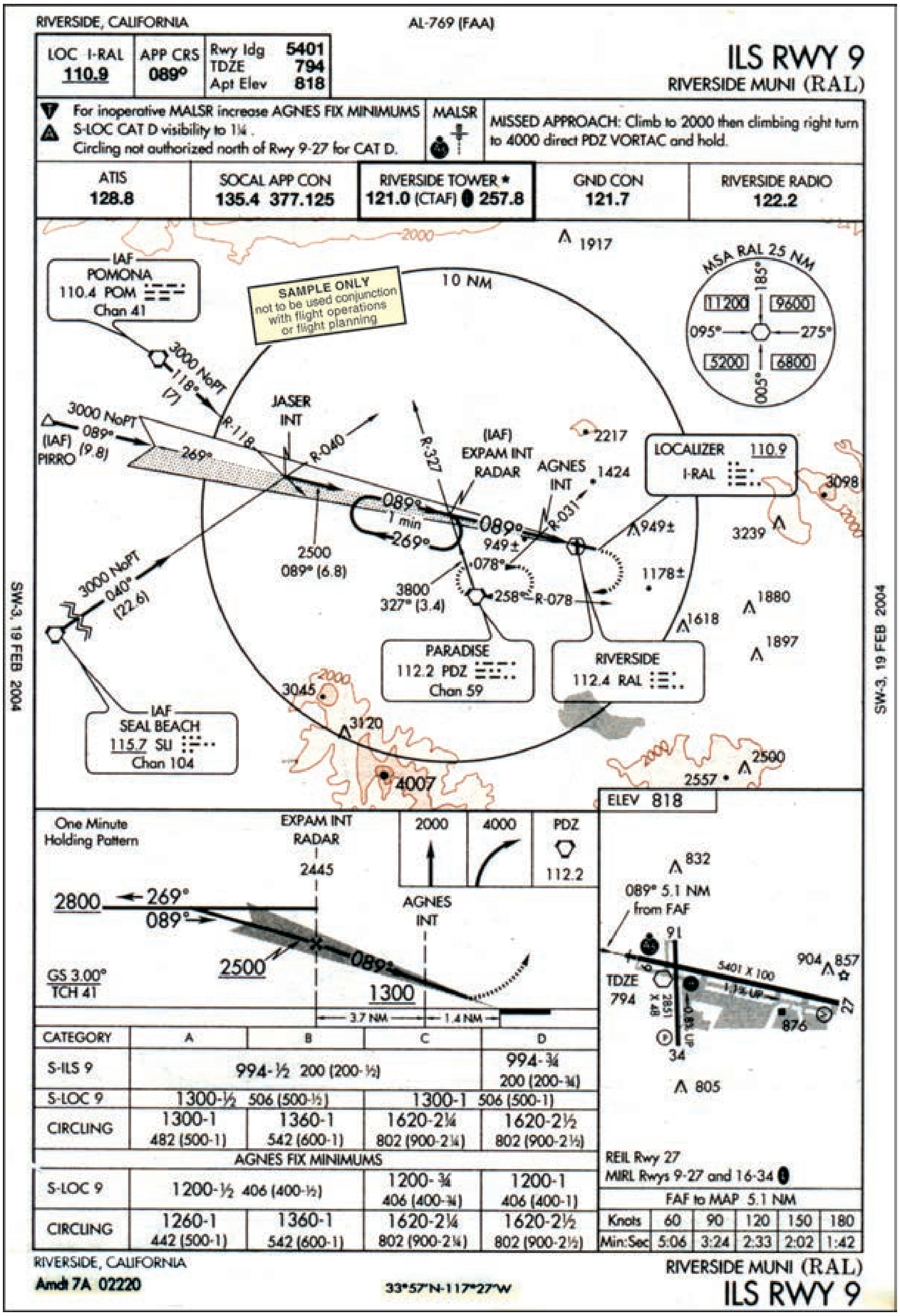


Figure 23-22 Riverside ILS Rwy 9 (NACO, reduced)

Answers are given on page 784.

Visual Maneuvering 24

As you near your destination airport in IFR conditions, there are three types of approaches possible:

- a *standard instrument approach* as published by NACO and *Jeppesen*, followed by a circle-to-land maneuver if not a straight-in approach procedure;
- a *contact approach* if visibility is at least 1 SM (special VFR conditions); or
- a *visual approach* (if VFR weather conditions exist).

Contact and visual approaches allow a pilot to avoid flying what may be a time-consuming instrument approach if VFR or special VFR conditions exist. They expedite the flow of air traffic and reduce pilot/controller workload by shortening the flight path to the landing.

To assist maneuvering pilots to locate the airport in conditions of visibility less than 3 miles and/or ceiling below 1,000 feet, the airport rotating beacon may be operated.

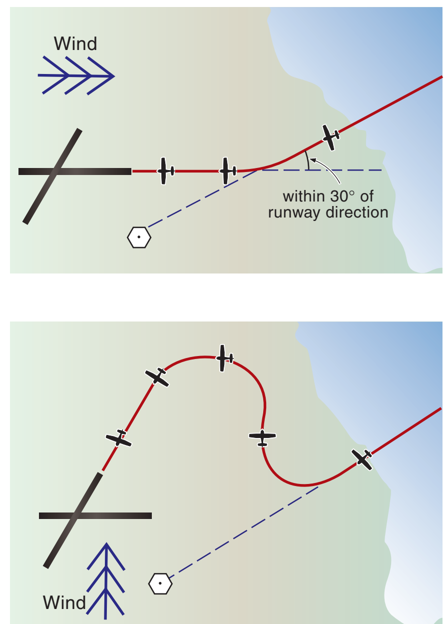


Figure 24-1 A straight-in approach and a circling approach.

Circling to Land

If the final approach direction of an instrument approach procedure does not align the airplane within ±30° of the landing runway, then it is technically no longer a *straight-in* procedure, and significant visual maneuvering (probably involving at least part of a traffic pattern) will be required to align the airplane with the landing runway.

Visual maneuvering is also known as *circling*, or *circle-to-land*. These terms are used to describe the *visual* phase of flight after completing an instrument approach, with the aim of maneuvering an aircraft into position for a landing on a runway to which a straight-in approach is not possible.

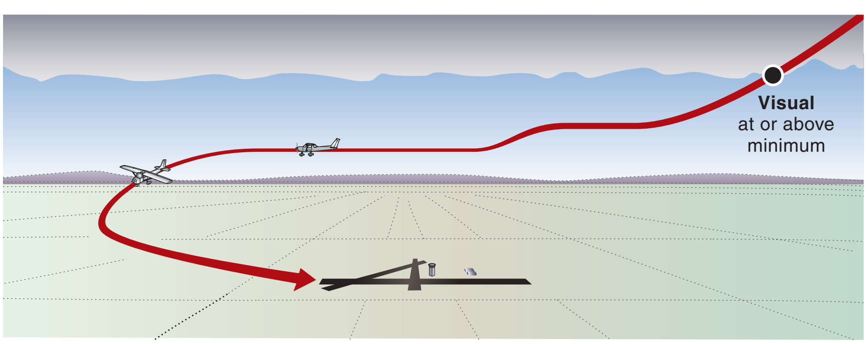


Figure 24-2 Typical maneuvering (circling) after becoming visual following an instrument approach.

Circling to land is most commonly used when it is necessary to make an instrument approach to one runway, but you wish to land on another runway. After becoming visual, you must then maneuver the airplane for a landing on the favored runway—for instance, using a Runway 27 ILS to become visual, followed by a circling approach and landing on the into-wind Runway 9, which is not served by an instrument approach.

The flight path that the pilot chooses to fly will vary depending on the situation—for instance, the pilot might choose to circle in a direction that avoids high terrain, low clouds or a heavy shower.

A circling approach is a more difficult maneuver than a straight-in approach because it often involves close-in maneuvering under low cloud bases and in rain or poor visibility. The circulation approach requires precise altitude flying. Pilots must pay close attention to maintaining altitude while flying a suitable flight path in order to position aircraft for landing. Constant observation of runway environments is necessary as well as maintaining a good lookout for obstructions and other aircraft.

The Visual Circling Maneuver

A circling approach is a nonprecision approach. Even if the approach is an ILS, your MAP will be based on nonprecision criteria (e.g. MDA, timing).

If you become visual at or above the circling MDA for the instrument approach, then you should maintain circling MDA, or higher, while you maneuver within the circling area, until you are in a position to commence descent to intercept a normal final approach. A circling approach is a visual flight maneuver, and you must remain visual throughout, otherwise a missed approach is to be carried out.

Each circling situation is different because of variables such as:

- the final approach direction of the instrument approach;
- the runway layout;
- wind direction and wind speed, and the selected runway for landing;
- local terrain; and
- meteorological conditions (especially cloud bases and visibility).

For instance, wind direction and speed usually determine the runway that should be used for landing. Cloud bases usually determine what pattern altitude is flown. If there is a fog bank on one side of the airport, then a circling approach on the other side of the airport in good visibility is preferable, regardless of whether a left or right pattern is involved.

When circling to land, follow the normal traffic pattern at or above MDA, if conditions permit. Otherwise, use common sense and stay VFR if you can.

If conditions permit, however, it is advisable to follow the normal traffic pattern, which at most airports is left-handed to provide the captain in the left seat with a good view of the runway, and to fly at the normal pattern altitude. If the clouds are lower, however, then a circling approach is legal at altitudes down to the circling minimum.

The term *circling* does not imply that the visual maneuvering should follow a circular pattern, but rather that the traffic pattern should be adjusted to suit the conditions. As a general rule, however, circling should be as close to a normal traffic pattern as conditions allow. This helps other aircraft in the pattern, as well as ATC, and keeps things as standard as possible for the pilot.

If, for instance, you become visual at 2,000 feet HAA on the instrument approach, well above the permitted minimum, then you should continue descent to normal pattern altitude and fly a normal pattern, rather than descend to a lower circling MDA. While training, however, your instructor may ask you to fly a pattern assuming particular cloud bases even though actual conditions do not require it.

Good attitude control is essential in the circling maneuver, with bank angle limited to 20° or standard-rate (maximum 30°), altitude maintained at or above circling MDA, and airspeed as desired. The airplane must also be configured for landing (with the landing gear and flaps extended as required), and all checks completed, before the landing is made. A well-flown circling approach is the sign of a competent pilot.

Descent Below Circling MDA

Descent below the circling MDA should not be made until:

- visual reference with the airport environment is established and maintained;
- the landing threshold is in sight; and
- the required obstacle clearance can be maintained on approach and the airplane is in a position to carry out a normal final approach and landing.

The most appropriate time to commence the descent from the circling MDA for a landing is when the normal landing descent profile is intercepted. The lower the circling MDA, the closer this will be to the airport. If, for instance, the airplane is circling at 400 feet HAA, the landing descent would not be commenced until on final. For higher circling MDAs, say 1,200 feet HAA, the descent for a landing may be commenced earlier to avoid unnecessarily high descent rates on final.

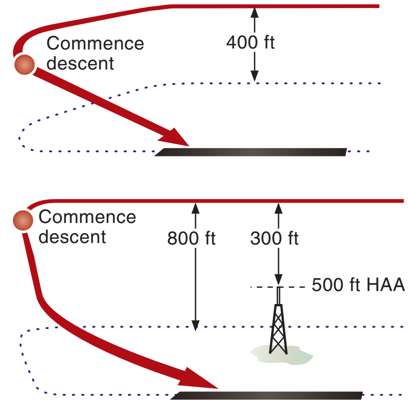


Figure 24-3
Achieve a normal landing profile.

Some instrument approaches do not have a straight-in minimum published, but only a circling minimum. If, however, you have the runway in sight when you are at or above the circling MDA, and you still have sufficient room to make a normal approach for landing straight in (and provided the runway is suitable in the wind conditions), you are permitted to land straight in without circling.

Pilot Initiative and Judgment is Required

It is impossible to design a single procedure that will cater to all circling situations—this is an area for pilot judgment and decision. Because the circling maneuver may have to be carried out in poor conditions, the pilot must be able to make firm decisions fairly quickly. This ability will come with experience and with good planning. The basic assumption in circling approaches is that, after initial visual contact, the runway environment (the runway, the runway threshold or approach lighting aids, or other markings identifiable with the runway) should be kept in sight while maneuvering in the traffic pattern at or above the circling MDA.

The actual altitude to be flown while maneuvering in the circling area will be governed by obstacle clearance and cloud ceiling. It is unusual for cloud bases to be absolutely flat; normally they are rather irregular or ill-defined, and fluctuate in height. For this reason, it is recommended that a vertical clearance of at least 200 feet is maintained between the airplane (flying at circling MDA or higher) and the actual cloud bases.

This separation is impossible to measure accurately of course, so it requires realistic estimation by the pilot who must:

- remain visual; and
- not descend below the circling MDA until in a position for a safe descent for landing.

If, for example, the circling MDA published for a particular airport is 550 feet HAA, then the pilot, seeing a forecast or reported cloud ceiling of 800 feet HAA, knows that the pilot will probably be operating in marginal conditions. You must not circle at a lower altitude than the circling MDA, no matter what the clouds do—if you fly into clouds while circling at the MDA, you must make a missed approach.

If you fly into clouds while circling at the MDA(H), you must make a missed approach.

The other consideration in circle-to-land maneuvers (besides cloud bases) is the minimum visibility required, typically 1 SM, 1 ¼ SM, or 1 ½ SM for circling maneuvers. The precise visibility is impossible for you to measure in flight, but you can estimate it, keeping in mind that it is your responsibility as pilot-in-command to judge whether sufficient visibility exists for safe visual maneuvering.

Keep the runway in sight at all times, except when it disappears beneath a wing in normal maneuvering, or if you are flying directly over the top of the runway to position yourself. If at any time during a circling approach you feel uncomfortable for any reason (such as lowering cloud bases, decreasing visibility, heavy rain or hail, turbulence, or windshear), or if you lose visual contact, then don't hesitate to execute a missed approach.

The Visual Maneuvering (Circling) Area

The *visual maneuvering area* (or circling area) is the area around an airport in which obstacle clearance has been considered by the FAA for aircraft having to maneuver visually before landing. To avoid penalizing slower and more maneuverable aircraft (that require less maneuvering area than faster airplanes), different aircraft categories based on maximum speed for circling have been devised. Circling speed is based on $1.3V_{S0}$ – 1.3 times the stalling speed at maximum weight in the landing configuration.

Category A airplanes maneuvering at 90 knots or less have a circling area defined by 1.3 NM radii from the runway thresholds. Category B airplanes maneuvering at between 91 and 120 knots have a circling area defined by 1.5 NM radii from the runway thresholds—a slightly larger area which might contain higher obstacles and therefore require a higher circling MDA.

If you decide to circle your Category A airplane at a speed higher than 90 knots (say 100 knots because of turbulence), then this effectively moves you into category B, with a larger circling area and possibly a higher MDA.

Note. NACO approach charts use Category A, B, C, and D to specify circling minimums. *Jeppesen* charts specify actual maximum speeds against the corresponding circling MDA and visibility (90 KIAS, 120 KIAS, etc.). Use the circling MDA applicable to your actual circling speed if using *Jeppesen* charts.

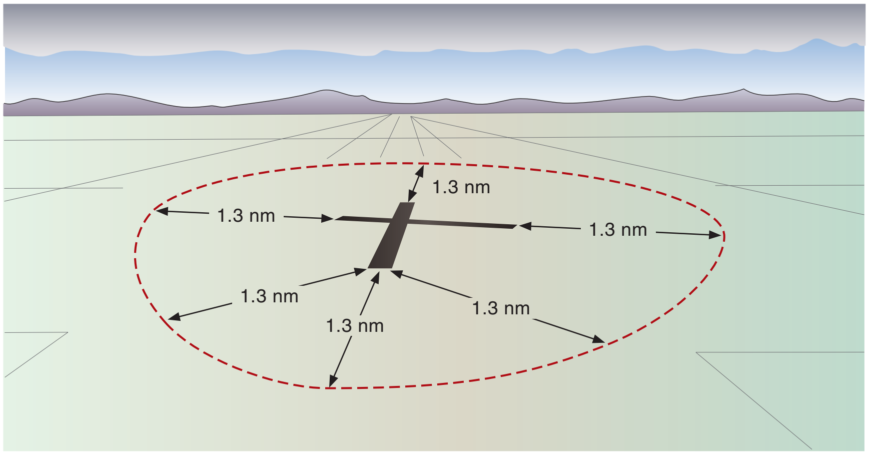


Figure 24-4 The visual maneuvering area for Category A airplanes (less than 90 knots).

Obstacle Clearance in the Visual Maneuvering (Circling) Area

Once the FAA has established its circling area, obstacles within this area are surveyed, and a safety margin of 300 feet added to ensure safe clearance from these obstacles at the circling MDA.

- If, for instance, the highest obstacle in the circling area is a tower 1,290 feet MSL, then the circling MDA is (1,290 + 300 =) 1,590 feet MSL.
- If there are no specific obstacles, then 100 feet is allowed for the growth of trees and the 300 feet safety margin added to this to give a lowest circling MDA of 400 feet HAA.

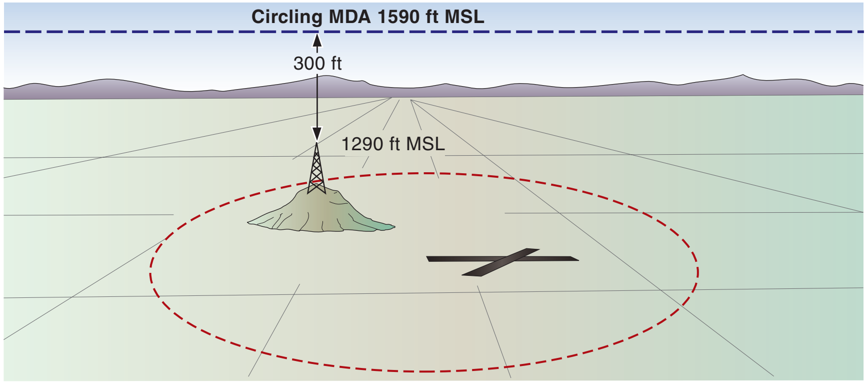


Figure 24-5
Calculation by FAA of circling MDA.

Sectorized Visual Maneuvering (Circling) Areas

The lower the circling MDA, the more accessible the airport is in poor weather, since it will allow a pilot to operate beneath lower cloud bases. In an attempt to achieve lower circling MDAs, the FAA can exclude from the circling area a sector that contains a particularly high and restrictive obstacle, provided it lies outside the final approach and missed approach areas.

If the FAA does exercise this option, and thereby lowers the circling MDA, then the pilot is prohibited from circling at this lowered altitude within the excluded sector that contains the obstacle(s).

For instance, an obstacle 800 feet HAA in the normal circling area requires a circling MDA of (800 + 300) 1,100 feet HAA, which operationally is very restrictive. By removing a sector that contains this obstacle from the permissible circling area, the FAA may be able to lower the circling MDA to say 400 feet HAA. A statement that circling in the excluded area is not authorized will be included on the instrument approach chart, such as "circle-to-land NA [not authorized] south of Rwy 8-26."

The Missed Approach Procedure When Circling

If you lose visual reference when circling to land after an instrument approach, then the missed approach procedure for that particular instrument approach should be followed.

The airplane may be in a slightly awkward position to follow the published missed approach procedure, depending on its position in the pattern, but it is expected that you will make an initial climbing turn toward the landing runway to track overhead the airport, from where you will continue climbing on the published missed approach course to the required altitude. This should keep the airplane clear of obstacles, first in the circling area and then in the missed approach area.

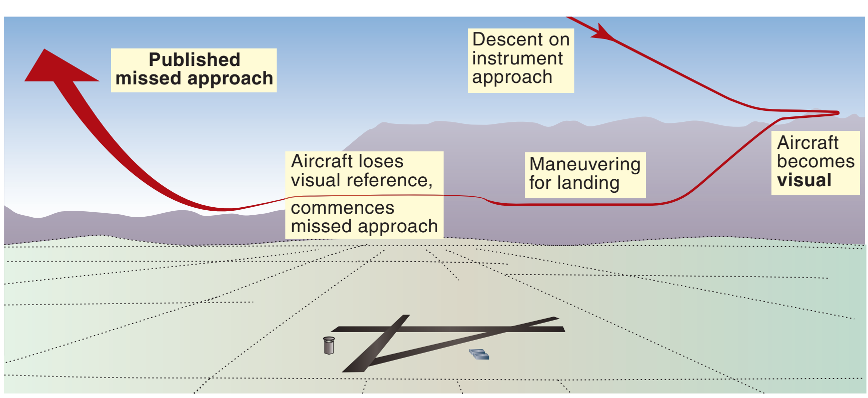


Figure 24-6
Making a missed approach when circling.

Since the circling maneuver may be accomplished in more than one direction, and since the airplane could be anywhere in the traffic pattern when visual reference is lost, the pilot will have to devise and follow a suitable flight path to establish the airplane on the prescribed missed approach course. This would depend on the airplane's position in the circling maneuver at the time visual reference is lost and the climb-out commenced, relative to the missed approach course itself.

When you decide to execute a missed approach, you must fly the airplane according to the procedure laid down in the airplane's flight manual—transitioning smoothly to a climb-out in a positive manner with prompt and precise attitude and power changes. A typical missed approach procedure may be:

- adopt the missed approach attitude and simultaneously apply go-around power;
- assume the missed approach configuration (gear up when a positive climb is achieved, flaps as required).

Remember the order of importance:

Aviate (fly the airplane!)

Navigate (head it toward where you have to go).

And finally Communicate (advise ATC).

As soon as comfortably established in the climb (there need be no rush!), turn toward the runway and the missed approach course. Attitude flying will require most of the pilot's attention, so at least from the time the pilot commences the circle-to-land maneuver he or she should have in mind:

- an initial heading to turn to if the pilot loses visual contact;
- the missed approach course; and
- the missed approach altitude.

When convenient, and once comfortably established in the climb-out, the pilot should advise ATC that he or she has commenced a missed approach.

Approaches with Circling Minimums Only

Some instrument approach procedures have only circle-to-land minimums published (no straight-in minimums). This is because the:

- runway is more than 30° out of alignment with the final approach path; and/or
- descent gradient from the FAF to the runway is excessive (greater than 400 feet/NM maximum), requiring a high rate of descent for a straight-in landing.

An example is the VOR/DME-A to South Lake Tahoe, CA. The "-A" (or "-B," or "-C" suffix) indicates *circling minimums only*. Circling MDA is 2,536 feet HAA. While the procedure is designed for circle-to-land, you may land straight-in if you see the runway early enough, and a normal stable approach and landing can be made. Extreme caution should be used in executing this type of approach. Good judgment might dictate that a circling approach is the safest procedure.

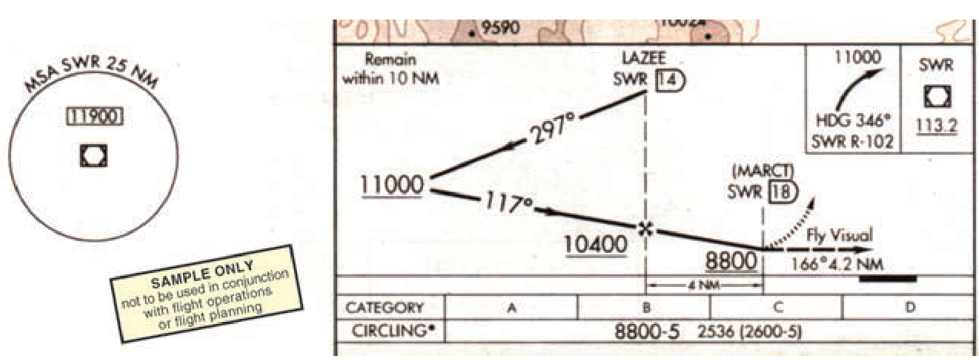


Figure 24-7 South Lake Tahoe (CA) VOR/DME-A.

Airports that Do Not Have a Published IAP

If arriving at an airport that does not have a published instrument approach procedure, the pilot should, where possible, become visual well away from the airport to allow time for orientation and planning of the visual pattern.

The options available to achieve this are:

1. Establish the aircraft in VFR minimums or better (for example, by requesting a clearance to descend to MEA/MOCA), then cancel IFR and proceed VFR to the airport; or
2. Descend through clouds using a published instrument approach procedure at a nearby airport, and transit visually to the destination airport in accordance with VFR.

When filing to an airport that has no IAP you must always have an alternate.

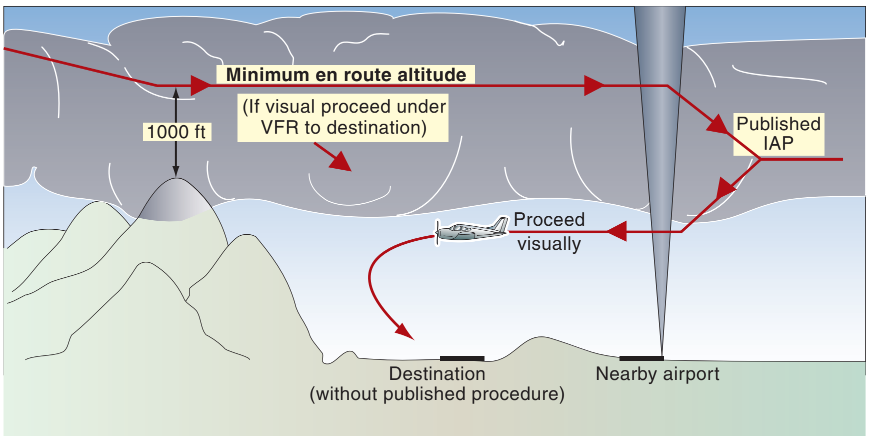


Figure 24-8 Arriving at an airport that does not have a published instrument approach.

Contact Approach

A contact approach may be used by an IFR pilot, with authorization from ATC, in lieu of a standard instrument approach procedure to that airport.

The pilot must request a contact approach—it may *not* be initiated by ATC—and the special VFR conditions that must exist are:

- clear of clouds;
- at least 1 statute mile visibility; and
- a reasonable expectation that these conditions, or better, will continue to the airport.

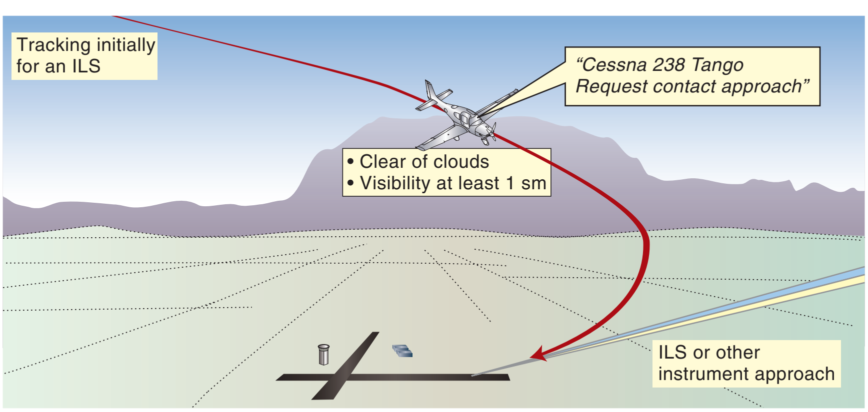


Figure 24-9 A contact approach.

ATC will issue a clearance for a contact approach on request if satisfied that:

- reported ground visibility at the airport is at least 1 SM;
- adequate separation from other IFR and special VFR traffic will exist; and
- weather conditions make this contact approach practical.

If not satisfied, ATC will deny your request for a contact approach, in which case you will proceed, as cleared, for a standard instrument approach. The pilot on a contact approach is responsible for obstruction clearance and separation from VFR traffic.

Visual Approach

ATC may issue a visual approach clearance, with or without pilot request, provided that VFR conditions exist. Prior to requesting, or accepting, a visual approach clearance, you must either:

- have the airport in sight; or
- have the preceding aircraft identified and in sight (in which case you should follow it, taking responsibility for separation and avoidance of wake turbulence).

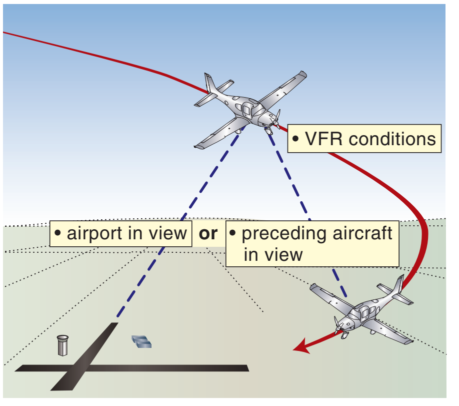


Figure 24-10 A visual approach.

If you have the airport in sight, but not the preceding aircraft, ATC may still issue a clearance for a visual approach, but will retain responsibility for separation. Radar service, if provided, is automatically terminated when you are instructed to contact the tower.

A visual approach clearance is an IFR authorization, and does not alter your IFR fight plan cancellation responsibility. For instance, you must still cancel your IFR flight plan if you land at a non-towered airport. At airports without an operating control tower, ATC will only authorize a visual approach if you advise them that a descent and landing can be completed in VFR conditions.

Visual Illusions

This topic was covered in some detail toward the end of the previous chapter. This serves as a reminder that visual illusions are possible to experience having transferred from instrument flight to visual flight—which hopefully will have occurred at or above the circling MDA(H) (minimum descent altitude). When maneuvering visually for a landing after an instrument approach, you should be well prepared to experience visual illusions but not be affected by them.

- *At night*, or in dark conditions, you should avoid the use of bright white light in the cockpit so that night-adaptation of your eyes is not impaired.
- *Hazy conditions* create an illusion of greater distance—pilots who are not aware of this illusion tend to fly too low on approach and touch the ground sooner than they expect.
- *Narrow runways* also create the illusion of being high—leading unsuspecting pilots into making too-low approaches and early touchdowns.
- *Upsloping runways* also create the illusion of being high—leading unsuspecting pilots into making too-low approaches and early touchdowns.
- *Downsloping runways* will appear short and you will feel you are low on slope, creating a tendency to make a steeper than normal approach.

Wake Turbulence on Approach

Be careful of wingtip vortices when making an approach in a light quartering tailwind.

Wake turbulence is caused by wingtip vortices from preceding aircraft, especially large and heavy airplanes that are flying slowly in a relatively clean configuration, at a high angle of attack. Heavy weights, high angles of attack and relatively clean configurations are typical after takeoff.

If such aircraft are ahead of you (taking off or landing), try to picture where their wake turbulence will be. The vortices will gradually drift down and be carried downwind. A light crosswind may carry the upwind vortex from a preceding aircraft on approach into your flight path, and a light tailwind may move its vortices into your touchdown zone—so be careful when making an approach in a light quartering tailwind.

In general, if you are approaching to land behind a large jet airplane, try and stay above its flight path if possible and land beyond its touchdown point.

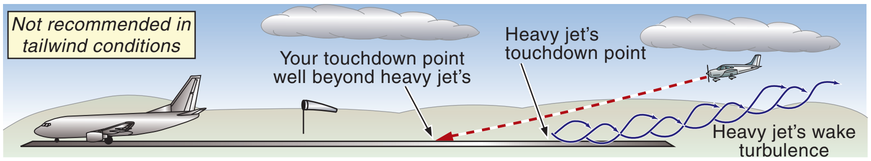


Figure 24-11 Avoidance of wake turbulence on your approach.

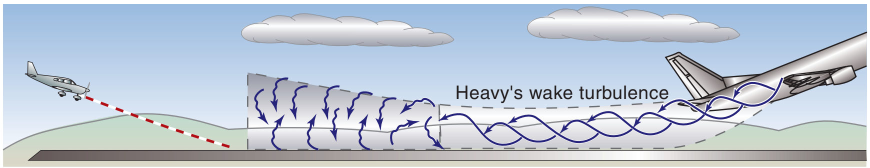


Figure 24-12 Landing behind a "heavy" that has just taken off.

Hydroplaning

Hydroplaning occurs when a small layer of water exists between the airplane tire and the runway surface. This can happen near takeoff and touchdown speeds when there is water or slush on the runway, especially if the runway is smooth. There will be almost no friction between the tire and the runway, in fact the tire may not even spin up, and so directional control may be difficult and braking may be totally ineffective.

If you suspect hydroplaning is a possibility because of standing water on the runway during heavy rain, you can consider delaying your takeoff or landing, or diverting to another airport.

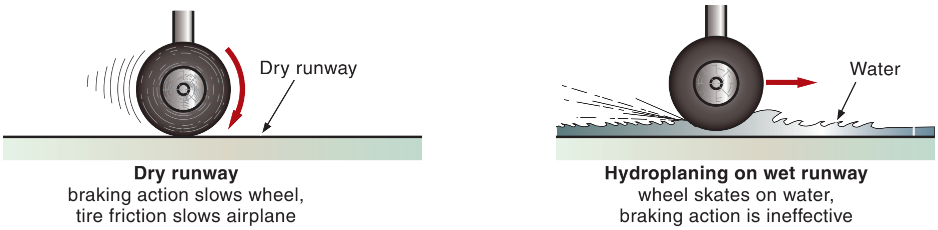


Figure 24-13 Low-friction surfaces significantly affect runway performance.

Review 24
Visual Maneuvering

1. What is a straight-in procedure?
2. What are non-straight-in instrument approach procedures known as?
3. When may a pilot commence a non-straight-in instrument approach procedure?
4. You should circle-to-land at the:
   a. decision height.
   b. circling MDA.
   c. straight-in MDA.
   d. alternate minimum.
5. You should commence descent from the circling MDA:
   a. only when aligned with the landing runway.
   b. to intercept a reasonable final approach path not requiring abnormal maneuvers.
   c. at any time in the pattern.
6. Can you make a straight-in landing if you are flying an instrument approach that has only circling minimums published?
7. What is the obstruction clearance in the circling area?
8. If the highest obstacle in the circling area is 450 feet HAA, how high would you expect the circling MDA to be?
9. If the circling MDA is 950 feet HAA, how high would you expect the highest obstacle in the circling area to be?
10. The circling area for an airplane that maneuvers at 90 knots or less is defined by what radii from the runway end?
11. The circling area for an airplane that maneuvers at 120 knots or less is defined by what radii from the runway end?
12. If V_{S0} for your airplane is 80 knots, what is your circling MDA? Which aircraft Category is this?
13. If V_{S0} for your airplane is 65 knots, what is your circling MDA? Which aircraft Category is this?
14. Does the issuance of a clearance to make a visual approach cancel your IFR flight plan?
15. If you lose visual reference circling-to-land, you should commence a missed approach:
    a. straight ahead.
    b. with an initial climbing turn toward the runway, then out on the missed approach course published for the IAP used.
16. Are you required to notify ATC that you have commenced a missed approach?
17. If conditions are suitable, what sort of approach may you make, with ATC approval, to avoid having to fly a standard instrument approach procedure?
18. What two conditions are necessary before ATC can authorize a visual approach?
19. Can ATC issue a visual approach without pilot request?
20. Can ATC issue a contact approach without pilot request?
21. The weather minimums for a visual approach are:
    a. higher than those for a contact approach.
    b. lower than those for a contact approach.
    c. the same as those for a contact approach.
22. What weather minimums must exist for a visual approach?
23. What weather minimums must exist for a contact approach?
24. Must a pilot request a contact approach?
25. If the reported visibility is less than 1 mile and you request a contact approach, would you expect ATC to issue one?
26. Can ATC assign a visual approach without pilot request?
27. On visual approaches, radar service automatically terminated when:
    a. ATC so advises.
    b. the pilot is instructed to contact the tower.
    c. after landing.
28. What causes wake turbulence?
29. When is wake turbulence greatest?
30. Can a light crosswind carry the upwind wingtip vortex of a preceding airplane over the runway?

31. The wind condition which prolongs wake turbulence of a preceding aircraft on the runway for the longest period of time is a:
a. a strong headwind.
b. a strong tailwind.
c. a strong crosswind.
d. a light crosswind.
e. a light quartering tailwind.

32. If possible, where should you try to land in relation to a preceding heavy jet airliner?

33. A strong headwind on approach suddenly shears to a calm wind, as can happen if you fly through a temperature inversion on approach. What airspeed change would you expect?

34. When can hydroplaning occur?

35. Where is the tire in relation to the runway surface during hydroplaning?

36. How does hydroplaning affect a pilotís ability to achieve directional control and good braking on the runway?

37. If an airport rotating beacon is operating during daylight hours in Class B, C, or D airspace, what does this indicate?

38. What action could a tower controller take during daylight hours to assist maneuvering pilots to locate the airport in poor conditions with visibility less than 3 miles and/or ceiling less than 1,000 feet?

Answers are given on page 785.

The VOR Instrument Approach 25

When executing a VOR approach, such as that published for Casa Grande (figure 25-1), the VOR is used as the tracking aid. Of course the VOR must be identified before you may use it for navigation. The coded ident for the Stanfield VORTAC near Casa Grande, on which the instrument approach is based, is TFD (*dah dit-dit-dah-dit dah-dit-dit*).

The top part of the instrument approach chart is a plan view for tracking and the bottom part of the chart is a profile view for vertical navigation.

You may track to the VORTAC at a safe altitude well above the minimum safe altitude (MSA), which is 4,200 feet MSL to the north and 5,600 feet MSL to the south and west. Note the high terrain (4,373 feet MSL) southwest of the airfield at approximately 12 DME TFD. The airport elevation is 1,462 feet MSL and the runway 5 touchdown zone elevation (TDZE) is 1,456 feet MSL. The airport elevation is always higher than the TDZEs since it is the highest point on any of the runways.

When overhead the VORTAC, you must enter the holding pattern based on the TFD VORTAC as the holding fix, holding southwest on the 228 radial, one minute inbound legs. The inbound holding course is 048-TO the VORTAC. Have 048 selected on the OBI and keep the CDI centered when tracking inbound. You may descend to not below 3,500 feet MSL in the holding pattern.

When ready to start the approach, commence the prelanding checks, and adopt an appropriate approach configuration (flaps/gear). You may fly inbound 048-TO the VORTAC not below 3,500 feet MSL and, once past the VORTAC (indicated by the first complete reversal of the flag from TO to FROM), you should start the stopwatch and commence descent. Overhead the VORTAC is the final approach fix (FAF) for this approach (✠). With 048 still set on the OBI, and FROM showing, you should fly a heading that keeps the CDI centered.

DME is available at Casa Grande, however it is not mandatory for this VOR approach. If it were, the approach would be published as a VOR/DME approach. Starting the stopwatch as you pass the VORTAC allows you to determine the position of the missed approach point (MAP) if the DME is not available to begin with, or if it fails while you are completing the approach. The table at the bottom right indicates that if your groundspeed is 90 knots then you will reach the MAP 5 minutes 12 seconds after passing over the VORTAC, which is the FAF. At GS 120 knots, it will take only 3 minutes 54 seconds.

You must not descend below the minimum descent altitude (MDA) 1,960 feet MSL until you are visual. The MDA 1,960 for a straight-in approach is 504 feet above the runway 5 touchdown zone elevation (TDZE) of 1,456 feet MSL (HAT 504 feet).

If you fly out of the clouds during the approach and are visual at the MDA, then at 6.4 DME (noted on the chart as a visual descent point, VDP) a normal descent to the runway 5 touchdown point may be commenced, provided you can see the approach end of the runway and wish to make a straight-in landing.

You should plan your descent from the final approach fix overhead the VORTAC to be at the MDA at or before the visual descent point if you want to make an unhurried and stable normal descent to land straight-in on runway 5. This means descending 1,540 feet (3,500 - 1,960) in 6.4 NM, which means a profile of (1,540 feet 6.4 NM =

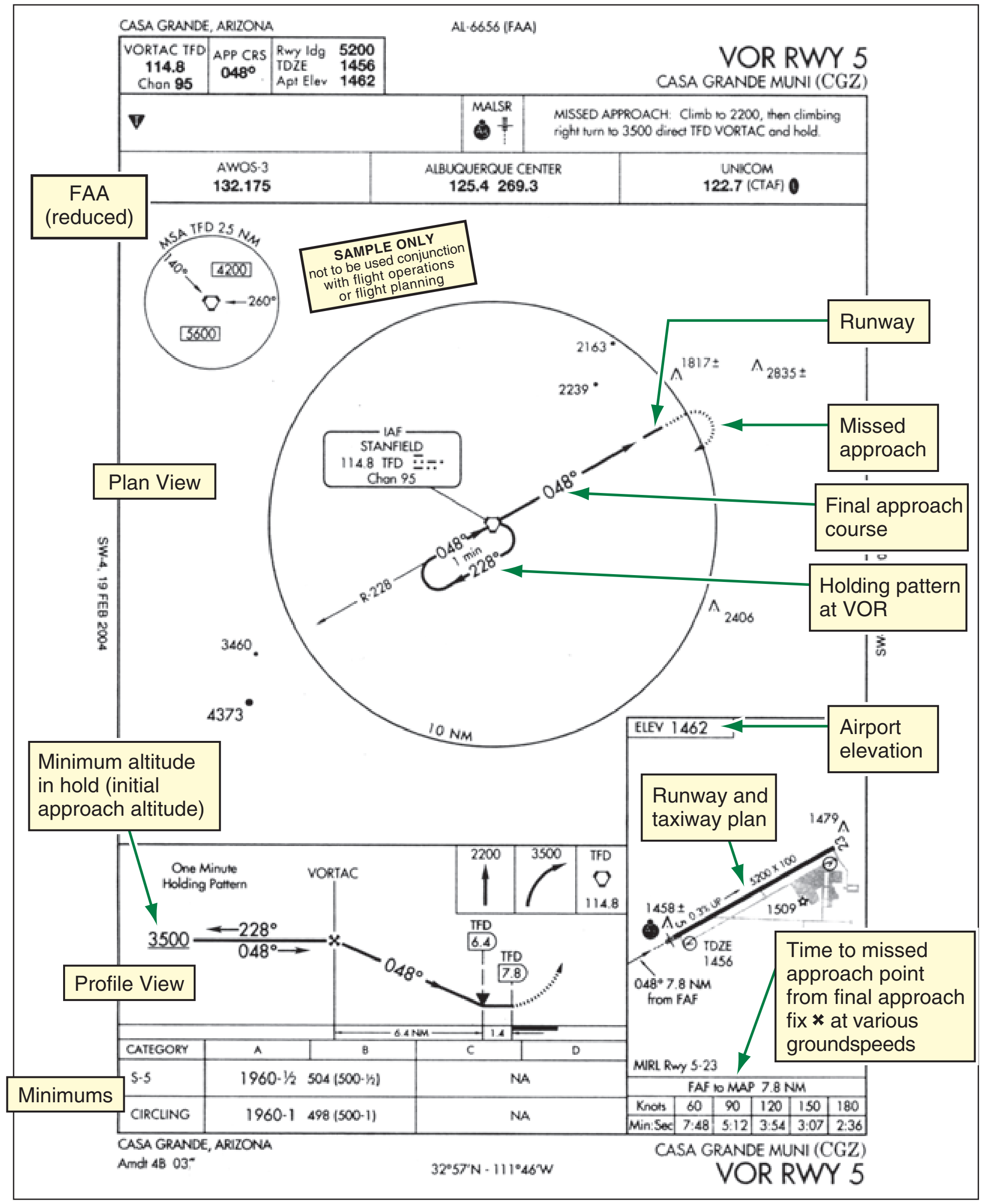


Figure 25-1 The Casa Grande RWY 5 VOR approach.

241 feet per NM) approximately 250 feet per NM. At a groundspeed of 60 knots this would require a rate of descent of 250 fpm; at a GS of 120 knots it would be 500 fpm; and at GS 90 knots, rate of descent would be 375 fpm. Descending to the MDA at or above these descent rates should position you well.

If you wish to circle to land, then the minimum altitude for this maneuver is also 1,960 feet MSL, the 1/2 SM visibility required for a straight-in landing is increased to 1 SM for a circling approach to land on runway 23. This is logical because you will have to maneuver away from the runway a little to position for the landing on Rwy 23. The circling MDA 1,960 feet MSL is 498 feet above the airport elevation, 1,462 feet MSL (the highest point on any of the runways), and is 498 feet HAA. (Height above touchdown zone (HAT), is not shown for circling minimums because you might circle-to-land on either runway.)

If you are not visual at the MDA, then you may track in at the MDA in IFR conditions to the missed approach point (MAP) at 7.8 DME, or until the appropriate time has expired. If you become visual at the MDA, you may maneuver to land straight-in or to circle, depending on how you see the situation; otherwise commence a missed approach at the MAP. The missed approach is shown by a dotted line, and detailed on the profile diagram.

Radar Approaches

There are two types of radar approaches that an instrument-rated pilot may make:

- *airport surveillance radar* (ASR) *approach*—usually called a surveillance approach, this is a *nonprecision* (no vertical guidance) radar approach, executed according to instructions issued by a radar controller whose equipment provides *range* (distance) and *azimuth* (course) information only (no accurate altitude information); these approaches may be made straight-in to a specific runway, or down to a circling altitude; and
- *precision approach radar* (PAR) *approach*—usually referred to simply as a PAR, this is a *precision* radar approach conducted straight-in to a specific runway, down to a much lower altitude than is possible with a surveillance approach. PAR is a precision approach aid, because *slope guidance* is provided. It is an approach and landing aid, rather than an aid for sequencing and separating aircraft.

PARs are only possible at a small number of airports, where radar equipment that provides very accurate range, azimuth and altitude information is installed.

Radar approaches are only available at those airports with published Civil Radar Instrument Approach Minimums, which are listed in each FAA Instrument Approach Procedures booklet. Special radar approach plates are published by *Jeppesen* for these airports. Figure 25-2 shows information for the radar approaches at Fort Huachuca, AZ, an airport with both ASR and PAR approaches. Note that the ASR minimums are higher than for the more precise PAR.

Surveillance Approaches

A surveillance approach is carried out by the pilot under the guidance of a radar approach controller who uses a special VHF-COM frequency (callsign *"… Radar"*) to issue:

- *horizontal navigation (course) instructions* in the form of a series of radar vectors, (headings to steer) to intercept and then maintain the final approach path, aligned with the extended centerline of the landing runway;
- *vertical navigation (descent) advice* of when to commence descent to the previously advised *minimum descent altitude* (MDA) and, if requested, a recommended altitude for each mile along the final approach path; and
- *arrival* at the *missed approach point* (MAP).

A 3° slope is approximately 300 feet per nautical mile.

The recommended altitudes provided by the controller will usually correspond to the normal instrument approach slope of 3° horizontal, which is a slope of 1-in-20 (derived from the 1-in-60 rule, which means that an angle of 3° is equivalent to 3 in 60, or 1 in 20). For every 1 NM (approximately 6,000 feet) traveled horizontally, the

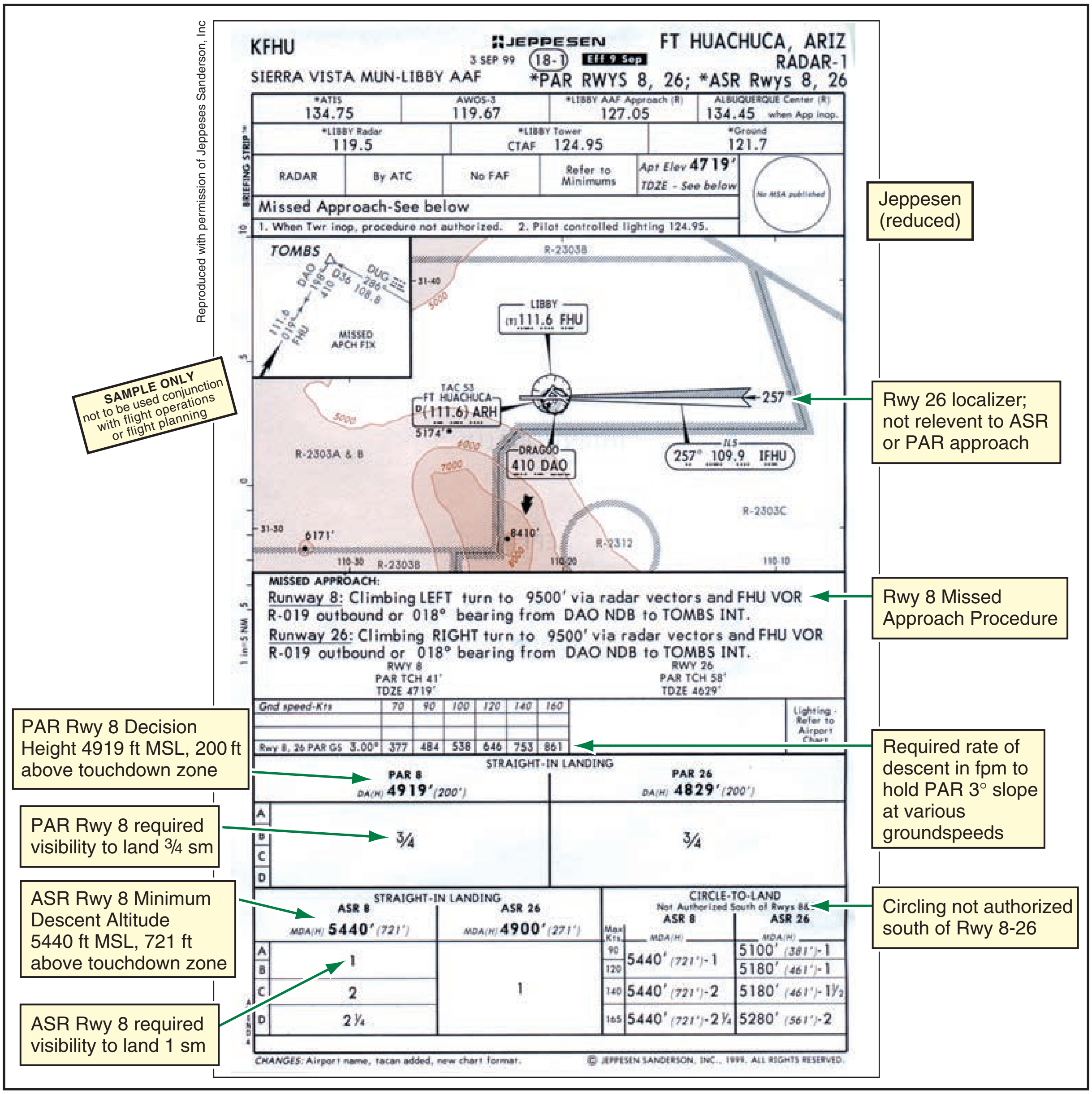


Figure 25-2 Approach plate for a PAR and SAR approach (Jeppesen).

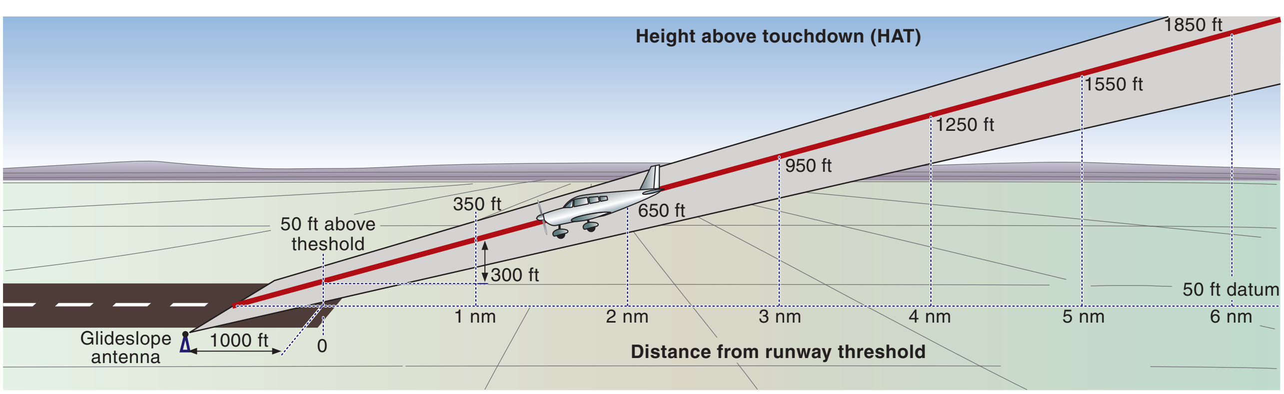


Figure 25-3 The normal instrument approach is 3°.

airplane must descend 1⁄20 of this distance to maintain a 3° slope (300 feet). Therefore, a 3° slope is approximately 300 feet/NM, which at 60 knots groundspeed is 300 fpm, and at 120 knots is 600 fpm.

Given that the airplane should cross the landing threshold at a height of 50 feet, it is relatively easy to derive a recommended *height/distance profile* for a 3° approach slope to any runway you like. Imagine the airplane moving backward up the 3° slope, from a point 50 feet above the threshold—it will pass through a series of points 300 feet higher for each 1 NM covered.

The figures shown in figure 25-3 represent the recommended *height above touchdown* (HAT) for a 3° slope. When you are actually flying an instrument approach (including a surveillance approach), the current local altimeter setting is selected in the pressure window, and so you must calculate an altitude indication equivalent to each HAT to monitor descent down the approach slope. The recommended altitude at each mile = touchdown zone elevation + HAT. The recommended altitudes provided by the radar controller during a surveillance approach are determined using the same sort of procedure.

Maintaining a 3° Descent

There is no instrument in most general aviation cockpits that is able to indicate descent in terms of feet/NM, although such an instrument would certainly make it easy to follow a 3° approach slope. However, you do have a vertical speed indicator that measures rate of descent in fpm, and an airspeed indicator that measures indicated airspeed in knots (NM/hr). With these instruments, it is possible to estimate the required descent rate for a 300 feet/NM slope. Because the approach path is measured in ground nautical miles, you should use the approximate groundspeed achieved at the approach IAS to increase the accuracy of the descent rate estimate:

- at a GS of 60 knots, the airplane will travel 1 NM in 1 minute, and so to maintain a slope of 300 feet/NM, a descent rate of 300 fpm will be required;
- at a GS of 120 knots, the airplane will travel 2 NM in 1 minute, and so to maintain a slope of 300 feet/NM, a descent rate of 600 fpm will be required; and
- at a GS of 90 knots, the airplane will travel 1.5 NM in 1 minute, and so to maintain a slope of 300 feet/NM, a descent rate of 450 fpm will be required.

Caution. The VSI in your aircraft may not be accurate so should be used only to establish an appropriate descent rate. The altimeter is primary as it has been tested and found accurate sometime in the past two years.

Example 25-1

An airplane has an approach speed of 75 KIAS (and assume IAS = TAS). To achieve a 3° slope of 300 feet/NM, the required rate of descent is:

1. in zero wind: TAS 75 knots, GS 75 knots, 375 fpm.
2. in 15 knots headwind: TAS 75 knots, GS 60 knots, 300 fpm.
3. in 30 knots headwind: TAS 75 knots, GS 45 knots, 225 fpm.
4. in 15 knots tailwind: TAS 75 knots, GS 90 knots, 450 fpm; in this case, you should be wary of continuing the approach to avoid exceeding the tailwind limitation for landing.

An easier method for rapid determination of an approximate descent rate to achieve a 3° slope is:

Rate of descent (fpm) for 3° slope = 5 × groundspeed (knots).

Example 25-2

Rate of descent in fpm for a 3 ° slope = 5 x groundspeed (knots).

At GS 80 knots, required descent rate is: 5 × 80 = 400 fpm.

Flying a Surveillance Approach

For a surveillance approach, the controller will radar vector your airplane to the final approach path, and then advise:
- the published *minimum descent altitude* (MDA) for the approach;
- the *missed approach point* (MAP), and the missed approach procedure; and
- when you are approaching the descent point.

> **Note.** If the landing is not to be made straight-in, then the controller will request your airplane's performance category, and provide the appropriate circling MDA.

The controller will instruct you when to commence descent to the MDA, at which point you should establish the airplane in a stable straight descent at a rate appropriate for a 3° slope (as discussed above). On final approach, the controller will provide:
- course guidance instructions (vectors) to keep the airplane tracking on the extended centerline; and
- distance from the runway or MAP at each mile on final and, if you have specifically requested this, the recommended altitude for each mile.

Guidance will be provided all the way to the MAP where, unless you have reported visual contact with the runway, the controller will instruct you to commence the missed approach procedure.

Landings from surveillance approaches are normally made straight-in. It is also possible to break off at a higher MDA to make a circling approach to the into-wind runway, should this be preferable for any reason. For instance, if use of the straight-in approach course for Runway 18 is not advisable because of weather to the north of the airport, then it may still be possible to make a surveillance approach from the south on Runway 36 instead, and then circle close-in to land on Runway 18. You should report when the airport/runway is in sight.

PAR Approaches

A PAR approach is similar to an ASR approach, except that the radar information used is much more precise, allowing a highly accurate approach to be made to a lower *decision height* (DH) than the *minimum descent altitude* (MDA) for an ASR approach. The PAR approach is a precision approach, based on both course and slope guidance. This means the pilot has a better chance of establishing visual contact with the runway in poor weather conditions.

Very sensitive radar equipment, separate from the standard ASR installation, is required for PAR approaches. A typical PAR installation consists of two antennas, scanning the vertical and horizontal planes within a narrow corridor covering the final approach path to a particular runway. The specialist PAR controller uses a radar screen that provides an accurate display of the airplane's position relative to both the final approach course (along the extended runway centerline), and the glide path, right down to the runway touchdown zone.

There are only a handful of airports in the continental U.S. where published PAR approaches are available for civil users (plus several more in Alaska), but many military airports are equipped to provide precision radar approaches (called GCAs, for Ground

Controlled Approaches). PAR or GCA approaches by civil aircraft are normally only used in an emergency, but they are quite easy to fly, and extremely accurate.

The PAR controller will vector you to the final approach course and advise when you are approaching the descent point. As the airplane intercepts the glide path, he or she will instruct you to *"Begin descent,"* and you should then commence a stabilized descent at the desired rate to maintain a 3° slope.

During more-or-less continuous transmissions while you are on final approach, the controller will advise you of the distance to go to the threshold and of any deviation from the required course and glide path. You must use gentle and coordinated alterations of pitch and heading to make immediate corrections in response to controller instructions.

You will be advised when the airplane reaches the DH (although you should, of course, monitor this yourself and start to scan for the runway as you approach the DH). If visual contact with the runway is not established at the DH, or if a safe landing is not possible, then you should initiate a missed approach. If you continue for a landing, the controller will provide course and glide path advice until you are over the threshold.

No-Gyro Approaches

If the heading indicator, and/or any other gyro-driven flight instrument, should fail or become unreliable during instrument flight (a partial panel situation), then you should declare an emergency and request a no-gyro approach. This may consist simply of radar vectors for a descent through the cloud base to establish in the landing pattern, but if available, ATC will direct you for a straight-in PAR or surveillance approach to a suitable runway.

Under these circumstances, you will usually not have reliable heading indications, and so the controller will tell you when to start and stop all turns that are required to intercept and maintain the final approach course. The controller will command you to "*Turn left*" and "*Stop turn* ." You should conduct the descent according to usual radar approach procedures, but must make all turns at standard-rate (3° per second) until established on final approach, after which half standard-rate turns are required. All turn instructions must be complied with immediately. It is possible for you to request a practice PAR, SSR, or No-Gyro Approach. If ATC is not too busy, they will honor your request. They need the practice, too.

Review 25

The VOR Instrument Approach

Refer to figure 25-4 to answer the following questions.

1. You are flying to Shelbyville from the South. You are asked by ATC to fly direct to SYI, and then you are cleared for the VOR 18 approach. Explain what you should do after crossing the VOR station.

2. The outbound portion of the approach and procedure turn must take place within 10 nautical miles of the SYI VOR. Why is this so important?

3. What is the minimum altitude that a pilot can execute the procedure turn when flying the VOR 18 approach at SYI?

4. Traditionally, the pilot will switch the OBS from the outbound to the inbound course when they are flying the procedure turn. Why is this a good practice?

5. Although DME can be used on this approach it is not required (DME would only be required if it appeared in the title of the approach, ie VOR/DME RWY 18). Without DME how will the pilot know when they have arrived at the Missed Approach Point?

6. This VOR approach lists the runway number in the title of this approach (VOR RWY 18) but from the airport sketch you can see that this approach is not lined up exactly with the runway centerline. Can you determine from the airport sketch why this VOR is not exactly lined up?

7. The missed approach instructions for the VOR RWY 18 approach at SYI direct the pilot to make a climbing right turn while simultaneously entering the depicted holding pattern. What, if anything, should the pilot do with the OBS setting during the missed approach procedure?

Answers are given on page 786.

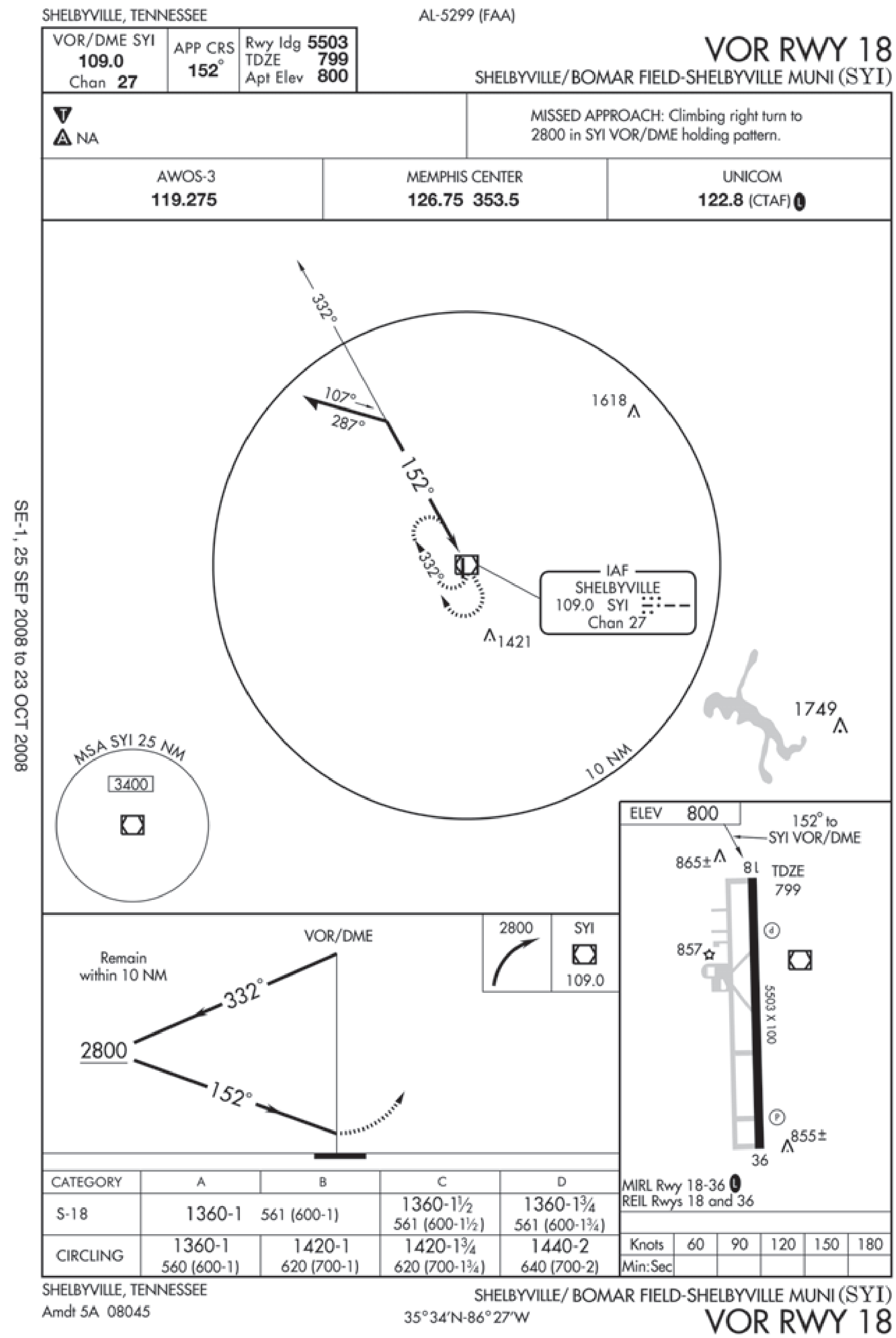


Figure 25-4 VOR RWY 18 approach

GPS Approaches 26

Pilots who have used Global Positioning System (GPS) for enroute navigation know that the system is accurate and easy to use. Many pilots started using GPS in their early VFR training and then integrated its use into IFR flying. The promise of GPS goes well beyond enroute navigation however. GPS, together with additional ground based equipment, has the potential to eventually provide every airport with an ILS-quality instrument approach.

Traditionally there have been two types of instrument approaches: precision and non-precision. The difference between the two is an electronic glide path. Precision approaches have an indicator on the flight deck that tells the pilot if they are above, below, or on the proper glide path to the runway. The most common of these precision approaches is the Instrument Landing System (ILS) (see chapter 27). Today, GPS has added a third type of approach a "semi-precision" approach. These approaches are called Approach with Vertical Guidance (APV) because they have a glideslope indicator on the flight deck, but they are not as accurate as a full ILS—at least not yet.

GPS Overlay Nonprecision Approach

When GPS was first used for instrument approaches, the procedure was simply placed over an existing non-precision approach. The original GPS approach procedures provided authorization to fly non-precision approaches based on conventional, ground-based NAVAIDs. Many of these approaches have been converted to stand-alone approaches, especially as NDB have gone off the air and the few that remain are identified by the name of the procedure and "or GPS." These GPS non-precision approaches are predicated upon the design criteria of the ground-based NAVAID used as the basis of the approach. As such, they do not adhere to the RNAV design criteria for stand-alone GPS approaches—and are not considered part of the RNAV (GPS) approach classification for determining design criteria (see figure 26-1).

GPS Stand-Alone/RNAV (GPS) Approach

RNAV (GPS) approaches are named so that airborne navigation databases can use either GPS or RNAV as the title of the approach. This is required for non-GPS approach systems such as VOR/DME based RNAV systems. In the past, these approaches were often referred to as stand-alone GPSs. They are considered non-precision approaches, offering only Lateral Navigation (LNAV) and circling minimums and have a Minimum Descent Altitude (MDA). The RNAV (GPS) Runway 18 approach for Alexandria, Louisiana incorporates only LNAV and circling minimums (see figure 26-2). A GPS approach that has LNAV minimums is not necessarily more accurate than traditional NDB or VOR non-precision approaches. To get the greater benefit of GPS for instrument approaches, greater accuracy is needed. A ground based antenna will hone in the satellite signals and narrow down the accuracy. That system is called the Wide Area Augmentation System (WAAS). The WAAS makes it possible for GPS to deliver not only lateral guidance but also vertical guidance—like a glideslope.

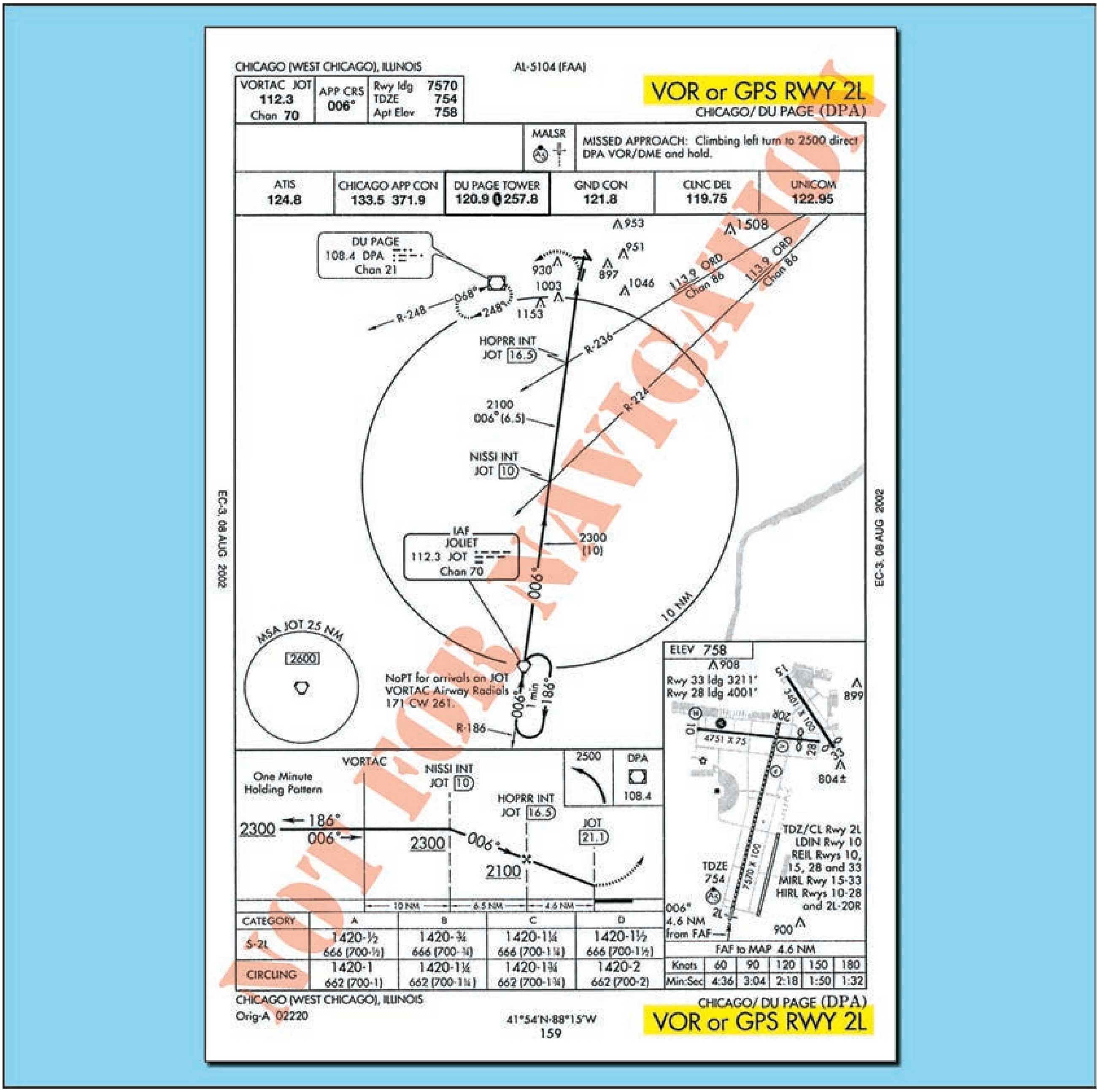


Figure 26-1 Traditional GPS Overlay Approach.

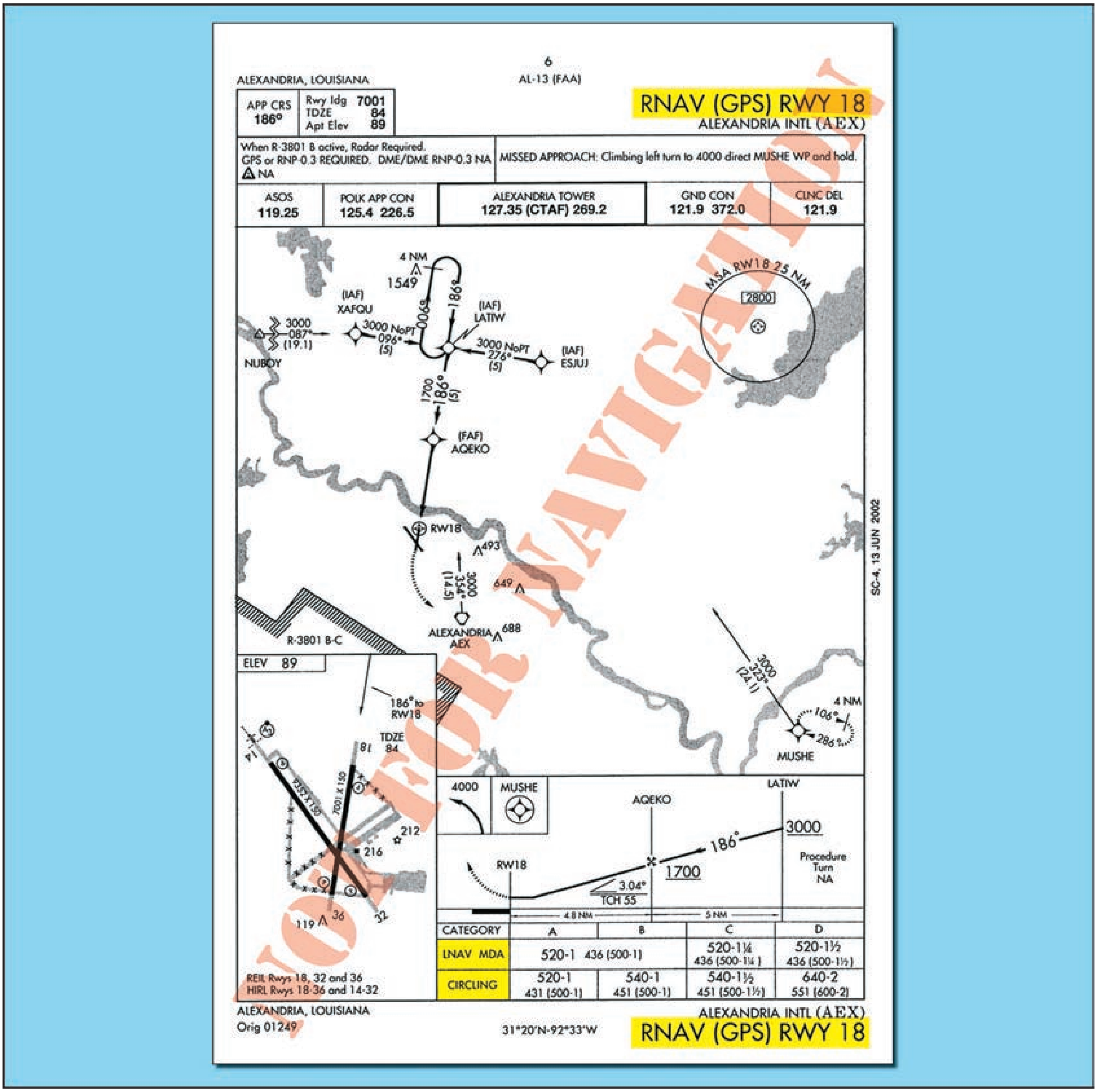


Figure 26-2 Alexandria International (KAEX), Alexandria, Louisiana, RNAV (GPS) Rwy 18.

Wide Area Augmentation System

The introduction of the Wide Area Augmentation System (WAAS) which became operational on July 10, 2003, provides even lower minimums for RNAV approaches that use GPS by providing electronic vertical guidance and increased accuracy. The Wide Area Augmentation System, as its name implies, augments the basic GPS satellite constellation with additional ground stations and enhanced position integrity information transmitted from geostationary satellites. This capability of augmentation enhances both the accuracy and integrity of basic GPS and may support electronic vertical guidance approach minimums as low as 200 feet HAT and ½ SM visibility. WAAS covers 95 percent of the country 95 percent of the time.

Vertical Navigation

One of the advantages of some GPS and multi-sensor FMS RNAV avionics is the advisory VNAV capability. Traditionally, the only way to get vertical path information during an approach was to use a ground-based precision NAVAID like the ILS Glide Slope. Modern RNAV avionics can display an electronic vertical path that provides a constant-rate descent to the minimum altitude of the approach.

Since these systems are advisory and not primary guidance, the pilot must continuously ensure the aircraft remains at or above any published altitude constraint, including step-down fix altitudes, using the primary barometric altimeter. The pilots, airplane, and operator must be approved to use advisory VNAV inside the FAF on an instrument approach.

VNAV information appears on selected conventional non-precision, GPS, and RNAV approaches. It normally consists of two fixes (the FAF and the landing runway threshold), a FAF crossing altitude, a vertical descent angle (VDA), and may provide a visual descent point (VDP). See figure 26-3. The published VDA is for information only, advisory in nature, and provides no additional obstacle protection below the MDA. Operators can be approved to add a height loss value to the MDA and use this derived decision altitude (DDA) to ensure staying above the MDA. Operators authorized to use a VNAV DA in lieu of the MDA must commence a missed approach immediately upon reaching the VNAV DA if the required visual references to continue the approach have not been established.

A constant-rate descent has many safety advantages over non-precision approaches that require multiple level-offs at step down fixes or manually calculating rates of descent. A stabilized approach can be maintained from the FAF to the landing when a constant-rate descent is used. Additionally, the use of an electronic vertical path produced by onboard avionics can serve to reduce CFIT, and minimize the effects of visual illusions on approach and landing.

In order to achieve the lowest minimums, the requirements of an entire electronic vertical guidance system, including satellite availability; clear obstruction surfaces; AC 150/5300-13, Airport Design; and electronic vertical guidance runway and airport requirements must be satisfied. The minimums are shown as DAs since electronically computed glide path guidance is provided to the pilot. The electronically computed guidance eliminates errors that can be introduced when using barometric altimetry.

A greater degree of accuracy is achieved when WAAS is used for both lateral and vertical navigation not just vertical as with the LNAV/VNAV approach. Combining WAAS lateral and vertical guidance produces an approach called the Localizer Performance with Vertical guidance or LPV approach. This approach has minimums similar

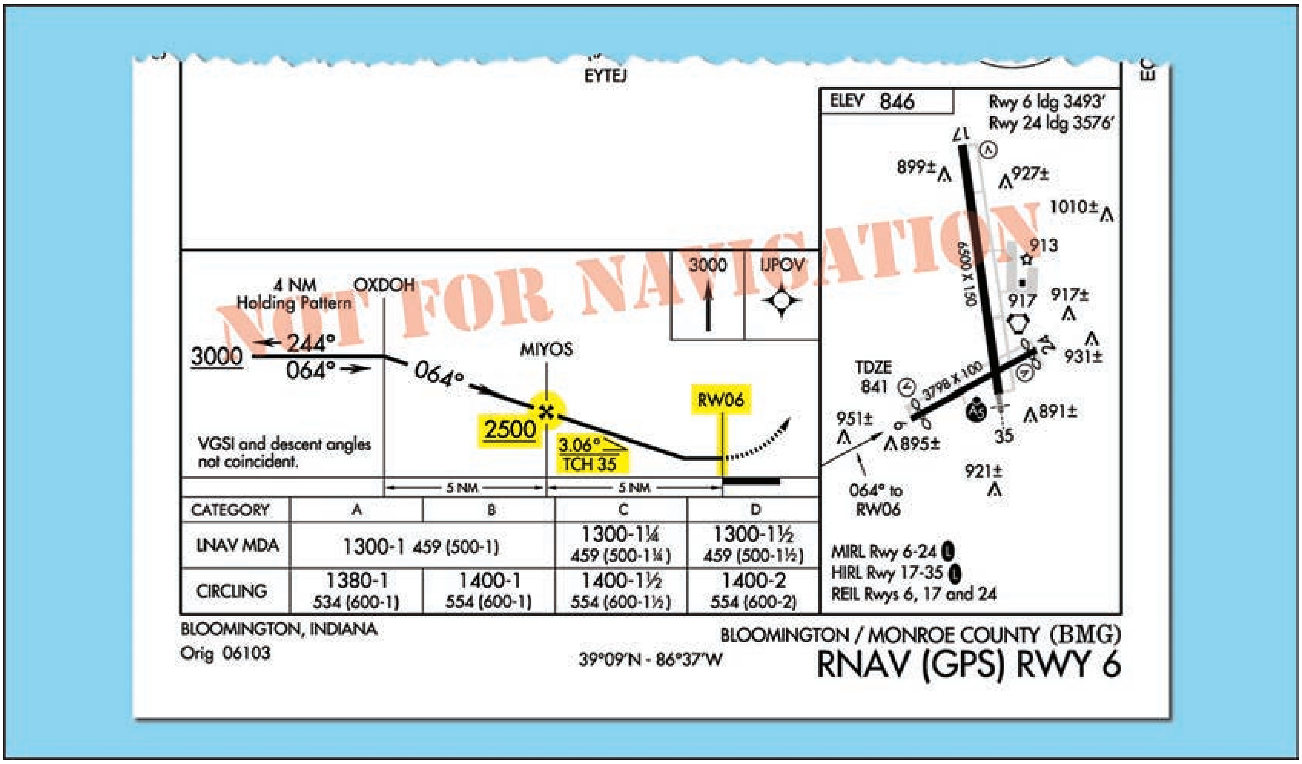


Figure 26-3 VNAV information.

to an ILS but is limited to areas where terrain is not a challenge. Approach minimums as low as 200 feet HAT and ½ SM as visibility is possible even though LPV is still considered a semi-precision and not a precision approach. However LPVs, like precision approaches, have a Decision Altitude (DA) like an ILS approach.

Full precision approach status will become available when The Local Area Augmentation System or LAAS becomes operational. LAAS further increases the accuracy of GPS and improves signal integrity warnings because LAAS is a ground station designed for use at a specific airport or runway.

Precision approach capability requires obstruction clearance and approach lighting systems to meet Part 77 standards for ILS approaches. An LAAS assisted approach is called the GNSS (Global Navigation Satellite System) Landing System or GLS. Some approach charts have GLS included in the minimums section but with the designation of NA for not authorized. For now the GLS line in approach charts is a place holder but when GLS approaches are in use they may be moved to a different chart all together—like ILS charts are separate now.

RNAV (GPS) approach charts presently can have up to four lines of approach minimums: LPV, LNAV/VNAV, LNAV, and Circling. Figure 26-4 shows how these minimums might be presented on an approach chart with the exception of GLS.

GPS has opened the door to many new approach possibilities which in turn increase the chances that a pilot will be successful in flying an approach to a landing at their destination airport, however there are more types of approaches to be familiar with.

Non-precision approaches have no electronic glideslope and their lowest altitude is called the Minimum Descent Altitude (MDA). These approaches include the NDB, VOR, VOR/DME, Radar, SDF, LDA, and LNAV.

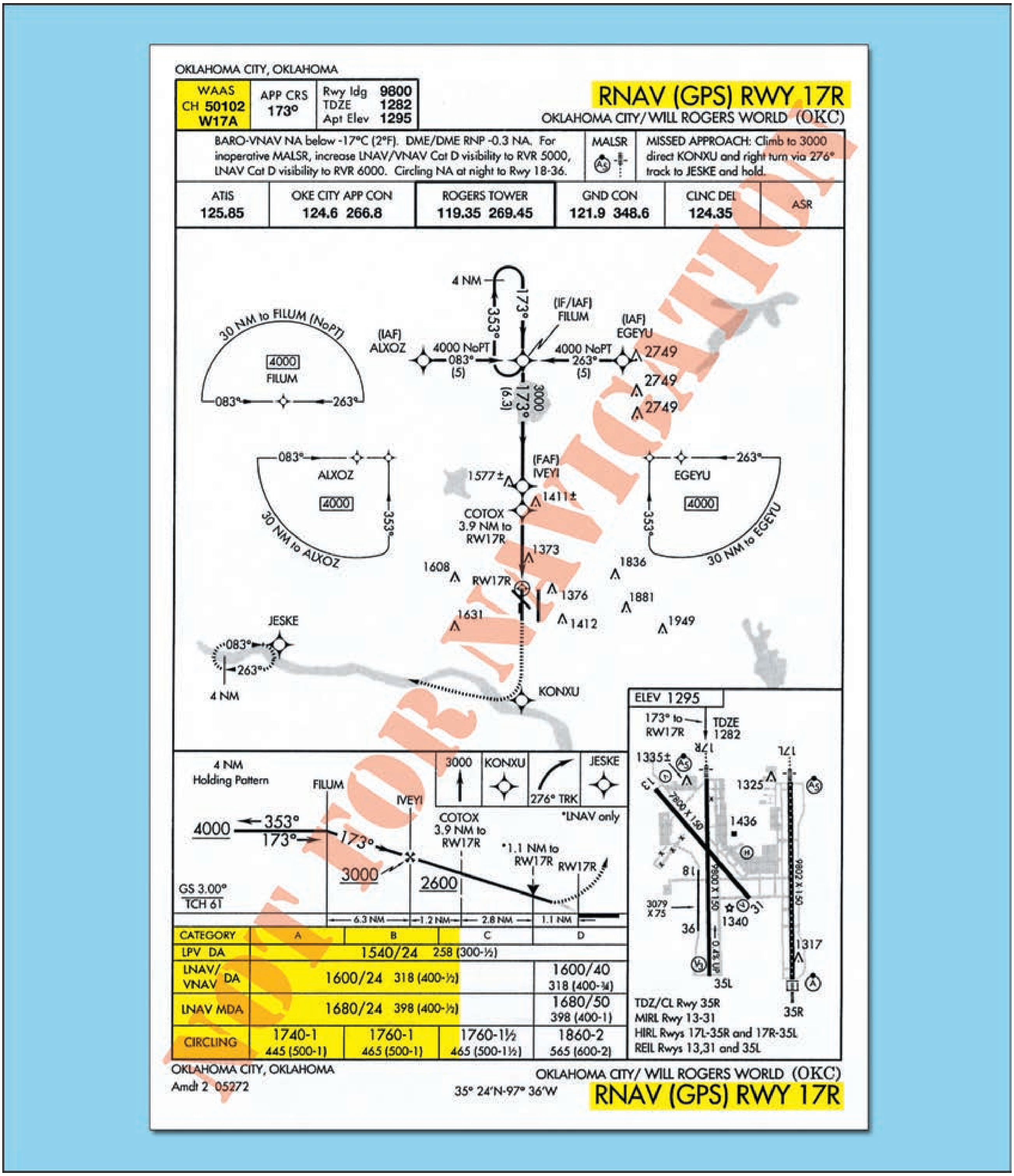


Figure 26-4 RNAV (GPS) electronic vertical guidance approach minima.

Semi-precision approaches use WAAS to add vertical guidance. This means that the pilot has an electronic glideslope. Still the accuracy is not high enough to be considered full precision. This type of approach has been designated APVs for Approach with Vertical guidance. APVs include LNAV/VNAV and LPVs. The lowest altitude on these approaches, like on an ILS, are called Decision Altitudes or DAs.

Precision approaches have an electronic glideslope that meets the highest accuracy standards. Today the most common of these is the Instrument Landing System—ILS, however when the LAAS systems are implemented another precision approach, the GLS, will be available.

Multiple Approaches to the Same Runway

GPS has also created the need to change the way instrument approaches are named. Traditionally one NAVAID would provide one instrument approach to a single runway or to a circle to land. Now there can be more than one GPS instrument approach to the same runway. To eliminate confusion, instrument approaches with the same guidance are annotated with an alphabetical suffix beginning at the end of the alphabet and working backwards for subsequent procedures. Figure 26-5 depict two GPS instrument approaches to the same runway and are designated the "Z" and "Y" approach.

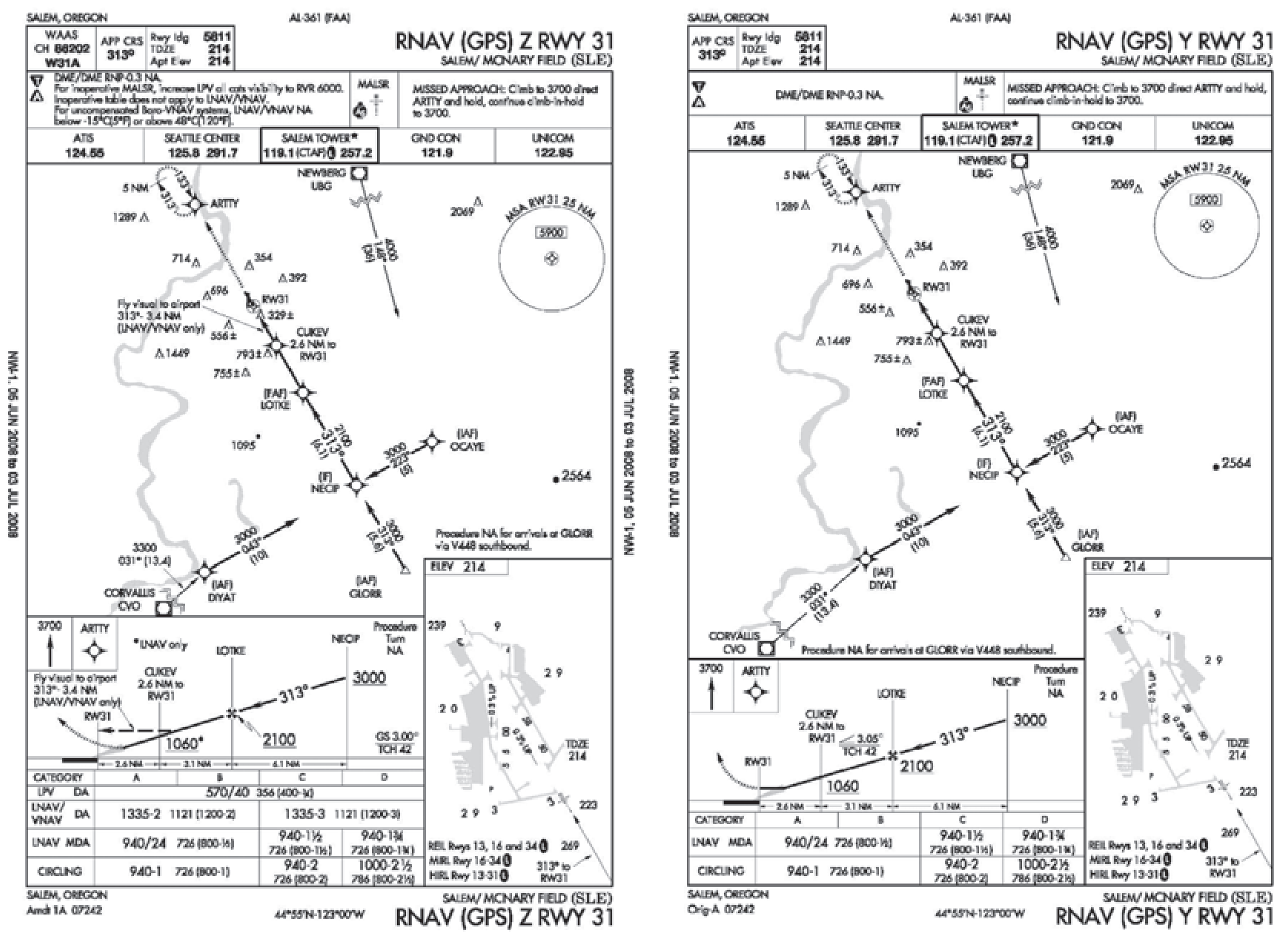


Figure 26-5 NACO Z and Y approach charts, Salem, Oregon.

Required Navigation Performance

As air traffic congestion increases it will be necessary to increase the accuracy of navigation so that essentially more airplanes can fit into the same airspace. To achieve this goal a set of Required Navigation Performance (RNP) criteria is being established. When an airplane flies through particular airspace it must navigate to within a pre-set tolerance. It does not matter which navigation equipment the pilot/airplane uses to meet the tolerance, RNP just requires that it be met. The RNAV system that will be used the most to achieve the RNP tolerance will be GPS.

The operational advantages of RNP include accuracy and integrity monitoring, which provide more precision and lower minimums than conventional RNAV. RNP DAs can be as low as 250 feet with visibilities as low as ¾ SM. Besides lower minimums, benefits of RNP include improved obstacle clearance limits, as well as reduced pilot workload. When RNP-capable aircraft fly an accurate, repeatable path, ATC can be confident that these aircraft will be at a specific position, thus maximizing safety and increasing capacity.

To attain the benefits of RNP approach procedures, a key component is curved flight tracks. Constant radius turns around a fix are called "radius-to-fix legs," or RF legs. These turns, which are encoded into the navigation database, allow the aircraft to avoid critical areas of terrain or conflicting airspace while preserving positional accuracy by maintaining precise, positive course guidance along the curved track. The introduction of RF legs into the design of terminal RNAV procedures increases airspace and allows procedures to be developed to and from runways that are otherwise limited to traditional linear flight paths or in some cases not served by an IFR procedure at all. Navigation systems with RF capability are a prerequisite to flying a procedure that includes an RF leg. Refer to the notes box of the pilot briefing portion of the approach chart in figure 26-6.

In the United States, all RNP procedures are in the category of Special Aircraft and Aircrew Authorization Required (SAAAR). Operators who want to take advantage of RNP approach procedures must meet the special RNP requirements outlined in FAA AC 90-101, Approval Guidance for RNP Procedures with SAAAR. Currently, most new transport category airplanes receive an airworthiness approval for RNP operations. However differences can exist in the level of precision that each system is qualified to meet. Each individual operator is responsible for obtaining the necessary approval and authorization to use these instrument flight procedures with navigation databases.

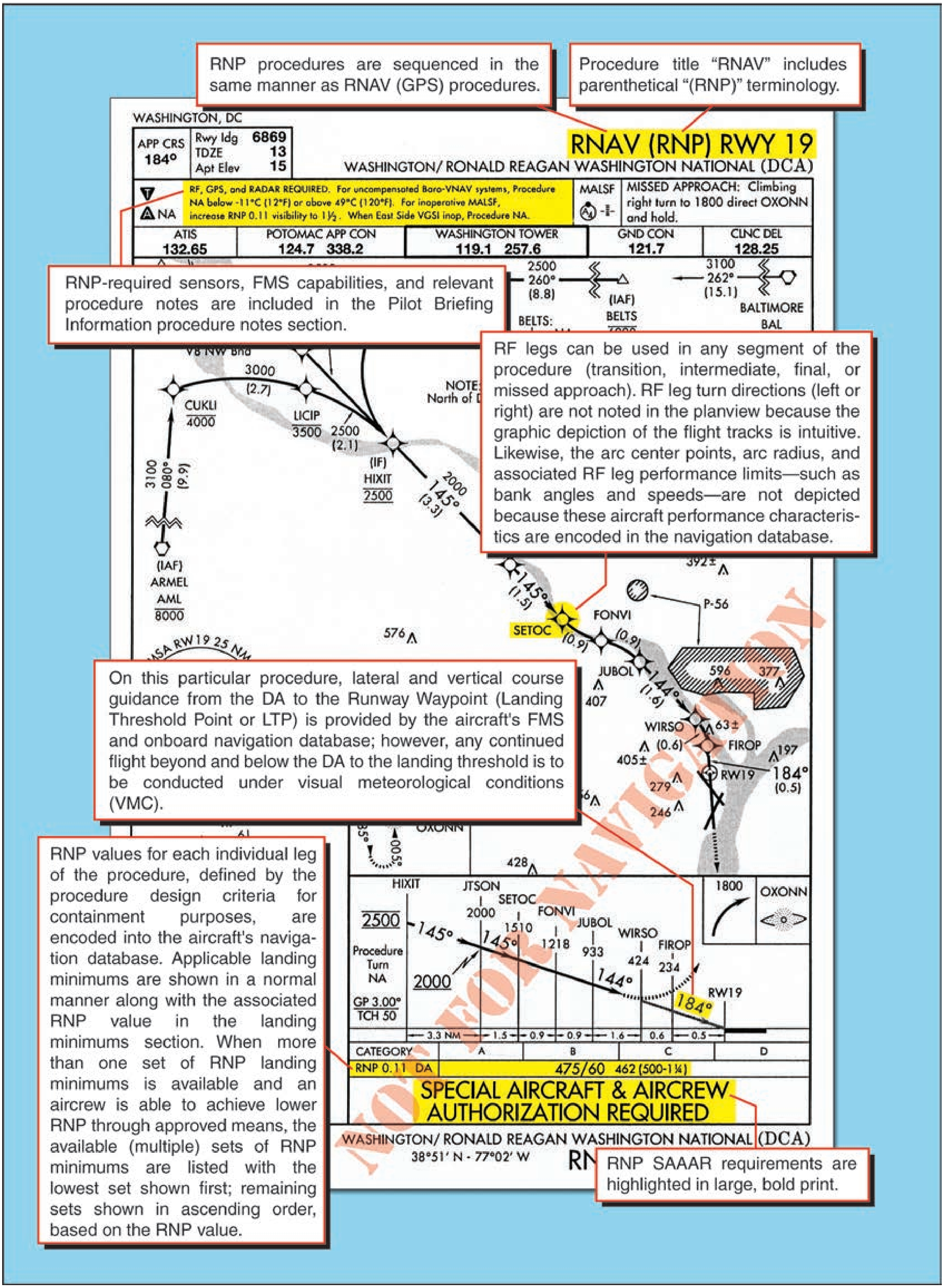


Figure 26-6 RNAV (RNP) approach procedure with curved flight tracks.

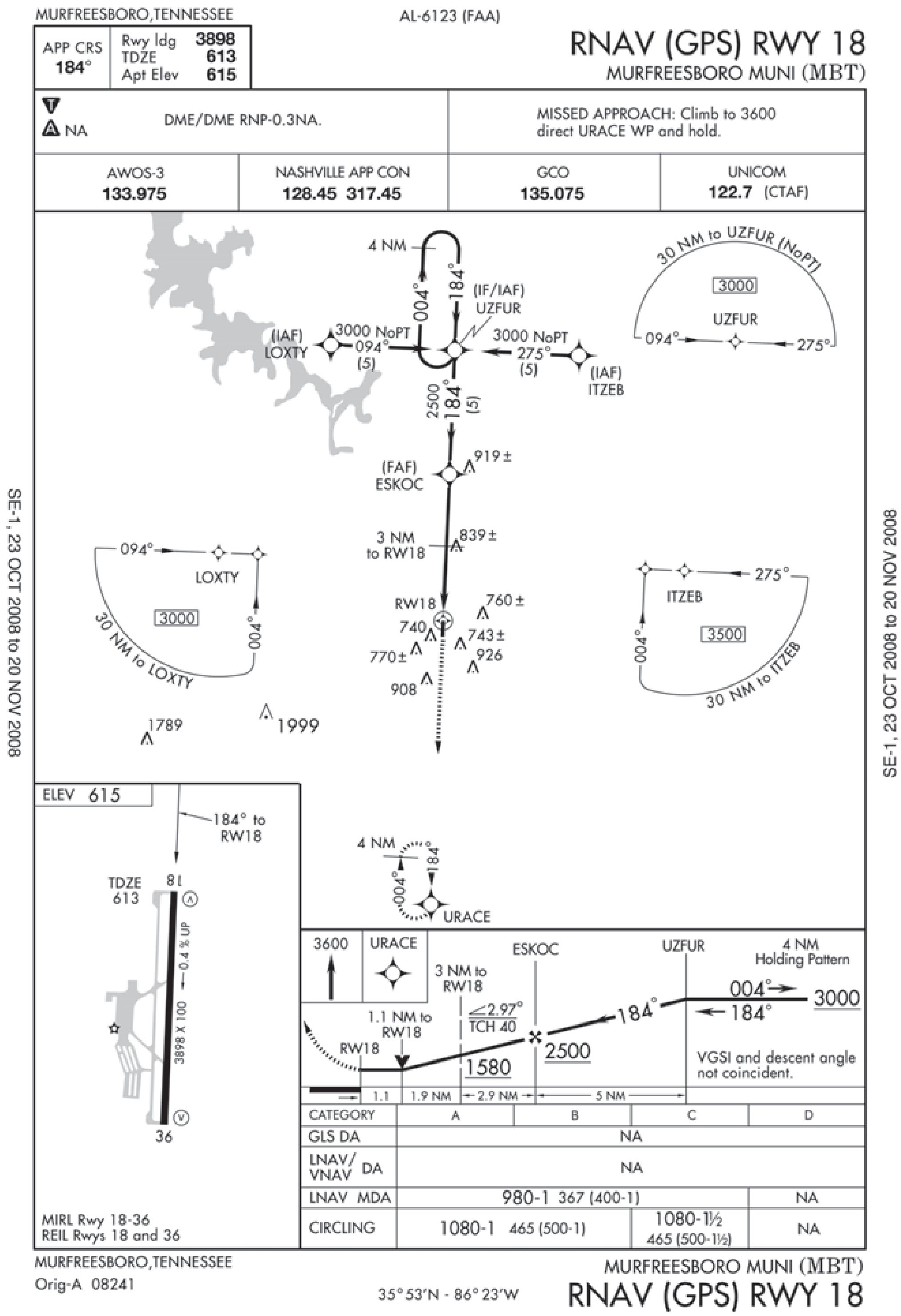
Review 26
GPS Approaches

1. What is LNAV and VNAV?
2. What is WAAS and LAAS?
3. What is RNP?
4. What is GLS?

Refer to the RNAV (GPS) RWY 18 approach at Murfreesboro, Tennessee for questions 5 through 7. See figure 26-7

5. What is the LNAV Minimum Descent Altitude and visibility requirement for a Category A aircraft?
6. If a pilot flies the RNAV (GPS) RWY 18 approach, but the wind favors a landing on runway 36, what procedure should the pilot use to make a safe landing on runway 36?
7. Why are both the GLS and LNAV/VNAV approach minimums listed as "NA" on the RNAV (GPS) RWY 18 approach?
8. What is indicated when the letters Z or Y appear in the title of an instrument approach: RNAV (GPS) Z RWY 12

Answers are given on page 787.



CATEGORY	A	B	C	D
GLS DA	NA			
LNAV/VNAV DA	NA			
LNAV MDA	980-1 367 (400-1)			NA
CIRCLING	1080-1 465 (500-1)		1080-1½ 465 (500-1½)	NA

Figure 26-7 RNAV (GPS) RWY 18 approach at Murfreesboro, Tennessee

Instrument Landing System (ILS) 27

The *instrument landing system* is known as the ILS. It enables a suitably equipped airplane to make a *precision approach* to a particular runway. A precision approach is one in which electronic glide slope guidance, as well as tracking guidance, is given. Each ILS is known by the airport and runway it serves, for example, the Lafayette ILS Rwy 10, in Indiana.

The instrument landing system has four main elements:

1. the *localizer*, which provides course guidance along the extended centerline of the runway (guidance in azimuth left or right of the extended centerline);
2. the *glide slope*, which provides vertical guidance toward the runway touchdown point, usually at a slope of approximately 3° to the horizontal, or 1:20 (vertical guidance above or below the glide slope);
3. *marker beacons*, which provide accurate range fixes along the approach path (usually an *outer marker* and a *middle marker*) are provided; and
4. *approach lights*, VASI (visual approach slope indicator), and other lights (touchdown zone lighting, runway lights, etc.) to assist in transitioning from instrument to visual flight.

There may be supplementary NAVAIDs available, including:

- a compass locator (NDB); and
- DME.

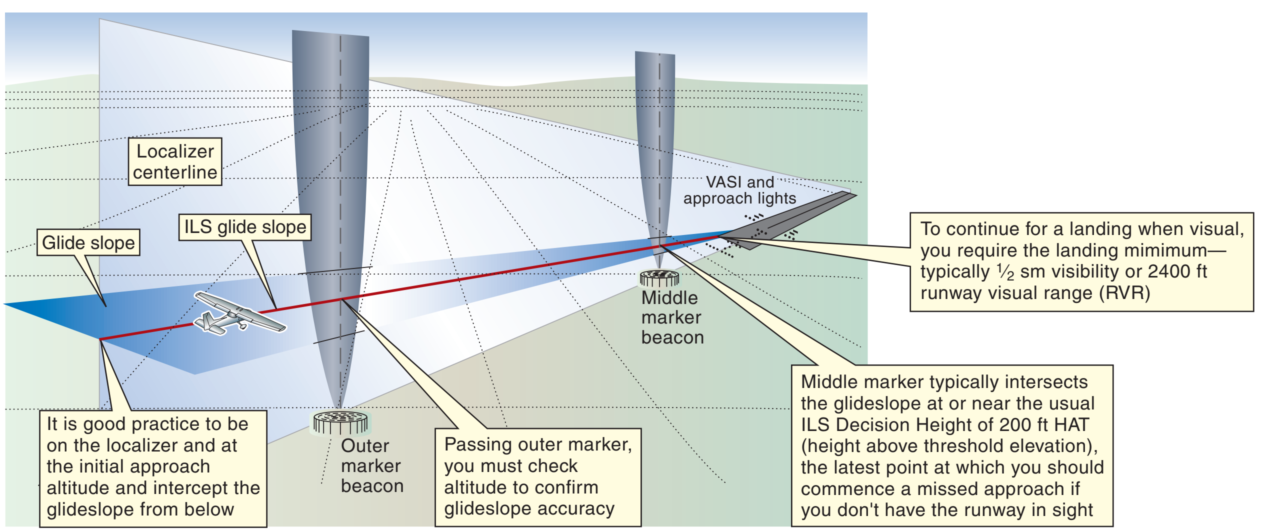


Figure 27-1 The instrument landing system.

The *outer marker* may be replaced as a range marker on some ILSs by a compass locator, a DME distance, or an ASR or PAR radar position from ATC. The *middle marker*, where more accuracy is required, may be replaced as a range marker on some ILSs by a compass locator or PAR radar position from ATC (but not by a DME distance or ASR radar position). These range markers provide you with an accurate distance fix along the localizer.

A co-located compass locator and outer marker will appear on the approach chart as "LOM." A co-located compass locator and middle marker will appear on the approach chart as "LMM."

The ideal flight path on an ILS approach, where the localizer plane and the glide slope plane intersect, is referred to as the *glide path*. The word *glide* is really a misnomer carried over from earlier days, since modern airplanes make powered approaches down the glide path, rather than glide approaches. However, the term glide path is still used.

Since ILS approaches will often be made in conditions of poor visibility or at night, there is always associated visual information that can be used once the pilot becomes "visual" (has the runway environment in sight). This may include approach lights leading toward the runway, runway lights, touchdown lights, and centerline lights. Lighting is indispensable for night operations, but it can also be invaluable during daylight hours in conditions of restricted visibility.

There may also be a visual approach slope indicator (VASI) situated near the touchdown zone to provide visual slope guidance during the latter stages of the approach. This, and other visual information, will assist you in maintaining a stable descent path toward the runway, where you can complete the landing.

The ILS is selected in the cockpit on the NAV/COM radio. Its cockpit display is usually the same instrument as for the VOR except that, in addition to the vertical localizer needle (CDI) that moves left and right for course guidance, there is a second needle or indicators that come into view. It is horizontal, and is able to move up and down to represent the position of the glide slope relative to the airplane. Some ILS indicators have needles that are hinged and move like wipers, others have needles that move rectilinearly. The airplane may be thought of as the center dot, and the intersection of the needles as the relative position of the glide path.

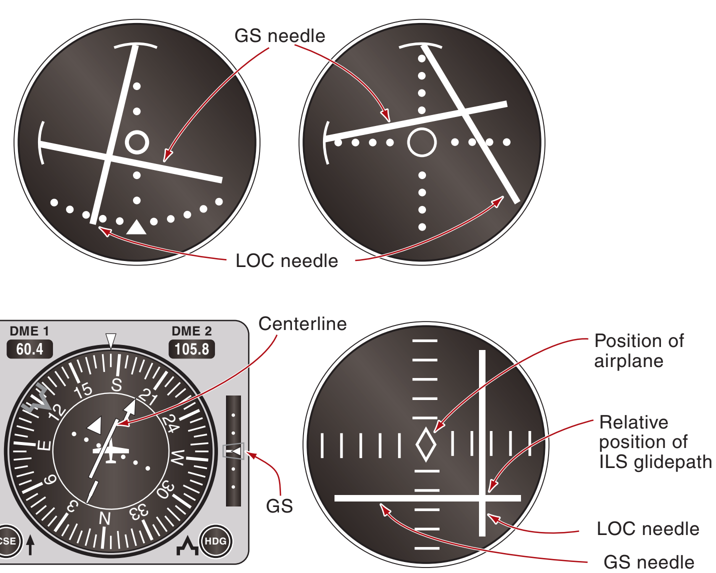


Figure 27-2 ILS cockpit displays.

The Localizer (Centerline)

The localizer provides directional guidance along the extended centerline of the landing runway. Its transmitting antenna, which may be 60 feet wide and 10 feet high, is positioned at the far end of the runway and typically 1,000 feet beyond the end so as not to be an obstacle to airplanes taking off.

Figure 27-3 The localizer transmitting antenna.

The localizer transmits a highly directional beam on a frequency in the VHF band between 108.10 and 111.95 MHz, the specific frequency being published on charts and in the A/FD. There are 40 localizer frequencies available, with all of them having an odd number as the first digit after the decimal point, such as 109.1, 108.3, and 110.5.

The Localizer Ground Equipment

The localizer antenna at the far end of the runway transmits two overlapping lobes of radio energy on the localizer's carrier frequency (such as 109.9 MHz for Los Angeles International Airport ILS Rwy 25 Right). The lobe on the left hand side of the approach course is modulated at 90 Hz (previously known as the *yellow* sector), and the lobe on the right hand side of the approach path is modulated at 150 Hz (the *blue* sector). The two lobes overlap to provide a path in line with the extended centerline of the runway.

The colors blue and yellow were once painted on the localizer cockpit display, but this is not the case on modern instruments.

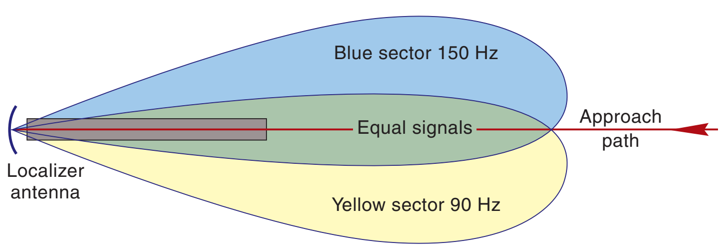


Figure 27-4 The localizer's radiation pattern.

The transmission pattern is adjusted for each ILS so that the course width, from full-scale FLY LEFT to full-scale FLY RIGHT, is 700 feet at the approach runway threshold. Since runways are of varying lengths, and since the localizer antenna is positioned beyond the far end of the runway, the angular width of localizer beams will vary between 3 and 6 degrees to achieve the 700 feet course width at the approach threshold.

A typical angular width of the localizer course, from full-scale FLY LEFT to full-scale FLY RIGHT (peg to peg), is 5°, that is, 2.5° either side of the localizer course centerline, but for different localizers this may vary from 1.5° to 3°.

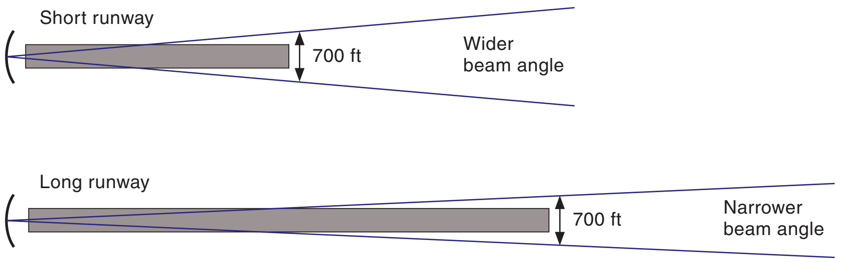


Figure 27-5 Peg-to-peg deflection is 700 feet at the landing threshold.

The localizer course information is accurate within the sectors shown in figure 27-6, from an altitude of 1,000 feet above the highest terrain along the course line to 4,500 feet above the elevation of the antenna site. Correct cockpit indications are assured if the airplane is in this airspace volume.

Outside this airspace, a correct localizer signal is not assured, and it is possible you may not even receive its coded *ident*.

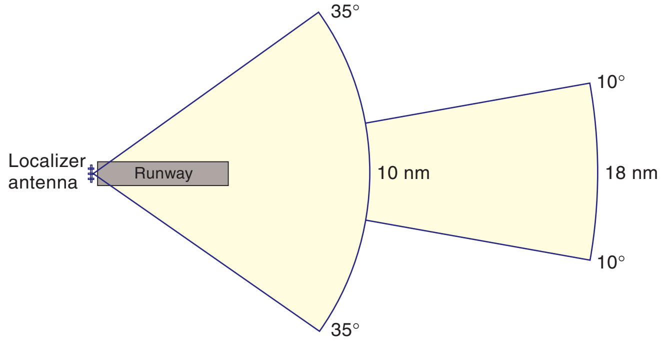


Figure 27-6 The protected airspace volume for the localizer signal.

The main function of the localizer is to provide *azimuth* guidance to an airplane on final approach to a particular runway. The signal transmitted out along the approach path is sometimes called the localizer *front course*.

Many localizers also transmit a *back course* (BC). This can be used for tracking when continuing overhead the runway and straight ahead following a missed approach, or when taking off and departing. In some countries, like the United Kingdom and Australia, the localizer back course is suppressed.

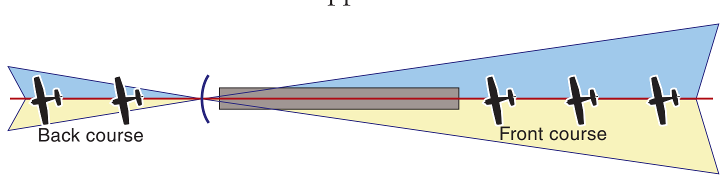


Figure 27-7 A localizer with both a front course and a back course.

The back course of a localizer does not have an associated glide slope for a precision approach in the opposite direction, although *false glide slope* signals might exist. Some localizer back courses are available for a nonprecision approach in the opposite direction to the normal front course approach, in which case a LOC BC instrument approach chart is published.

Do not confuse the back course of a localizer with an ILS for the reciprocal runway, which will be a totally different installation with its own transmitting antennas. ATC will never have opposing ILSs in service simultaneously. For instance, you would not expect to find *ILS Rwy 8 Left* and *ILS Rwy 26 Right* operating simultaneously, since they would be directing airplanes to opposing ends of the one runway.

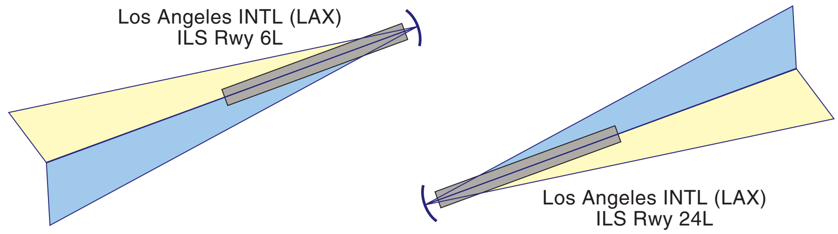


Figure 27-8 Two different ILSs serving opposite runways.

The Localizer Airborne Equipment

Always positively identify a localizer before using it for navigation.

The localizer transmits on one of 40 frequencies in the VHF band between 108.10 and 111.95 MHz. The specific frequency is published on the relevant instrument approach chart. You can select this frequency on the VOR/ILS, and must identify the localizer by its Morse code *ident* before using it. The localizer ident is always a four-letter coded identifier beginning with I, "*dit-dit*." Some modern radios decode and display the identifier.

Oakland ILS Rwy 11 is I-AAZ on frequency 111.9 MHz; Oakland ILS Rwy 27R is I-OAK on frequency 109.9 MHz; Cincinnati ILS Rwy 20L is I-LUK on frequency 110.9 MHz; and, as expected, the Cincinnati LOC BC 2R is the same localizer I-LUK on 110.9 MHz, since the 2L LOC BC is part of the 20R localizer. Have a look at your own Instrument Approach Procedures booklet for similar examples.

Identifying the localizer serves to identify the ILS (including the glide slope). For instance, identifying the Cincinnati 20L localizer I-LUK also identifies its glide slope. Correct identification is vital before an ILS (or any NAVAID for that matter) is used.

For the localizer to be usable, it must be identified, and there should be no red OFF flag associated with the vertical needle. If the OFF flag is visible, then the signal being received at the airplane is not sufficiently strong, and so the CDI indications will be unreliable and should not be used.

The airplane's NAV/COM receiver, when tuned to a localizer frequency, compares the strengths of the two signals (150 Hz and 90 Hz) it receives, and produces a voltage that energizes the localizer needle in the cockpit instrument. If the 150 Hz signal is stronger (which will occur if the airplane on approach is out to the right), then a voltage is fed to the localizer needle that moves it to the left. This indicates that the localizer centerline is to the left of the airplane on approach.

If the signals are of equal strength, then the localizer needle is centered, providing an ON COURSE indication. If the 90 Hz signal predominates, then the voltage fed to the localizer needle moves it to the right, indicating that the airplane will need to move to the right to get back on centerline.

Full-scale deflection will occur when the airplane is displaced approximately 2.5° or more from the localizer centerline. This means that the CDI (with the five dots either side of center) is four times more sensitive when it is tuned to a localizer (at 0.5° per dot), compared with when it is tuned to a VOR (at 2° per dot). Full-scale deflection of the CDI selected to a localizer is 2.5° or more off the localizer centerline; full-scale deflection of the CDI selected to a VOR is 10° or more off the selected radial. Usable localizer signals may be obtained up to ±35° from course centerline, giving full-scale deflection beyond ±2.5°. Outside the protected signal volume, the OFF flag will come into view, and no ident will be heard.

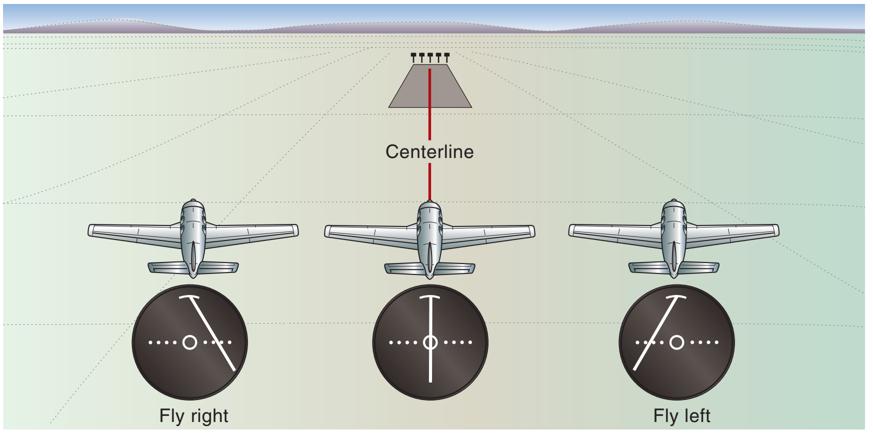


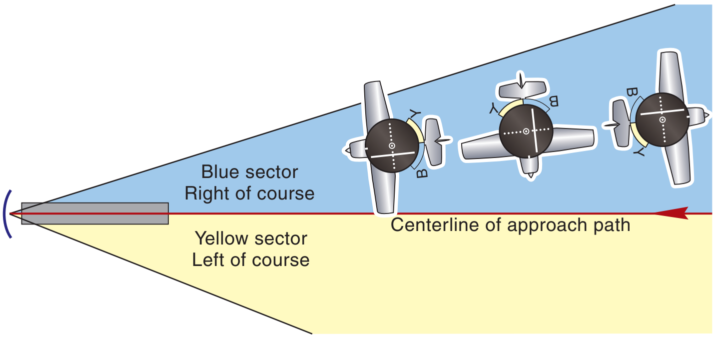
Figure 27-9 An airplane on approach—fly toward the CDI.

Note. The angular width of a localizer beam is adjusted to provide a beam width (peg-to-peg) of 700 feet at the approach-end runway threshold for all ILS approaches. Consequently, full-scale deflection of the localizer needle can actually represent angles between 1.5° and 3°, depending on the length of the runway and the distance of the localizer antenna from the upwind end. The angular deviation per dot varies for the localizer needle, with 0.5° per dot being average.

The localizer course is a single fixed course, unlike the VOR, which gives the pilot a choice of 360 radials using the omni bearing selector (OBS). With a localizer frequency selected on the NAV/COM, the OBS has absolutely no significance, and changing it will have no effect on the indications of the CDI needle. It is good operating procedure, however, to dial in the inbound track of the localizer, using the OBS, simply as a reminder. It is also a habit that you will find useful if you happen to fly an airplane equipped with an HSI.

The localizer cockpit indicator does not provide any heading information, but only position information. It simply indicates how many degrees the airplane is displaced from the localizer course, and in which sector it is (left or right of course). A one-dot deviation on the localizer is approximately 0.5°, which is roughly equivalent to 50 feet/NM left or right of centerline.

Figure 27-10 The CDI indicates angular displacement from the localizer, and does not give heading information. It does show where the centerline would be if you were flying toward the station.



Localizer Failure

If the localizer signal fails, then the whole ILS approach becomes unauthorized (including the glide slope), and an ILS approach in such a situation is not permitted. If only the glide slope signal fails, the localizer is still available.

Flying the Localizer

The ILS cockpit instrument is a *performance* instrument. It should be included in the selective radial scan when it is being actively used. Having gained that information (which, in this case, is the position and/or movement of the localizer needle), your eyes should return to the attitude and heading indicators.

Any corrections to heading to regain or maintain the localizer course can then be made with small coordinated turns on the attitude indicator. The heading indicator can be checked for heading, and the ILS cockpit indicator can be checked again for position and/or movement of the localizer needle. Concentrate on the HI and AI for your attitude flying, with an occasional glance at the CDI to see how the tracking is going. Do not chase the CDI.

The localizer beam is quite narrow, full-scale FLY LEFT to full-scale FLY RIGHT being only about 5°, and so any intercept of the localizer should be made at no more than 30°. Even when the CDI is pegged at full-scale deflection during the intercept, other NAVAIDs, such as a compass locator, if available, should be used to monitor closure with the localizer.

Once the CDI starts moving, indicating that you are approaching the centerline, turn immediately onto course and steer the localizer course ± estimated WCA. Hold this heading for a few seconds, even if the CDI needle is not centered, and then observe its position and motion, if any. Then, with gentle turns using the flight instruments, position the airplane on the localizer centerline and steer a suitable reference heading to maintain it.

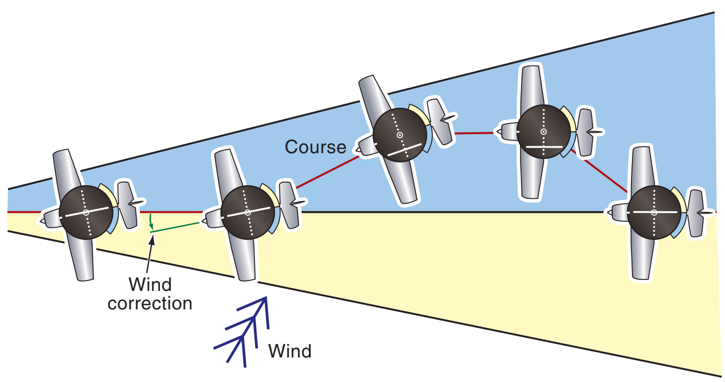


Figure 27-11 Typical heading corrections for a deviation right of centerline.

The aim is to fly a heading that will maintain the airplane on centerline. If a crosswind exists, a wind correction angle will be required, and the airplane heading will differ slightly from the published inbound course of the localizer. The wind will probably weaken in strength as the airplane descends, and there will also be gusts and lulls, so periodic adjustments to heading can be expected.

Apply a wind correction angle that will keep the airplane on centerline.

For an airplane on approach, the localizer needle indicates which way the airplane should move to regain the centerline. If the localizer needle is to the left, then the airplane should be flown left. On approach, the CDI acts as a command instrument; to regain centerline, fly toward the needle.

On approach the CDI is a command instrument fly toward the needle.

You should aim to capture the localizer as soon as possible on the approach, and ensure that small deviations are corrected before they can become large deviations. An ILS approach normally requires many such heading corrections to regain and maintain the localizer centerline. This is only to be expected, because wind effect will almost certainly vary along the glide path.

The CDI needle displays angular displacement from the centerline and, because the localizer beam width narrows as the runway is approached (a bit like a funnel), it will become more and more sensitive during the descent. Heading corrections should become finer and finer, ±5° at the start of the approach, ±2° toward the end.

A typical *heading bug* on a heading indicator has an angular width of about 12°, or 6° either side of center. If such a heading bug is used as a heading datum on the HI, then most heading changes necessary to maintain the localizer can be contained within its angular width.

You should initially steer a heading that stops the needle moving, even if it is not perfectly centered, and hold that heading for a few seconds as a reference heading using the HI. Glance at the CDI to observe its position and any movement, then make gentle turns using the flight instruments to return the airplane to the localizer centerline and keep it there. Employ normal attitude instrument flying techniques using the flight instruments, with just an occasional glance at the CDI. You should aim to have the correct heading determined by the time you reach the outer marker, with the CDI centered and steady. Any tendency for the CDI to move after you have passed the outer marker can be remedied with small changes of heading, about ±2°.

When tracking outbound from a localizer, the CDI is a noncommand instrument.

Tracking over the runway and outbound on the back course, the CDI remains a command instrument, so fly toward the needle to regain course centerline. If you reverse heading, however, the CDI becomes a non-command instrument (or has reverse sensing). When tracking outbound on a localizer front course, which is sometimes necessary when positioning the airplane for an ILS, the CDI will still indicate which sector the airplane is in (left or right of course), and will display the angular displacement from centerline as if the airplane were on approach. To regain centerline the airplane must be turned away from the CDI needle because it is acting as a non-command instrument when the airplane is flying outbound. When "flying" a non-command instrument, you must fly away from the CDI to pull it back into the center.

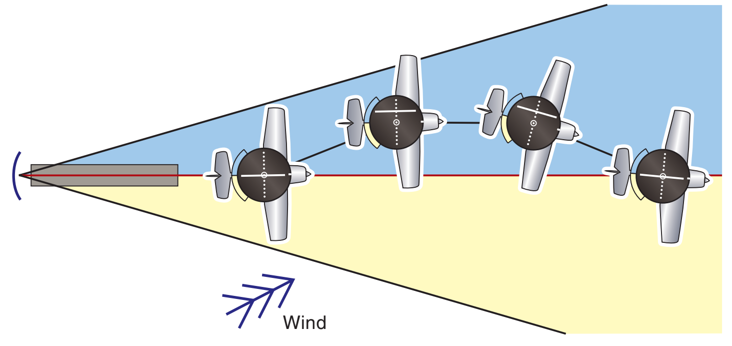


Figure 27-12 Tracking outbound on a localizer (reverse sense).

The situation is the same tracking inbound on a localizer back course, when the basic CDI becomes a non-command instrument. Some runways have a LOC BC nonprecision approach, based on tracking inbound on the back course of the ILS serving the opposite runway.

Some ILS indicators have a BC switch that enables the pilot to electronically reverse the signals to the CDI and, when flying inbound on a localizer back course or outbound on a front course, convert the CDI back to a command instrument. The switch needs to be reversed with each reversal of heading.

Additional tracking guidance is always useful (especially when tracking outbound on a localizer, or inbound on a back course), and in many ILS and LOC BC approaches this additional guidance can be obtained from a compass locator.

Flying the Localizer with an HSI

The horizontal situation indicator (HSI) combines a slaved compass card and CDI, providing the pilot with an excellent plan view of the airplane's position relative to the localizer course. Even though the HSI course arrow setting does not affect the deviation of the localizer needle, the picture presented will be much more meaningful and useful if you set the inbound localizer course.

The HSI is always a command instrument.

A significant advantage of the HSI over the basic ILS indicator is that, because the course arrow and CDI move with the slaved compass card as the airplane changes heading, the HSI remains a command instrument at all times (provided you have the localizer course set), even when you are tracking outbound on an ILS or inbound on a LOC BC. Another advantage is that one instrument (the HSI) replaces two (the HI and CDI), thereby reducing the scanning workload for the pilot.

The horizontal situation indicator simplifies the interception of a localizer because of the clear plan view it presents to you. For instance, figure 27-13 shows the airplane steering a magnetic heading of 175° about to intercept the localizer which has a magnetic course of 200, an approximate 25° intercept. If you maintain MH 175, the CDI will center and then pass to the left of the model airplane, indicating that you have flown through the localizer. To intercept the course without flying through the radial, lead out of the turn before the CDI actually centers. A good technique is to achieve a rate of turn that keeps the top of the CDI aligned with the heading index—the faster the CDI is moving, the faster the rate of turn will have to be. You should be able to roll out exactly on course.

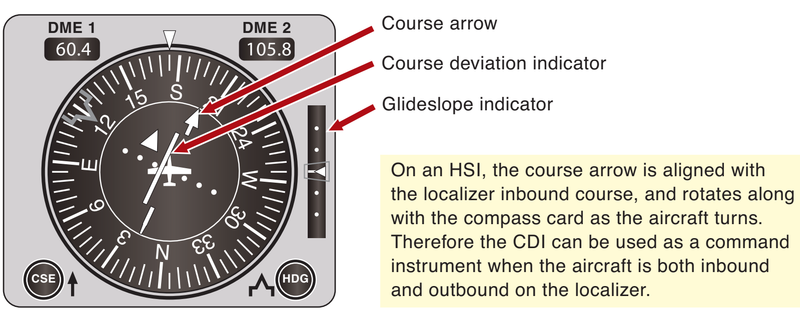


Figure 27-13 A horizontal situation indicator tuned to an ILS.

Note. If you accidentally set the reciprocal of the inbound localizer course, you will get reverse sensing. Always set the inbound localizer course on the HSI, then even when flying a localizer back-course approach, you will always have a command instrument. In other words, fly the back course approach with the front course selected on the HSI.

The Glide Slope

The most suitable approach path to a runway for most aircraft to follow is a slope of 3° to the horizontal (a gradient of 1 in 20, or 5%) which intersects the runway approximately 1,000 feet in from the approach threshold. The 3° slope provides a descent of approximately 300 feet for every 1 NM traveled horizontally, which gives a reasonable rate of descent for most airplanes at typical approach speeds—600 fpm at 120 knots groundspeed, for instance, and 450 fpm at 90 knots groundspeed—multiply GS × 5 to give rate of descent (ROD).

Some instrument approach charts show a *rate of descent versus groundspeed* table, specifying what rate of descent is required, at that groundspeed, to remain on the glide slope. (This is especially valuable information if the electronic glide slope fails and you are forced to fly a localizer-only approach).

The glide slope is the component of an ILS that provides vertical guidance during the approach, and it is usually adjusted to allow airplanes to precisely follow this "ideal" 3° descent path (a slightly different angle may be used for some ILS installations, e.g. 2.5°).

With a slope of 300 feet per nautical mile, you can expect a 3° glide slope to be:

- 3,000 feet HAT (height above touchdown) at approximately 10 NM to touchdown;
- 2,100 feet HAT at approximately 7 NM; and
- 1,500 feet HAT at approximately 5 NM.

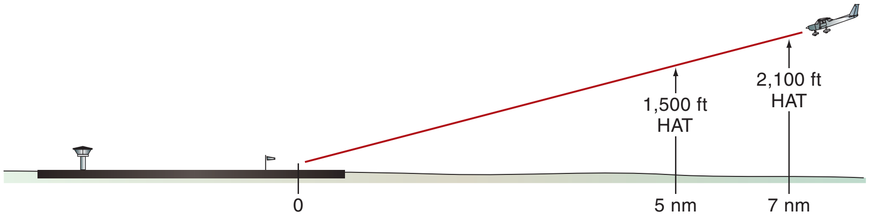


Figure 27-14 A 3° glide slope loses altitude by about 300 feet per nautical mile.

The approximate altitude along the glide slope can be checked by multiplying the distance from the touchdown in miles by 300. For example, at 2 NM from touchdown the airplane should be about 600 feet above the touchdown zone elevation (TDZE). If the TDZE is 2,350 feet MSL, 600 feet HAT is indicated on the altimeter by 2,950 feet MSL. Also remember that 50 feet threshold crossing height (TCH) should be added if you are using distances from the threshold.

The Glide Slope Ground Equipment

The glide slope transmitting antenna is usually situated 750–1,250 feet in from the runway threshold to ensure that any airplane flying the glide slope will have adequate wheel clearance over the threshold and any objects and/or terrain on approach. On some runways, the glide slope transmitting antenna may be positioned further in if there are high and restricting obstacles on the approach path. The *threshold crossing height* (TCH) of the glide slope is published on the ILS approach chart. The main wheels on some larger airplanes follow a much lower flight path than the glide slope receiving antenna, which could be located near the nose of the airplane or somewhere else significantly higher than the wheels.

The aim when flying a glide slope is not to touch down on the "numbers," but to touch down in the designated *touchdown zone* (TDZ), near where the glide slope intersects the runway (about 1,000 feet in from the threshold).

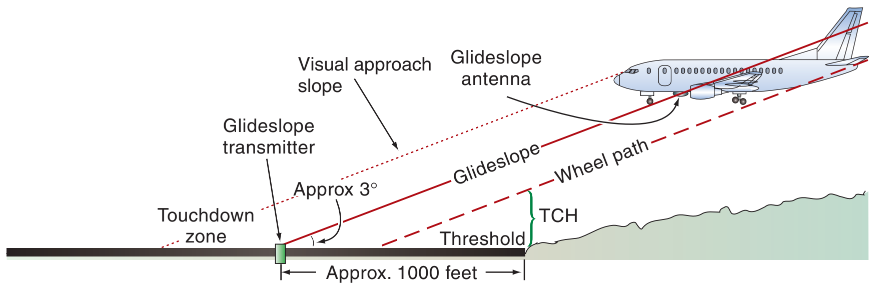


Figure 27-15
The glide slope transmitter is approximately 1,000 feet in from the runway threshold.

As well as being located, on average, some 1,000 feet in from the threshold, the glide slope transmitting antenna is usually offset by 400–600 feet to one side of the centerline, both to avoid being an obstacle to aircraft operating on the runway, and to prevent interference with the glide slope signal by nearby aircraft on the ground. The glide slope is transmitted on an ultra high frequency (UHF) carrier wave using a similar principle to the localizer transmission (that of two overlapping lobes), but the transmission pattern is slightly more complex.

A large 90 Hz lobe overlaps a 150 Hz lobe in the vertical plane. The actual glide slope, formed where the two signals are equal, is typically inclined at 3° to the horizontal, but some glide slopes may be shallower at 2.5°, and others may be steeper at 3.5°. It may not seem much of an increase in approach angle, but a 4° slope is extremely steep, very noticeable in the cockpit and possibly difficult to maintain in some jet transport airplanes.

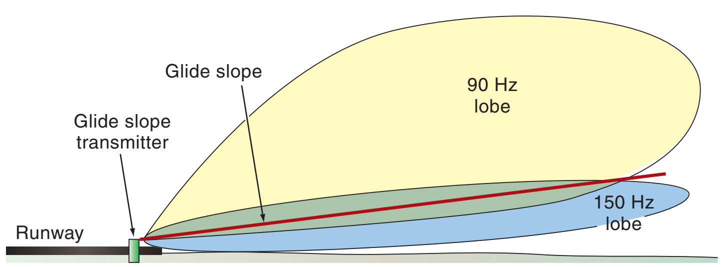


Figure 27-16 The glide slope.

The overlap area of the two signals is about 1.4° thick, which means the useful signals extend 0.7° above and below the precise glide slope. The glide path is calibrated out to 10 NM, although signals can be received at greater distances.

Unfortunately, because of ground reflection of some of the transmissions, there may be more than one overlapping of the lobes, giving rise to a *false glide slope*. The first false glide slope may be formed at approximately 12.5° to the horizontal—well above the true glide slope. One or more false glide slopes may exist, and do not be surprised when a false on-slope indication is given in the cockpit when the aircraft could not possibly be on slope, for instance at 12,000 feet *height above airport* (HAA) when only 10 NM from the airport, or when maneuvering around the airport to intercept the ILS.

There will also be *reverse sensing* with a false glide slope, and usually the glide slope needle will oscillate, making it fairly obvious that the signal is a false one. If the localizer transmits a back course, then there will probably be false glide slope signals in that area which can cause the glide slope OFF flag to flicker in and out of view. Be prepared to recognize a false glide slope signal for what it is when you see one, and to disregard it.

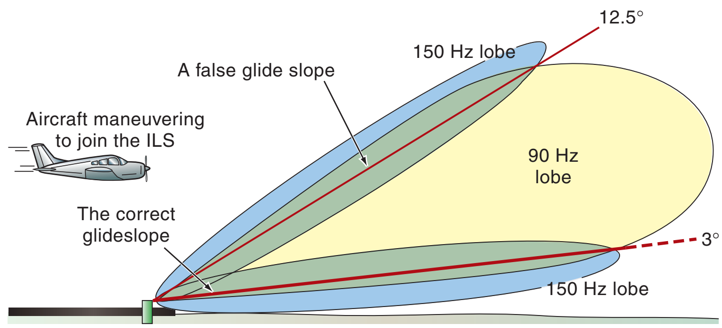


Figure 27-17 Beware of false glide slopes.

False glide slopes will not occur below the true glide slope, so intercept the glide slope from below, being careful to follow the altitudes on the approach plate.

The problem of false glide slopes is easily solved if the pilot has in mind the altitude/distance relationship of the true glide slope, which is 300 feet/NM. Also, and most importantly, there is no false glide slope below the true glide slope—any false glide slopes will be above it, and will be inclined at least 10° (probably 12.5°) to the horizontal. For this reason it is recommended that you should always intercept the glide slope from below.

It is preferable, for example, to fly in from 10 NM at 2,500 feet HAA to intercept the glide slope at about 8 NM to go, than to descend steeply from above the glide slope in an attempt to intercept it. Transitions from the en route phase of flight on a published ILS approach are normally designed so that interception of the glide slope from below will occur.

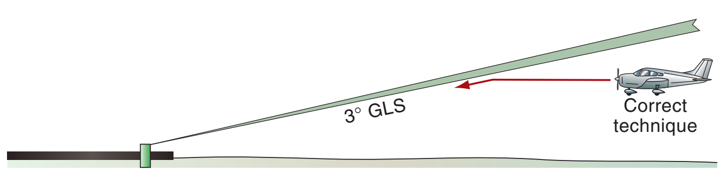


Figure 27-18 Ideally, intercept the glide slope from below, following the published approach altitudes.

The glide slope signals are usually accurate out to about 10 NM, but descent based on the glide slope indication should not be commenced until the airplane has first intercepted the localizer.

The ILS Rwy 27 at South Bend, Indiana, is designed so that an airplane over any of the initial approach fixes (IAFs) may maneuver quite comfortably to join the localizer inbound not below 2,400 feet MSL, and then intercept the glide slope from below. From LINGS IAF (initial approach fix) and GOSHEN IAF, the localizer intercept is a turn onto final course. From MISHA IAF, fly MC 092 outbound followed by a procedure turn to join MC 272 inbound.

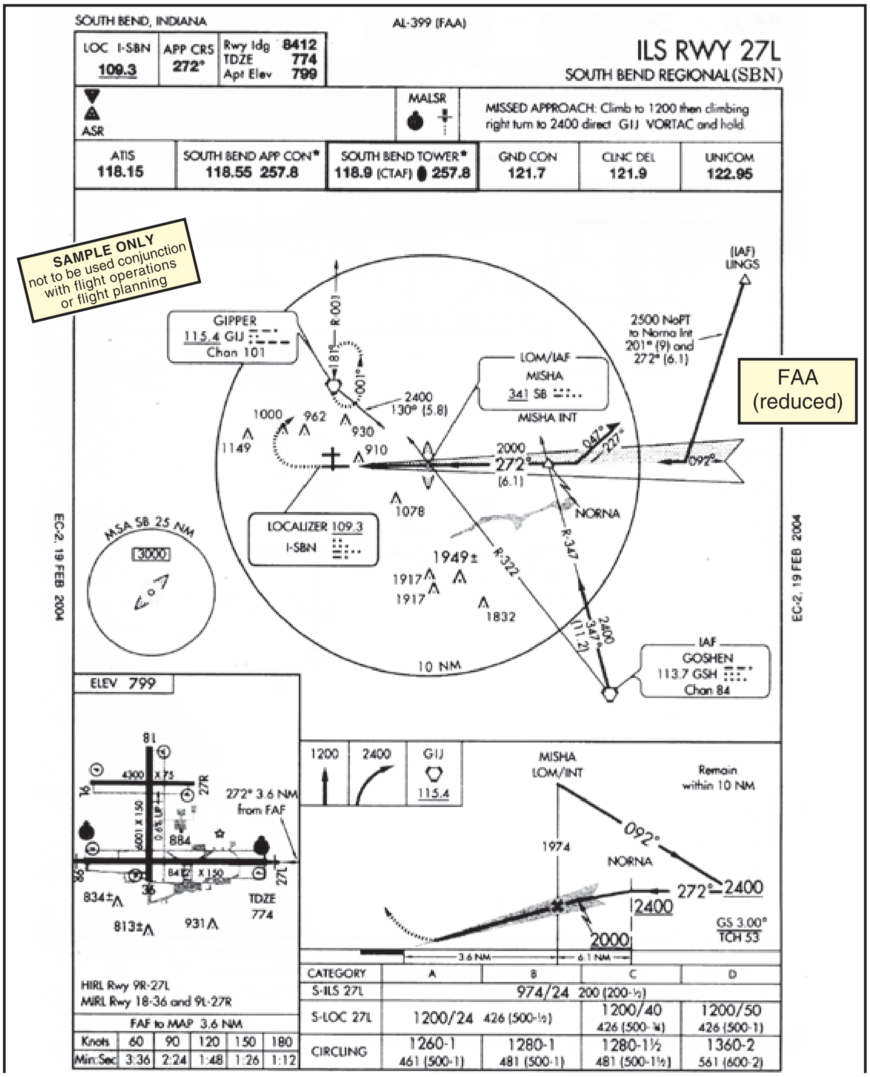


Figure 27-19 The South Bend, Indiana, ILS Rwy 27.

The Airborne Glide Slope Equipment

The position of the glide slope relative to the airplane is indicated by the horizontal needle of the NAV/COM cockpit display. This needle may be hinged, and move like a wiper, or it may move up and down in a straight line. To be certain that the glide slope signal is usable, the red OFF flag must be out of view. The vertical glide slope scale on the typical ILS indicator consists of 5 dots above and below the central position, although the first dots UP and DOWN may be joined in a circle.

A unique glide slope transmission frequency is paired with each localizer frequency, so that the pilot automatically selects the associated glide slope when he or she tunes the localizer on the NAV/COM, without even knowing the glide-slope frequency.

The glide slope receiver in the airplane compares the relative strength of the two signals, producing a voltage that positions the glide slope needle. If the 90 Hz signal is stronger because the airplane is above the glide slope, then the glide slope needle moves down. This indicates that the airplane must FLY DOWN to recapture the glide slope. It is the airplane which moves to the glide slope (and not vice versa).

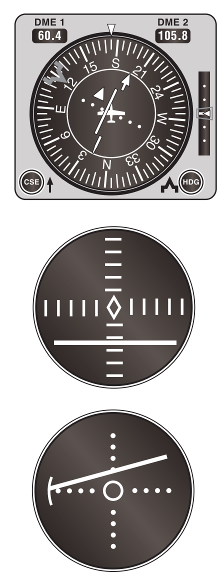


Figure 27-20 Different displays of glide slope.

Conversely, if the airplane is below the glide slope, the needle will move up—indicating FLY UP to rejoin the glide slope. This does not mean the airplane must actually climb to recapture the glide slope. Flying level, or even just reducing the rate of descent, as the airplane flies toward the runway may be sufficient.

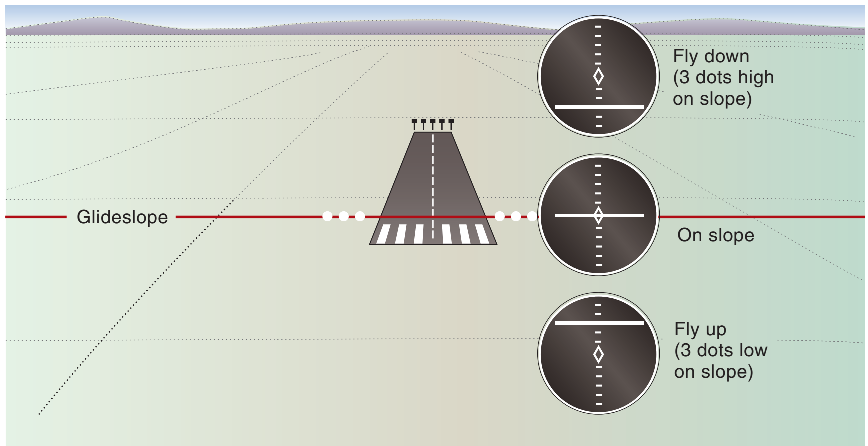


Figure 27-21 The glideslope needle indicates where the glideslope is with respect to the airplane.

A full-scale FLY UP indication means the airplane is 0.7° or more below the glide slope. Deviation from the glide slope is referred to in terms of dots rather than degrees, there being 5 dots up and 5 dots down on the instrument.

Do not allow the aircraft to go below the glide slope by more than half the full-scale FLY UP deflection. Go around.

Keep the airplane right on glide slope, to the best of your ability, and do not exceed more than one-half full-scale FLY UP deviation below slope to retain adequate obstacle clearance toward the end of the approach. Half-scale FLY UP puts the airplane 0.3 or 0.4° below slope, which is significant, since the glide slope is inclined at only about 3° to the horizontal, and full-scale deviation is 0.7° below this.

As a general rule, make a strong effort to stay right on glide slope throughout the approach. A full-scale FLY DOWN indication means the airplane is 0.7° or more above the slope.

Full-scale deflections once the ILS approach has been commenced are not acceptable, since the deviation from slope is at least 0.7°, and it could be even more! There is no indication of just how far the airplane is above or below slope when the glide slope needle is fully deflected.

The typical 0.7° full-scale deviation (above or below the ideal 3° glide slope) is equivalent to about 70 feet per nautical mile from touchdown, which is a vertical deviation in feet from the glide slope of:

- 700 feet at 10 NM;
- 350 feet at 5 NM;
- 210 feet at 3 NM;
- 140 feet at 2 NM;
- 70 feet at 1 NM; and
- a few feet at the runway threshold.

From peg-to-peg on the glide slope is 1.4°; peg-to-peg on the localizer is typically 5°; peg-to-peg on the VOR is 20°. Thus the glide slope needle is 3 times as sensitive as the localizer needle, and 12 times as sensitive as a VOR needle.

The glide slope signal is only approved for navigation down to the lowest authorized *decision height* (DH) or *decision altitude* (DA) for that particular ILS, and any reference to glide slope indications below that altitude must be supplemented by visual reference to the runway environment. A Category I ILS is approved for use down to DH 200 feet HAT, a Category II ILS is approved for use down to DH 100 feet HAT, and a Category III ILS is approved for use down to DH 0 feet HAT (requiring sophisticated equipment and highly trained pilots).

If the glide slope fails, but not the localizer, then you may still be permitted to carry out a nonprecision *localizer approach*, without electronic slope guidance, using the localizer for guidance in azimuth, and using range markers (such as the marker beacons, DME distances or a compass locator) for descent to suitable altitudes which will be marked on the profile part of the instrument approach chart.

Referring back to the South Bend ILS Rwy 27 profile, you may cross the SB LOM not below 2,000 feet MSL and, for a straight-in approach to runway 27 in instrument conditions, descend further:

- for a *precision* ILS approach, using the electronic glide slope, down to a *decision altitude/decision height* (DA/DH) of 974 feet MSL; or
- for a *nonprecision* localizer approach, without electronic slope guidance, down to a minimum descent altitude (MDA) of 1,200 feet MSL.

If only the full ILS procedure is approved for a particular runway, and a localizer only approach without the use of a glide slope is not authorized, then the chart will carry the warning LOC ONLY N/A.

Flying the Glide Slope

Flying the glide slope is similar to flying straight-and-level, except that the aim is to keep the airplane on a constant descent plane, rather than on a level plane at constant altitude. In level flight, the altimeter is checked regularly to ensure altitude is being maintained; during an ILS, the glide slope needle is checked regularly to ensure that the desired slope is being maintained.

The typical 3° glide slope requires a loss of altitude of 300 feet per nautical mile which:

- at a groundspeed of 60 kt (1 NM/minute) requires a rate of descent of 300 fpm;
- at a groundspeed of 90 kt (1 NM/minute) requires a rate of descent of 450 fpm;
- at a groundspeed of 120 kt (2 NM/minute) requires a rate of descent of 600 fpm.

Notice that a quick method of estimating the required rate of descent for an ILS is simply 5 × groundspeed. By estimating your groundspeed, and then flying an appropriate rate of descent on the VSI, you will go close to holding the glide slope without even looking at the ILS indicator.

For instance, an approach speed of 90 KIAS into a 20-knot headwind will result in a groundspeed of 70 knots, so the correct rate of descent to hold glide slope will be (5 × 70) = 350 fpm. If the headwind decreases, your groundspeed will be greater for the same airspeed, and so you would require a higher rate of descent to hold slope. Periodically refer to the glide slope needle, and adjust the rate of descent as required to hold the glide slope.

The ILS indicator is a *performance* instrument. It should be included in the selective radial scan when information from it is desired. Having gained that information (which, in this case, is the position and/or movement of the glide slope needle), your eyes should return to the attitude indicator. Any corrections to regain or maintain the glide slope can then be made with a small pitch attitude change on the AI. The ILS indicator can then be checked again for position and/or movement of the glide slope needle.

Hold the glide slope with small pitch attitude changes. A process similar to bracketing track is used to regain and then maintain the glide slope, although in this case it is pitch attitude that is altered slightly, rather than heading.

Hold the glide slope with small pitch attitude changes.

If, for instance, the airplane goes below glide slope while a particular pitch attitude is held, then it should be raised slightly and held until the glide slope is regained. Once back on slope, the pitch attitude can be lowered slightly (but not quite as low as before), so that the glide slope is maintained.

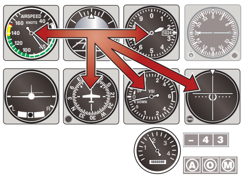


Figure 27-22 Scan pattern.

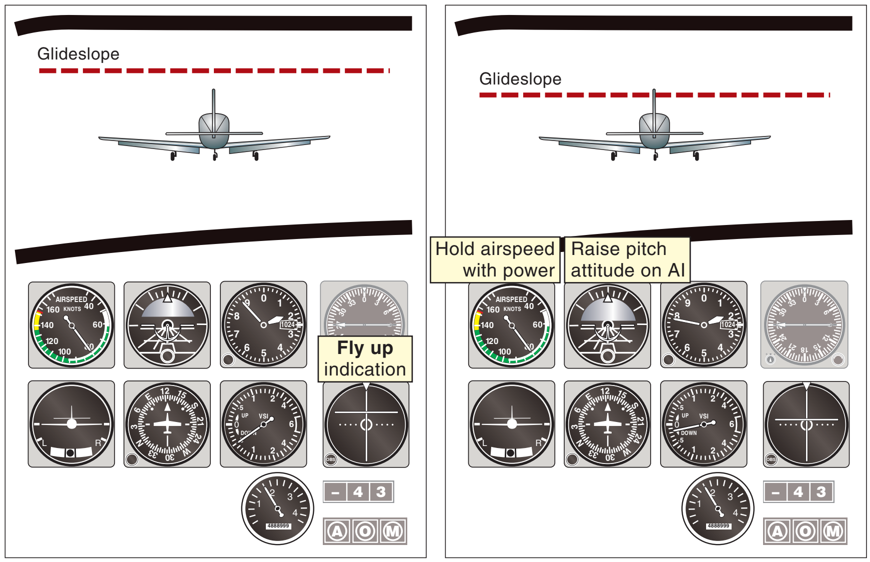


Figure 27-23 Hold glide slope with elevator (attitude indicator), and airspeed with throttle.

Hold airspeed with power.

Hold airspeed with power. There is also a target airspeed to be achieved on an ILS approach and, as in level flight, airspeed can be controlled with power. With pitch attitude changes to regain and maintain glide slope, small airspeed changes will occur. Fluctuations of ±5 knots are normally acceptable, but any trend beyond this should be corrected by a power alteration. Typically 1 inch MP or 100 rpm is sufficient, although greater power changes may be required in strong and gusty wind conditions or in windshear.

Maintaining glide slope and airspeed is one sign of a good instrument pilot. Flight path and airspeed (in other words the performance of the airplane) are controlled by attitude and power on an ILS approach. If you have a good scan and quick response, then small deviations from the glide slope will be corrected with a small pitch change immediately, and will not develop into large deviations which might require a power adjustment as well.

Flying the glide slope involves energy management. If the airplane is slightly below glide slope and slightly fast, then the excess speed can be converted to altitude (or to a reduced rate of descent) by raising the pitch attitude on the AI, and flying up to regain slope. Conversely, if the airplane is above glide slope and slightly slow, the pitch attitude on the AI can be lowered slightly, and the airplane flown down to regain glide slope, possibly with a small speed increase.

- Hold glide slope with pitch attitude on the AI.
- Hold airspeed with power.

Since it displays angular displacement, the glide slope needle will become more accurate and more sensitive as the airplane flies closer to the runway. Therefore, corrections on the attitude indicator to hold glide slope should become finer and finer as the runway is approached.

Marker Beacons

ILS marker beacons transmit a highly focused vertical signal pattern, often described as elliptical or fan-shaped, which can only be received by an airplane as it passes directly overhead. Because the radio energy is transmitted upward, it is not possible to track to a marker beacon (unlike an NDB or compass locator whose energy is transmitted in all directions). A typical ILS has two markers positioned along the localizer to provide range (or distance) check points. They are:

- *the outer marker* (OM) at between 4 and 7 NM from the runway threshold; and
- *the middle marker* (MM) at 3,500 feet (0.6 NM) from the runway threshold.

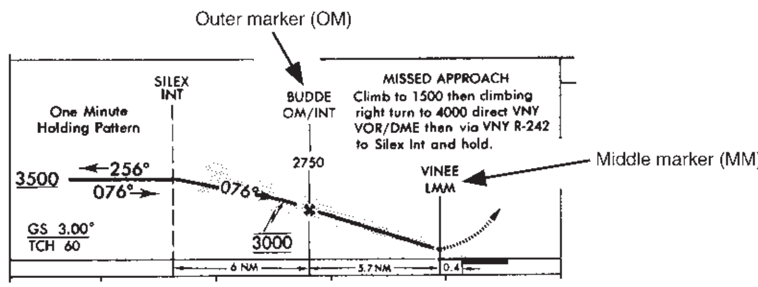


Figure 27-24 The outer marker and the middle marker.

Both markers operate on the same VHF frequency of 75 MHz, but each provides a different aural Morse code identification. There is no interference between the signals because their transmission volume is upward and very localized.

The airborne equipment consists of a marker receiver which indicates passage of the airplane over a marker by a light flashing in the cockpit and an aural Morse code ident. You can hear the ident through the headset or speaker, and see the light flashing (one of three color-coded lights on the instrument panel). You do not have to make any specific selection in the cockpit to receive the marker beacons, other than have the marker beacon switch ON.

The *outer marker* (OM) is located between 4 and 7 NM from the runway threshold. The airplane, if it is on glide slope, should therefore be at approximately 1,400 feet HAT as it passes overhead the OM. The precise MSL altitude crossing the OM is specified on the profile diagram of the particular ILS, and you should check this on the altimeter as the airplane passes over the OM.

The cockpit indications of passage over the outer marker are:

- a continuous aural series of low-pitched (400 Hz) dashes transmitted at two per second (-*dah-dah-dah-dah-dah-dah-dah*-); and
- a flashing blue (or aviation purple) light synchronized with the aural *"dah-dahs."*

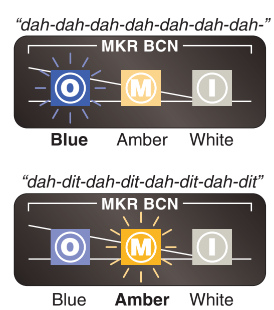


Figure 27-25
Cockpit indications of the outer marker (top), and middle marker (below).

The middle marker (MM) is located approximately 3,500 feet (0.6 NM) from the landing threshold, where the glide slope is approximately 200 feet HAT (height above touchdown). This is near the decision height (DH) and missed approach point (MAP) for the ILS approach. The middle marker crossing altitude may or may not be specified on the charts, since at this stage in the approach the pilot may be visual, depending on the particular approach minimums.

The cockpit indications of passage over the middle marker are:

- an aural series of alternating medium-pitched (1,300 Hz) dots and dashes transmitted at six per second (-*dah-dit-dah-dit-dah-dit-dah-dit*-); and
- a flashing amber light synchronized with the aural *dah-dits.*

Some ILSs have an *inner marker* (IM) between the middle marker and the landing threshold that has an aural *"-dit-dit-dit-dit-"* signal at 3,000 Hz (high- pitched) and 95 dot/dash combinations per minute, and a synchronized flashing white light.

Some localizer back courses have a *back course marker* (BCM) that has an aural *"dit-dit dit-dit dit-dit"* signal, and a synchronized flashing white light. The BC marker is used to indicate the LOC BC final approach fix (FAF).

The marker beacon signals increase in strength fairly quickly as the airplane nears the marker beacon, remain very strong for a number of seconds, and then quickly fade away as the airplane moves further along the approach. Many airborne receivers have a HIGH/LOW sensitivity switch, LOW sensitivity giving a much narrower vertical pattern. For instrument approaches, the sensitivity switch is normally set to HIGH, because the airplane will be at a low level during the instrument approach, and the marker beacon signal will only be heard and seen for a few seconds.

Other Means of Checking Glide Slope

Not all ILS installations have an outer marker and/or middle marker. For example, the Hayden, Colorado, ILS/DME Rwy 10 has neither. The glide slope, however, can be checked at the final approach fix (FAF) at 7.8 DME from the *I-HDN* DME (automatically selected along with the ILS on the NAV/COM). If you are exactly on glide slope at 7.8 DME, the altimeter should read close to 8,608 feet MSL.

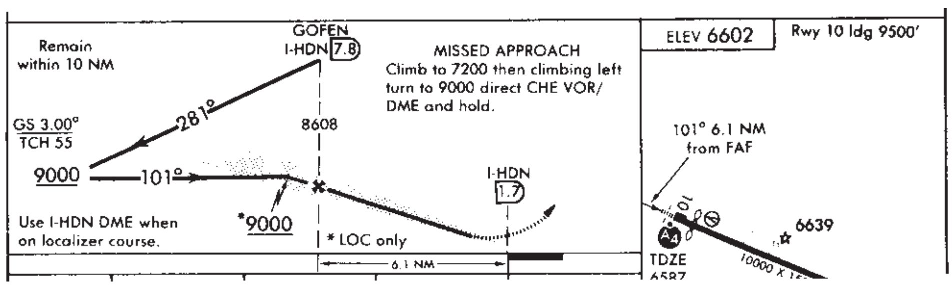


Figure 27-26 A typical ILS/DME Rwy 10 profile diagram.

The DME can be helpful in providing approximate slope guidance, or protection from underlying obstructions, if the electronic glide slope is not working or is not part of the approach. For example, the localizer back course approach at Tucson International, Arizona, LOC/DME BC Rwy 29R, has a number of DME/altitude restrictions.

Descent from 8,000 feet MSL may be commenced at 20 DME using the *I-TUS* localizer back course and DME, followed by an approach slope:

- not below 7,200 feet until 13.5 DME;
- not below 6,100 feet until 9.5 DME;
- not below 4,800 feet until 5 DME, the final approach fix (FAF);
- not below 3,600 feet until 2 DME; and
- not below MDA 3,120 feet until visual, otherwise a missed approach at 0.3 DME.

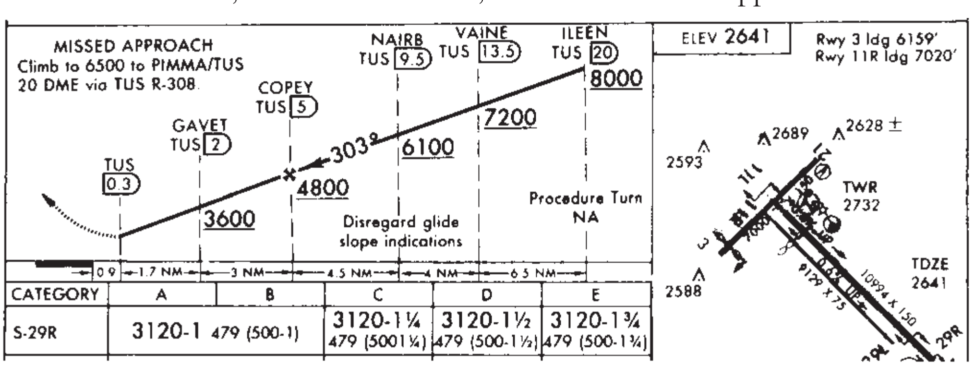


Figure 27-27 Tucson International, AZ, LOC/DME BC Rwy 29R profile diagram.

Approach Lights and Other Lights

The aeronautical lighting facilities provided at an airport that can assist a pilot to maneuver the airplane in conditions of poor visibility or at night consist of:

- approach lighting;
- a visual approach slope indicator (VASI);
- touchdown zone lighting; and
- runway edge lighting.

Approach Light Systems (ALS)

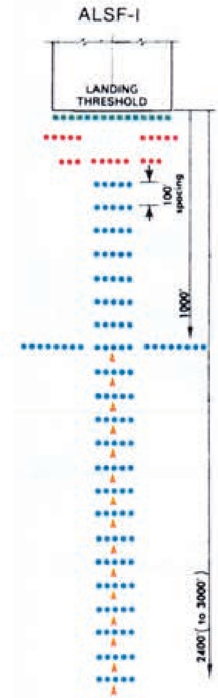
At many airports, the *approach light system* (ALS) extends out from the approach end of the runway to well beyond the physical boundaries of the runway, possibly into forested or built-up areas. Approach lights do not mark the boundaries of a suitable landing area—they simply act as a lead-in to a runway for a pilot on approach to land. ALS lighting is a standardized arrangement of white and red lights, consisting basically of *extended centerline lighting*, with *crossbars* sited at specific intervals back along the approach path from the threshold, out to a distance of:

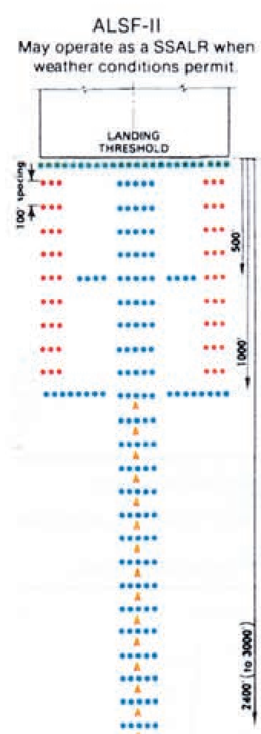
- 2,400–3,400 feet for precision instrument approach runways; or
- 1,400–1,500 feet for nonprecision instrument approach runways.

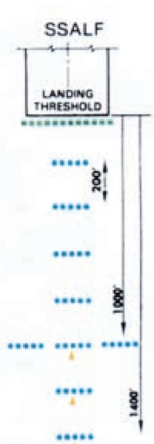
Approach light systems assist you to transition from instrument flight to visual flight for a landing. In minimum visibility conditions at the decision height, say visibility H statute mile (2,400 feet), the approach lights might be the only part of the runway environment that you can see, the runway and the VASI still being more than H mile away, yet you may continue with the approach.

The approach lighting provides you with a visual indication of how well the airplane is aligned with the extended runway centerline (lateral guidance), as well as helping you to estimate the distance the airplane has to fly to touchdown during the latter stages of the instrument approach. This is especially useful in conditions of low visibility. In situations where no visible horizon exists, the approach lights can also assist you to visually judge the bank attitude of the airplane.

There are various types of approach light systems in use, the sophistication of the system depending on the importance of the airport and the frequency and type of operations. Some typical precision instrument runway ALSs are shown in figure 27-28.







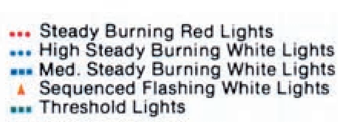


Figure 27-28 Approach lighting systems for precision instrument runways.

Particulars of airport lighting are shown in the instrument approach procedures (IAP) publications.

Some approach lighting systems include *sequenced flashing lights* (SFL), or *runway alignment indicator lights* (RAIL), which appear to the pilot as a ball of white light traveling toward the runway at high speed (twice per second) along the extended centerline.

The runway threshold is marked with a row of green lights, and some runway thresholds have flashing strobes either side to act as *runway end identifier lights* (REIL).

- MALSR is a medium intensity approach light system (MALS) with runway alignment indicator lights.
- Touchdown zone lighting consists of two rows of transverse light bars located symmetrically about the runway centerline, normally at one-hundred-foot intervals. The basic system extends 3,000 feet along the runway.
- Runway alignment indicator lights (RAIL) consist of sequenced flashing lights which are installed only in combination with other light systems.
- Runway end identifier lights (REIL) provide rapid and positive identification of the approach end of a particular runway.

The view from the cockpit approaching a typical precision instrument runway in poor conditions is shown on the front cover of this book.

Visual Approach Slope Indicator (VASI)

In conditions of poor visibility and at night, when the runway environment and the natural horizon may not be clearly visible, it is often difficult for a pilot to judge the correct approach slope of the airplane toward the touchdown zone of the runway. A number of effective visual slope indicators have been invented to assist a pilot to stay on the slope in this situation; lateral guidance is provided by the runway, the runway lights or the approach light system.

Two-Bar VASI

Remember: Red over white: you're all right.

White over white: you're high as a kite.

Red over red: you're probably dead.

The typical two-bar VASI has two pairs of wingbars extending outboard of the runway, usually at 500 feet and 1,000 feet from the approach threshold. It is sometimes known as the *red/white system*, since the colors seen by the pilot indicate right on slope, or too high or too low. The pilot will see:

- all bars white if high on approach;
- the near bars white and the far bars red if right on slope; and
- all bars red if low on slope.

During the approach, the airplane should be maintained on a slope within the white sector of the near bars and the red sector of the far bars. If the airplane flies above or below the correct slope, the lights will change color, there being a pink transition stage between red and white.

The plane of the VASI approach slope only provides guaranteed obstacle clearance in an arc 10° left or right of the extended centerline out to a distance of 4 NM from the runway threshold, even though the VASI may be visible in good conditions out to 5 NM by day and 20 NM by night. Before using VASI information, therefore, the airplane should be within this arc, and preferably aligned with the extended runway centerline. In general, an approach descent using VASI should not be initiated until the airplane is visually aligned with the extended runway centerline. On instrument approaches, once the VASI comes into view you may use it to adjust your approach path.

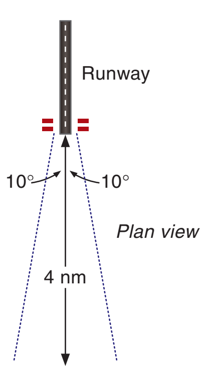


Figure 27-29
The extent of useful VASI information.

There are other operational considerations when using the red/white VASI. At maximum range, the white bars may become visible before the red bars, because of the nature of red and white light. In haze or smog, or in certain other conditions, the white lights may have a yellowish tinge about them.

When extremely low on slope, the two wingbars (all lights red) may appear to merge into one red bar. At close range to the threshold this would be a critical situation with respect to obstacle clearance, and require urgent pilot action.

Some VASI systems use a reduced number of lights, in which case they may be known as an Abbreviated VASI or AVASI.

Do not begin a VASI descent until the airplane is visually aligned with the extended centerline.

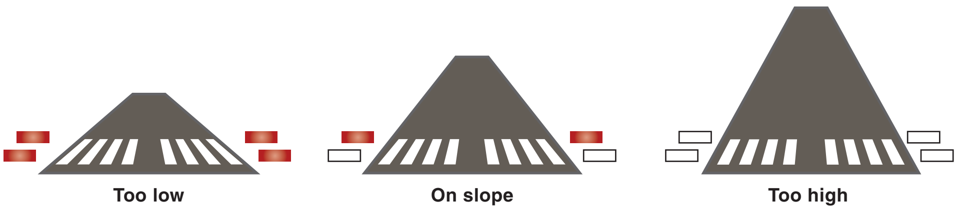


Figure 27-30 Perspectives on approach using a two-bar VASI.

Three-Bar VASI

The three-bar VASI has an additional bar at the far end, intended to assist the pilots of long-bodied airplanes such as the *Boeing 747* or the *Airbus A300.* The approach slope guidance given by any VASI depends on the position of the pilot's eyes. Since the wheels of an airplane with a very long fuselage will be well below the pilot's eyes, it is essential that the eyes follow a parallel but higher slope to ensure adequate mainwheel clearance over the runway threshold. The additional wingbar farther down the runway makes this possible.

Pilots of such airplanes should use the second and third wingbars and ignore the first. When the pilot's eyes are positioned on the correct slope for a long-bodied airplane, he or she will see the top bar red, the middle bar white (and ignore the lower bar which is also white).

Pilots of smaller airplanes should refer to only the two nearer wingbars and ignore the more distant wingbar, which is for large airplanes. On slope, the indications should be (top bar red and ignored), middle bar red and lower bar white.

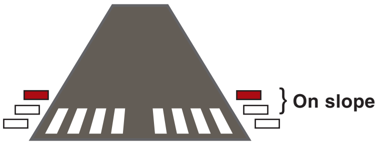


Figure 27-31 Correct view for the pilot of a long-bodied airplane using the three-bar VASI.

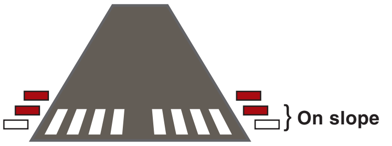


Figure 27-32 Correct view for the pilot of a smaller airplane using the three-bar VASI.

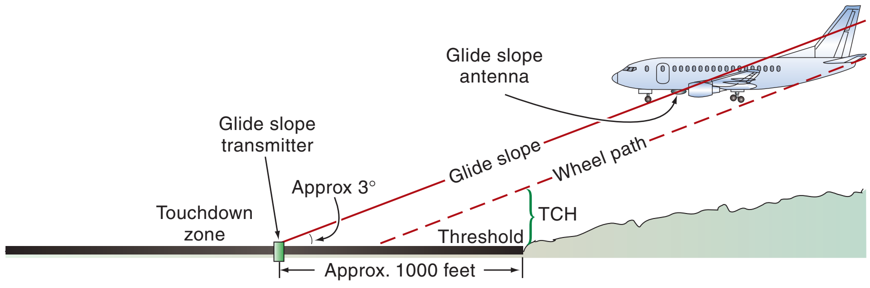


Figure 27-33 A three-bar VASI ensures adequate wheel clearance over the threshold for long-bodied aircraft.

Precision Approach Path Indicator (PAPI)

PAPI is a development of the VASI and also uses red/white signals for guidance in maintaining the correct approach angle, but the lights are arranged differently and their indications must be interpreted differently. PAPI has a single wingbar which consists of four light units on one or both sides of the runway adjacent to the touchdown point. There is no pink transition stage as the lights change from red to white.

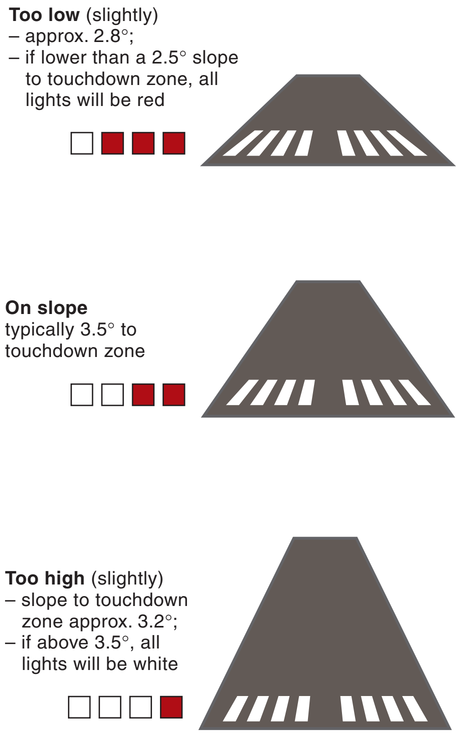


Figure 27-34 Slope guidance using PAPI.

- "T" on both sides of runway.
- All lights variable white.
- Correct approach slope—only cross bar visible.
- Upright "T"—fly up.
- Inverted "T"—fly down.
- Red "T"—gross undershoot.

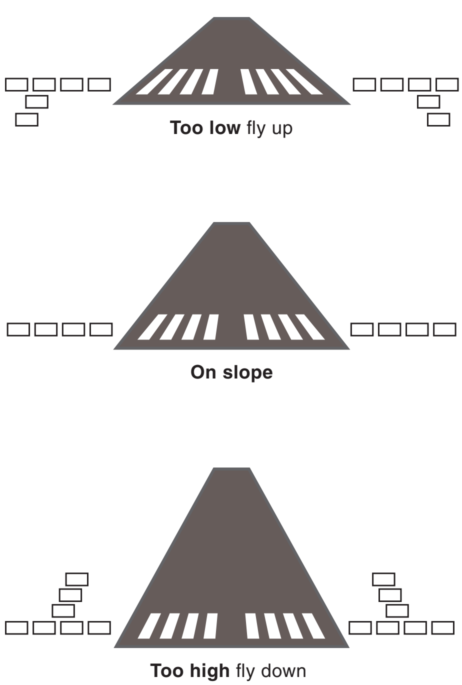


Figure 27-37 The T-VASI.

If the airplane is on slope, the two outer lights of each unit are white and the two inner lights are red. Above slope, the number of white lights increase, and below slope the number of red lights increase.

Pulsating Visual Approach Slope Indicator (PVASI)

PVASI consists of a single light unit positioned on the left side of a runway adjacent to the touchdown point, which projects three or four different "bands" of light at different vertical angles, only one of which can be seen by a pilot on approach at any one slope position. The indications provided by a typical PVASI are:

- well above glide slope: fast-pulsing white;
- above glide slope: pulsing white;
- on glide slope: steady white (or alternating red/white for some systems);
- below glide slope: pulsing red;
- well below glide slope: fast-pulsing red.

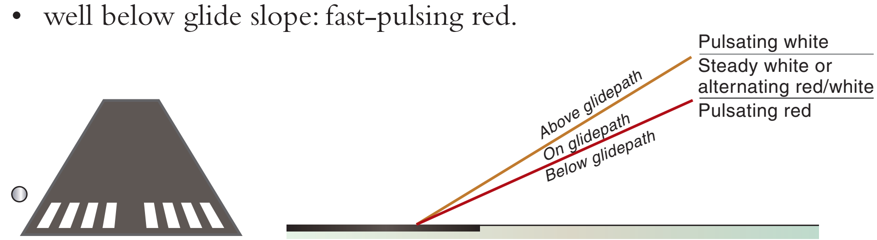


Figure 27-35 The PVASI.

Tri-Color VASI

The tri-color VASI is a short-range visual slope aid (½ mile by day, 5 miles by night), and consists of a single-light unit that indicates:

- amber if above slope;
- green if on slope; and
- red if below slope.

Caution: when the aircraft descends from green to red, the pilot may (or may not) see a dark amber color during the transition from green to red.

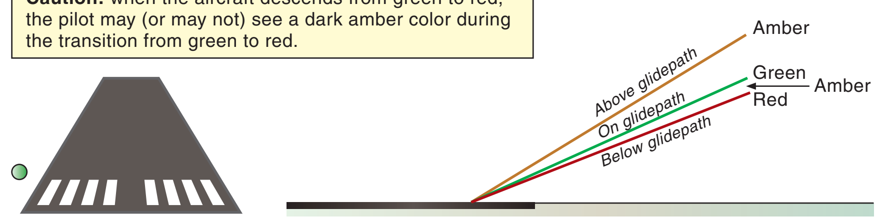


Figure 27-36 The tri-color VASI.

T-VASI

The T-VASI is a system that has a horizontal bar of white lights either side of the runway aiming point. If the airplane is right on slope, you will only see these lights. If you are high on slope, single lights will appear above this bar, forming an inverted-T, and indicating FLY DOWN. If you are low on slope, single lights will appear below the bar, forming a T, and indicating FLY UP. The number of vertical lights give an indication of how far off slope you are. If you are extremely low, the lights turn red.

Runway Lighting

Runway lighting defines the boundaries of the actual landing area, and some systems provide you with distance-down-the-runway information as well.

Runway Edge Lights

Runway edge lights outline the edges of runways during periods of darkness or restricted visibility. They are classified according to the intensity or brightness they are capable of producing:

- HIRL: High Intensity Runway Lights;
- MIRL: Medium Intensity Runway Lights;
- LIRL: Low Intensity Runway Lights.

Runway edge lights are white, except on instrument runways where yellow replaces white for the last 2,000 feet (or last-half on runways shorter than 4,000 feet), to form a caution zone for landings in restricted visibility. When the pilot sees the white edge lights replaced by amber, he or she has some idea of how much runway is left for stopping.

In-Runway Lighting

Some precision approach runways have additional in-runway lighting embedded in the runway surface consisting of:

- *touchdown zone lights* (TDZL): bright white lights either side of the runway centerline in the touchdown zone (from 100 feet in from the landing threshold to 3,000 feet or the half-way point, which ever is the lesser);
- *runway centerline lighting system* (RCLS): flush centerline lighting at 50 feet intervals, starting 75 feet in from the landing threshold to within 75 feet of the stopping end; RCLS also includes runway remaining lighting, where the centerline lighting seen by a stopping airplane is:
  - initially all white;
  - alternating red and white from 3,000 feet-to-go point to 1,000 feet-to-go;
  - all red for the last 1,000 feet;
- *taxiway lead-off lights*: alternate green and yellow from runway centerline to runway holding position; expedites movement of aircraft from runway; and
- *land and hold short lights*: used to indicate the hold short point on certain runways which are approved for *land and hold short operations* (LAHSO), and they consist of a row of pulsing white lights installed across the runway at the hold short point.

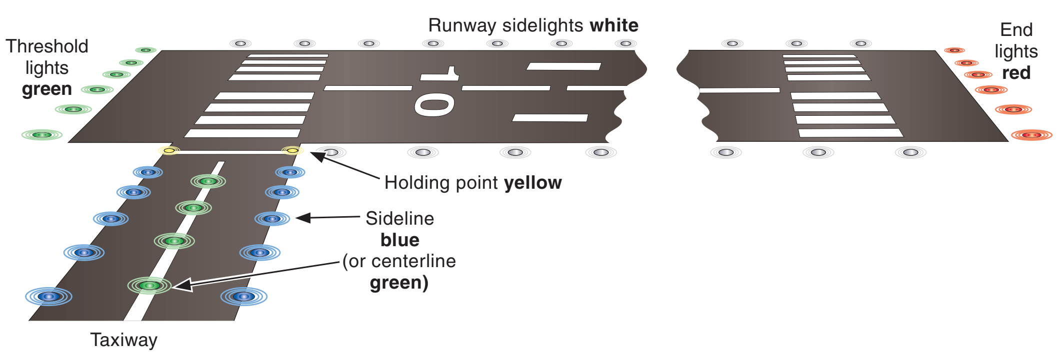


Figure 27-38 Runway lighting.

Runway End Lights

The runway end lights show green to aircraft on approach and red to airplanes stopping at the far end.

Runway End Identifier Lights

Runway end identifier lights (REIL) consist of a pair of synchronized white flashing lights located each side of the runway threshold at the approach end. They serve to:
- identify a runway end surrounded by many other lights;
- identify a runway end which lacks contrast with the surrounding terrain; and
- identify a runway end in poor visibility.

Taxiway Lights

While not directly associated with a precision approach, it does help if you can exit the runway onto a taxiway with confidence. Taxiways are lighted in one of two ways for the guidance of pilots with either:
- one line of *centerline green* taxiway lights; or
- two lines of taxiway *blue edge* lights.

At some airports, there is a mixture of the two types, centerline green on some taxiways, and blue edge on others. At certain points on the taxiway, there may be *red stop-bars* installed, to indicate the position where an airplane should hold position, for instance before entering an active runway.

Control of Lighting Systems

The approach lights and runway lights at an airport are controlled by:
- the control tower personnel (when the tower is active);
- the FSS, at some locations where no control tower is active (but this FSS function is gradually being eliminated); or
- the pilot (at selected airports).

The pilot may request ATC or FSS to turn the lights on (or off), or to vary their intensity if required. On a hazy day with restricted visibility, but with a lot of glare, maximum brightness might be necessary; on a clear dark night, a significantly lower brightness level will be required. At many non-towered airports, and when ATC and/or FSS facilities are not manned, airborne control of the lights is possible using the radio. The A/FD specifies the type of lighting available, and the radio frequency used to activate the system.

To use an FAA-approved pilot-controlled lighting system, simply select the appropriate VHF frequency on the NAV-COM, and depress the microphone switch a number of times. A good technique involves keying the mike 7 times within 5 seconds, which will activate the lights at maximum intensity, and then subsequently keying it a further 5 or 3 times for medium or low intensity respectively, if desired.

Don't get caught in the dark! All pilot-controlled lighting operates for 15 minutes from the most recent transmission.

All pilot-controlled lighting operates for 15 minutes from the time of the most recent transmission. If pilot-controlled lights are already on as you commence an approach, it is good airmanship to reactivate them and thereby ensure availability for the duration of the approach and landing.

Precision Instrument Runway Markings

To assist pilots transitioning to a visual landing at the conclusion of a precision instrument approach, precision instrument runways have specific markings.

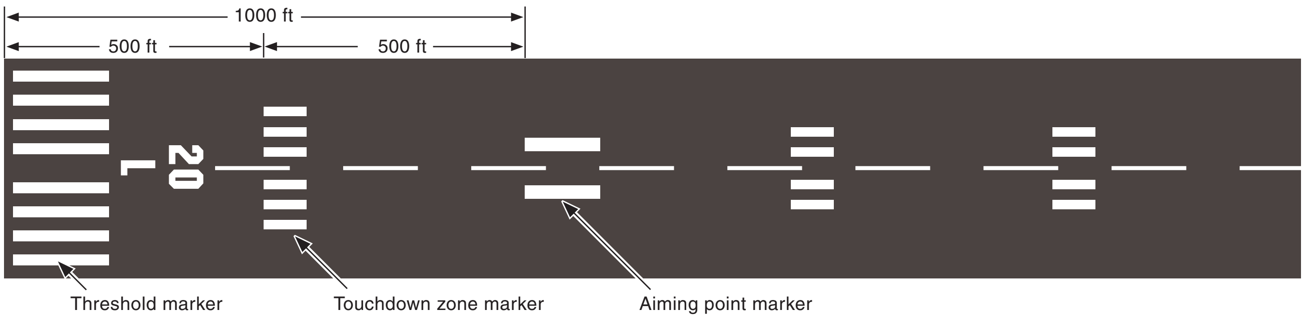


Figure 27-39 Markings on a precision instrument runway.

A displaced threshold on an instrument runway is indicated by arrows in the middle of the runway leading to the displaced threshold mark. The runway edge lights to the displaced threshold appear red to an airplane on approach, and to an airplane taxiing to the displaced threshold from the absolute end of the runway. They appear white when taxiing back from the displaced threshold toward the absolute end of the runway. The green runway end lights seen on approach to a runway with a displaced threshold are found off the edge of the runway.

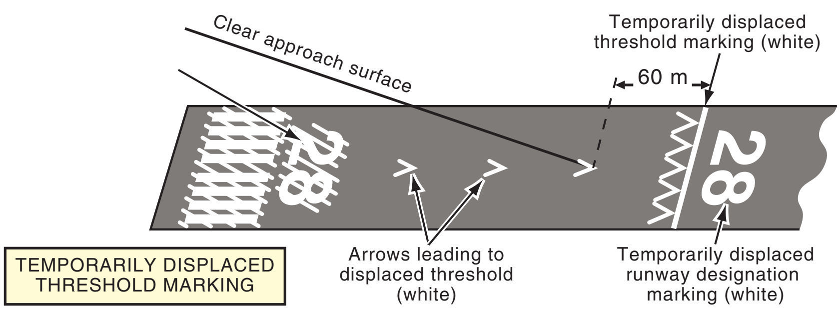


Figure 27-40 Chevron and arrow displaced threshold markings.

The runway surface with arrows to the displaced threshold is available for taxiing, takeoff and landing roll-out, but not for landing. The initial part of this runway is a non-touchdown area. If chevrons rather than arrows are used to mark the displaced threshold, then the surface is not available for any use, other than aborted takeoff from the other direction.

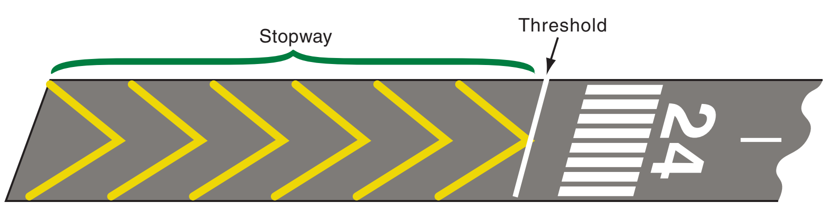


Figure 27-41 Chevron and arrow displaced threshold markings.

Inoperative ILS Components

If some component of an ILS, or a visual aid, is inoperative (say, approach lighting), then higher minimums may be required. This is specified in the *Inoperative Components* or *Visual Aids Table* in each NACO Terminal Procedures book, and on each *Jeppesen* chart. If more than one ILS component is inoperative, use the highest minimum required by any single unusable component.

ILS glide slope inoperative (or "GS out") minimums are published on NACO and *Jeppesen* instrument approach charts as localizer (LOC) minimums.

(1) ILS, MLS, and PAR

Inoperative Component or Aid	Approach Category	Increase Visibility
ALSF 1 & 2, MALSR, & SSALR	ABCD	¼ mile

(2) ILS with visibility minimum of 1800 RVR

ALSF 1 & 2, MALSR, & SSALR	ABCD	To 4000 RVR
TDZI RCLS	ABCD	To 2400 RVR
RVR	ABCD	½ mile

(3) VOR, VOR/DME, VORTAC, VOR (TAC), VOR/DME (TAC, LOC, LOC/DME, LDA, LDA/DME, SDF, SDF/DME, RNAV, and ASR

Inoperative Component or Aid	Approach Category	Increase Visibility
ALSF 1 & 2, MALSR, & SSALR	ABCD	½ mile
SSALS, MALS, & ODALS	ABC	¼ mile

(4) NDB

ALSF 1 & 2, MALSR, & SSALR	C ABD	½ mile ¼ mile
MALS, SSALS, ODALS	ABC	¼ mile

Figure 27-42
NACO Inoperative Components and Visual Aids tables.
Note: the tables may be amended by notes on the particular approach plate.

Flying a Typical ILS

The relevant instrument approach procedure (IAP) chart should be checked for currency, and thoroughly studied before commencing the approach. Briefing an approach is the process of identifying the key elements of the procedure, such as missed approach, minimums, and inbound course. A standard practice for professional pilots, the approach briefing can enhance the safety of any instrument landing procedure. Even though the chart can be referred to during the actual approach, it is helpful to build up an overall view of where the airplane is and what path it will follow. As an example, the published NACO Burbank-Glendale-Pasadena ILS RWY 8 chart (plan and profile) follows, with a sketch (figure 27-44) of how the approach will be flown.

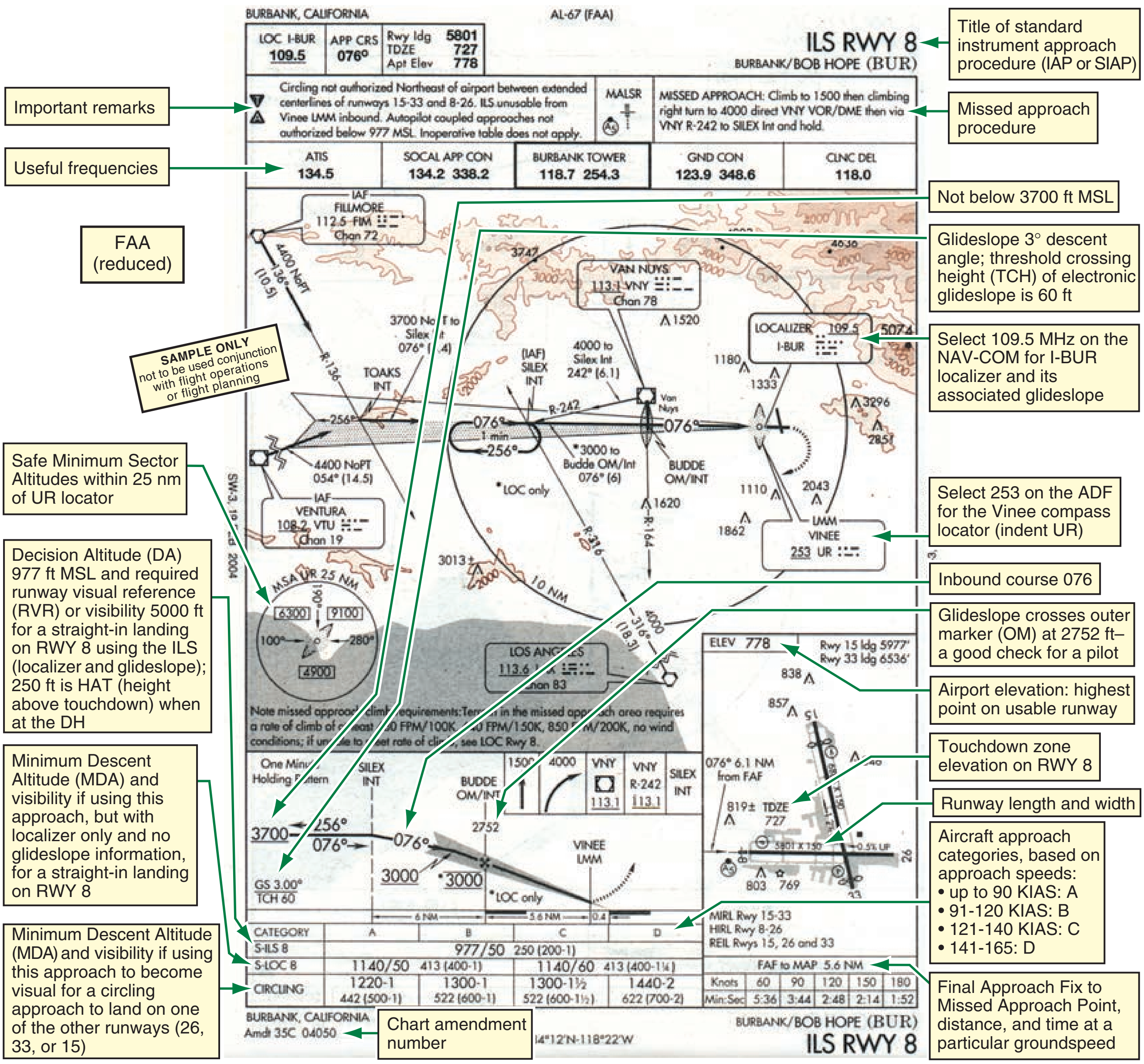


Figure 27-43 Burbank Rwy 8 ILS approach plate.

The appropriate minimums should be determined. For a straight-in approach on Runway 8 using the full ILS (S-ILS 8), the *decision altitude/decision height* (DA/DH) for a Category A airplane (a typical light aircraft) is DH 977 feet MSL, with a visibility or *runway visual range* (RVR) of 5,000 feet (1 SM) being required to land. If the electronic glide slope is not available, and the approach is made using the localizer only without the glide slope (S-LOC 8), the minimums increase to a *minimum descent altitude* (MDA) of 1,140 feet MSL, with 1 SM visibility required for landing. To circle and land on another runway, the minimums are further raised to 1,220 feet and 1 SM.

The *missed approach* procedure should always be reviewed and alternative action planned if there is any doubt that a successful landing can be made. Low clouds fluctuating around the decision height, poor visibility, heavy rain, or anything that might prejudice your arrival, should lead you to consider alternate airports.

There is always a (remote) possibility that an essential ground aid required for the landing will become unserviceable (caused by a lightning strike or flooding during a storm, for instance).

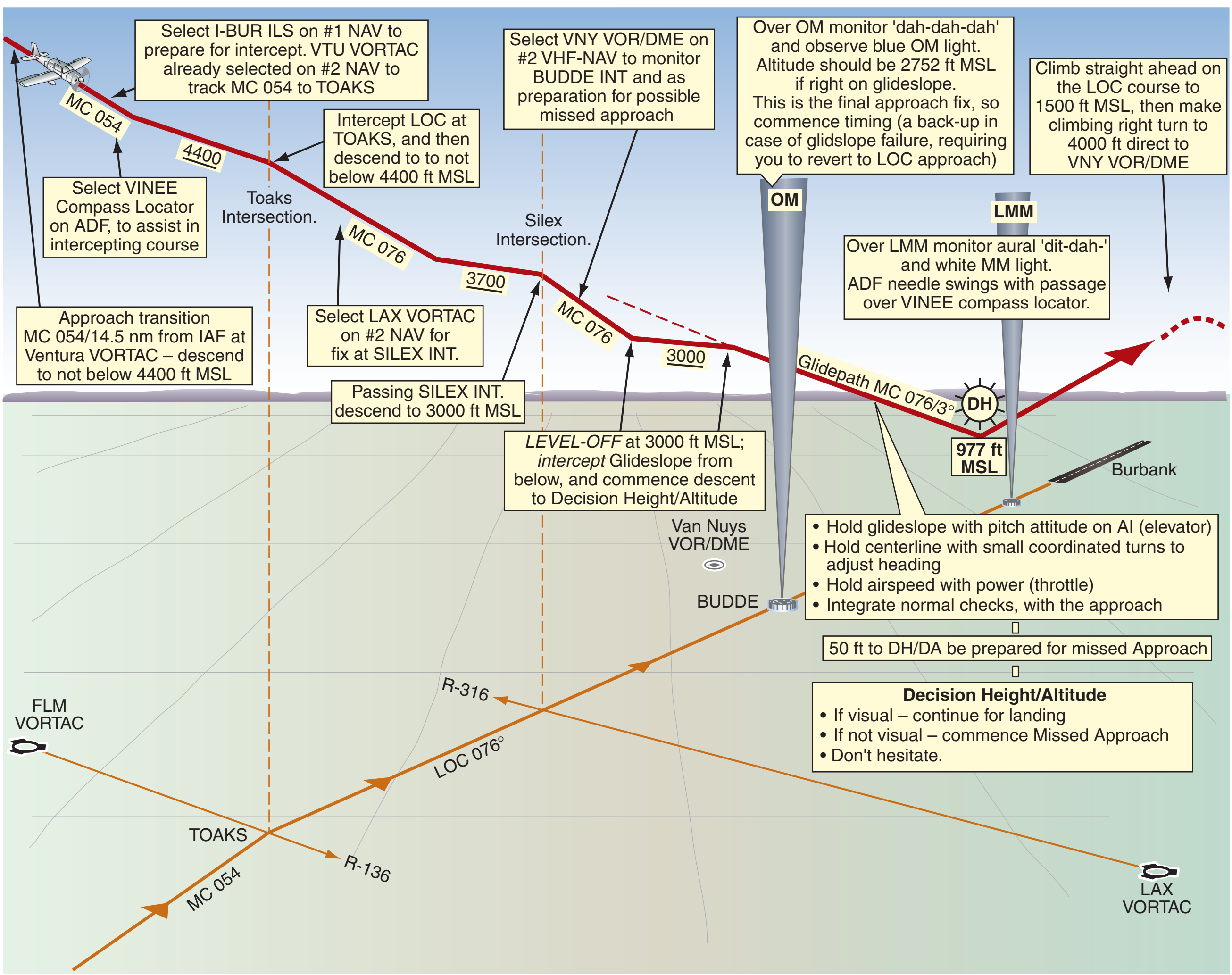


Figure 27-44 Flying the Burbank ILS Rwy 8 approach.

The fuel situation must be considered, and the minimum fuel on board required for diversion should be calculated. Allow for reserves. Is there fuel enough for more than one approach before diverting? How much fuel is available for holding? Is the weather at the alternate airport still suitable for an approach? Prepare for the approach well before reaching the airport, so that, once there, you can devote sufficient attention to flying the ILS approach.

Track to the airport following the normal route and using the normal en route tracking aids, maintaining the appropriate altitude. The minimum safe altitudes within 25 NM of VINEE compass locator (UR) are quite high, up to 9,100 feet MSL in the northeast sector, but ATC may clear you to lower altitudes and provide radar vectors to expedite your arrival. All clearances, headings, altitudes and pressure settings passed by ATC should be repeated. All NAVAIDs must be identified before being used.

If a *holding pattern* has to be entered, then plan to use the correct entry procedure based on the airplane's heading when it reaches the holding fix (see figure 27-45). See Chapter 28 for more information on holding and pattern entries.

"Stacking" airplanes in holding patterns until a slot on the ILS becomes available is common during busy periods at major airports. As each airplane departs the bottom of the stack and proceeds into the ILS, the other airplanes can be cleared down one at a time. This will be the procedure used if ATC informs you that "timed approaches are in progress."

In some instrument approach procedures, a *DME arc* may be flown to position an airplane on an ILS (figure 27-46).

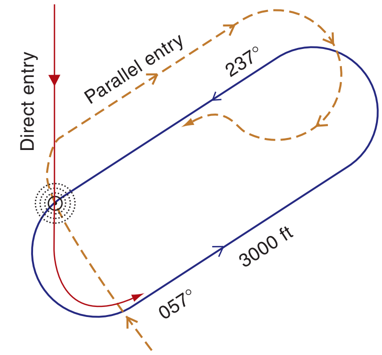


Figure 27-45
Holding pattern entry.

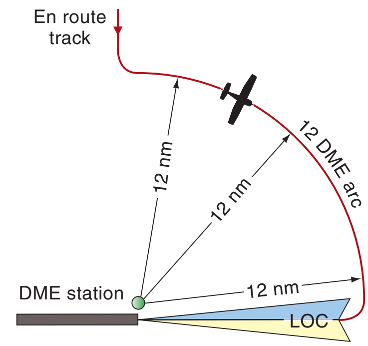


Figure 27-46
A DME arc.

For the Burbank Rwy 8 ILS, the airplane will fly from the VENTURA initial approach fix (IAF) to join the localizer at 4,400 feet at TOAKS intersection. The 054 degree radial from VENTURA is called a *feeder route* and comprises the initial approach segment.

- Select NAV-1 to the Rwy 8 ILS I-BUR, 109.5 MHz, inbound 076, and identify.
- To assist in the intercept, select the ADF to VINEE compass locator, 253 kHz, identify UR, and test.
- Continue tracking MC 054 from VENTURA with VOR selected on NAV-2.

Use the ADF to assist the intercept, since the CDI will not start to move until you are within 2.5° of the localizer. The intercept, from MC 054 to localizer MC 076, is only 22°, which is satisfactory. If the intercept was greater, say 60°, it would be a good technique to break the intercept to about 30° just prior to the CDI starting to move. You can judge this using the position and rate of closure of the ADF needle.

If you are approaching the localizer centerline and have not yet been authorized for the approach, query ATC as to whether they want you to either maintain the last assigned heading (possibly for traffic reasons) or to intercept the localizer. In some cases, they will have you fly through the approach course and then turn back inbound. You cannot descend to approach altitude until ATC has cleared you for the approach.

If you are authorized to make the approach, turn to MC 076 as soon as the CDI starts to move. Hold your reference heading, MC 076 plus or minus the estimated wind correction angle, and check the CDI. There is no need for you to center it immediately, just so long as it does not move to full-scale deflection; it is more important to establish a reference heading that stops CDI movement, and then subsequently make gentle turns about the reference heading to center the CDI.

Heading changes of ±5° may be required early in the approach while you are becoming established, but after the final approach fix you should be able to manage with small adjustments of ±2°.

Thorough preparation will reduce your workload during the approach.

Integrate the normal operational requirements into the approach so that the whole thing flows smoothly, without undue haste or panic. Radio calls, prelanding checks, configuration and airspeed changes—the sorts of things that occur on all approaches—still must be attended to. Having prepared for the approach early in order to reduce the workload later on, you should now be able to sit back (more or less) and calmly follow the procedure, attending briefly to other duties as required.

After intercepting the localizer at TOAKS, track to the SILEX Intercept, descending to not below 3,700 feet MSL. While not essential, NAV-2 (if it is available) may be selected to the 316 radial of the LAX VOR, since its intersection with the localizer defines SILEX. You are now in a good position if ATC requests you to hold at SILEX.

Passing SILEX, descend to not below 3,000 feet, indicated on the chart by. The glide slope needle will move from the upper peg as you intercept the glide slope from below. Commence a descent at your estimated rate of descent. There are various techniques recommended for intercepting the glide slope, and your instructor will give you good advice, possibly to:

- lower the landing gear, thereby increasing drag, and pitch slightly down to maintain speed and achieve the desired rate of descent; or
- reduce power, and pitch slightly down.

Again, there is no need to immediately center the needle. It is more important to establish the correct rate of descent and hold the desired airspeed, provided the glide-slope needle does not go to the upper or lower peg. The VSI can be of great assistance. When settled down in the descent, make minor pitch adjustments to center the glide-slope needle. Airspeed changes, if required, may be made with power (followed by a pitch change, if necessary, to hold the glide slope). Changes in wind speed and/or direction (*windshear*) will require a response. Windshear is discussed on pages 661–666.

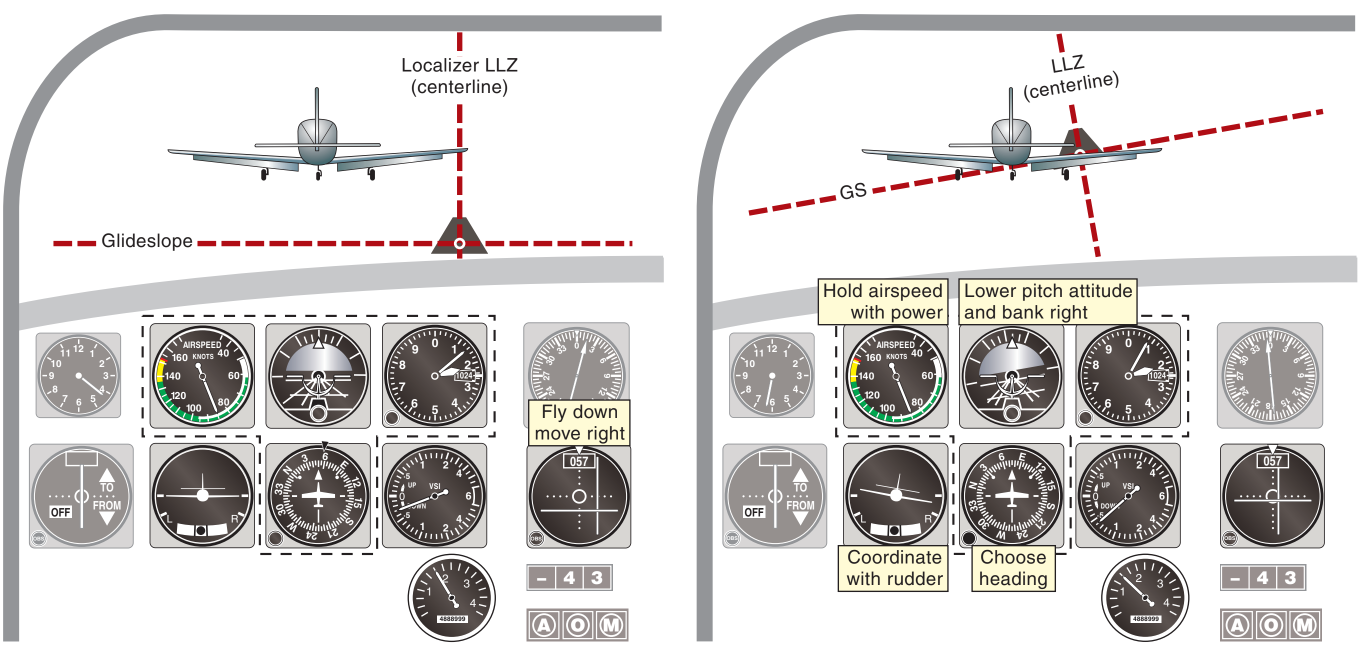


Figure 27-47 Flying the ILS final approach.

The ILS indicator is a navigation *performance* instrument—do not use it to make attitude changes, nor to "fly the needles." Periodically note the position of the localizer and glide-slope needles, then return to the flight instruments and make appropriate minor attitude adjustments on the AI, and steer your selected heading on the HI. Several seconds later, check the ILS indicator, and then move your eyes back to the flight instruments.

Remember that the flight path in clouds or out of clouds is the same, the airplane does not know the difference; the main difference, if any, is in your psychological state—and if you treat the instrument indications merely as substitute visual indications, and keep visualizing your progress down the glide path toward the runway, you can proceed comfortably as in a normal visual approach.

When past SILEX, tune NAV-2 to Van Nuys VOR (VNY), in preparation for a potential missed approach. NAV-1, with the Burbank Rwy 8 ILS selected, is still your primary navigation instrument.

You should pass the *outer marker* (flashing blue light and "*dah-dah-dah-dah-*") at 2,752 feet on the altimeter. Start the stopwatch. The outer marker is the final approach fix (FAF), and you should have the localizer and the glide slope tied down, with only small pitch and heading changes being required. You should be right on speed, with your hand on the throttle. Before landing checks should be complete, with only final flaps to go.

Note. If there is a glide-slope failure prior to the outer marker, and you have to revert to a *localizer approach*, you should cross the outer marker at 3,000 feet, indicated by 3000, and then descend to the minimum descent altitude (MDA) 1,140 feet. 3000 means a mandatory altitude; you should not be above or below that altitude. You may hold the MDA in the hope of becoming visual before the missed approach point (MAP), whose position you can determine with the stopwatch (at groundspeed 90 knots, 3 minutes 44 seconds after the outer marker).

Assuming the full ILS is working (including the glide slope), proceed down to the decision height (DA/DH) 977 feet MSL, occasionally looking up from the instruments for signs of the runway environment, such as approach lights or the runway itself. If you break out of the clouds at the DA/DH or above, and the required visibility of 1 SM or more exists, you may proceed with the landing. Select final flaps, as required. If the in-flight visibility is below minimums, you may not go below the DA or make a landing. Judging in-flight visibility is your job. The ALS makes a good yardstick since they are of known dimensions; i.e. the ALSF-1 is 3000 feet or half a mile long.

If you do not break out of the clouds at or above the DA/DH, or if the required minimum visibility of 5,000 feet (1 SM) does not exist, then you should immediately commence the *missed approach* at the DA/DH, by initiating a climb, adopting the missed approach configuration, after passing through 1,500 feet MSL, starting a climbing right turn toward the Van Nuys VOR, climbing to 4,000 feet. Van Nuys is already selected on your NAV-2. If you have only one NAV, turn to an estimated heading, say MH 290, and then select Van Nuys VOR when comfortable. If no "climb to" altitude is published, you should initiate a climb to at least the altitude for circling minimums before making any turns.

The missed approach is not an emergency procedure, but simply part of the normal instrument approach procedure that provides you with a safe flight path if weather is below minimums, or if, for any reason, you decide not to proceed with the landing. The missed approach is, however, a maneuver that you must commence efficiently and without delay when you reach the DA/DH.

International Terminology (DA versus DH)

Jeppesen charts for U.S. airports use international (ICAO) terminology for presenting the minimum altitude on an approach; this differs slightly from the NACO instrument approach chart presentation of minimums.

Precision Approaches (ILS, MLS) with Glide Slope

Jeppesen charts use the term *decision altitude (height)*, abbreviated DA(H), in place of just *DH* (decision height), as on FAA charts. For example, DA(H) 495´(200´) means the decision altitude is at 495 feet MSL, which is 200 feet AGL above touchdown (HAT). Refer to the example in figure 27-48: the *Jeppesen* Visalia, CA, ILS approach chart excerpt.

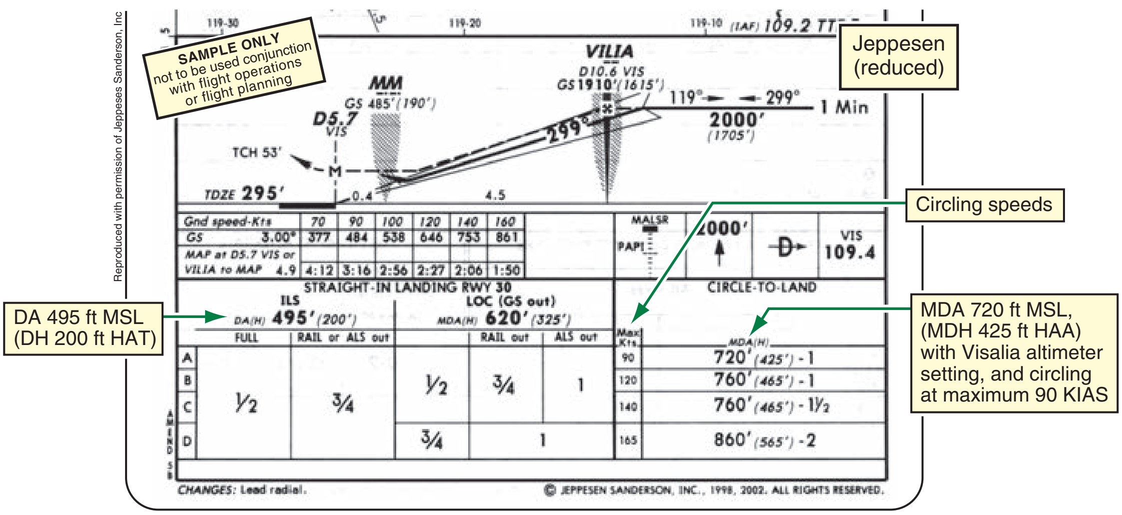


Figure 27-48 Excerpt from the Visalia, California ILS Rwy 30 Jeppesen approach chart.

Nonprecision Approaches (VOR, NDB, GPS) no Glide Slope

Jeppesen uses the term *minimum descent altitude (height)*, abbreviated MDA(H). FAA charts use just MDA. For example, the *Jeppesen* Las Vegas, N Mex, VOR approach Rwy 2 chart shows the minimum as: MDA(H) 7,540´(675´), where 7,540 feet is the MDA (MSL altitude) and 675 feet is the height above airport (HAA).

> **Note.** United Kingdom, European and Australian ILS approach plates use the international system.

Simultaneous Approaches

At some airports with parallel instrument runways separated by at least 4,300 feet, simultaneous ILS (or MLS) approaches may occur, with different aircraft flying down different parallel paths to different runways. When simultaneous approaches are in progress, you should monitor the tower frequency for radar advisories or instructions.

> **Note.** At some airports with parallel runways with only 2,500 feet between centerlines, so-called *parallel ILS approaches* may be conducted, but aircraft on the adjacent localizers will be staggered by at least two miles. At some airports with

converging runways, ATC may conduct simultaneous *converging ILS approaches*. The two approach courses will be well separated, the two missed approach points must be at least three miles apart, and the two missed approach courses must be well separated.

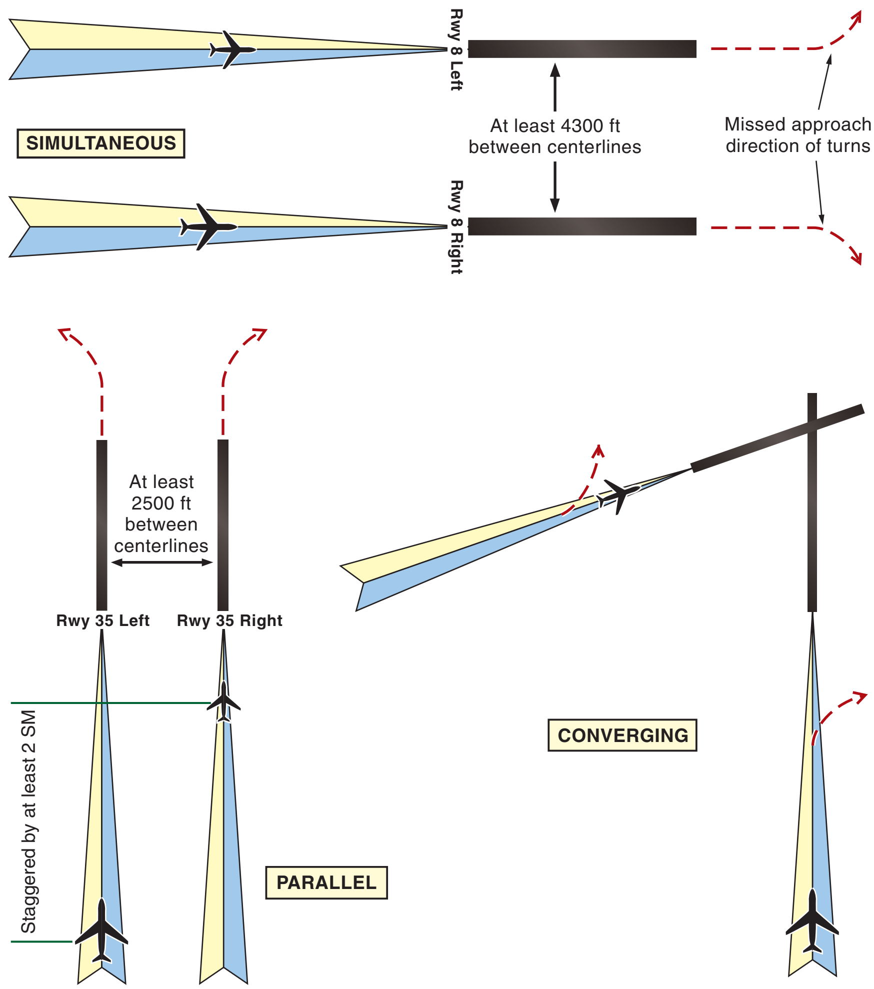


Figure 27-49 Simultaneous, parallel and converging approaches.

The Sidestep Maneuver

The sidestep maneuver is a visual maneuver accomplished by the pilot after flying an instrument approach to one runway, becoming visual, and then sidestepping (with coordinated turns) to land straight-in on a parallel runway which is not more than 1,200 feet to either side of the runway on which the instrument approach is based.

You should commence the sidestep maneuver as soon as you are visual and have the runway environment in sight.

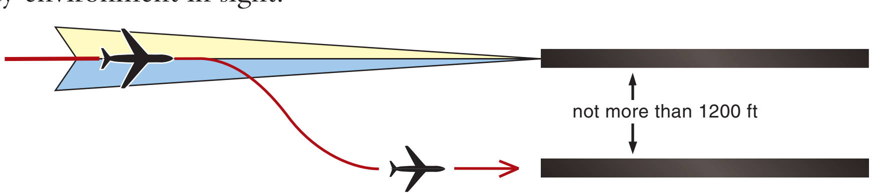


Figure 27-50 The sidestep maneuver.

The Localizer-Type Directional Aid (LDA)

The localizer-type directional aid (LDA) is comparable to a localizer but is *not* aligned with the runway. In other words, using an LDA you will have to maneuver for a landing after becoming visual. The LDA does not have a glide slope as part of the LDA procedure (unless specified in the approach title).

Straight-in LDA minimums may be published if the alignment does not exceed 30° between the LDA course and the runway. Circling minimums only are published where this alignment exceeds 30°.

A good example of efficient ATC use of NAVAIDs is the LDA approach at Van Nuys airport using the localizer part of the Burbank ILS. Since the Van Nuys runway is at almost 90° to the LDA course, only circling minimums are published. If you break out of the clouds at or above the MDA 2,600, and if the required minimum visibility of 1 ¼ SM exists, you may commence a circle-to-land maneuver at Van Nuys.

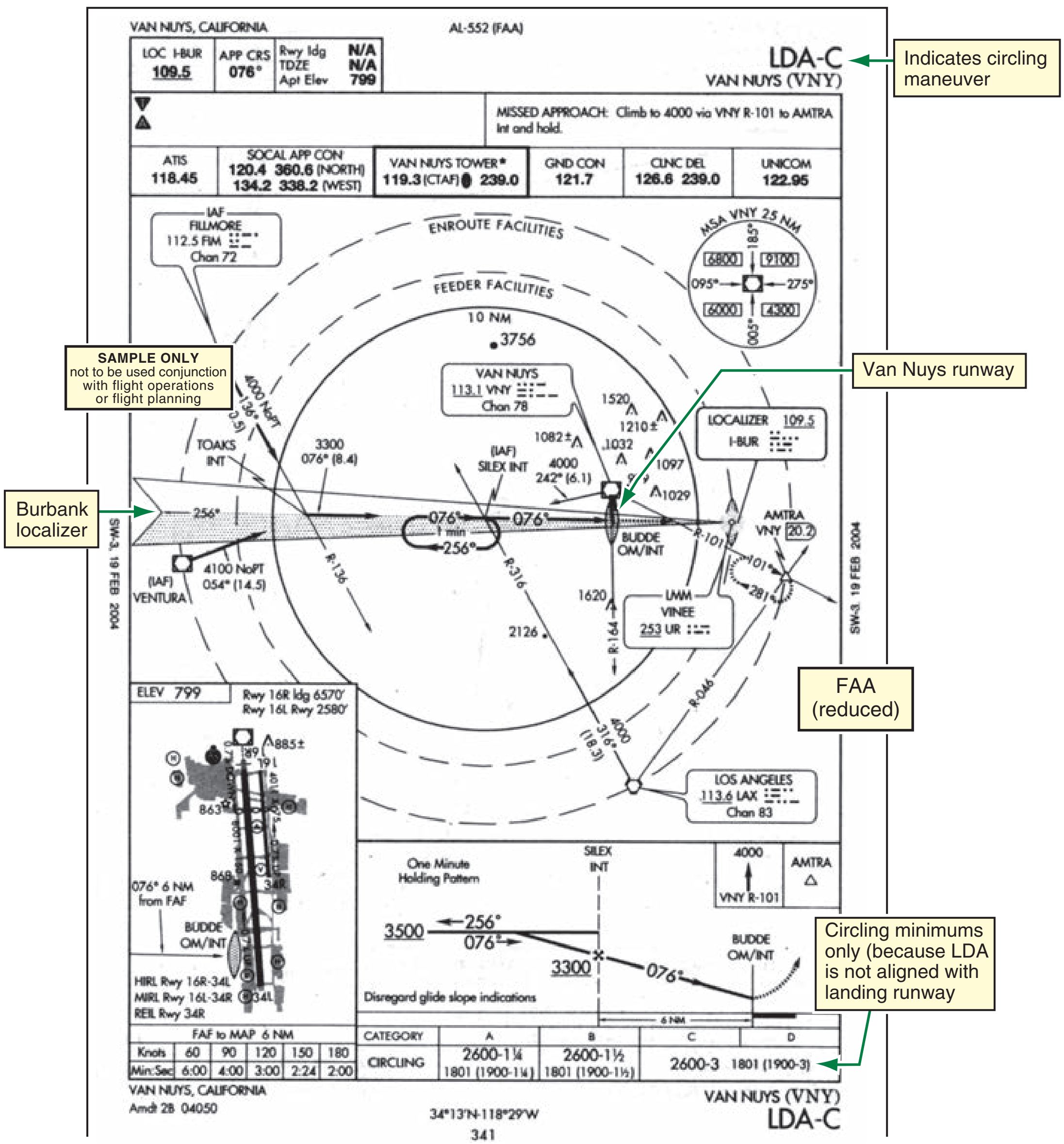


Figure 27-51 Van Nuys LDA-C.

The Simplified Directional Facility (SDF)

The SDF is similar to a localizer except:

- its course width may be greater at 6° or 12°, resulting in less precise course guidance (but still good); and
- the SDF course may be offset slightly from the runway centerline, but this will be noted on the SDF approach chart.

The full-scale FLY LEFT or FLY RIGHT signals of the SDF are not usable outside 35° either side of course. Like the LDA, the SDF does not have a glide slope.

Review 27

Instrument Landing System (ILS)

ILS Specifications

1. How far above touchdown is the glide slope of a typical ILS at the middle marker (MM)?

2. If all ILS components are operating and the required visual references are not established, what is the latest point at which you may commence a missed approach?

3. Which range facility associated with the ILS is identified by the first two letters of the localizer identification group?

4. Which range facility associated with the ILS is identified by the last two letters of the localizer identification group?

5. The Pueblo, Colorado ILS RWY 26R has a coded identifier I-TFR. What is this in Morse code (dits and dahs)? What coded identifier (in dits and dahs) would you expect to hear on the outer marker?

6. What indications are received on an ILS as you pass over the outer marker?

7. What indications are received on an ILS as you pass over the middle marker?

8. What indications will you receive on an ILS as you pass over the inner marker, if one is associated with the approach?

Refer to figure 27-52 for questions 9 to 13.

9. At 500 feet HAT, approximately 1.9 NM from the runway, what deviation above or below slope is indicated by a 1 dot deviation of the ILS glide-slope needle?

Note. The splay angles and instrument-deflection values of the glide slope and localizer depicted in figure 27-52 are for study purposes only. Characteristics of actual ILS equipment installed at airports may vary from these figures.

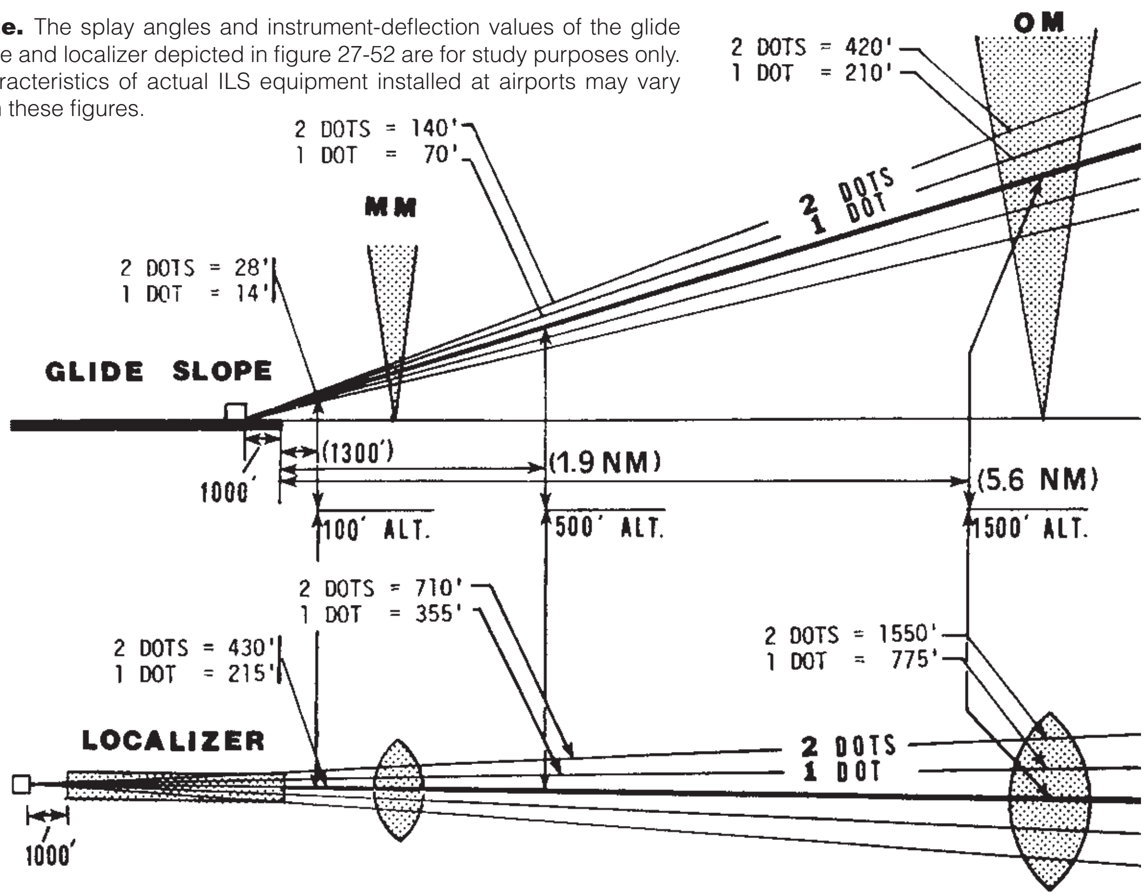


Figure 27-52 Glideslope and localizer illustration (from the FAA Instrument Computerized Testing Supplement).

10. At 100 feet HAT, approximately 1,300 feet horizontally from the runway, what deviation above or below slope is indicated by a 1 dot deviation of the ILS glide-slope needle?
11. At 500 feet HAT, approximately 1.9 NM from the runway, what deviation left or right of the localizer (approximate feet) is indicated by a 1 dot deviation of the ILS localizer needle?
12. At 100 feet HAT, approximately 1,300 feet horizontally from the runway, what deviation left or right of the localizer is indicated by a 1 dot deviation of the ILS localizer needle?
13. At 1.9 NM, the glide-slope needle is 2 dots below its central position, and the localizer needle is 2 dots left of its central position. What is the lateral and vertical deviation from the desired flight path?
14. What does RVR stand for?
15. Having become visual on an ILS approach, what typical landing minimum is required?

HSI and ILS

16. What is the preferable technique when using an HSI to fly a localizer?
17. What will be the result if you accidentally set the reciprocal of the inbound localizer course on the HSI?

Refer to figures 27-53 and 27-54 for questions 18 to 23.

18. Will HSI presentation G cause the HSI to act as a command instrument?
19. Presentation G indicates that the aircraft could be at position:
    - **a.** 1.
    - **b.** 2.
    - **c.** 3.
    - **d.** 4.
    - **e.** 7.
20. At position 4 with the HSI set correctly, the indication will be presentation:
    - **a.** F.
    - **b.** G.
    - **c.** H.
    - **d.** A.
21. At position 6 with the HSI set correctly, the indication will be presentation:
    - **a.** F.
    - **b.** G.
    - **c.** H.
    - **d.** A.
22. At position 11 with the HSI set correctly, the indication will be presentation:
    - **a.** F.
    - **b.** G.
    - **c.** H.
    - **d.** A.
23. The following HSI presentations correspond to which position(s)?
    - **a.** Presentation A.
    - **b.** Presentation B.
    - **c.** Presentation C.
    - **d.** Presentation D.
    - **e.** Presentation E.
    - **f.** Presentation F.
    - **g.** Presentation G.
    - **h.** Presentation H.
    - **i.** Presentation I.

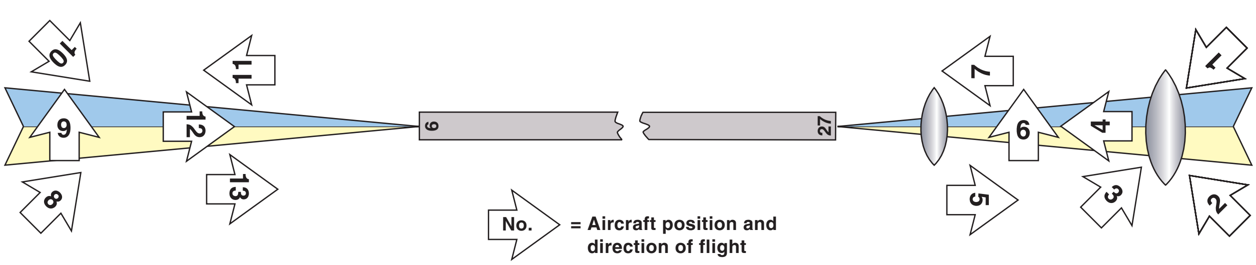


Figure 27-53 27 Localizer with back course—questions 18-23.

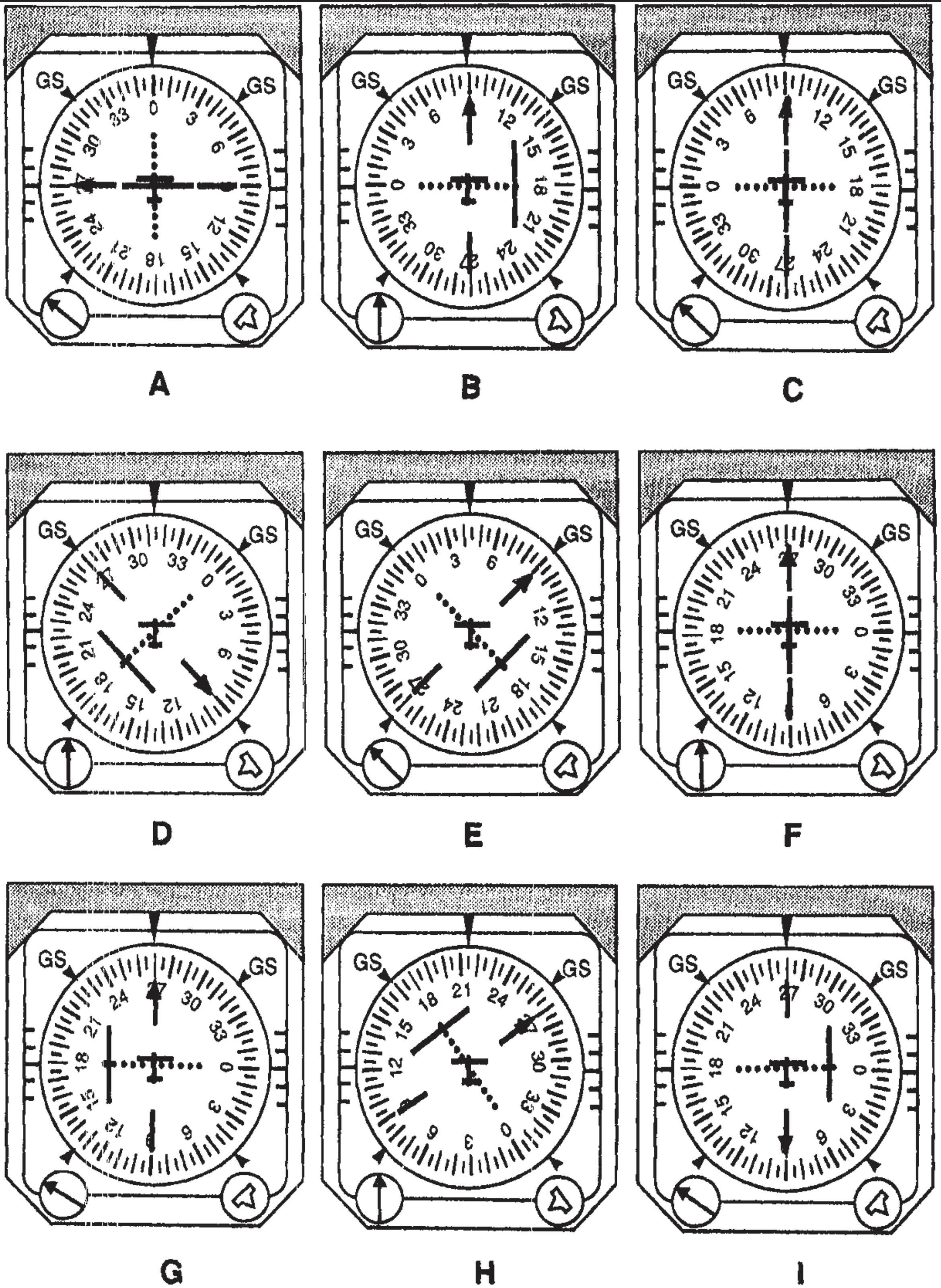


Figure 27-54 Questions 18 to 23.

Unusable ILS Components

24. If two components of an ILS are unusable, the appropriate minimum to use is:
    a. the highest minimum required by any single component that is unusable.
    b. the same minimum for the fully operational ILS.
    c. the normal minimum plus 100 feet.
25. What may be substituted for the ILS outer marker, if unusable? (Six possibilities!)
26. What may be substituted for the ILS middle marker, if unusable?
27. Without glide slope, what does ILS become?
28. What happens to the minimum if the glide slope of an ILS becomes unusable?
29. The minimums for the Durango-La Plata County, Colorado ILS/DME RWY 2 are:
    - S ILS-2 6,839-½ 200 (200-½); and
    - S-LOC 2 6,980-½ 341 (300-½).

    a. What is the ILS DA (feet MSL)?
    b. How many feet above the touchdown point is this?
    c. What is the minimum if the glide-slope warning flag appears after passing the final approach fix inbound?
    d. What sort of minimum is this?
30. If the glide-slope warning flag appears after becoming visual on an ILS approach, are you permitted to continue the approach to a landing?

Flying the Approach

31. While being radar vectored, if crossing the ILS final approach course becomes imminent and an approach clearance has not been issued, what action should you take?
32. You think you will not be able to lose sufficient height in time to commence an ILS correctly. What two options are available to enable you to lose the excess height?
33. Ideally, drift corrections to maintain the localizer should be so accurately established before reaching the outer marker that completion of the approach inside the outer marker should require what heading change (±°)?
34. What does the rate of descent required to stay on an ILS glide slope depend on?
35. You reduce the indicated airspeed as you descend down an ILS glide path in steady wind conditions. Would you expect to alter the rate of descent to stay on slope? If so, how?
36. You are on slope—glide-slope needle and localizer needle are both centered, but 10 knots too fast. What is your initial correction?
37. You fly into a steadily decreasing headwind. What will happen to your groundspeed? What should happen to the rate of descent in order to stay on the ILS glide slope?
38. If you do not become visual, what is the latest point at which you should commence the missed approach?

Lighting, and Precision Instrument Runway Markings

39. What is the usual glide-slope angle for an on-slope VASI indication?
40. What are the on-slope indications of a two-bar VASI?
41. What are the too-high indications of a two-bar VASI?
42. What are the too-low indications of a two-bar VASI?
43. What are the on-slope indications for a pilot of a small aircraft on a three-bar VASI?
44. What are the slightly too-high indications for a pilot of a small aircraft on a three-bar VASI?
45. What are the grossly too-high indications for a pilot of a small aircraft on a three-bar VASI?
46. What are the too-low indications for a pilot of a small aircraft on a three-bar VASI?
47. How should a pilot of a long-bodied airplane treat the three-bar VASI?
48. What are the on-slope indications for a pilot of a long-bodied aircraft on a three-bar VASI?
49. If you are at a safe altitude with respect to obstacle clearance, e.g. at the MDA, and all bars of a three-bar VASI appear red, what should you do?
50. You have flown an ILS, become visual, and are using the VASI when the glide slope fails. Can you continue under these conditions?
51. The plane of the VASI approach slope only provides guaranteed obstacle clearance within what arc?

52. What color does the tri-color VASI show in the following situations:
  a. when the aircraft is above slope?
  b. when the aircraft is on slope?
  c. when the aircraft is below slope?

53. PAPI lights are white-white-red-red. What does this mean? What is the usual slope?

54. PAPI lights are white-red-red-red. What does this mean? What is your slope likely to be?

55. PAPI lights are red-red-red-red. What does this mean? What is your slope likely to be?

56. PAPI lights are white-white-white-red. What does this mean? What is your slope likely to be?

57. PAPI lights are white-white-white-white. What does this mean? What is your slope likely to be?

58. What does REIL stand for? What is it and what is it used for?

59. On a precision approach runway, what is:
  a. the distance from the approach threshold to the touchdown zone marker?
  b. the distance from the approach threshold to the fixed distance marker?
  c. the distance from the beginning of the touchdown zone marker to the beginning of the fixed distance marker?

60. How is a displaced threshold on an instrument runway indicated?

61. Which of the following is a displaced threshold available for?
  a. Taxiing.
  b. Takeoff.
  c. Landing.

62. Is a displaced threshold at the runway stopping end available for landing rollout?

63. At night, you taxi out onto the end of a runway with the green displaced threshold lights visible ahead. Are you permitted to commence takeoff before you reach these lights?

Simultaneous Approaches

64. When simultaneous approaches are in progress, which frequency should you listen out on for radar advisories?

65. What distance must there be between the centerlines of parallel runways for simultaneous approaches to be permitted?

The Sidestep Maneuver

66. You are cleared for the ILS Runway 7-left approach, sidestep to Runway 7-right. When should you commence the sidestep maneuver?

67. Under what conditions may the sidestep maneuver be performed?

LDA, SDF and ILS Approaches

68. What is the width (°) of an LDA course and a normal localizer course?

69. Is a normal localizer course aligned with the runway?

70. Is an LDA course aligned with the runway?

71. Does the LDA provide glide-slope guidance?

72. Is the SDF more precise than the LDA?

73. What is the width of an SDF course?

74. May the SDF course be aligned with the runway?

75. Does the SDF provide glide-slope guidance?

76. What is a localizer front course with an associated glide slope called?

77. Will a localizer back course have an associated glide slope?

Answers are given on page 787.

Holding Patterns, Procedure Turns, and DME Arcs 28

There are various maneuvers that an instrument pilot must be able to perform efficiently, including:

- *holding patterns*—for delaying action in a racetrack pattern;
- *procedure turns*—for course reversal in instrument approaches; and
- *DME arcs*—for transiting from en route to final approach course.

Unless suitable fixes, radar vectoring by ATC, or a DME arc permit a direct entry into an instrument approach procedure, a positioning turn of some kind may be necessary. *Course reversals* can be made using procedure turns, teardrop turns, or by following the appropriate sector entry for a published racetrack pattern.

Holding Patterns

A *holding pattern* is a predetermined maneuver designed to keep an aircraft within a specified airspace while awaiting further clearance from ATC. Holding is a delaying action and onward flight ceases until the airplane is cleared to proceed.

A holding pattern is a delaying action on the part of ATC. Being asked to hold is essentially being asked to wait.

The delaying action could be required for a number of reasons, such as waiting for further en route clearance, waiting until other aircraft have commenced an ILS approach and an approach slot has become available, or waiting until a storm has moved away from the destination airport.

A holding pattern is generally a *racetrack* shape with five basic elements:

1. *the holding fix;*
2. *the holding radial or bearing;*
3. *the position of the holding pattern relative to the fix,* expressed as one of the eight cardinal points of the compass (northeast, south, etc.);
4. *the direction of turns* (right-hand unless specified otherwise); and
5. *the timing* (or, in the case of mileage legs, distance).

Also, the holding altitude is important and so is the time at which you can expect a further clearance.

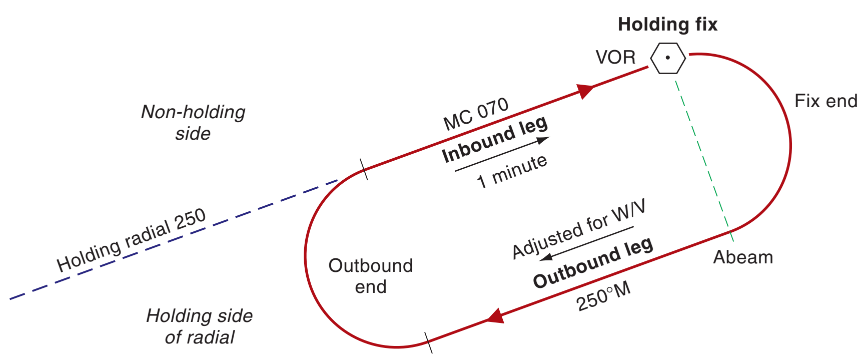


Figure 28-1 A typical holding pattern (usually right hand).

The *minimum holding altitude* (MHA) is the lowest holding altitude prescribed for a holding pattern which:

- assures navigation signal coverage;
- assures communications; and
- meets obstacle clearance requirements.

A typical holding pattern, as illustrated in figure 28-1, uses a VOR ground station as the holding fix, the 250 radial southwest of the VOR as the holding radial (inbound leg is 070-TO the holding fix), with standard right-hand turns.

Holding Fixes

The location of an IFR holding fix is usually specified by reference to one or more NAVAIDs or some other navigation device. The most common holding fixes are:

- *overhead a navigation aid*, such as a VOR, NDB, or the outer marker on a localizer; or
- *an intersection of two VOR radials* (a VOR/VOR fix), or a DME fix along a particular VOR radial (a VOR/DME fix).

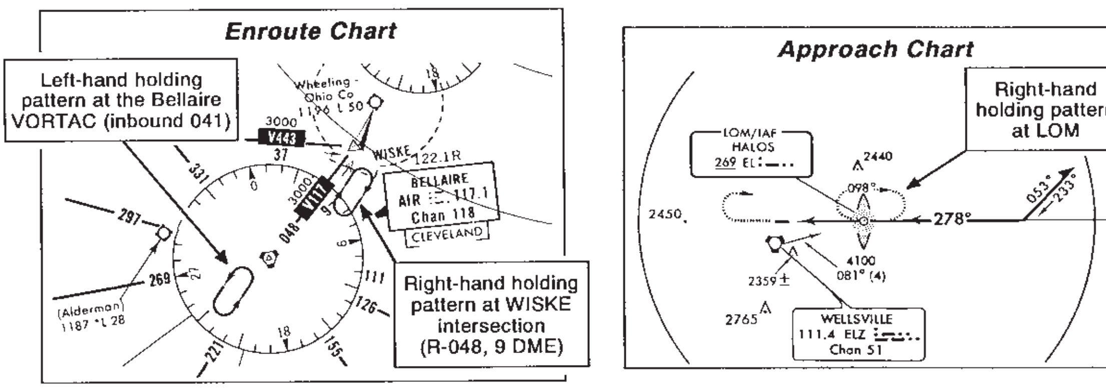


Figure 28-2 Examples of holding fixes.

The Standard Holding Pattern

The standard holding pattern, as shown in figure 28-1, has:

- *right-hand turns*; and
- *a one-minute inbound leg*.

If left-hand turns are required, then "left turns" will be specified in the ATC clearance or on the chart. If no mention is made of the direction of turns then they are right-hand. The "1 minute" applies to holding at or below 14,000 feet MSL. Above 14,000 feet MSL, the time is extended to 1 ½ minutes. It may also be extended by ATC. Some holding patterns, rather than being based on *time*, are based on *DME distance outbound*.

Published Holding Patterns

Many holding patterns are published on the en route charts and instrument approach charts as illustrated in figure 28-2, and an ATC clearance to hold in that pattern would be given as: "cleared to (fix), hold (direction) as published." For example: "cleared to Bellaire VORTAC, hold southwest as published."

Not all holding patterns are illustrated on charts, but those that are will be in sufficient detail for you to enter and maintain correctly. They may have other chart details superimposed on them, but with experience, the holding details are easily read. Holding patterns should be flown within any time limitations or published leg length.

Non-Published Holding Patterns

Never accept a holding clearance without an EFC!

If the holding pattern is not charted, ATC will issue you with holding instructions at least 5 minutes prior to reaching the fix, if possible. ATC instructions to hold will include the following information:

- the holding fix;
- *the direction of holding* from the fix in terms of the eight cardinal compass points (southeast, west, northwest, etc.);
- *the radial,* course, bearing, airway or route on which the aircraft is to hold;
- *leg length* (in minutes if different to standard timing, or as a DME distance outbound);
- *direction of turn* if left-hand turns are required (otherwise right turns);
- *expect further clearance* (EFC) time and any pertinent additional delay information. The EFC time is given so you will know what time to leave the hold in case of a communication failure.

Some typical ATC clearances to hold are:

"Cleared to the Huguenot VORTAC, hold east on the zero nine zero radial, expect further clearance at 1134."

"Cleared to the Revloc VORTAC, hold southwest on the two one zero radial, left turns, expect further clearance at 2215, anticipate additional two zero minute en route delay."

"Hold south of RUBER on the zero one niner radial of the Huguenot VORTAC, expect further clearance at 1905."

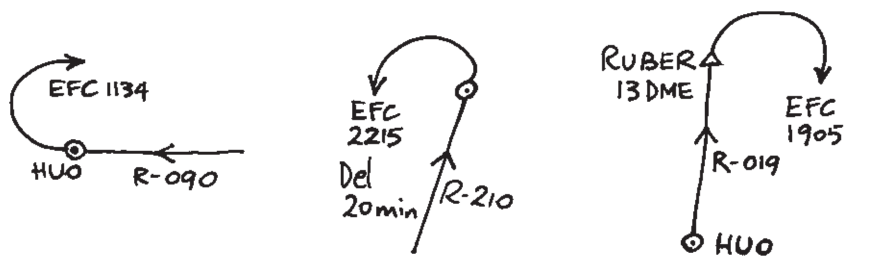


Figure 28-3 Sketching impromptu holding patterns.

These improvised holding patterns sometimes cause problems for inexperienced instrument pilots but, if you develop good techniques to handle them, they will cause you no concern at all. When given a clearance to hold in a nonpublished holding pattern, you should write down the details, or sketch a diagram.

1. Start at the fix.
2. Draw the specified direction from the fix, then show an arrow on it toward the fix (the direction of the inbound leg).
3. Show the direction of turn at the fix (left turn if specified, otherwise right).
4. Note any other details (EFC, DME distance, etc.).

Speeds in Holding Patterns

When 3 minutes or less from the holding fix, the pilot is expected to start a speed reduction so as to cross the fix at or below the maximum holding airspeed. ATC will give you holding instructions at least five minutes before the fix if possible, so you should have two minutes or more to get organized before having to slow down. For all aircraft between minimum holding altitude (MHA) and 6,000 feet MSL, holding speed is 200 KIAS. For all aircraft between 6,001 and 14,000 feet MSL, holding speed is 230 KIAS. For all aircraft 14,000 feet MSL and above, holding speed is 265 KIAS. Exceptions to these speeds will be indicated by an icon. These speeds ensure you stay within protected airspeed. If ATC does not issue holding instructions or a further clearance before you reach a clearance limit, then you should hold. Enter the published pattern at the fix, or if there is no published holding pattern, enter a standard right-turn one-minute holding pattern.

Timing in Holding Patterns

It takes 4 minutes to complete one circuit of a basic holding pattern.

A complete one-minute holding pattern will, if flown perfectly in no-wind conditions, take four minutes. The inbound leg should be one minute at or below 14,000 feet MSL (one-and-one-half minutes above 14,000 feet MSL). The 180° standard-rate turns at either end should each take one minute, and the outbound leg, in no-wind conditions, will also take one minute—making a total of four minutes.

Normal timing of the outbound leg commences from abeam the fix outbound. If the abeam position cannot be determined, then start timing when the wings are level after rolling out of the turn, at the outbound wings-level position. In a two-minute holding pattern, the straight legs are increased to two minutes, the complete pattern then taking six minutes in no-wind conditions, and occupying more airspace.

Adjust your holding pattern legs to arrive over the fix at your EFC.

Occasionally, the delay required during holding is less than four minutes, in which case the timing of the outbound leg can be adjusted for the airplane to arrive overhead the fix at the desired time. For instance, if you arrive at the fix inbound at 1443 UTC and have an EFC 1446, then you have only three minutes to absorb. The 180° turns at either end of the holding pattern will each take one minute, leaving only one minute to be lost in the outbound and inbound legs. In no-wind conditions, a thirty second outbound leg should give you a thirty second inbound leg, with the airplane arriving overhead the fix inbound at 1446. In windy conditions, some timing adjustment outbound will be required.

Tracking in Holding Patterns

The main tracking leg of a holding pattern is the inbound leg toward the holding fix. Normal tracking procedures are followed using the tracking aid (which may be a VOR, NDB or localizer) by applying a wind correction angle so that the desired inbound course is maintained.

Monitor the tracking periodically on the VOR cockpit indicator, or the ADF if the hold is based on an NDB. The tracking aid will act as your navigation performance instrument. Most of your attention should be on the attitude flying instruments (monitoring altitude, airspeed and heading), with an occasional scan of the navigation instruments (VOR, DME, ADF). Any adjustments to heading called for by deviations on the navigation instruments should be made with reference to the attitude indicator and the heading indicator.

The outbound turns after crossing the fix, and the inbound turn at the end of outbound leg, should be standard-rate turns, and should never exceed 30° bank angle (25° if a flight director system is used).

During the turn outbound, and on the outbound leg, there is no direct tracking aid, so you have to estimate a suitable heading. Both the turns and the outbound leg of the holding pattern are modified according to the estimated wind effect, so that the standard-rate turn to rejoin the inbound leg will bring the airplane out right on course. You should check the tracking instrument during this inbound turn to determine if you will overshoot or undershoot the inbound course, in which case you can take early corrective action.

Corrections for Wind in Holding Patterns

Aim for a neat pattern with a one-minute inbound leg.

The aim when flying a normal holding pattern is to fly a neat pattern and intercept an inbound leg that takes 1 minute exactly to the fix.

The initial outbound leg should be flown for 1 minute, so that the wind effect can be established on the subsequent inbound leg. The initial pattern is, more or less, a trial run so you can make timing and tracking adjustments to later patterns. It may take several patterns before you get the tracking and timing perfect.

In no-wind conditions, the ground track of the holding pattern will be a straightforward racetrack pattern, with the outbound timing commencing as the airplane passes abeam the fix, and with the outbound leg (where there is no tracking aid) simply being the reciprocal of the inbound leg and flown for one minute.

Headwinds and Tailwinds

If there is a strong tailwind outbound, then 1 minute outbound will carry the airplane much further than in no-wind conditions and will carry the plane even further downwind during the turn inbound. With an airspeed of 90 knots, for instance, the groundspeed will be 110 knots outbound with a 20-knot tailwind and only 70 knots inbound. The 20-knot wind acting for the 3 minutes from overhead the fix to rejoining the inbound leg will have carried the airplane an extra 1 NM downwind compared with the no-wind situation. It will be a long haul at the slower groundspeed back to the fix (well in excess of one minute), unless some correction to the outbound timing is made.

A reasonable correction is to reduce the timing of the next "1-minute" outbound leg by 2 seconds per knot of the estimated tailwind. For instance, with a 20 knot tailwind outbound, reduce the timing by 40 seconds to only 20 seconds outbound before commencing the standard-rate turn inbound. Conversely, in a strong headwind outbound, add 2 seconds per knot. The timing is commenced when abeam the fix, or when the wings are level.

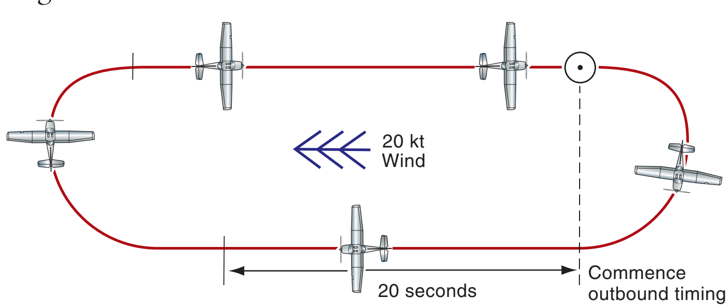


Figure 28-4 Adjust outbound timing to allow for head/tail wind.

The effect of your outbound timing correction will become evident on the next inbound leg. Further timing corrections to the following outbound legs may be required to achieve the perfect one-minute inbound leg.

Another method of adjusting the timing of the outbound leg is to double the inbound time deviation from the desired one minute, and apply it appropriately to the next outbound leg. For instance, if the inbound leg takes only 45 seconds, 15 seconds short of the desired one minute, double this to 30 seconds and add it on to the next outbound leg. This will extend the outbound leg, and lengthen the inbound leg (hopefully to 1 minute exactly). Conversely, if the inbound leg took 1 minute 10 seconds, then shorten the next outbound leg by 2 × 10 = 20 seconds.

The correction to timing can also be found by setting the following formula on your navigation computer, when outbound again after the first pattern:

$$\frac{\text{Initial outbound time}}{\text{Initial inbound time}} = \frac{\text{Adjusted outbound time (to be found)}}{\text{Required inbound time (say 60 seconds, know)}}$$

Crosswinds

In strong crosswind conditions, the airplane will tend to be carried downwind both on the straight legs and during the turns. The inbound course to the fix is the easiest part of the pattern to fly, since the inbound course has a direct tracking aid, and a suitable wind correction angle on the inbound leg can easily be found by applying normal tracking corrections to maintain the inbound course.

For both the turns and the outbound leg, however, measures to counter the wind effect can only be estimated, since they have no direct tracking aid. One turn will be downwind, the outbound leg will have a crosswind, and the other turn will be into a headwind. Common sense and a little experience, however, will enable you to handle this effectively, and to fly an outbound leg that will enable you to intercept the inbound leg with a neat standard-rate turn.

In the holding pattern illustrated below, a strong tailwind on the standard-rate turn outbound will increase its *ground radius*, the path followed over the ground. If the airplane then flies the published outbound heading without any adjustment for wind, it will be carried even further downwind. The standard-rate turn inbound, with its much smaller ground radius into the wind, will then place the airplane well short of the required inbound course, and the attempt to regain it will require a long haul back into the wind. The result is an unsatisfactory holding pattern. With some thought, however, this can be remedied.

On the outbound leg, simply applying a comparable drift allowance to that used on the inbound leg will cause the airplane to parallel the inbound leg; however it will not overcome the problem of the different ground radiuses of the turns. To allow for this, it is recommended that when a particular wind correction angle (WCA) is used on the inbound leg, you should apply a triple wind correction angle into the wind on the outbound leg, to a maximum of 30°.

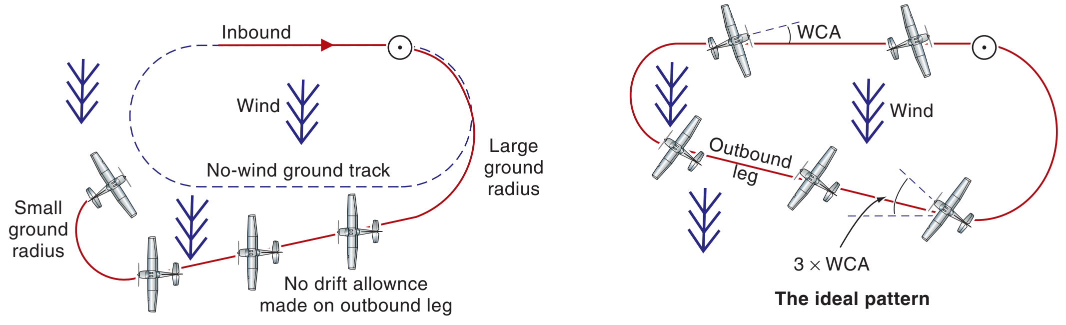


Figure 28-5 Apply 3 WCA on the outbound leg.

Note. This is one of many techniques. Your instructor will advise his or her preferred method—many prefer only a double WCA, or even less if the outbound leg exceeds 60 seconds.

For instance, if an 8° WCA to the left is used inbound, then a 24° right WCA should be applied outbound. This means that the outbound heading will be modified from 270° to 294°. The standard-rate turn at the outbound end of the holding pattern should then bring the airplane back onto the required inbound course, or at least close to it.

The triple drift allowance can be thought of as:

- one drift allowance to allow for the wind effect during the outbound turn; plus
- a second drift allowance to allow for the drift on the outbound leg; plus
- a third drift allowance to allow for wind effect during the turn to the inbound leg.

If the triple drift allowance (to a maximum of 30°) results in an outbound heading within 30° of the wind direction, then there will be little drift on the outbound leg itself, in which case the correction can be reduced to a double drift allowance, 2 × WCA, to allow for the wind effect only in the turns.

The success of the outbound leg drift allowance will be discovered when turning to rejoin the inbound leg. It is unlikely that it will have been perfect. If too great a correction was made, then the airplane will fly through the inbound course. Continue the turn, not exceeding standard-rate or a 30° bank angle, and make a shallow intercept of the inbound leg from the non-holding side. If the outbound wind correction was too small, then the turn inbound will have to be stopped early until the inbound course is regained.

Aim to regain the inbound course without delay and then make suitable adjustments to tracking and timing for the next run around the pattern. It may take several complete holding patterns to get the timing and the tracking really tied down. There is protected airspace around holding patterns to allow for minor deviations, but you should always aim to be as accurate as possible.

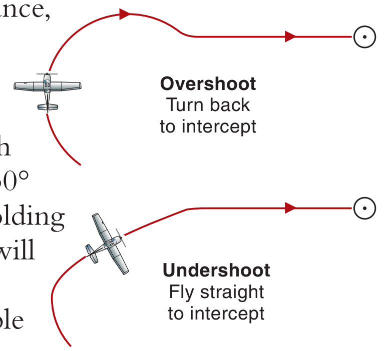


Figure 28-6
Rejoining the inbound leg.

Summary of the Wind Corrections for a Holding Pattern

1. Apply a triple wind correction angle outbound, to a maximum of 30°. If the resulting outbound heading is within 30° of the wind direction, reduce it to a double WCA.
2. Reduce the outbound timing by 2 seconds per 1 knot of tailwind (and increase it by 2 seconds per knot for a headwind component), or (Method 2) double the time-deviation inbound, and apply to the next outbound leg.

Entering a Holding Pattern

There may be some maneuvering required to join a holding pattern, since an airplane can approach the holding fix from any direction. Surprisingly, entering the holding pattern is often more difficult than maintaining the pattern.

Three types of *sector entry* have been devised, based on the direction of the inbound holding course and an imaginary line angled at 70° to it, from the fix and cutting the outbound leg at about one-third of its length. How the airplane joins the pattern depends on the heading of the airplane as it initially approaches the holding fix.

There are three standard entries:
- *parallel (sector 1);*
- *teardrop (sector 2); and*
- *direct (sector 3).*

You may, however, enter the hold any way you please, as long as you stay within the protected area.

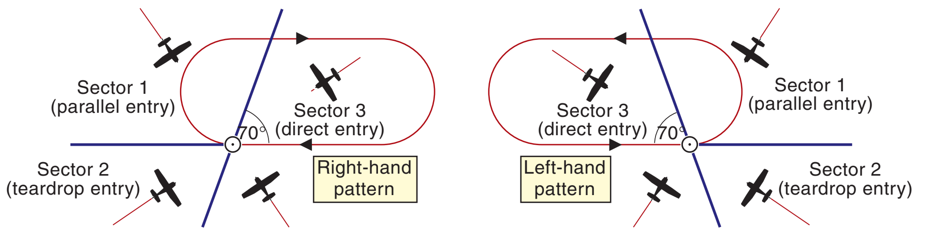


Figure 28-7 The three sectors.

Sector 1 Entry is a Parallel Entry

- Fly to the fix and turn to an outbound heading to parallel the inbound course. Do not backtrack on it—just fly parallel to it on the non-holding side for a period of 1 minute.
- Turn in the direction of the holding side through more than 180° to either intercept the inbound leg or return to the fix (you will actually cut across the inbound leg, and re-intercept it from the holding side).
- On reaching the fix, turn to follow the holding pattern.

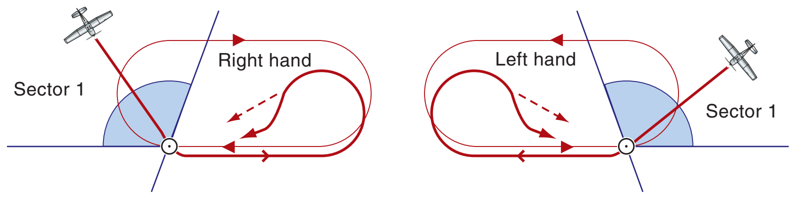


Figure 28-8 The Sector 1 parallel entry.

Sector 2 Entry is a Teardrop Entry

- Fly to the fix and turn to a heading for a 30° teardrop, to make good a track within the pattern (on the holding side) at 30° to the reciprocal of the inbound leg for a period of one minute.
- Turn in the direction of the holding pattern to intercept the inbound leg.
- Track to the fix, and proceed with normal holding patterns.

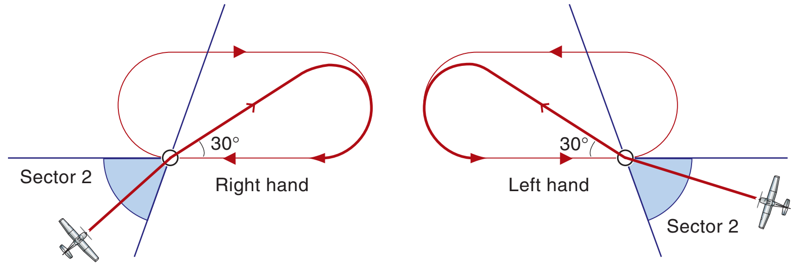


Figure 28-9 The Sector 2 teardrop entry.

Sector 3 Entry is a Direct Entry

- Fly to the fix and turn to follow the holding pattern
- If a full 180° turn (or greater) is required to take up the outbound heading, then start turning as soon as you reach overhead the fix. If, however, the turn to the outbound leg is less than 180°, then hold heading for an appropriate time past the fix before commencing the standard-rate turn. For instance, if the turn is less than 180° by 45° (which at standard-rate of 3° per second would take 15 seconds), maintain the original heading for 15 seconds before turning.

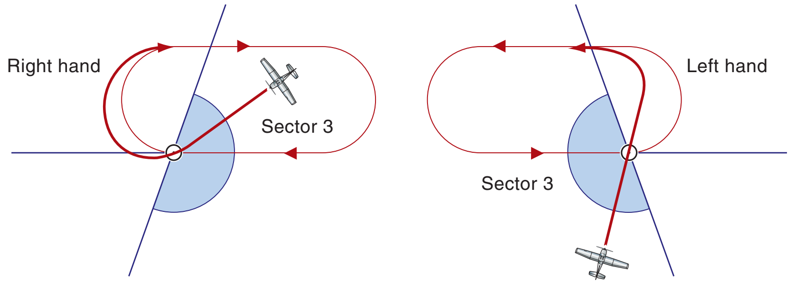


Figure 28-10 The Sector 3 direct entry.

Entering a holding pattern correctly and efficiently, and at the right speed (175 KIAS or less for propeller-driven aircraft), is a sign of a good instrument pilot. Holding patterns often precede an instrument approach, so a good holding pattern, including the entry, is a good start to the approach.

You should report at the holding fix and report your altitude as you fly over it initially. You should also report leaving the holding fix as you depart the holding pattern having received a further clearance.

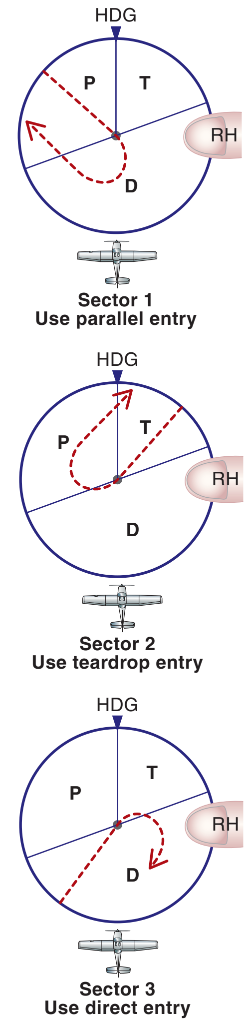


Figure 28-11 Visualizing the sector entry on the HI—standard left-hand pattern.

How to Determine the Sector Entry

There are two simple methods of determining which sector entry to use when joining a holding pattern—one method using a chart, the other visualizing the entry on the heading indicator.

Method A—On a Chart.

This method involves sketching the allocated holding pattern on your chart, placing the 70° line over the fix and the one-third point of the outbound leg, and then determining your sector entry. This is the traditional method shown in the previous figures.

Method B—Using the Heading Indicator (HI).

It is easy to visualize the entry using the heading indicator as you approach the holding fix. First, imagine the holding fix to be at the center of the HI. For the standard *right-hand holding pattern*, place your right thumb on the HI and imagine a line sloping up to the right at the 70° position relative to your heading. The teardrop sector is immediately above your thumb; (Thumb = Teardrop). If the inbound course of the holding pattern lies:

1. Ahead to the left—a Sector 1 parallel entry.
2. Ahead to the right—a Sector 2 teardrop entry.
3. Behind—a Sector 3 direct entry.

> **Note.** The easiest way to determine in which sector the inbound course lies is to note where the outbound course from the holding fix is. For instance, if the inbound course of the holding pattern is MC 060, then look for its reciprocal 240 on the HI.

For the nonstandard *left-hand holding pattern*, the situation ahead is simply reversed. Place your left thumb on the HI and imagine a line sloping up to the left at the 70° position relative to your heading. The teardrop sector is immediately above your thumb; (Thumb = Teardrop). If the inbound course of the holding pattern lies:

1. Ahead to the right—a Sector 1 parallel entry.
2. Ahead to the left—a Sector 2 teardrop entry.
3. Behind—a Sector 3 direct entry.

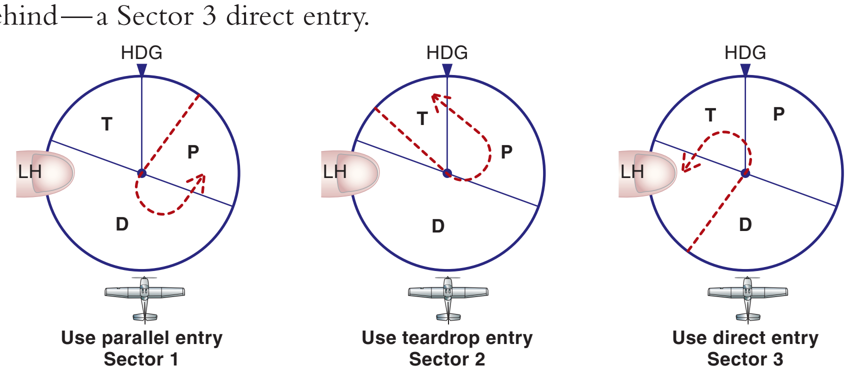


Figure 28-12 Visualizing the sector entry on the HI nonstandard left-hand pattern.

Holding at an NDB

Many holding patterns use an NDB or locator as the holding fix. In figure 28-13, typical ADF indications are shown as the pilot initially tracks to the NDB, and then joins the holding pattern. Passage over the NDB is indicated by the ADF needle swinging from ahead to behind.

Timing on the outbound leg should begin abeam the fix. If you cannot determine the abeam position, then commence timing at the wings-level position at completion of the outbound turn.

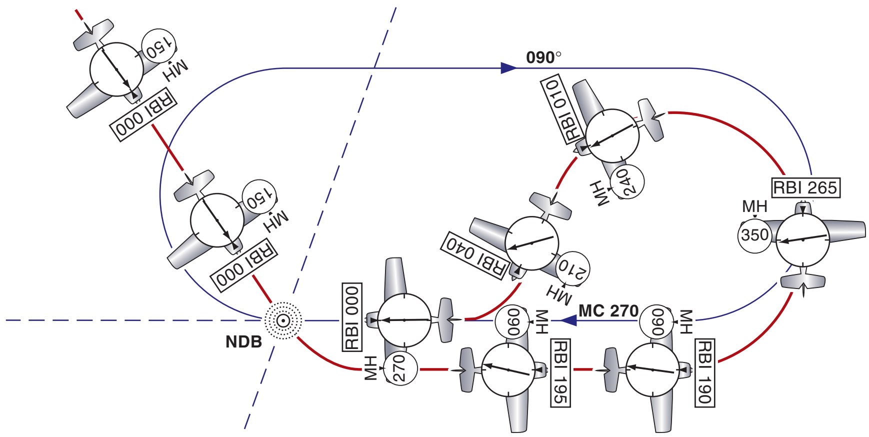


Figure 28-13 Making a Sector 1 entry using the ADF.

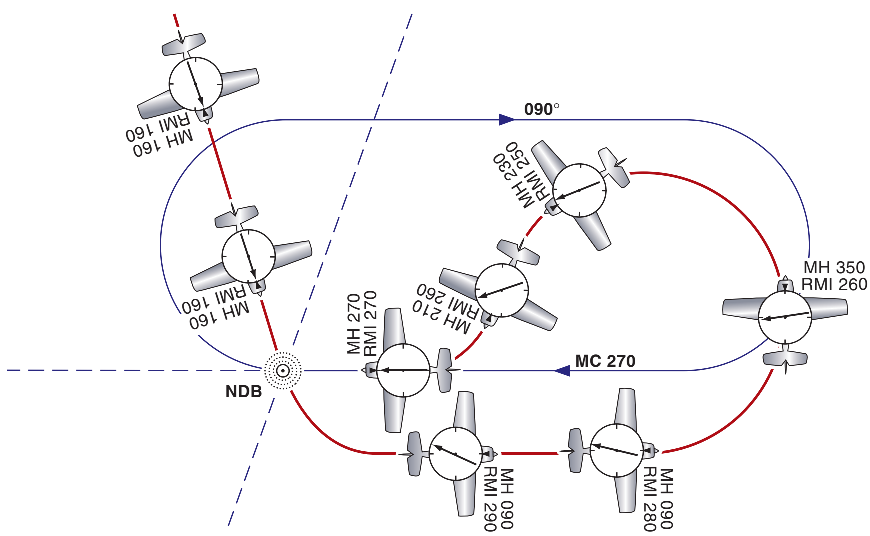


Figure 28-14 Making the same Sector 1 (parallel) entry using an RMI.

Holding at a VOR

Many holding patterns use a VOR ground station as the fix. In figure 28-15, typical VOR cockpit indications are shown as the pilot initially tracks to the VOR ground station, and then joins the racetrack holding pattern. Passing overhead the fix will be indicated by the first complete reversal of the TO-FROM flag.

While not essential, you may track out on the teardrop entry with the appropriate radial selected in the OBS. What is essential, however, is that you must select the inbound course in the OBS throughout the holding pattern.

Timing of the outbound leg should commence at the abeam fix position, indicated by the TO-FROM flag changing from FROM to TO, provided the inbound course is selected in the OBS.

Remember that when flying outbound in the pattern you will be flying a heading, and not tracking on a radial. When outbound, the VOR indicator will show reverse commands (since it has the inbound course selected in the OBS), with the CDI on the opposite side of the instrument to the inbound course.

When turning inbound, however, you will be heading in the same direction as the course selected in the OBS, and so the VOR indicator will be a command display. The usual VOR cockpit indicator is not heading-sensitive, hence the reverse commands outbound; if you are lucky enough to have an HSI, then the slaved compass card will make it a command instrument throughout the whole pattern.

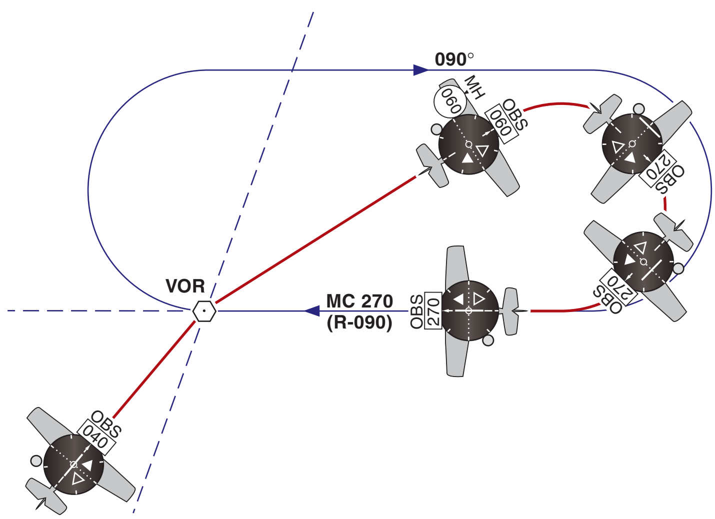


Figure 28-15 Making a Sector 2 entry using the VOR.

Holding at a VOR/VOR Fix

Holding at a fix defined by two VOR radials, as many intersections are, is made easier if you have two VOR sets in the cockpit.

- *Use VOR-1* to track on the desired course, which may be an airway; and
- *Select VOR-2* to the crossing radial that pinpoints the fix. When its CDI centers, you are at the fix.

If you select the crossing radial (*from* the VOR, rather than the bearing to the station) on VOR-2, the CDI will be on the *same side* as the ground station as you approach the radial, will center, and then move to the other side as you pass the radial.

It may be difficult to determine the abeam position outbound in this pattern, since you are abeam an intersection rather than a ground station, in which case you can start the outbound timing from wings-level on the outbound heading.

Ensure that you copy the holding instructions accurately: "Cleared to Avery intersection, hold southwest on Victor-One-Two-Three" is a different clearance from "Cleared to Avery intersection, hold northeast on Victor-One-Two-Three."

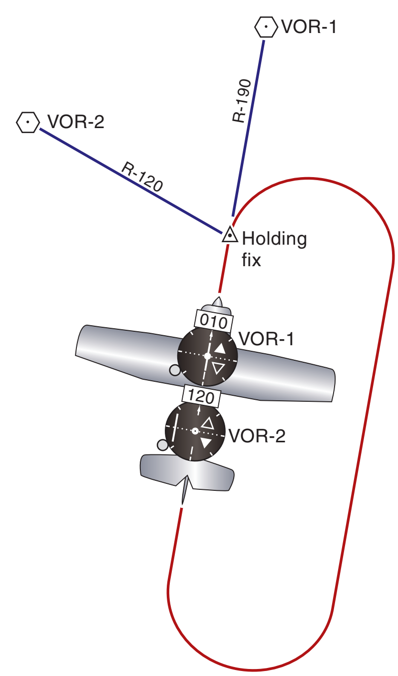


Figure 28-16 Holding at an intersection using two VORs.

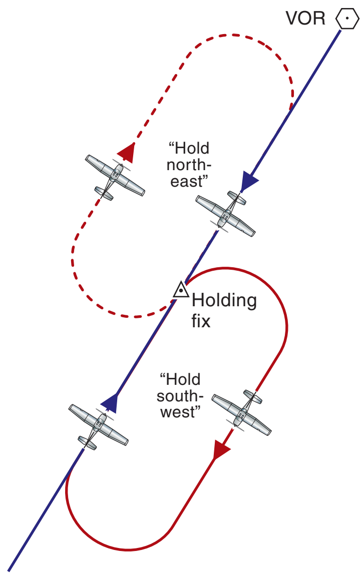


Figure 28-17
Holding toward, and away from, a VOR at an intersection.

After crossing the fix initially, select the OBS to the inbound course of the holding pattern. If you are holding toward the VOR, the TO flag will show throughout the pattern. If you are holding away from the VOR, the FROM flag will show throughout the pattern.

With only one VOR cockpit display, holding at a fix defined by radials from two different VOR ground facilities becomes a little more difficult, with switching between VORs necessary.

When established on the course to the fix using the *tracking* VOR, and approaching the fix, select the frequency of the second VOR and set the *intersecting* radial in the OBS.

When the CDI centers, you are at the fix, and can start the standard-rate turn to the outbound leg.

There is no need to reselect the tracking VOR and the inbound course until you are about to turn inbound. Then, having established the airplane on the inbound course, and being certain of tracking overhead (or close to the fix) by the tracking CDI remaining centered, reselect the second VOR and its radial to determine the fix.

Repeating the procedure amounts to only two re-selections every pattern.

Holding at a VOR/DME Fix

Use the seven T's at each turn to ensure that all appropriate tasks are completed. Time-turn-twist-tracking-throttle-talk-think. While you should consider all of the T's, some of them need not be actioned in a holding pattern, such as twist, because the OBS will remain the same right around the pattern.

A holding fix can also be specified using a DME distance along a particular VOR radial. Many intersections are determined in this manner.

In a DME hold, the controller will specify the length of the outbound leg that you should fly, rather than specifying an inbound time. If the fix distance is 15 DME, and the specified leg length is 5 NM, then you would turn outbound at the 15 DME holding fix, and commence your turn inbound at:

- 20 DME if the inbound holding course is toward the VOR; or
- 10 DME if the inbound holding course is away from the VOR).

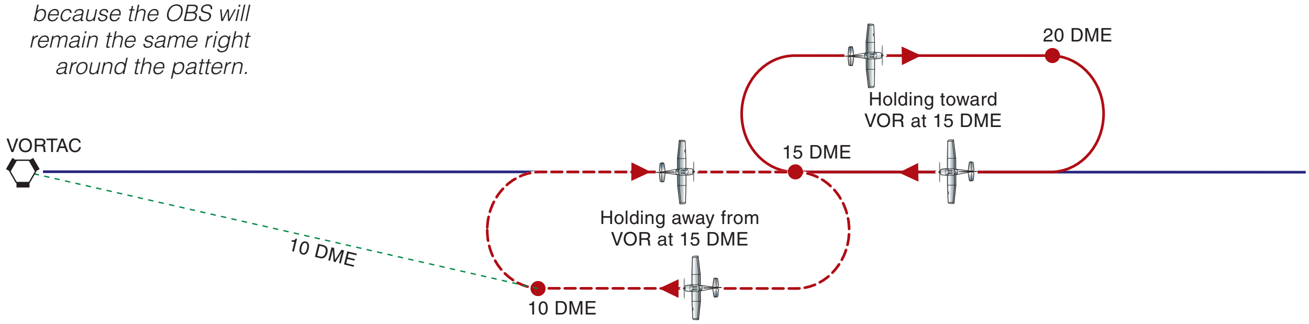


Figure 28-18 Holding at a VOR/DME fix.

Holding at an ILS Outer Marker

This method of holding is often shown on ILS approach charts. The inbound course to the holding fix is the localizer (supported by the locator NDB if needed), with the fix being defined by passage over the outer marker or locator. (See figure 28-19.)

Because the localizer CDI is four times as sensitive as the VOR CDI, the locator NDB can prove useful when intercepting the inbound course, since close in to the airport the CDI may move from the full-scale position with a rush, whereas the ADF needle will move progressively and continually show position.

Timed Approaches from a Holding Fix

At busy airports, ATC may use timed approaches by assigning each pilot in an approach sequence a time to depart the holding fix inbound. For nonprecision approaches (VOR, NDB), the holding fix may be the final approach fix (FAF).
For precision approaches (ILS), the holding fix may be the outer marker, or a fix used in lieu of the outer marker. Nonradar procedures or radar vectors may be used by ATC.

When given a time to leave the holding fix, you should adjust the timing of the last outbound leg to leave the fix inbound as closely as possible to the designated time. Normally the preceding aircraft will be two minutes ahead of you, and the one to follow you will be given a time two minutes behind you.

Adjust the timing of the last outbound leg to leave the fix inbound at the designated time.

The normal separation is 2 minutes or 5 miles, which will be extended to 3 minutes or 6 miles for a small aircraft behind a heavy aircraft. If a number of aircraft are holding in a stack, they will be descended progressively by ATC as the lower levels in the pattern are vacated.

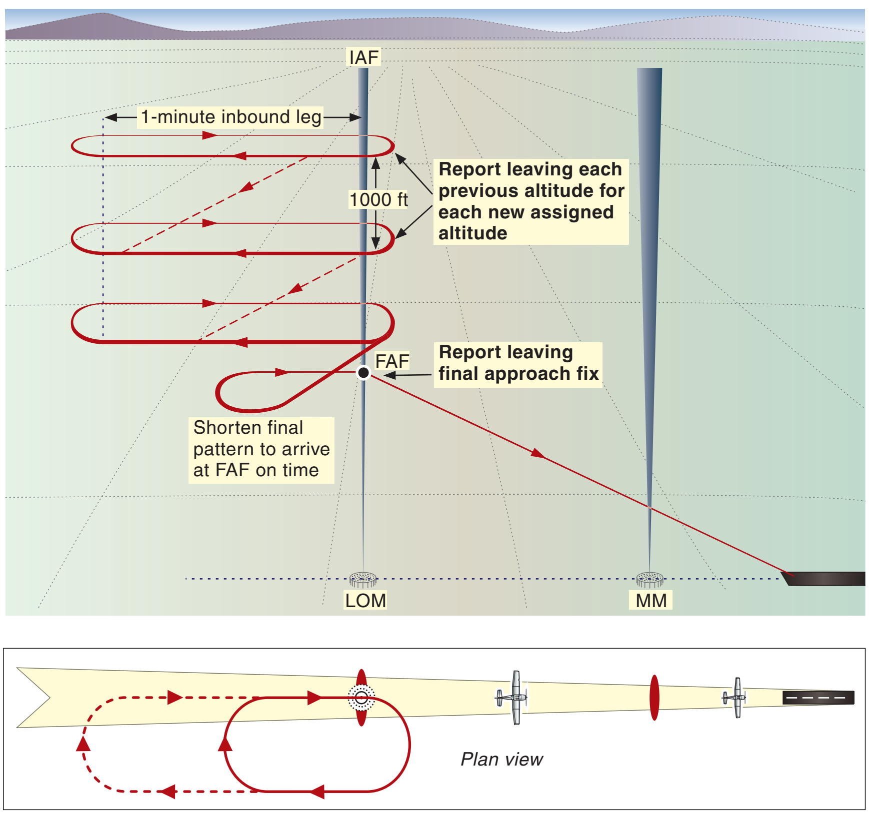


Figure 28-19 Separation on approach and landing using timed approaches.

Timed approaches will only be conducted under the following conditions:

1. A control tower is in operation.
2. Direct ATC/pilot communications are maintained.
3. If more than one missed approach procedure is available, none require a course reversal.
4. If only one missed approach procedure is available, course reversal is not required, and the reported ceiling and visibility are equal to or better than the highest prescribed circling minimums for the approach.
5. When cleared for the approach, the pilot shall *not* make a procedure turn.

Procedure Turns

A procedure turn is a common maneuver used for course reversal, and is often used to position an airplane on the intermediate approach segment or final approach course of an instrument approach to land. The maximum speed in a procedure turn is not greater than 200 KIAS, and the maneuver should normally be completed within 10 NM of the procedure turn fix (or as published on the individual chart). This is commonly known as the *procedure turn limit*. The procedure turn fix can be identified on the profile view of the approach as the point where the instrument approach procedure begins.

A procedure turn can be performed anywhere within the 10 NM limit, but it must be made in the direction depicted on the approach chart. In other words, that entire side of the approach course is protected. If you are being radar vectored or if "NoPT" is shown on the chart, then you do not need to perform a procedure turn. If there is no procedure turn depicted, then a procedure turn is not authorized.

The 45°/180° Procedure Turn

The 45° procedure turn is the course reversal procedure most commonly shown on instrument approach charts. It is the maneuver used to reverse the direction of an airplane flying outbound, and to establish it inbound on the intermediate or final approach course.

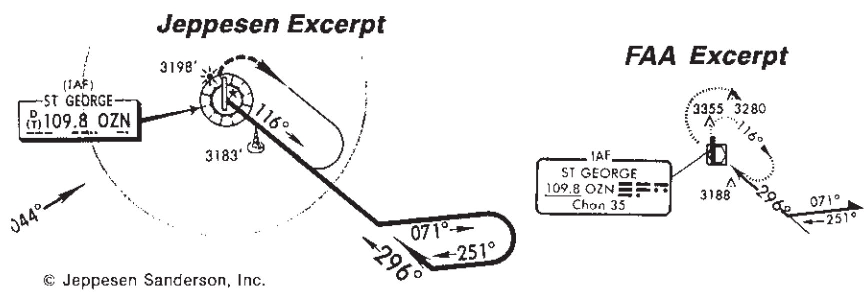


Figure 28-20
The 45° procedure turn.

The 45° procedure turn consists of:

- an outbound track from the fix (normally for one or two minutes);
- a turn of 45° away from the outbound track (usually held for one minute from the start of the turn, plus or minus wind correction in terms of both drift and time);
- a 180° turn in the opposite direction, to intercept the inbound track.

Left or right in a description of the procedure turn refers to the direction of the initial turn. Pilots may use other than the 45/80 degree turn. Unless a teardrop procedure track is depicted or a hold is shown, the type of turn is up to the discretion of the pilot.

The 80°/260° Procedure Turn

The 80° procedure turn may be used in lieu of the 45° procedure turn although, for various reasons, it is a less common method in the U.S. It consists of:

- an outbound course away from the fix;
- a turn of 80° away from the outbound course in the prescribed direction;
- followed almost immediately by a 260° turn in the opposite direction to intercept the inbound course.

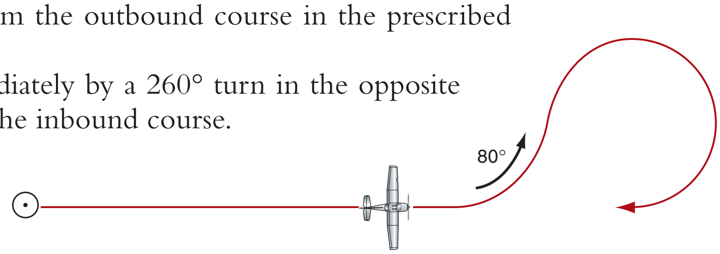


Figure 28-21
The 80° procedure turn.

If the initial turn is into a strong headwind, then the 80° heading can be held for a brief time (an extra 1 second per knot of headwind), before the 260° turn is commenced. If the initial turn puts a strong tailwind behind the airplane, then stop turning before 80° is reached, and gently roll immediately into the reversal turn.

The Base Turn or Teardrop Turn

The base turn, used to reverse direction by more than 180°, is a teardrop pattern which consists of:

- a specified outbound course and timing or distance;
- followed by a turn to intercept the inbound course.

A teardrop procedure, or penetration turn, is sometimes used to permit an aircraft to reverse direction and lose considerable altitude within reasonably limited airspace. It may consist of departure from an initial approach fix on an outbound course, followed by a turn toward and intercepting the inbound course prior to the intermediate fix or point (see figure 28-22).

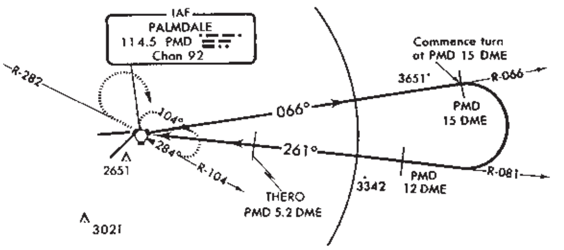


Figure 28-22 A teardrop turn (FAA chart).

A standard-rate turn in slower aircraft may result in too small a radius of turn, and a short straight leg might be required in the middle of the turn, before continuing the turn to intercept the inbound course. Teardrop turns must be flown as depicted.

Positioning in a Racetrack Pattern

Many instrument approaches start at the holding fix, and simply by carrying out a sector entry into the holding pattern, the airplane is in position to start the approach.

When a holding pattern replaces the procedure turn, the standard entry and the holding pattern must be followed, except when radar vectoring is provided or when NoPt is shown on the approach course.

However, if there is any delay in approval to start the approach or if you need to lose excess altitude, the airplane can remain in the holding pattern (with ATC approval).

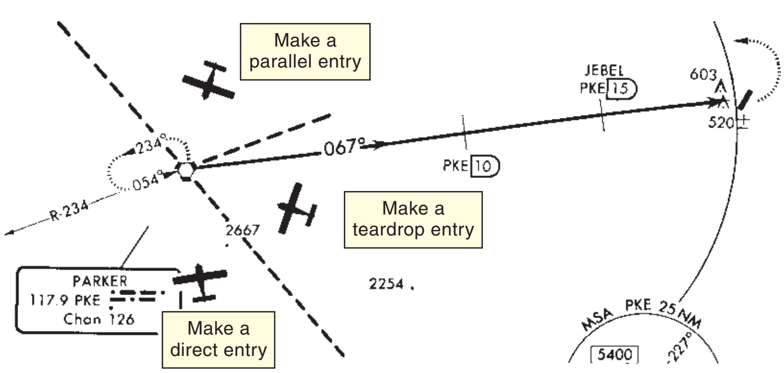


Figure 28-23 Positioning in a holding pattern (FAA chart).

DME Arcs

A DME arc is a curved maneuver flown at a specific distance from the DME ground facility. It is usually flown as a series of short straight legs, rather than as a steady curve. The DME arc is often used to transition from the en route phase of a flight to the intermediate approach segment or final approach course of an instrument approach to land. DME arcs are also used in some Departure Procedures (DPs).

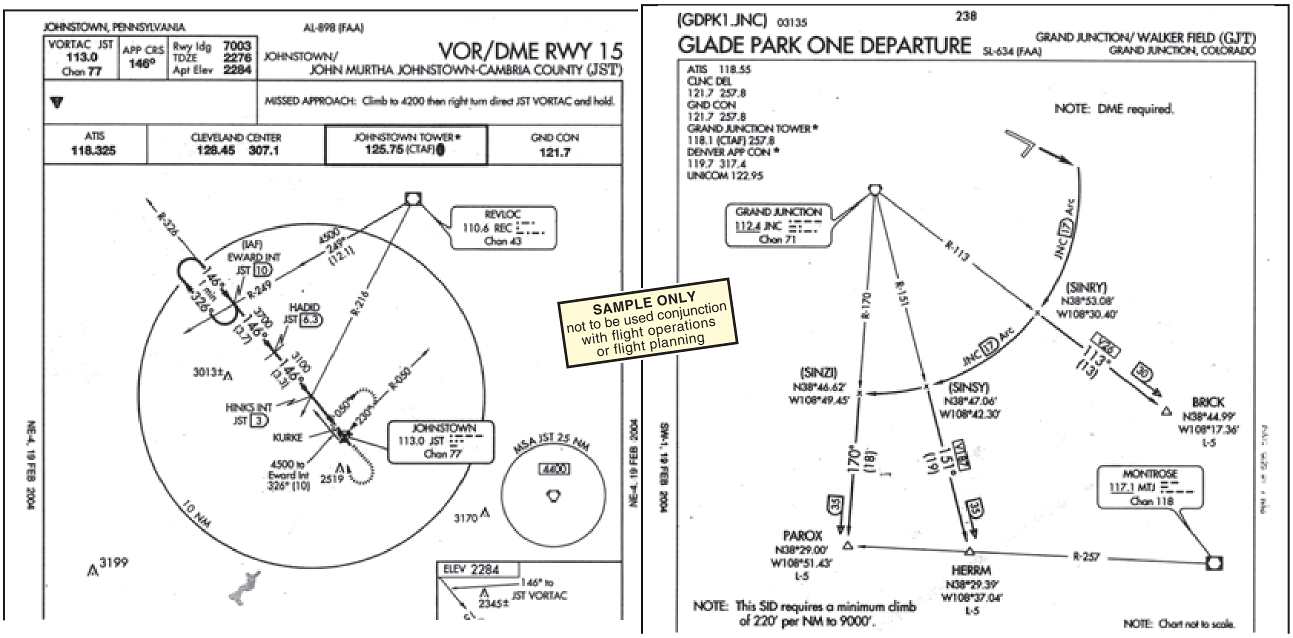


Figure 28-24 DME arcs (FAA charts).

Intercepting a DME Arc

If you are tracking directly to a VOR/DME ground facility, then you will have to turn 90° to intercept the DME arc. Starting the 90° turn with just under 1 NM to run to the arc should give you an accurate intercept, to join the 10 DME arc, start turning at about 10.5 DME. The heading to use can be easily read off the VOR indicator or the HSI 90° wingtip position prior to starting the turn.

Maintaining a DME Arc Using an RMI or ADF

The easiest way to maintain a DME arc is to use an RMI (or an ADF if appropriate), by keeping the needle approximately on the wingtip, and flying a series of short straight legs, keeping the DME distance within the required limits. The protected airspace of a DME arc is the same as an airway, extending 4 NM either side of the arc, but you should aim to stay within 1 NM of the specified arc.

If the airplane flies a straight path tangential to the arc, it will fly away from it, the DME distance will increase, and the needle will fall behind the wingtip. As the needle falls to 10° behind the wingtip, turn 20° in the direction of the arc, which will place the needle 10° ahead of the wingtip.

Then fly a constant heading until the needle falls behind the wingtip again, and repeat the procedure. The DME distance will decrease slightly as you fly abeam the ground station, and then increase again. Make your turns so that the DME arc accuracy is met. If anything, a DME arc is easier to maintain if you are a little on the inside of it, since a straight path will tend to increase the distance and bring you back onto the arc, whereas if you are on the outside of it and do not make a correcting turn, you will fly further away from the arc.

Having conquered the DME arc with 20° heading changes, you might like to try holding it more accurately with only 10° heading changes, from 5° ahead of the wingtip reference to 5° behind it. A good way to practice DME arcs is to fly part of a 12 DME arc around a VORTAC in one direction, turn and fly an 11 DME arc in the other direction, followed by progressively smaller arcs in alternating directions.

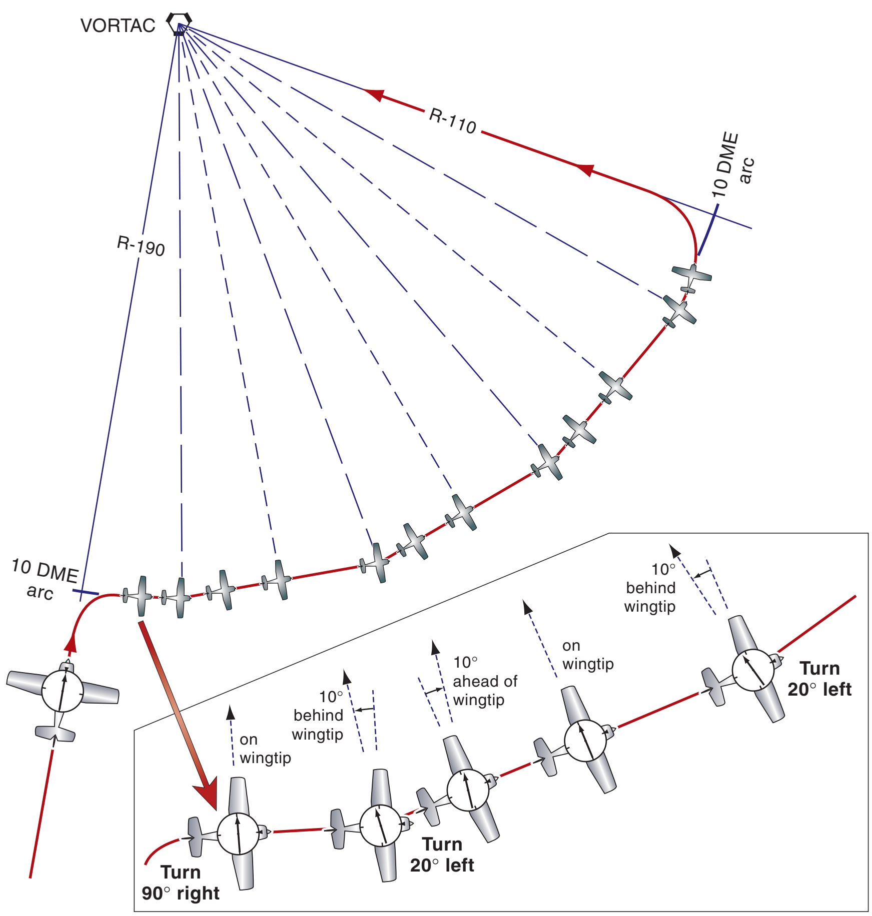


Figure 28-25 Flying a DME arc.

Allowing for Wind in a DME Arc

If there is any crosswind, then a wind correction angle into the wind will be required, and the abeam reference will need to be either a little ahead of the wingtip (if the wind is from within the arc), or a little behind the wingtip if the wind is from outside the arc. The wind effect will change as your heading changes. Monitor DME distance and keep it within limits with appropriate turns. See figure 28-26.

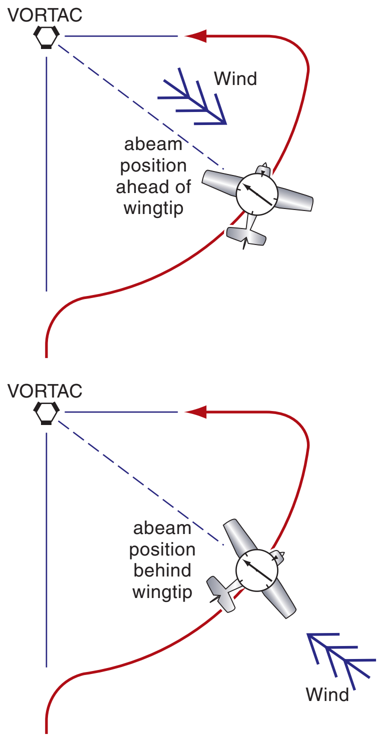


Figure 28-26
Allowing for a crosswind in a DME arc.

Maintaining a DME arc Using the VOR Indicator

To use a normal VOR cockpit display to maintain a DME arc, the easier method is to select the radial 10° ahead of the current position, just giving full-scale CDI deflection on the same side as the VOR ground facility.

As you approach the selected radial, the CDI will center, and then move to full-scale deflection on the side away from the arc. Make a 20° correction turn in the direction of the arc, and select a new radial 20° further on, causing the CDI to move to full-scale on the inside of the arc.

Monitor the DME distance and keep it within limits with appropriate turns. For each deviation of ½ NM outside the arc, a correction of 10–20° toward the arc should be sufficient.

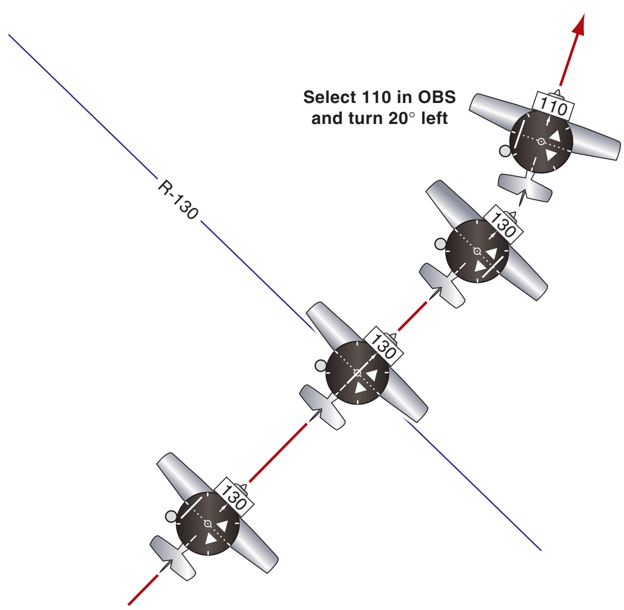


Figure 28-27 Maintaining a DME arc using VOR indicator.

Intercepting the Approach Radial from a DME Arc

As you move around the arc, you will eventually approach the inbound radial. On a 10 DME arc, commencing the intercept turn 5° before reaching the required radial is generally sufficient (at half-scale deflection if using a VOR) for you to roll out right on the inbound course. Closer in than 10 DME, or if traveling at high speed, you should increase the lead angle. Some charts specify a lead-in radial to the inbound course as guidance. You may like to vary this depending on your airspeed and the wind-effect. Tracking inbound, you should set the inbound course with the OBS so that the VOR indicator is a command instrument.

Review 28

Holding Patterns, Procedure Turns, and DME Arcs

1. The shape of a typical holding pattern is a:
   a. circle.
   b. racetrack.
   c. rectangle.
   d. ellipse.
2. How long will a complete one-minute holding pattern take if flown perfectly in no-wind conditions?
3. How much should the timing be adjusted by in strong head/tailwind conditions on the outbound leg of a holding pattern?
4. How much should the timing be adjusted by with an estimated 15-knot tailwind component on the outbound leg of a holding pattern?
5. While tracking guidance is usually available to you on the inbound leg to the holding fix, on the outbound leg there generally is none. What correction is recommended on the outbound leg in strong crosswind conditions?
6. If a 5° WCA to the left is required to track correctly on the inbound leg of a holding pattern, what is a suitable correction on the outbound leg?
7. Sketch three diagrams of a holding pattern showing the three sector entries.
8. What is a Sector 1 entry also known as?
9. What is a Sector 2 entry also known as?
10. What is a Sector 3 entry also known as?
11. Sketch the pattern of a 45°/180° procedure turn used to reverse direction.
12. Refer to figure 28-28. You arrive at the 15 DME fix steering MH 350 with an ATC clearance to: *"hold west of the one five DME fix on the zero eight six radial of the XYZ VORTAC, five mile legs, left turns."* What is the correct procedure?
13. Refer to figure 28-29. You arrive at the 15 DME fix steering MH 250 with an ATC clearance to: *"hold west of the one five DME fix on the two six eight radial of the DEF VORTAC, five mile legs, left turns."* What is the correct procedure?
14. When should the timing for the first leg outbound in a nonstandard holding pattern be commenced?
15. If the position abeam the holding fix cannot be determined, when should you commence timing?
16. To ensure proper airspace protection, what is the recommended maximum speed in a holding pattern for propeller-driven aircraft?
17. What is the recommended maximum speed in a holding pattern above 14,000 feet MSL for propeller-driven aircraft? What is it if you are flying a jet?
18. What is the recommended maximum speed for a jet in a holding pattern below 14,000 feet MSL? What is the lowest holding altitude that provides adequate protection known as?
19. When should the timing outbound begin if established in a holding pattern at an NDB?
20. When should the timing outbound begin if established in a holding pattern at a VOR?

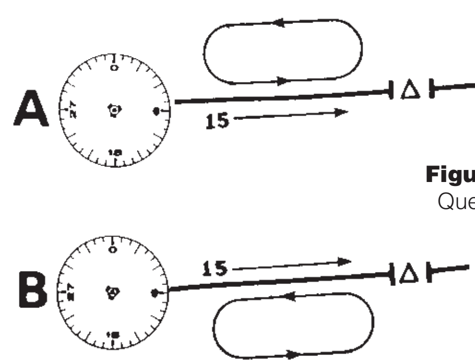


Figure 28-28 Question 12.

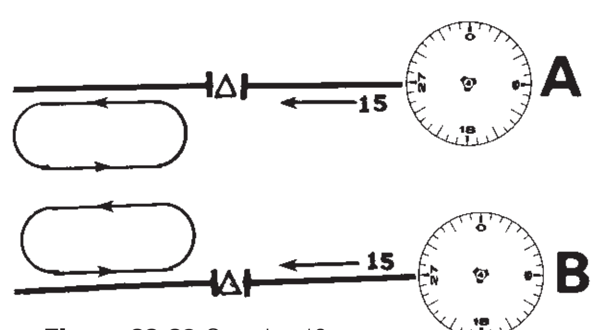


Figure 28-29 Question 13.

Refer to figure 28-30 for questions 21 to 23.

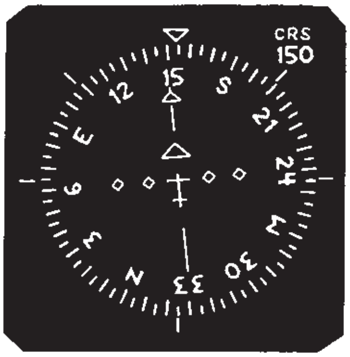


Figure 28-30 Questions 21 to 23.

21. A pilot receives the ATC clearance: *"cleared to the Point Reyes VORTAC, hold west on the two seven zero radial."*
- **a.** Will the pattern be left or right turns?
- **b.** What is the MC for the inbound leg of the holding pattern?
- **c.** What is the recommended procedure to enter the holding pattern?
- **d.** In which direction is the first turn after crossing the VOR?
- **e.** What will be your approximate MH?

22. A pilot receives the ATC clearance: *"cleared to the Point Reyes VORTAC, hold north on the three six zero radial, left turns."*
- **a.** Will the pattern be left or right turns?
- **b.** What is the MC for the inbound leg of the holding pattern?
- **c.** What is the recommended procedure to enter the holding pattern?
- **d.** In which direction is the first turn after crossing the VOR?
- **e.** What will be your approximate MH?

23. A pilot receives this ATC clearance: *"cleared to the Point Reyes vortac, hold south on the one eight zero radial."*
- **a.** Will the pattern be left or right turns?
- **b.** What is the MC for the inbound leg of the holding pattern?
- **c.** What is the recommended procedure to enter the holding pattern?
- **d.** In which direction is the first turn after crossing the VOR?
- **e.** What will be your approximate MH?

Refer to figure 28-31 for questions 24 to 27.

Figure 28-31 Questions 24 to 27.

24. A pilot receives this ATC clearance: *"hold east of the Dingo VOR on the zero niner zero radial, left turns."*
- **a.** Will the pattern be left or right turns?
- **b.** What is the MC for the inbound leg of the holding pattern?
- **c.** What is the recommended procedure to enter the holding pattern?
- **d.** In which direction is the first turn after crossing the VOR?
- **e.** What will be your approximate MH?

25. A pilot receives this ATC clearance: *"hold south of the Dingo VOR on the one eight zero radial."*
- **a.** Will the pattern be left or right turns?
- **b.** What is the MC for the inbound leg of the holding pattern?
- **c.** What is the recommended procedure to enter the holding pattern?
- **d.** In which direction is the first turn after crossing the VOR?
- **e.** What will be your approximate MH?

26. A pilot receives this ATC clearance: *"hold north of the Dingo VOR on the three six zero radial, left turns."*
- **a.** Will the pattern be left or right turns?
- **b.** What is the MC for the inbound leg of the holding pattern?
- **c.** What is the recommended procedure to enter the holding pattern?
- **d.** In which direction is the first turn after crossing the VOR?
- **e.** What will be your approximate MH?

27. A pilot receives this ATC clearance: *"cleared to the Dingo VOR, hold west on the two seven zero radial."*
   a. Will the pattern be left or right turns?
   b. What is the MC for the inbound leg of the holding pattern?
   c. What is the recommended procedure to enter the holding pattern?
   d. In which direction is the first turn after crossing the VOR?
   e. What will be your approximate MH?

Refer to figure 28-32 for questions 28 to 30.

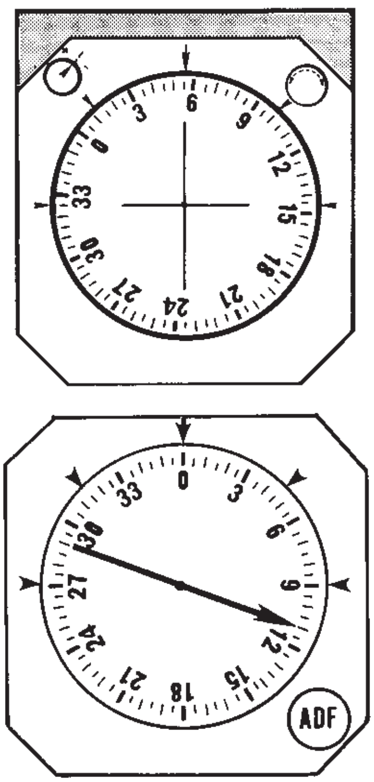


Figure 28-32 Questions 28 to 30.

28. You receive the ATC clearance: *"cleared to the Gaffa NDB, hold southwest on the two three zero degree bearing."* At station passage, you note the indications as shown in figure 28-32.
   a. Will the pattern be left or right turns?
   b. What is the MC for the inbound leg of the holding pattern?
   c. What is the recommended procedure to enter the holding pattern?
   d. In which direction is the first turn after crossing the NDB?
   e. What will be your approximate MH?

29. You receive this ATC clearance: *"cleared to the Gaffa NDB, hold northeast on the zero four zero degree bearing, left turns."* At station passage, you note the indications as shown in figure 28-32.
   a. Will the pattern be left or right turns?
   b. What is the MC for the inbound leg of the holding pattern?
   c. What is the recommended procedure to enter the holding pattern?
   d. In which direction is the first turn after crossing the NDB?
   e. What will be your approximate MH?

30. You receive this ATC clearance: *"cleared to the Gaffa NDB, hold southeast on the one four zero degree bearing, left turns."* At station passage, you note the indications as shown in figure 28-32.
   a. Will the pattern be left or right turns?
   b. What is the MC for the inbound leg of the holding pattern?
   c. What is the recommended procedure to enter the holding pattern?
   d. In which direction is the first turn after crossing the VOR?
   e. What will be your approximate MH?

31. Adjustments in timing of each holding pattern are made on which leg?

32. Where a holding pattern is specified in lieu of a procedure turn, what is the time limitation for executing the holding maneuver? When is the maneuver considered complete?

33. Does a control tower need to be in operation for a timed approach from a holding fix?

34. Does there need to be direct communication between the pilot and ATC for a timed approach from a holding fix?
35. Is any course reversal required for a timed approach from a holding fix if there is more than one missed approach procedure?
36. When making a timed approach from a holding fix at the outer marker, which fix should the pilot leave inbound at the assigned time? Can the holding pattern be adjusted to achieve this?
37. Does the pilot need to be in communications with the tower for a timed approach from a holding fix?
38. For a timed approach from a holding fix with only one missed approach procedure available, do the reported ceiling and visibility minimums need to be lower, equal to, or greater than the prescribed circling minimums for the instrument approach procedure?
39. What is a procedure turn commonly used for?
40. If you are far too high to commence an approach for which you have been cleared, can excess altitude be lost in the holding pattern?
41. A procedure turn should normally be completed within what distance of the procedure turn fix?
42. To maintain a right-hand DME arc with no crosswind component, where should the bearing pointer be in relation to the right wingtip?
43. To maintain a right-hand DME arc with a right crosswind component, where should the bearing pointer be in relation to the right wingtip?
44. To maintain a right-hand DME arc with a left crosswind component, where should the bearing pointer be in relation to the right wingtip?
45. What is a suitable heading change for each ½ NM you have drifted outside a DME arc?
46. Can course reversal or positioning to commence an instrument approach be achieved by entering an appropriate holding pattern?
47. You are required to hold at an intersection, with an EFC time of 1245. At 1238 you experience a two-way radio communications failure. What action should you take with your transponder? At what time should you depart the holding fix? Should you continue on the cleared route in IFR conditions?

Answers are given on page 789.

Normal Instrument Flight on a Partial Panel 29

The failure of a flight instrument in instrument conditions is one of the most challenging situations a pilot can face. We trust the flight instruments with our safety, so when one fails we must detect the failure as quickly as possible. Continuing to rely on an instrument that is providing inaccurate information will make it difficult to maintain aircraft control and ultimately could lead to an unusual attitude or worse. "Partial panel" is the term used when one or more of the aircraft's flight instruments is/are not working. Glass cockpit airplanes, even with their advanced technology, are still not immune to flight instrument failures, and failures of flight instruments are becoming more and more rare as technology improves. However, the knowledge and skill necessary to safely perform partial panel flight is important to master regardless of whether your aircraft has a PFD or traditional instruments.

In actual IMC flight, partial panel is an emergency and should be declared as such. Information given in the chapter is for training/survival purposes only.

The three fundamental skills of instrument flying are:

- instrument cross-check (scan);
- instrument interpretation; and
- aircraft control.

For the exercises on the partial panel, one or more of the flight instruments is assumed to have failed. A good scan to begin with if you suspect a failure is the inverted-V scan, which helps you to quickly establish which instrument or system has failed.

It is possible to cope quite comfortably once you know what instruments are available to you on a partial panel. Even though there is less information available, the airplane flies exactly the same and responds in exactly the same way to any pilot control inputs, regardless of which instruments are or are not working. It is helpful to cover inoperative instruments to prevent confusion.

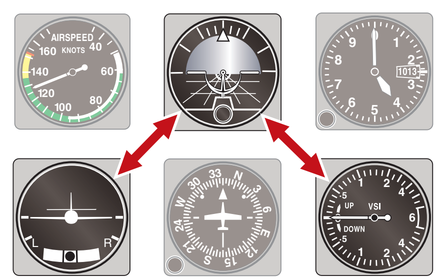


Figure 29-1
Use the inverted-V scan to identify a failure.

Establishing a Failure

Cross-Check Available Instruments

If any instrument has failed, then a cross-check of the other instruments should enable the pilot to isolate it and disregard its indications. The AI is the master instrument, and its loss is perhaps the most difficult to cope with. The AI could be lost as a result of its power source failing (electrical or vacuum), or its gyroscope could tumble and become unusable during an extreme unusual attitude. It may re-erect itself after some time.

Vacuum Failure

In many aircraft, both the AI and HI are powered by suction or pressure. Their gyroscopes are driven by an airflow induced through them by the vacuum system. A suction failure could lead to the loss of both of these instruments. This is the common partial panel situation (unusable attitude indicator and heading indicator). In such a case, the aircraft is controlled by reference to the *performance instruments*:

1. Nose-high or nose-low information can be derived from the ASI, altimeter and VSI.
2. Bank information can be derived from the electrically powered turn coordinator, with the magnetic compass available to supply heading information.
3. Coordination is shown by the simple ball that never suffers a power failure.

The ASI, altimeter, VSI and magnetic compass may experience some lag or delay before the precise performance is indicated after some attitude or power change, so any new attitude should be held for a few seconds to allow the readings to settle down, before additional control adjustments are made.

Electrical Failure

An electrical failure may make electrically driven instruments unusable. This could include the attitude indicator, the heading indicator and the turn coordinator. An electrical failure could also make the pitot heater unavailable, leading to icing problems with the pitot-static system unless the pilot avoids icing conditions. Usually, electrically powered gauges will display an OFF warning flag when power is lost.

Electrical failure will make the radios unusable, unless there is an emergency source of power available (such as the battery). Instrument navigation without VOR or the ADF is difficult. Radar assistance may be requested, but this requires NAV/COM to be working.

Following an electrical failure, check that the master switch is ON, and check any circuit breakers or fuses for the particular item. Do not interrupt your scan of the operating flight instruments for more than a few seconds at a time. If an electrically powered instrument has indeed failed and cannot be restored, then cross-checking the other instruments will help to compensate for its loss.

Note. The master switch in some aircraft also acts as a circuit breaker, particularly those master switches that are split rocker switches, and so they can be turned off and on to recycle. This may restore full or partial electrical power.

Pitot Tube Blockage

Figure 29-2
Pitot tube covers.

A damaged pitot tube affects the airspeed indicator, as will an iced-up pitot tube, but the use of electric pitot heat in icing conditions generally prevents the occurrence of icing problems in the pitot-static system.

A more serious situation is a pitot cover that has not been removed prior to flight. As well as probably being impossible to remedy in flight, it indicates that the pilot has been derelict in duties at the preflight stage. Preflight checks of the pitot tube are important. Remove the pitot cover, and check the pitot tube for damage and blockages, possibly by insects.

If the ASI becomes unusable in flight, then all is not lost. Selecting a suitable attitude on the AI and suitable power on the power indicator should result in the desired performance, even though airspeed information is not available.

Static Vent Blockage

A damaged or blocked static system affects the airspeed indicator, the altimeter, and the VSI. If totally blocked, a constant static pressure may be trapped in the system. The altimeter indication will not alter, and the VSI will remain on zero, even when the airplane changes altitude. In clouds or at night, this could be dangerous.

The ASI will indicate an incorrect airspeed. The indicated airspeed is a measure of dynamic pressure (*dynamic pressure = pitot (total) pressure - static pressure*). Therefore, as the airplane climbs, the too-high static pressure trapped will cause the ASI to read too low. The danger on the climb is to follow the false ASI reading and speed up, possibly exceeding V_{NE}.

Conversely, on descent the trapped static pressure will be too low, causing the ASI to read too fast. The danger on descent is to follow the false ASI indication and slow up, possibly to the point of stalling.

As a safeguard against the undesirable effects of a blocked static system on pressure instrument indications, most aircraft are fitted with an alternate static source in the cockpit. If this is selected by the pilot when a static blockage occurs, or is suspected, then the affected instruments should become usable again.

As a last resort, if both normal and alternate static sources are blocked and unusable (a most unlikely event), the instrument glass of the VSI can be broken to admit cabin static pressure into the whole static system. If you do not damage the inner mechanism of the VSI, it will read in reverse, showing a descent when the aircraft is climbing, and vice versa. This is because the direction of the airflow through the "metered leak" is reversed.

If you do damage the inner workings of the VSI when you break the glass, then the VSI could indicate anything.

Cabin pressure in a nonpressurized aircraft is slightly lower than the external static pressure, because of the venturi effect caused by the airplane's motion through the air. This slightly lower static pressure will cause the altimeter to read 50-100 feet too high, and the ASI to read 5 knots or so too high. The VSI will show a brief climb as the lower static pressure is introduced, but it will then settle down and read accurately.

Adapting to Suit the Situation

When using only a partial panel make smooth and gentle changes using the "Change—Check—Hold—Adjust—Trim" technique. This allows time for performance instruments to stabilize.

Whatever instrument fails, the resourceful pilot should be able to cope, using whatever resources remain, and adapting control of the aircraft to suit the situation. For instance, without the aid of the attitude indicator, which responds directly and immediately to any attitude changes, the effects of inertia appear to be more marked than usual.

Therefore, when using only a partial panel, the pilot must develop the ability to make smooth and gentle changes using the *"Change—Check—Hold—Adjust—Trim"* technique, using the instruments that are available, and avoiding chasing the needles.

Because the immediate and direct presentation of attitude changes on the attitude indicator is missing on a partial panel, and because performance instruments like the ASI, altimeter and VSI suffer some lag, it is even more important that the pilot holds any new attitude to allow time for the performance instruments to stabilize, before further adjustments are made.

Therefore, in a partial panel situation, reduce the rate and extent of control movements compared with when operating on a full panel. The lag in readings will be less severe, and there will be less tendency to over-react by chasing the needles. Small control movements should be made, then checked and held while the performance instruments catch up with the change and settle into their correct readings. Then, fine-tune with further adjustments if necessary, before trimming off any steady control pressures.

On partial panel, just look at the instruments that give you the information you want.

The scan for each maneuver when using a partial panel will need to be modified to increase reference to the serviceable instruments, and to bypass the unusable instruments. This is simpler than it sounds—just look at the instrument that will give you the information you want. If it is bank angle you want, and the AI is not usable, then refer to the turn coordinator. It will not tell you bank angle directly, but it will tell you if the airplane is turning and, if it is, which way and at what rate. From this information, you can gain some idea of bank angle.

During your early learning stages, actually covering the instruments not to be used will ensure that you do not respond to incorrect information obtained subconsciously from them.

Interpreting Pitch Attitude on a Partial Panel

The attitude indicator is a control instrument. It is the best guide to pitch attitude, since it gives a direct and immediate picture of the attitude of the airplane relative to the horizon. However, for practice in flying on a partial panel, it may not be available. If the attitude indicator is indeed unusable, then the pilot can determine the pitch attitude of the airplane using the three pressure instruments which derive their information from the pitot-static system. They are the airspeed indicator, the altimeter and the vertical speed indicator.

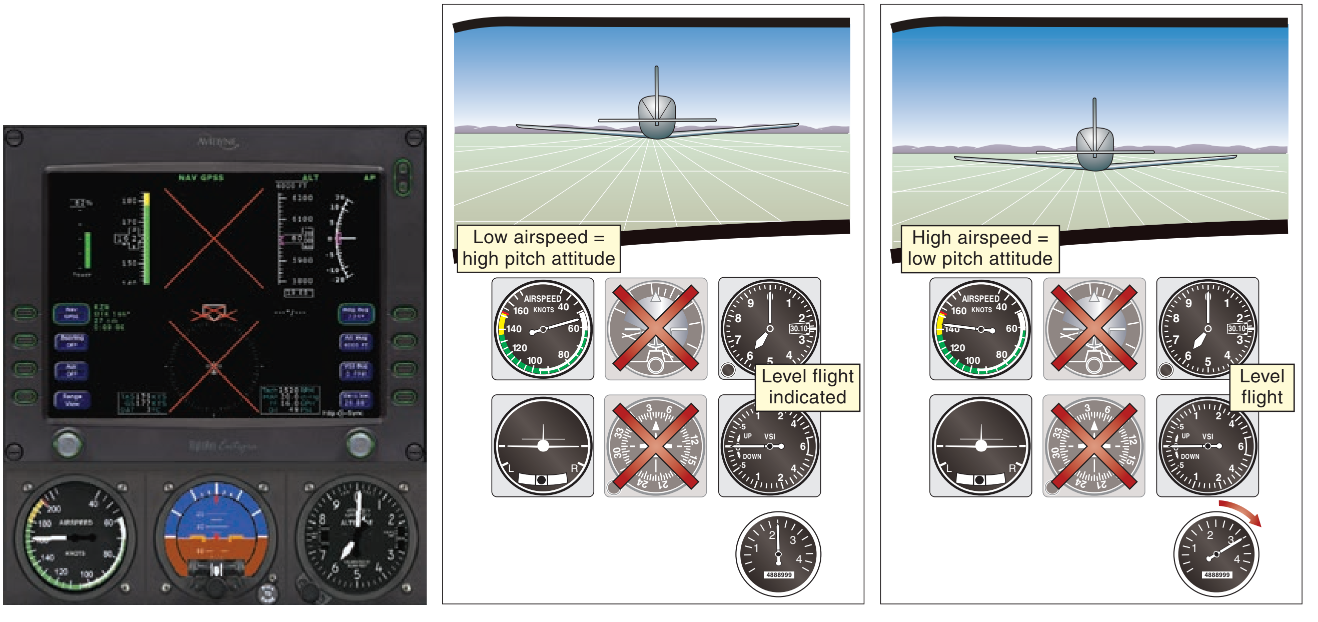


Figure 29-3 Using the pressure instruments to determine pitch attitude (without the attitude indicator).

The *altimeter* not only indicates altitude, but can also provide information regarding pitch attitude. If altitude is remaining constant, then the pitch attitude is correct for level flight at that power setting, whereas increasing or decreasing altitude would indicate a pitch attitude that is too high or too low.

The *airspeed indicator*, as well as indicating airspeed, can also provide information regarding pitch attitude. If the ASI shows that the desired airspeed is being maintained, then the pitch attitude for the power set is correct. If it indicates an increasing airspeed, or an airspeed that is too high, then the pitch attitude is too low for the power set. Conversely, if the ASI indicates a decreasing airspeed, or an airspeed that is too low, then the pitch attitude is too high for the power being used.

Used in conjunction with the altimeter, the ASI is an extremely valuable guide to pitch attitude, but it should be remembered that because of its inertia, an airplane will take some time to change speed, and therefore the ASI indication must have settled before it can confidently be regarded as an accurate indication of pitch attitude. In other words, hold any new attitude for a few seconds to allow the airspeed and the ASI to settle.

The *vertical speed indicator* not only indicates the rate of climb or descent, but also can provide information regarding pitch attitude. If the VSI indication remains approximately zero, then the pitch attitude is correct for level flight at that power, whereas a significant and sustained departure from zero on the VSI would indicate a pitch attitude that is either too high or too low for level flight.

In a climb or descent, a steady and fairly constant VSI reading can be used to support information on pitch attitude from the other performance instruments. Remember that large or sudden changes in pitch attitude may cause the VSI to initially give reverse indications—another reason for avoiding dramatic attitude changes when flying on a partial panel. Similarly, the VSI may read erratically in turbulence, so only use sustained VSI readings as a source of information regarding pitch attitude.

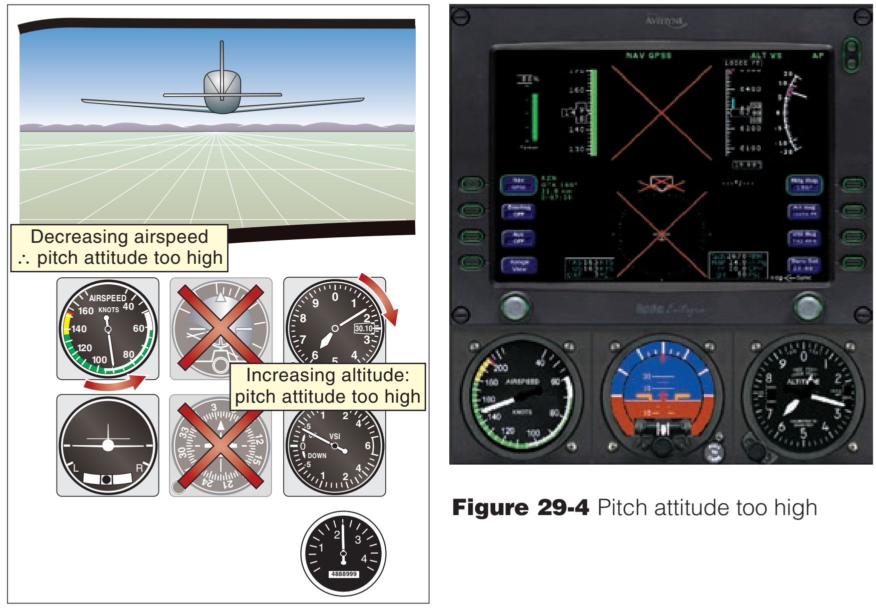


Figure 29-4 Pitch attitude too high

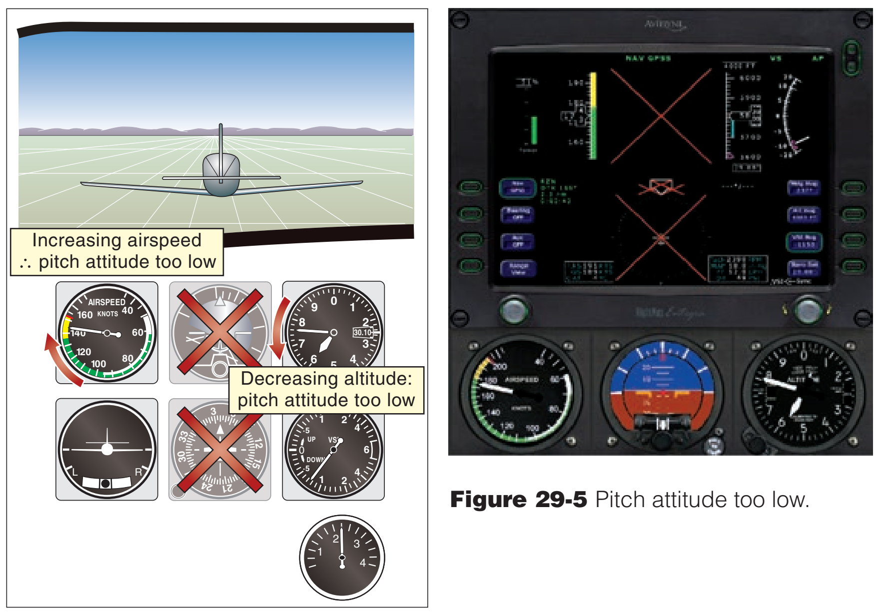


Figure 29-5 Pitch attitude too low.

Interpreting Bank Attitude on a Partial Panel

The attitude indicator is the best guide to bank attitude, since it gives a direct picture of the attitude of the airplane relative to the horizon. However, for practice in flying on a partial panel, it may not be available. If the attitude indicator is indeed unusable, then the pilot can determine the bank attitude from the turn coordinator and ball, and the heading indicator (if it is working, which it may not be) or the magnetic compass.

For the purpose of this exercise, the heading indicator is assumed to be unusable (say because the suction has failed both to it and to the attitude indicator). If, in a real situation, the HI is working, then use it.

A steady zero reading on the turn coordinator, with the ball centered, means that the wings are level. If the turn coordinator reading is not zero and the ball is centered,

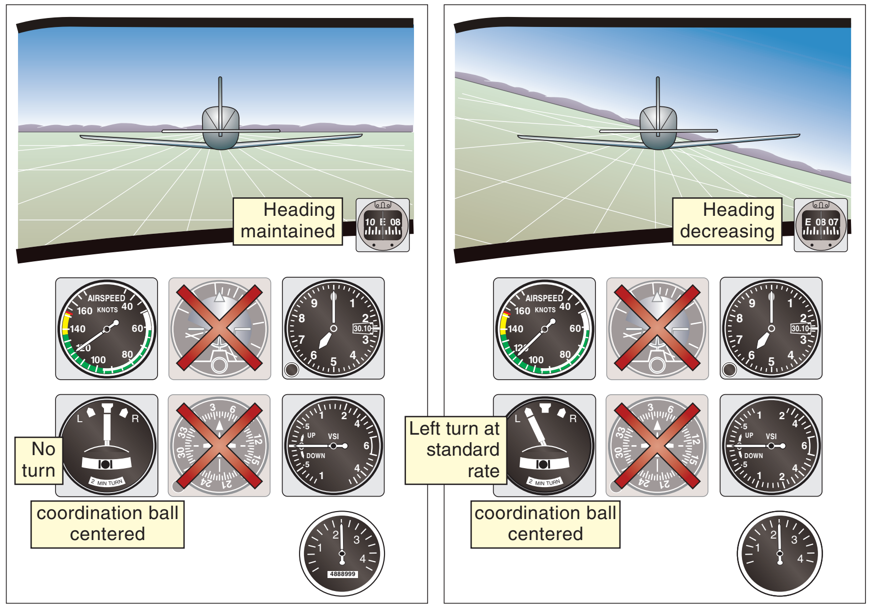


Figure 29-7 Determining bank attitude on a partial panel with a turn-and-bank indicator.

If the airplane is in coordinated flight (ball centered), any indication of turning will mean that the airplane is banked.

then the direction and rate of turn will be indicated. In most instrument flying, the normal rate of turn is standard-rate, which is a change of heading at 3° per second.

While most modern aircraft are fitted with a turn coordinator, there are some still fitted with a turn-and-bank indicator. The modern turn coordinator is a superior instrument. As well as indicating *rate of turn* (as does the turn-and-bank indicator), the turn coordinator also shows *rate of bank* because of the slightly angled internal mounting of its gyroscope.

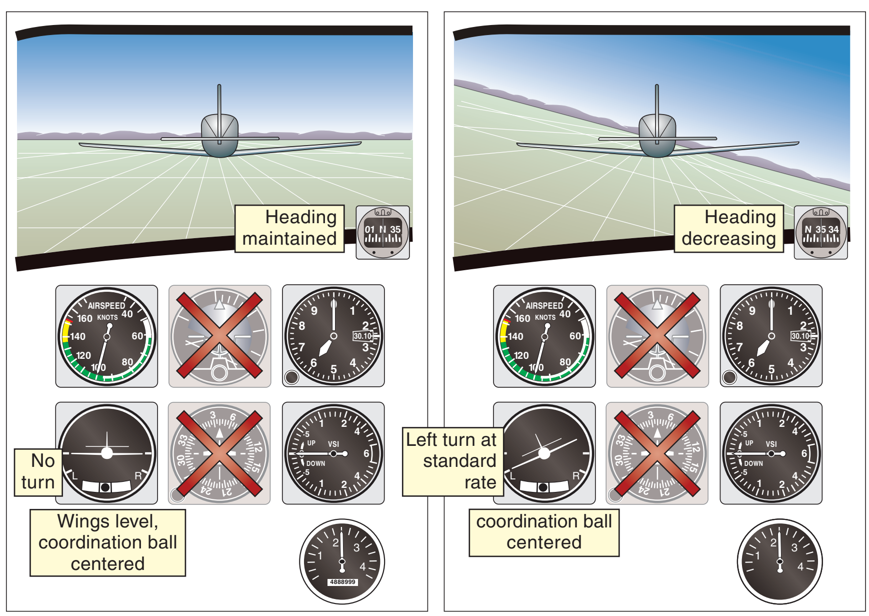


Figure 29-6 Determining bank attitude on a partial panel.

The turn coordinator responds immediately when an airplane banks, even before the airplane actually starts turning. It is therefore an easier instrument to use when trying to keep the wings level. The turn coordinator shows both roll and yaw; the turn-and-bank indicator shows yaw only.

Remember that the turn coordinator does not give pitch information.

The turn coordinator is especially valuable for lateral control if the attitude indicator is unusable. But remember that, even though it has symbolic wings to indicate banking and turning, the turn coordinator does not give pitch information.

If, for some reason, the turn coordinator or turn-and-bank indicator is not working, then bank information can be derived from the heading indicator or magnetic compass.

If the heading is constant on the HI and the ball centered, then the wings are level. If the heading is changing at 3° per second (15° heading change in 5 seconds) and the ball is centered, then the wings are banked sufficiently to give a standard-rate turn (bank angle = airspeed/10 + ½ the answer).

If the heading is constant and the ball is centered, the wings are level.

If All Gyros Fail

If all gyroscopes fail (extremely improbable, but see figure 29-8), then the best technique is to fly toward an area where you can become visual, keeping the wings level by maintaining a constant heading on the magnetic compass. This is easiest on a heading of south when you are in the northern hemisphere, because the magnetic compass is most sensitive on this heading (vice versa in southern hemisphere).

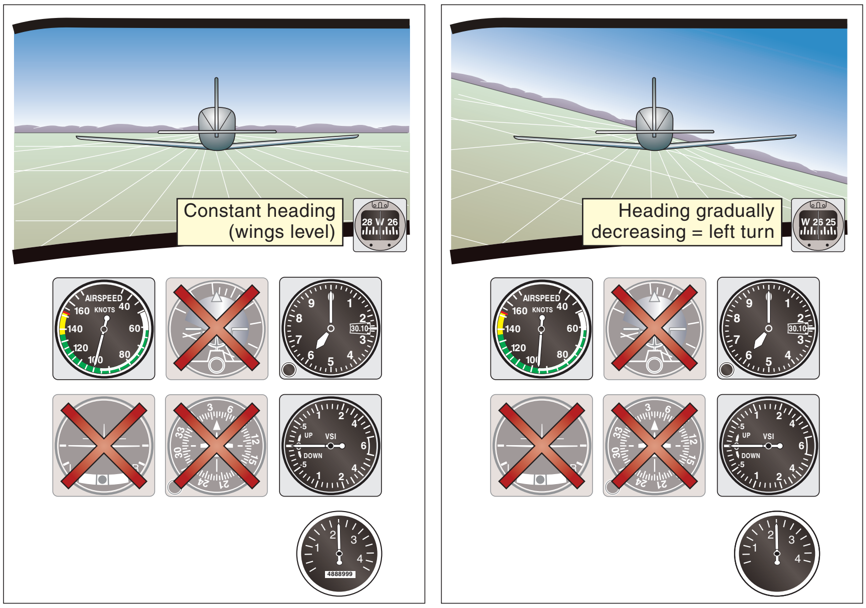


Figure 29-8 Determining bank attitude on a totally failed panel.

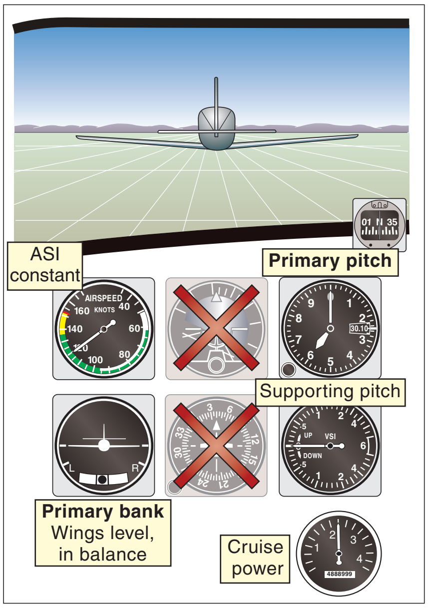


Figure 29-9 Achieving straight-and-level flight on a partial panel.

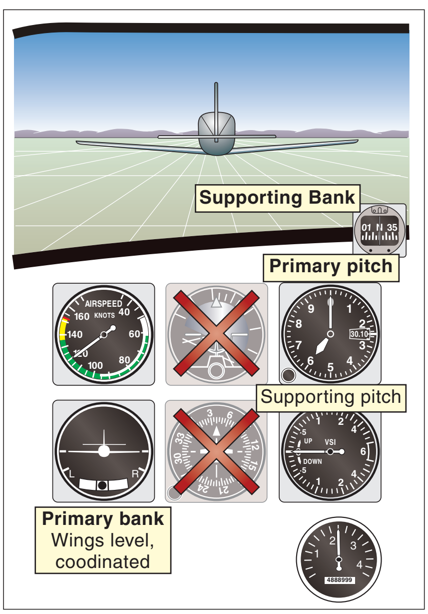


Figure 29-10
Maintaining heading and altitude.

Straight-and-Level Flight on a Partial Panel

Setting cruise power and placing the airplane in the cruise attitude will provide cruise performance, with the airplane in straight-and-level flight.

To achieve straight-and-level flight at a particular altitude on a partial panel without the use of the AI:

- set cruise power on the power indicator;
- hold the wings level with reference to the turn coordinator, with the ball centered;
- adjust the pitch attitude with reference to the altimeter and VSI; and
- trim.

The following describes how to maintain straight-and-level flight at the chosen altitude once it has been achieved.

Heading

Maintain heading by keeping the wings level using the turn coordinator, and the ball centered. Heading can be checked on the heading indicator if it is working, otherwise on the magnetic compass.

Any corrections to heading should be made with gentle coordinated turns (half standard-rate on the turn coordinator, which is 1.5° per second, should be more than adequate). The heading indicator, if usable, will indicate heading directly but, if the magnetic compass is used, then some allowance will be needed to undershoot on northerly headings and overshoot on southerly headings.

Altitude

Any tendency to drift off altitude caused by a slightly incorrect pitch attitude will first be shown on the VSI, and minor adjustments with the elevator can be made almost before any change is registered on the altimeter. In turbulent conditions, however, the VSI tends to fluctuate, in which case the altimeter will be the more useful instrument. Aim to stay accurately on altitude.

Minor deviations of less than 100 feet can generally be corrected with very small pitch alterations; any deviation in excess of 100 feet may also require a small power change as well as an attitude change. Keep in trim to make the task easier.

Airspeed

Airspeed is normally accepted once cruise power has been set. If, however, precise airspeed control is desired, then this can be achieved with power. Once cruise speed is achieved, ensure that the airplane is in trim, otherwise altitude and/or airspeed will be difficult to maintain.

To change airspeed in straight-and-level flight, a coordinated change of both power and pitch attitude will be required. Greater precision using only a partial panel of instruments can be achieved if these changes are gradual and smooth.

Higher Airspeed

A higher speed requires more power and a lower pitch attitude. Remember that a power increase causes a *pitch up/yaw left* tendency in most aircraft, and this should be resisted with gentle control pressures. Therefore, as power is slowly increased with the throttle to achieve a speed increase, monitor the VSI (backed up by the altimeter) to determine the small increases in forward pressure required on the control column to maintain altitude, and keep the ball centered with a slight increase in (right) rudder pressure.

Refer to the turn coordinator to ensure that wings are kept level, so that heading is maintained. Power adjustment may be required to maintain the desired airspeed.

Once stabilized at the desired speed, retrim the aircraft. The heading indicator (if available) or the magnetic compass (once it has settled down) can be checked to verify heading.

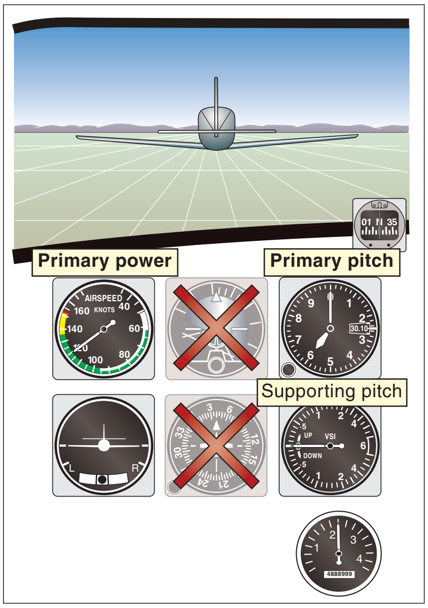


Figure 29-11
Changing airspeed on a partial panel.

Lower Airspeed

Reducing the airspeed requires less power and a higher pitch attitude. The power reduction will cause a *pitch down/yaw right* tendency, which the pilot should be ready to counteract. The VSI can be used to anticipate any tendency to lose altitude, prevented by use of the elevator, and the turn coordinator and ball can be used to prevent any tendency to drift off heading. Once the desired lower airspeed is achieved, minor power adjustments with the throttle may be required. The airplane should then be retrimmed.

Use P-A-T, power—attitude—trim to climb on partial panel.

Climbing on a Partial Panel

Entering a Climb

The procedure to enter a climb using only a partial instrument panel is the same as with a full panel: P-A-T, power-attitude-trim. Smoothly apply climb power (mixture RICH if necessary); remember: there will be a pitch-up tendency as power is applied. Keep the wings level on the turn coordinator and the ball centered to stay coordinated. Raise the nose to the climb attitude with back pressure on the control column.

Hold the new pitch attitude until the airspeed indicator stabilizes. The VSI will show a climb and, once you are familiar with the particular airplane, this will provide useful backup information to the ASI regarding correct pitch attitude. An initial trim adjustment will assist in maintaining the new attitude. Once the airspeed has settled, minor adjustments can be made with the elevator to fine tune the airspeed, and then the airplane can be trimmed precisely to maintain the desired climbing speed. Adjustment of power may be required to ensure correct power is maintained at the lower airspeed.

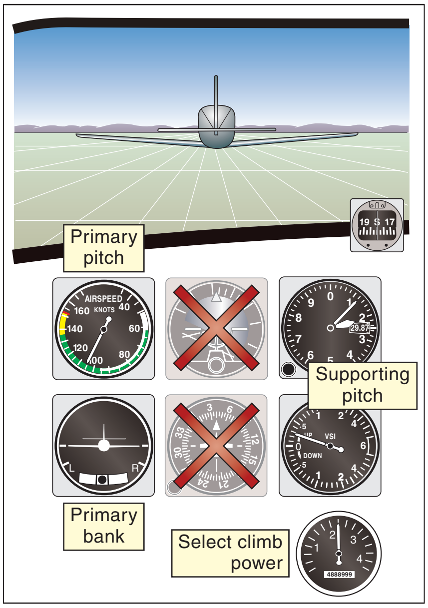


Figure 29-12
Entering the climb on a partial panel.

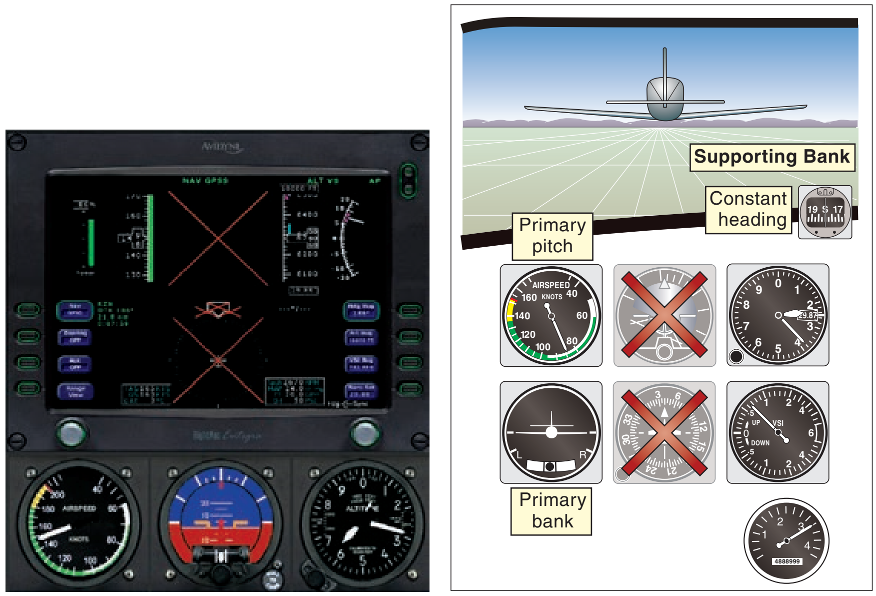


Figure 29-13 Maintaining the climb on a partial panel.

Maintaining a Climb

To maintain a straight climb on a partial panel, hold the pitch attitude with reference to the ASI, which is the primary indicator of correct pitch attitude during the climb. Use the VSI for rate climbs. Maintain heading by keeping the wings level on the turn coordinator and the ball centered. Heading can be checked on the heading indicator or magnetic compass. Being in trim will make life easier.

Periodically check engine temperatures and pressures in the climb. The engine is working hard and the cooling airflow is less, but this check should not take more than one or two seconds and should not distract you from your main scan of the flight instruments.

Leveling Off from a Climb

To level off at a particular altitude, it is important that the altimeter has the correct setting in its pressure window (the current local altimeter setting for operations below 18,000 feet MSL, and standard pressure 29.92 in. Hg above).

Scan the altimeter more frequently as the desired altitude is approached, and shift focus for pitch control from the ASI to the altimeter. Start leveling off smoothly before actually reaching the desired altitude, a suitable lead-in being 10% of the rate of climb (say 40 feet before the altitude for a rate of climb of 400 fpm).

Use A-P-P-T: attitude—pause—power—trim when leveling off from a partial panel climb.

The procedure to level off is A-P-P-T, attitude-pause (for airspeed to increase)-power-trim. Gradually and slightly lower the pitch attitude toward the low airspeed level flight position, noting a decreasing climb rate on the VSI, and capture the desired altitude with reference to the altimeter. Keep the wings level and the ball centered to maintain heading. Make small attitude and trim adjustments as the airplane accelerates. Once the airspeed has increased to the desired cruising value on the ASI, smoothly reduce power, and then trim the airplane.

Once the airplane is stabilized, the scan becomes that for normal straight-and-level flight, although particular attention should be paid to the ASI in the early stages to ensure that adequate power is set to maintain the desired airspeed.

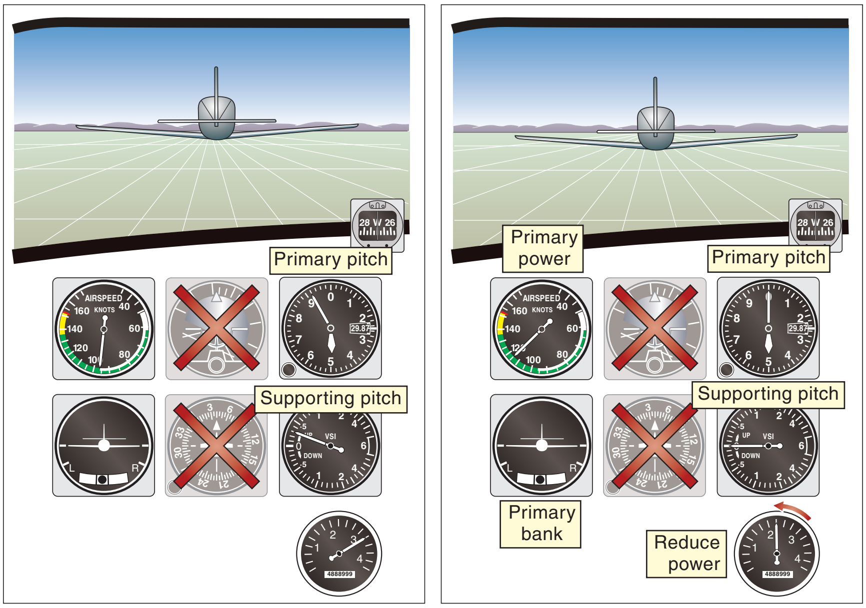


Figure 29-14 Leveling off from a climb on a partial panel.

Descending on a Partial Panel

Entering a Descent

A descent will require less power and a lower pitch attitude than for level flight. To enter a descent, the procedure is P-A-T, power-attitude-trim. Smoothly reduce the power (mixture control RICH as required, carburetor heat HOT if necessary) with the throttle.

Use P-A-T, power—attitude—trim to descend on partial panel.

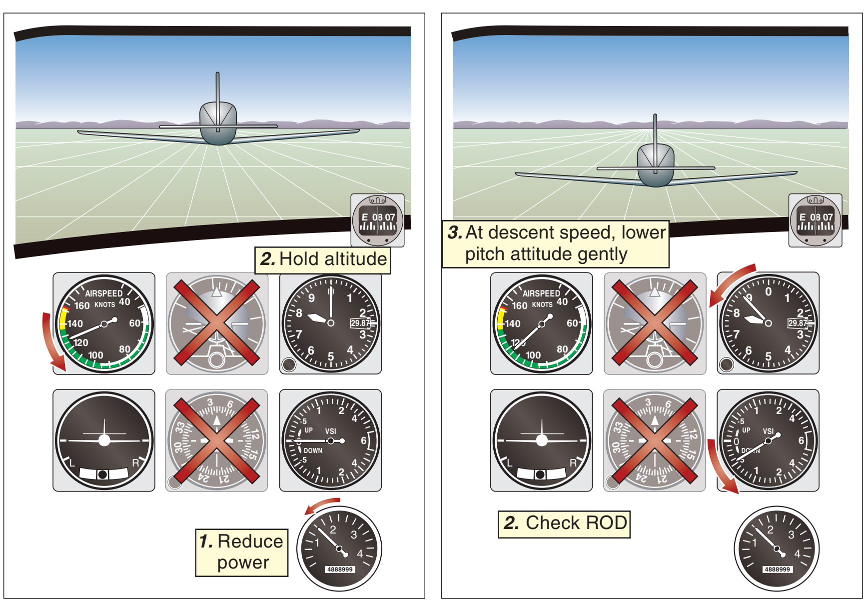


Figure 29-15 Entering a descent.

Hold the wings level and the ball centered to maintain heading, and hold the pitch attitude with slight back pressure until the desired descent airspeed on the ASI is almost reached in level flight, at which time the nose can be gently lowered slightly to maintain airspeed.

If the descent airspeed is to be the same as the level airspeed, then the pitch attitude should be lowered simultaneously with the power reduction. Remember that there will be a natural tendency for the nose to drop and yaw as power is reduced.

The VSI can be used to monitor trends in vertical performance. An initial trim adjustment as soon as the descent attitude is adopted is acceptable to remove most steady control pressure, followed by fine adjustments to the pitch attitude to maintain the desired airspeed and a final fine trim adjustment.

Maintaining a Descent

To maintain the descent on a partial panel:

- maintain heading with wings level on the turn coordinator and the ball centered, checking heading against the heading indicator or the magnetic compass; and
- maintain airspeed with gentle changes in pitch attitude, using the ASI and VSI. If a particular rate of descent is required, then coordinated use of power and attitude can be used to achieve it, with the airspeed being monitored on the ASI, and the rate of descent being monitored on the VSI.

In a powered descent, minor adjustments to power may be required to ensure that the correct descent power is set.

In a prolonged descent with low power, thought should be given to clearing the engine every 1,000 feet or so by applying power into the green arc for a few seconds to keep the engine and oil warm, to avoid carbon fouling of the spark plugs and to keep warm air available to the carburetor heat.

Applying the extra power, and then removing it, should not distract you from scanning the flight instruments for more than a few seconds. Be prepared to counteract pitch/yaw tendencies as the power is changed.

Figure 29-16 Maintaining a descent on a partial panel.

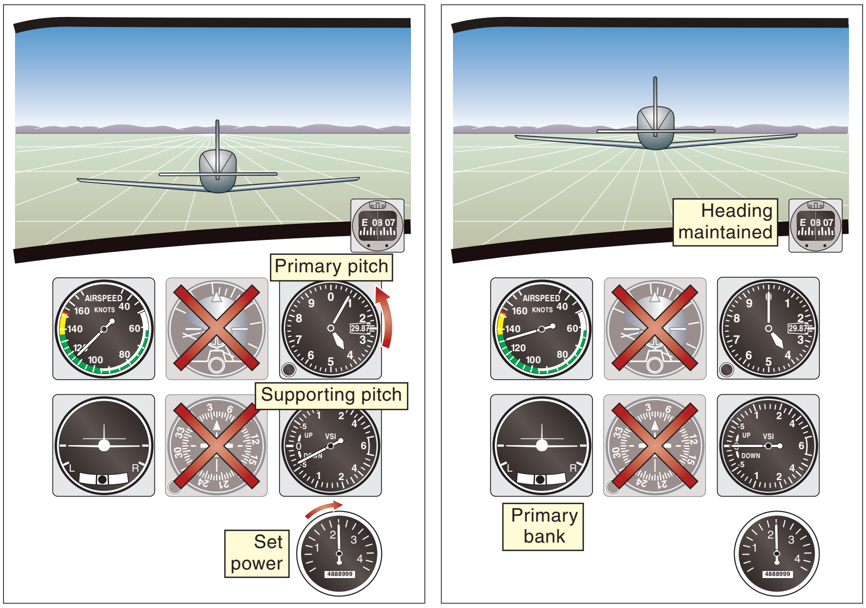


Figure 29-17 Leveling off from a descent on a partial panel.

Leveling Off from a Descent

To level off from a descent at a particular altitude, it is important that the altimeter has the correct setting in its pressure window. As the desired altitude is approached, the focus for pitch attitude control should shift from the ASI to the altimeter, and the leveling off maneuver started before the altitude is actually reached (a suitable lead-in being 10% of the rate of descent).

The procedure to level off from a descent is P-A-T, power-attitude-trim. Smoothly increase power to the cruise setting (stay coordinated) and raise the pitch attitude, noting that the VSI shows a reducing rate of descent, and aim to capture the desired altitude precisely on the altimeter. Trim the airplane. Revert to the normal straight-and-level scan, checking the altimeter for altitude, and initially checking the ASI to ensure that the desired airspeed is indeed being maintained. If not, adjust the power, hold altitude with elevator, and retrim.

Level off from a descent with P-A-T, power—attitude—trim.

Entering a Climb from a Descent

Entering a climb from a descent, such as in a go-around, is a more demanding maneuver on a partial panel than on a full panel, since a large and fairly rapid power increase, accompanied by a higher pitch attitude, is required. The large pitch attitude change may cause the VSI to give a reversed reading initially, so it must be disregarded until its reading has stabilized.

Executing a go-around on partial panel is an emergency situation, not a normal operation. This is a training exercise only; a partial-panel go-around should be avoided at all costs in a real-world situation.

Turning on a Partial Panel

To turn to a specific heading, the best instruments to use for directional guidance are (in order of preference):

- the heading indicator; or
- the stopwatch (for timed turns—standard-rate being 3° per second); or
- the magnetic compass (with its associated turning and acceleration errors).

Heading Indicator

If the heading indicator is used, then it must first have been aligned with the magnetic compass while in steady straight-and-level unaccelerated flight. The HI is the simplest direction instrument to use.

Clock and Turn Coordinator

If the HI is not usable, then a timed turn with clock and turn coordinator is the preferred method. This method can be quite accurate. Once established in straight flight on the new heading, the magnetic compass will soon settle down and allow the heading to be cross-checked.

Magnetic Compass

If, however, the magnetic compass has to be used during the turn, then the roll-out should occur before any desired northerly heading is indicated on the compass (by about 30° in a standard-rate turn), and after any desired southerly heading is indicated. These corrections are for the northern hemisphere, and are reversed in the southern hemisphere.

No allowances need be made when using the magnetic compass to turn to easterly or westerly headings, and lesser corrections will be required for intermediate headings.

Level Turn on a Partial Panel

Before Entering a Turn

Prior to commencing a turn, ensure that you are stabilized in steady straight-and-level flight, exactly on altitude, on speed, and in trim. Check the heading indicator (if available) or the magnetic compass for the present heading, establish the required direction for the turn (left or right) to take up the new heading, and decide on the rate of turn that will be used.

Standard-rate is suitable for significant heading changes, but just a few degrees of heading change can be achieved satisfactorily at half standard-rate. Calculating the time required for the turn, whether using the HI or the compass, always provides a convenient backup. The ASI, altimeter and VSI should all be stable before rolling into a level turn using a partial panel.

Entering a Level Turn

To enter a level turn, note the time in seconds on the clock (or set the stopwatch going), bank in the desired direction using coordinated aileron and rudder until the turn coordinator shows standard-rate, (at which point the ailerons should be neutralized to stop further banking) and keep the ball centered with rudder pressure.

Altitude can be maintained by counteracting any trend on the VSI with elevator, which will probably require a slight back pressure. In turbulent conditions, the altimeter may be more useful than the VSI which could be fluctuating. Neutralizing the ailerons will hold the bank angle fairly constant, but minor corrections will have to be made continually to maintain standard-rate on the turn coordinator.

Maintaining a Level Turn

To maintain a level turn, hold standard-rate on the turn coordinator using the ailerons, and keep the ball centered with rudder pressure. Hold altitude on the altimeter by

Figure 29-18 Entering and maintaining a level turn using a partial panel.

picking up any trend on the VSI and counteracting it with elevator. The altimeter will confirm that the precise altitude is being maintained.

The ASI will show the expected loss of several knots, which is acceptable, unless a constant airspeed is desired, in which case you must add some power while turning. It is not necessary to trim in the turn, since it is a transient maneuver and straight flight will shortly be resumed. As the desired heading is approached, bring the heading indicator (HI, clock or compass) increasingly into the scan.

Rolling Out of a Level Turn

To roll out of a level turn, anticipate the desired heading by some degrees and decrease bank with coordinated aileron and rudder until the turn coordinator shows wings level. Hold altitude using the VSI and altimeter, smoothly relaxing any back pressure held during the turn. Allow the magnetic compass to settle down in steady straight flight, then check it for heading and make any necessary adjustments with small coordinated turns.

Climbing Turn on a Partial Panel

The climbing turn is normally entered from a straight climb, and is more easily achieved if the airplane is first well-established and trimmed in the straight climb. Climbing airspeed should be maintained in the climbing turn, therefore the primary performance guide to pitch attitude is the ASI.

To enter a climbing turn, bank the airplane with coordinated aileron and rudder until the desired rate of turn is indicated on the turn coordinator. Adjust the pitch attitude with reference to the ASI. It will be slightly lower than in the straight climb, if airspeed is to be maintained.

Maintain the climbing turn with reference to the turn coordinator and the ASI, and bring the heading indicator (HI, clock or magnetic compass) into the scan as the desired heading is approached.

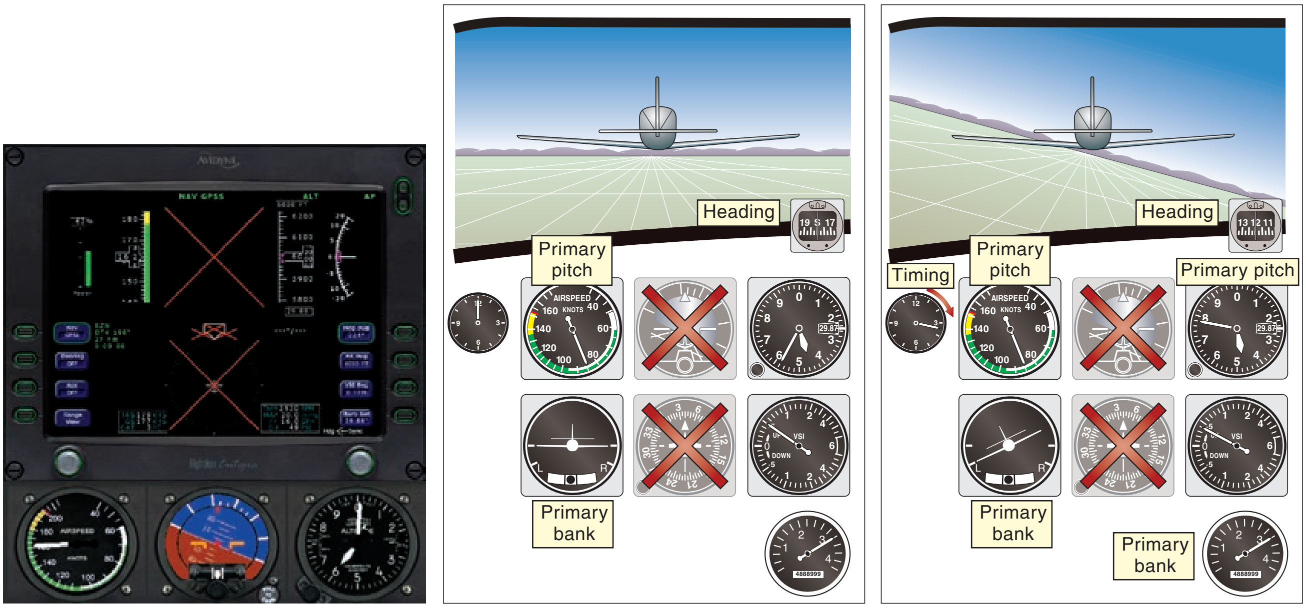


Figure 29-19 Entering and maintaining a climbing turn on a partial panel.

Roll out of the climbing turn into a straight climb with coordinated aileron and rudder, achieving wings level with the turn coordinator, ball centered, and maintain climbing airspeed with reference to the ASI.

Descending Turn on a Partial Panel

The descending turn is normally entered from a straight descent, and is more easily achieved if the airplane is well-established and trimmed in the straight descent. Descent airspeed should be maintained in the descending turn, therefore the primary performance guide to pitch attitude is the ASI.

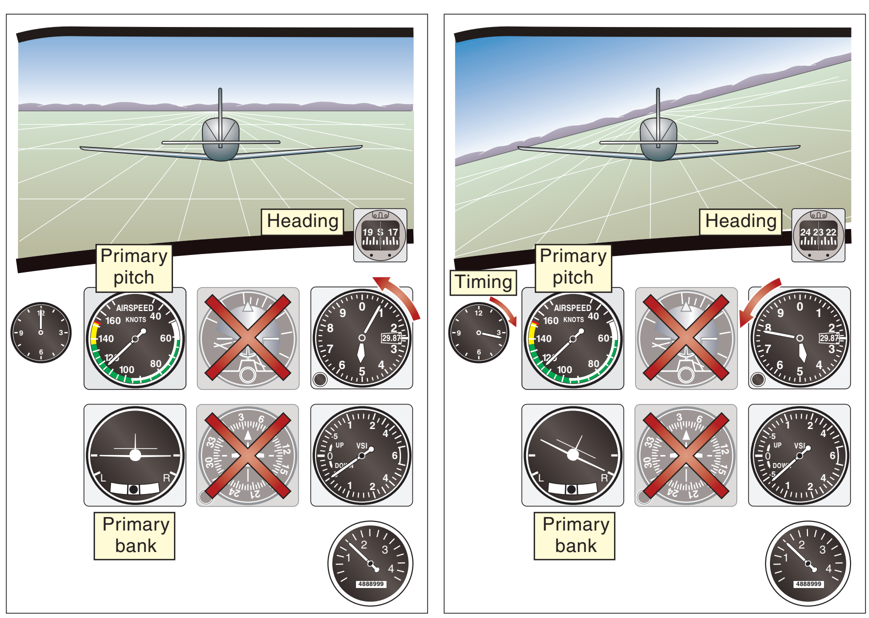


Figure 29-20 Entering and maintaining a descending turn on a partial panel.

To enter a descending turn, bank the airplane with coordinated aileron and rudder until the desired rate of turn is indicated on the turn coordinator. Adjust the pitch attitude with reference to the ASI. Pitch attitude in a descending turn will be slightly lower than in the straight descent for airspeed to be maintained.

To maintain the descending turn, hold bank angle with reference to the turn coordinator, and hold pitch attitude with reference to the ASI. Bring the heading indicator (HI, clock or magnetic compass) into the scan as the desired heading is approached.

Roll out of the descending turn into a straight descent with coordinated aileron and rudder, achieving wings level with the turn coordinator, ball centered, and maintain descent airspeed with reference to the ASI.

Partial Panel in the Glass Cockpit

Combining all the flight instruments onto a single computer screen has changed the definition and training of what has been traditionally known as "partial panel." When viewing the traditional "six pack" of instruments, a partial panel has meant that one or more of the six instruments has failed while all others perform normally.

Instrument pilots learn to continue flying with a partial panel by discarding the information from failed or erroneous instruments and begin using information from combinations of standby instruments. Partial panel situations can occur even with computerized flight instruments. The Primary Flight Display (PFD) displays information that is sent to it from the Laser Ring Gyros of the Attitude Heading Reference System and the Pitot-Static system through the Air Data Computer (ADC). Those systems can fail independently or through natural occurrences such as ice and therefore can create a partial panel situation.

One of the greatest advantages of feeding computerized information to the PFD is that the computer monitors the system's status. When the computer detects a loss of information, due to the loss of input such as the failure of the gyro or the pitot tube becoming blocked, warning flags under most conditions appear on the screen to inform the pilot.

Figure 29-21 illustrates the failure of an Air Data Computer (ADC). Glass Cockpit airplanes still have traditional pitot tubes and static ports, but the pressure information is sent to the ADC instead of directly to the instrument. If the pressure information from either the pitot tube or static port is interrupted, the ADC will not receive and process that information. Computer logic is programmed into the ADC. In the case of pitot blockages, parameters are set to determine why there is a lack of ram pressure. This is why failure flags are not shown when the aircraft is parked on the ramp. However, computer logic cannot always determine if the system is problematic. In the event water has drained into the pitot-static system, erroneous information can sometimes be presented.

The PFD has built-in protections to isolate either the air data or attitude information in case of actual system failures with the corresponding system. In most avionics,

Figure 29-21
PFD with ADC failure indications.

Figure 29-22
PFD with AHRS failure indications.

a red "X" symbol has been programmed to replace the degraded information on the PFD.

Backup instruments are a requirement on every glass cockpit aircraft from a Cirrus to a Boeing. In the event of a glass instrument/system failure, the related standby instrument will provide accurate information. However, most general aviation aircraft are not equipped with dual pitot/static systems. Without this extra equipment in case of pitot/static blockage, both the primary and standby instruments will be affected. Know your individual aircrafts system.

Most standby attitude indicators are electrically driven, and have individual battery backups. It is still important to keep them in your instrument scan and note their operation during the pre-flight.

One of the greatest benefits of a glass cockpit is the addition of an enhanced attitude indicator. The extra size and the invention of new synthetic vision systems increase situational awareness. Compared with its round dial predecessors, the attitude indicator on a PFD has several benefits. The recognition that the AHRS has failed is instantaneous in the glass cockpit. The red "X" symbol appears immediately as the failure occurs, which does not happen with round dial instruments. The failure of a vacuum system, for example, and the subsequent failure of manual gyroscopic instruments do not come with a clear warning. If the air flow that spins the gyros stops, the gyros themselves don't stop immediately. It takes time for the gyros to spin down and this makes the failure difficult to recognize in flight. This misleading information is not possible with a PFD.

Figure 29-22 indicates the loss of the Attitude Heading Reference System (AHRS). When the pilot sees the failure indication displayed he/she knows immediately to move to other PFD information and to utilize the standby attitude indicator. At that point the skills needed to continue safe flight with a partial panel glass aircraft are the same as the skills needed to fly partial panel on round dials. The pilot would have to cross reference information between the portion of the PFD that is working correctly and the standby instruments. Figure 29-22 illustrates that the airplane is in a descending left turn and in coordinated flight. The turn and coordination information comes from the standby attitude gyro and inclinometer. Information on the actual heading of the airplane would come from the Magnetic Compass. The utilization of the GPS track can also be a helpful aid.

Dealing with a partial panel situation takes practice and an understanding of what has failed. Recognizing which sources can provide replacement information is an important skill. A good deal of a pilot's training involves training for failures, but by using the correct redundant information the pilot can still maintain control of the airplane and fly safely through the loss of an instrument.

Review 29

Normal Instrument Flight on a Partial Panel

1. Which instruments, in addition to the AI, are pitch instruments?

2. Which instrument provides the most pertinent information (primary) for pitch correction in the following:

a. straight-and-level flight?
b. level turning flight?
c. climbing flight?
d. descending flight?
e. straight flight?
f. a standard-rate turn?

3. What is the flight situation in figure 29-23?

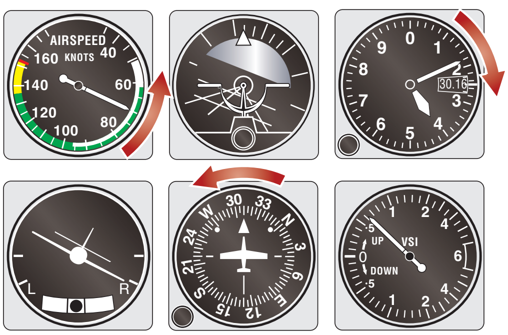


Figure 29-23 Question 3.

4. What is the situation in figure 29-24 if maximum power has been applied?

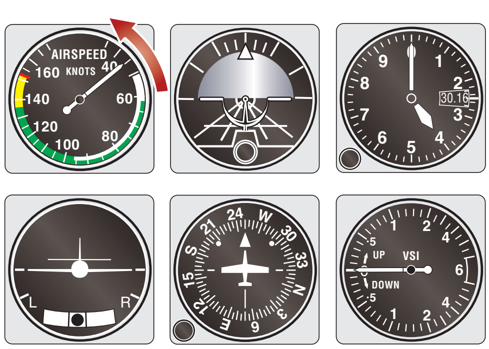


Figure 29-24 Question 4.

5. Which instruments, in addition to the AI, are bank instruments?

6. Where are direction indications available from if the heading indicator is malfunctioning?

7. Name the pressure instruments.

8. Which instruments use static pressure?

9. Which instrument uses pitot pressure?

10. Name the gyroscopic instruments.

11. Name the gyroscopic instruments typically powered from the vacuum system.

12. What is the flight attitude in figure 29-25?

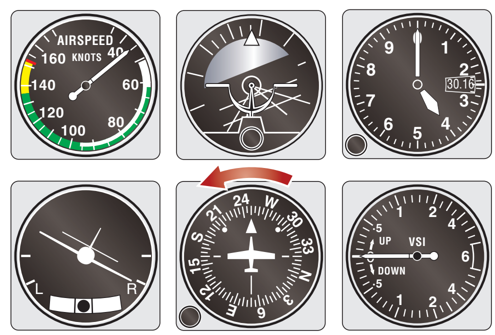


Figure 29-25 Question 12.

13. What is the flight situation in figure 29-26? Cruise power is applied.

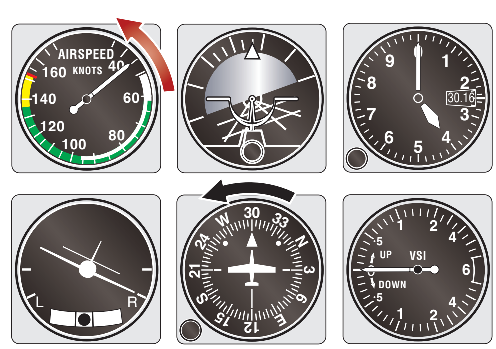


Figure 29-26 Question 13.

14. While recovering from an unusual flight attitude without the aid of the attitude indicator, how is reaching approximate level attitude indicated?

15. Interpret the flight attitude in figure 29-27.

Figure 29-27 Question 15.

16. Interpret the flight attitude in figure 29-28.

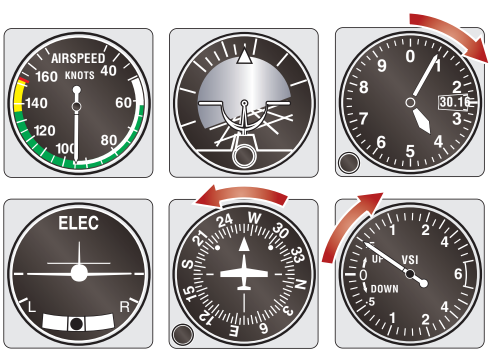


Figure 29-28 Question 16.

17. Interpret the flight attitude in figure 29-29, and determine the action to take (if any) to return the airplane to normal straight-and-level flight.

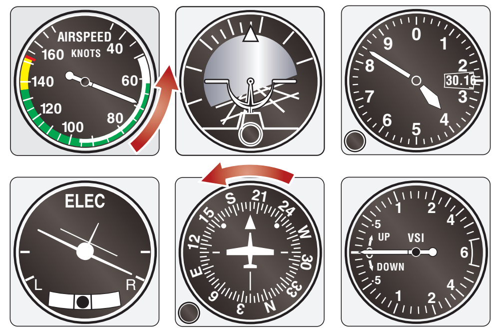


Figure 29-29 Question 17.

18. If the airplane is in an unusual flight attitude and the AI has exceeded its limits, which two instruments should be relied on to determine the pitch attitude before starting recovery?

19. What is the primary bank instrument in unaccelerated level flight on a specific heading?

20. The heading indicator is inoperative. What is the primary bank instrument in unaccelerated level flight for holding a specific heading?

Answers are given on page 790.

Weather

Wind, Air Masses, and Fronts 30

The Nature of the Atmosphere

Air density and air pressure decrease with altitude up to the tropopause, where the lapse rate changes abruptly.

The earth is surrounded by a mixture of gases which are held to it by gravity. The mixture of gases is called air, and the space it occupies is called the atmosphere. The atmosphere is important to pilots because it is the medium in which we fly.

Air density and air pressure decrease with altitude. Temperature also decreases with altitude, until a certain level in the atmosphere known as the *tropopause*, above which the temperature does not vary much. Another way of saying this is that at the tropopause the temperature lapse rate changes abruptly.

Wind direction is the direction from which the wind is blowing. Wind strength is expressed in knots.

The space between the earth's surface and the tropopause is called the *troposphere*, and it is in this part of the atmosphere that most of the water vapor is contained, and where most of the vertical movement of air and the creation of "weather" (clouds) occurs. Unstable air, if forced aloft, will tend to keep rising and possibly cause cumuliform clouds. Stable air, if forced aloft, will tend to stop rising and possibly form stratiform clouds. The term "wind" refers to the flow of air over the earth's surface. This flow is almost completely horizontal, with only about $1/1{,}000$ of the total flow being vertical.

The primary cause of weather is uneven heating of different areas of the earth by the sun.

The tropopause is approximately 65,000 feet above the equator, and descends in steps to approximately 20,000 feet over the poles. Jetstream tubes of winds 50 knots or greater can form along the breaks. The average altitude of the tropopause in mid-latitudes is about 37,000 feet. The part of the atmosphere directly above the tropopause is called the stratosphere, and high-flying jets often cruise up there. It experiences little change in temperature or vertical movement of air, contains little moisture, and so there is an absence of clouds.

The Cause of Weather

The primary cause of weather is uneven heating of different areas of the earth by the sun. The warmer air is less dense and tends to rise, causing pressure changes, and so circulation of the air begins.

Winds

On weather charts, places of equal pressure are joined with lines called isobars. Air will tend to flow into the lower pressure areas (resulting from the warm air rising) from the higher pressure areas. The greater the pressure gradient, the closer the isobars are together, the greater the pressure gradient force causing winds to start blowing across the isobars.

The wind that initially moves across the isobars is caused to turn right (in the Northern Hemisphere) by the Coriolis force. The Coriolis force acts on a moving parcel of air. It is not a real force, but an apparent force resulting from the passage of the air over the rotating earth.

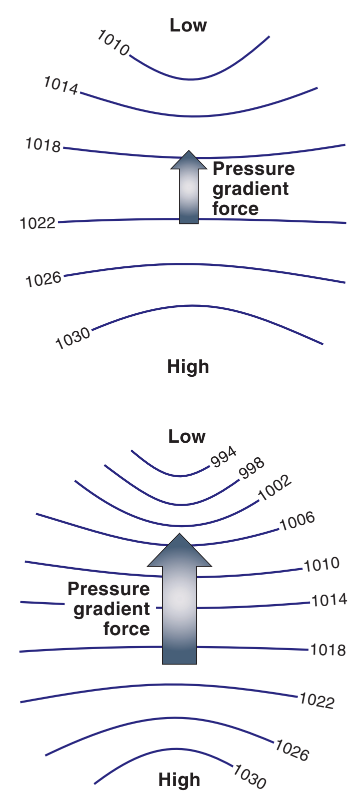


Figure 30-1
The pressure gradient force will start a parcel of air moving.

Imagine a parcel of air that is stationary over point A on the equator. It is in fact moving with point A as the earth rotates on its axis from west to east. Now, suppose that a pressure gradient exists with a high pressure at A and a low pressure at point B, directly north of A. The parcel of air at A starts moving toward B, but still with its motion toward the east due to the earth's rotation.

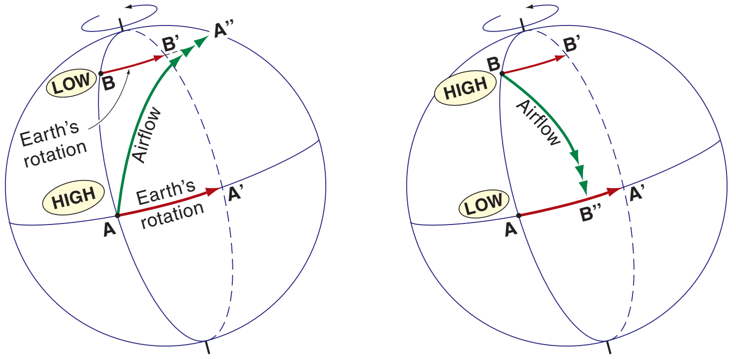


Figure 30-2
The Coriolis force acts towards the right in the Northern Hemisphere.

The further north one goes away from the equator, the less is this easterly motion of the earth, and so the earth will lag behind the easterly motion of the parcel of air. Point B will only have moved to B′, but the parcel of air will have moved to A″. In other words, to an observer standing on the earth's surface the parcel of air will appear to turn to the right. This effect is caused by the Coriolis force.

If the parcel of air was being accelerated in a southerly direction from a high pressure area in the Northern Hemisphere toward a low near the equator, the earth's rotation toward the east would "get away from it" and so the air flow would appear to turn right also—A having moved to A′, but the airflow having only reached B′ to the west.

The faster the airflow, the greater the wind speed, the greater the Coriolis effect—if there is no air flow, then there is no Coriolis effect. The Coriolis effect is also greater in regions away from the equator and toward the poles, where changes in latitude cause more significant changes in the speed at which each point is moving toward the east.

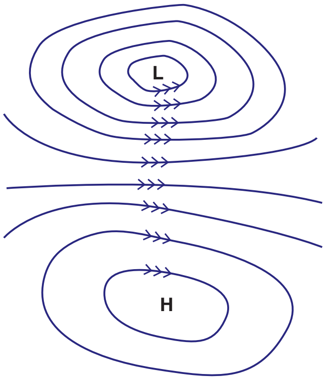


Figure 30-3
Winds flow clockwise around a high and counterclockwise around a low in the Northern Hemisphere.

In the Northern Hemisphere, the Coriolis force deflects the winds to the right, until the Coriolis force balances the pressure gradient force, resulting in the *geostrophic wind* or the *gradient wind* that flows parallel to the curved isobars, clockwise around a high and counterclockwise around a low. (In the Southern Hemisphere, the situation is reversed and winds are deflected to the left.)

In the *friction layer* between about 2,000 feet AGL and the surface, friction slows the winds down—a lower wind speed means less Coriolis effect, and so winds, due to the friction effect reducing the wind speed, will tend to flow at an angle across the isobars toward the lower pressure.

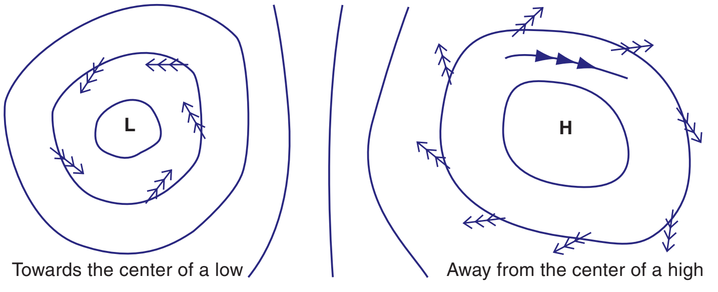


Figure 30-4
Friction causes the surface winds to weaken in strength and flow across the isobars.

Windshear

Windshear is the variation of wind speed and/or direction from place to place. It affects the flight path and airspeed of an airplane and can be a hazard to aviation.

Windshear is the variation of wind speed and/or direction from place to place or from one altitude to another, and is often present around cold or warm fronts.

Windshear is generally present to some extent as an airplane approaches the ground for a landing, because of the different speed and direction of the surface wind compared to the wind at altitude. Low-level windshear can be quite marked at night or in the early morning when there is little mixing of the lower layers, for instance when a temperature inversion exists.

Windshear can also be expected when a sea breeze or a land breeze is blowing, or when in the vicinity of a thunderstorm. Cumulonimbus clouds have enormous updrafts and downdrafts associated with them, and the effects can be felt up to 10 or 20 NM away from the actual cloud. Windshear and turbulence associated with a thunderstorm can destroy an airplane.

Windshear often is present in the wind changes that occur around fronts, usually prior to the passage of a warm front, and during or just after the passage of a cold front. It is also likely to be present in the air surrounding a fast moving jetstream.

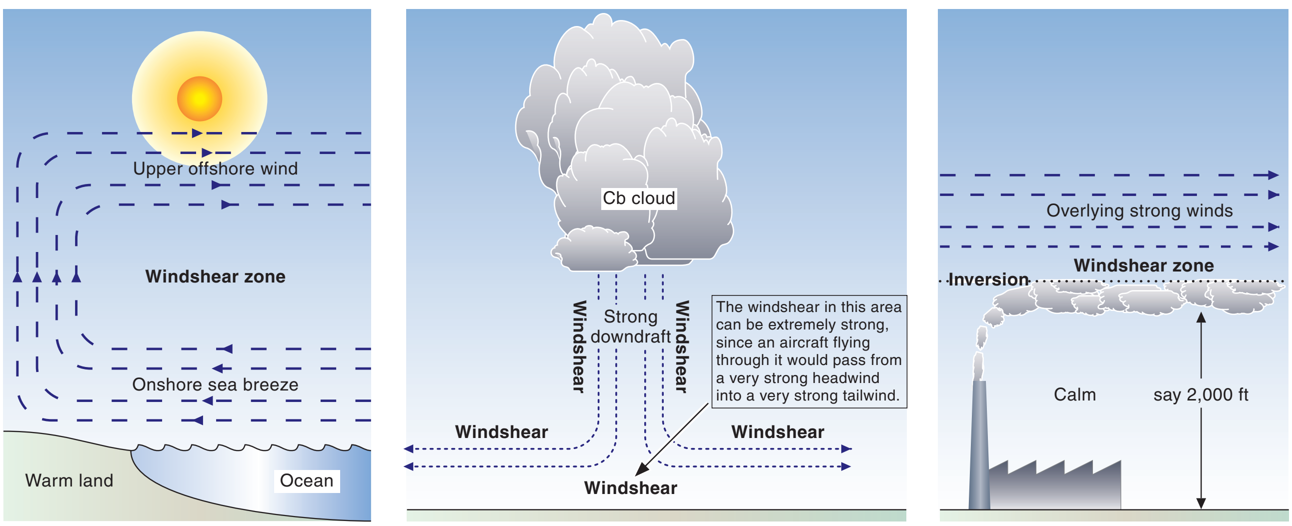


Figure 30-5 Windshear is a change of wind speed and/or direction between various places.

Windshear on the Approach

An understanding of windshear helps explain why alterations of pitch attitude and/or power are continually required to maintain a desired flight path, just as changes in heading are required to maintain a steady course.

The study of windshear and its effect on airplanes, and what protective measures can be taken to avoid potentially dangerous results, is still in its infancy and much remains to be learned.

What is certain is that every airplane and every pilot will be affected by windshear—usually the light windshears that occur in everyday flying, but occasionally a moderate windshear that requires positive recovery action from the pilot. On rare occasions, severe windshears can occur from which a recovery may even be impossible. A little knowledge can help you understand how to avoid significant windshear, and how best to recover from an inadvertent penetration.

Windshear Terminology

A *windshear* is defined as a change in wind direction and/or wind speed in space. This includes updrafts and downdrafts. Any change in the wind velocity (be it a change in speed or in direction) as you move from one point to another is a windshear. The stronger the change and the shorter the distance within which it occurs, the stronger the windshear.

- *Updrafts* and *downdrafts* are the vertical components of wind. The most hazardous updrafts and downdrafts are those associated with thunderstorms.
- The term *low-level windshear* is used to specify any windshear occurring along the final approach path prior to landing, along the runway and along the takeoff/initial climb-out flight path. Windshear near the ground (below about 3,000 feet) is often the most critical in terms of safety for the airplane. Windshear is quite common when there is a low-level temperature inversion.
- *Turbulence* is eddy motions in the atmosphere which vary both with time and from place to place.

The Effects of Windshear on Aircraft

Most of our studies have considered an airplane flying in a reasonably stable air mass which has a steady motion relative to the ground, in a steady wind situation. We have seen how an airplane climbing out in a steady headwind will have a better climb gradient over the ground compared to the tailwind situation, and how an airplane will glide further over the ground downwind compared to into wind.

An actual air mass does not move in a totally steady manner—there will be gusts and updrafts and changes of wind speed and direction etc., which the airplane will encounter as it flies through the air mass. These windshears will have a transient effect on the flight path of an airplane.

An Example of Windshear

Even when the wind is relatively calm on the ground, it is not unusual for the light and variable surface wind to suddenly change into a strong and steady wind at a level only a few hundred feet above the ground. If we consider an airplane making an approach to land in these conditions, we can see the effect the windshear has as the airplane passes through the shear.

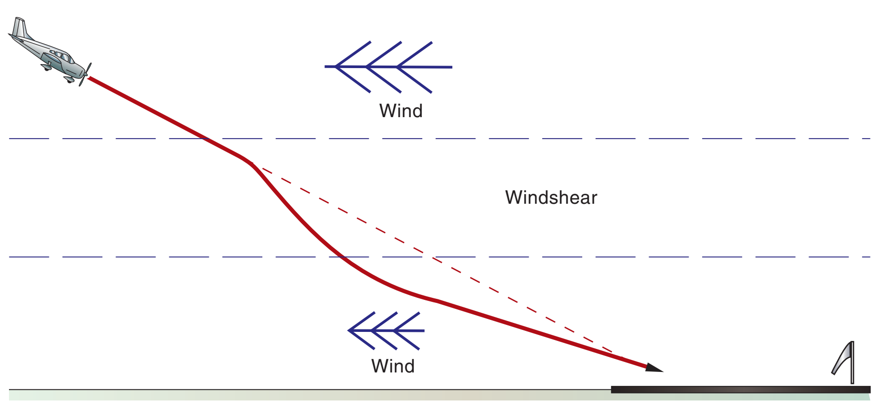


Figure 30-6 A typical windshear situation—calm on the ground with a wind at altitude.

An airplane flying through the air will have a certain inertia depending on its mass and its velocity relative to the ground. Its inertia makes it resistant to change. If the airplane has an airspeed of 80 knots and the headwind component is 30 knots, then the inertial speed of the airplane over the ground is (80 - 30) = 50 knots.

When the airplane flies down into the calm air, the headwind component reduces reasonably quickly to (let us say) 5 knots. The inertial speed of the airplane over the ground is still 50 knots, but the new headwind of only 5 knots will mean that its airspeed has suddenly dropped back to 55 KIAS.

The pilot will observe a sudden drop in indicated airspeed and a change in the performance of the airplane—at 55 KIAS the performance will be quite different to that available at 80 KIAS. The first indication of windshear to a pilot is usually a sudden change in indicated airspeed.

The normal reaction with a sudden loss of airspeed is to add power or to lower the nose to regain airspeed, and to avoid undershooting the desired flight path. The stronger the windshear, the greater the changes in power and attitude that will be required. Any fluctuations in wind will require adjustments by the pilot, and this is why you have to work so hard sometimes, especially when approaching to land.

Windshear Effects on an Aircraft's Flight Path

The effects of windshear on an airplane's flight path depend on the nature and location of the shear.

Overshoot Effect

Overshoot effect is caused by a windshear which results in the airplane flying above the desired flight path and/or an increase in indicated airspeed. The nose of the airplane may also tend to rise.

Overshoot effect may result from flying into an increasing headwind, a decreasing tailwind, from a tailwind into a headwind, or an updraft. Overshoot effect is sometimes referred to as a *performance-increasing* windshear, since it causes an increase in airspeed and/or altitude.

Undershoot Effect

Undershoot effect is caused by a windshear which results in an airplane flying below the desired flight path and/or a decrease in indicated airspeed. The nose of the airplane may also tend to drop.

Undershoot effect may result from flying into a decreasing headwind, an increasing tailwind, from a headwind into a tailwind, or into a downdraft. Undershoot effect is sometimes referred to as a *performance-decreasing* windshear, since it causes a loss of airspeed and/or altitude.

Note. The actual effect of a windshear depends on:

1. the nature of the windshear;
2. whether the airplane is climbing or descending through that particular windshear; and
3. in which direction the airplane is proceeding.

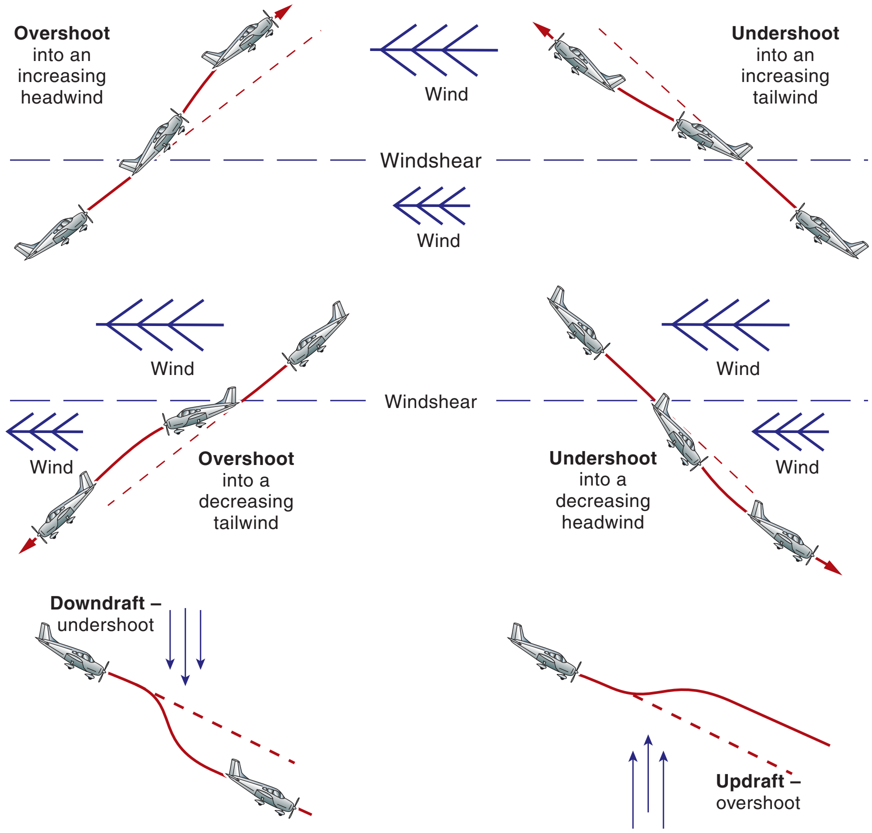


Figure 30-7 Six common windshear situations.

Windshear Reversal Effect

Windshear reversal effect is caused by a windshear which results in the initial effect on the airplane being reversed as the aircraft proceeds further along the flight path. It would be described as overshoot effect followed by undershoot, or undershoot followed by overshoot effect, as appropriate.

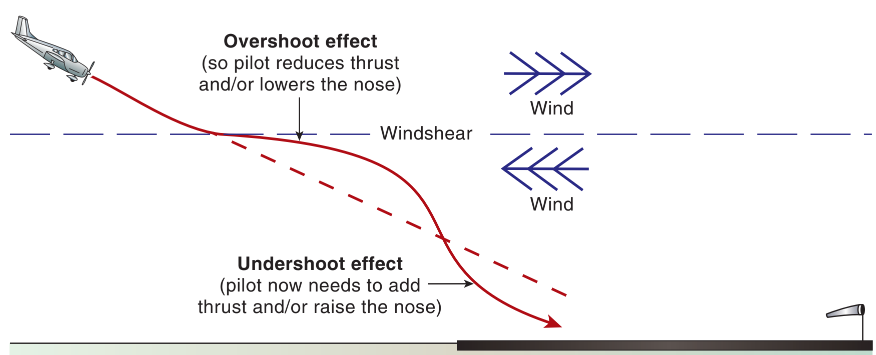


Figure 30-8 Windshear reversal effect.

Windshear reversal effect is a common phenomenon that pilots often experience on approach to land, when things are usually happening too fast to analyze exactly what is taking place in terms of wind. The pilot can, of course, observe undershoot and overshoot effect and react accordingly with changes in attitude and/or power.

Crosswind Effect

Crosswind effect is caused by a windshear which requires a rapid change of aircraft heading to maintain a desired track (not uncommon in a crosswind approach and landing because the crosswind component changes as the ground is neared).

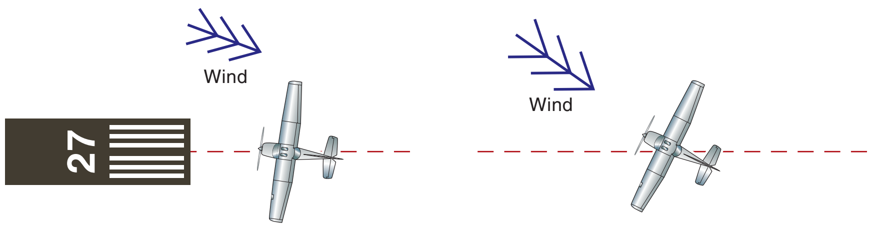


Figure 30-9 Crosswind effect.

The Causes of Windshear

There are many causes of windshear. They include obstructions and terrain features which disrupt the normal smooth wind flow, localized vertical air movements associated with cumulonimbus (thunderstorms) and large cumulus clouds (gust fronts, downbursts and microbursts), low-level temperature inversions, sea breezes and jet streams.

The following phenomena are known to be strongly associated with the occurrence of windshear, and a pilot should exercise appropriate caution if any are observed, especially during takeoff and landing:

- roll clouds and/or dust raised ahead of an approaching squall line;
- strong, gusty surface winds at an airport with hills or large buildings located near the runway;
- windsocks on various parts of the airport indicating different winds (some airports are equipped with a low level windshear alert system (LLWAS), which is designed to detect such a situation, allowing ATC to provide advisory warnings to landing and departing aircraft);
- curling or ring-shaped dust clouds raised by downdrafts beneath a convective cloud (even if the ceiling is relatively high);
- virga associated with a convective cloud (rain falling from the base of the cloud and evaporating before reaching the ground causing a cold parcel of air which may descend rapidly); or
- thunderstorms.

Avoid thunderstorms and cumulonimbus (Cb) clouds.

In particular, we strongly recommend that all thunderstorms and cumulonimbus clouds be avoided. A strong downburst from the base of one of these clouds will spread out as it nears the ground. If an airplane encounters one of these on takeoff or landing, the initial effect may be an overshoot followed immediately by an extreme undershoot. You should delay the approach and hold in the vicinity until the storms move on, or divert. Takeoff should also be delayed.

Pilots are strongly encouraged to promptly report any windshear encounters. Windshear PIREPs will assist other pilots in avoiding windshear on takeoff and landing. Reports should always include a description of the effect of the shear on the airplane, such as "loss of 30 knots at 500 feet."

As well as considering the potential for windshear on final approach to land, you should also think about the possibility of wake turbulence caused by the wingtip vortices from preceding aircraft (especially heavy aircraft flying slowly at high angles of attack).

If possible, stay above the flight path of a preceding heavy jet aircraft, and land beyond its touchdown point. Be especially cautious in light quartering tailwinds—the crosswind component can cause the upwind vortex to drift onto the runway and the tailwind component can drift the vortices into your touchdown zone.

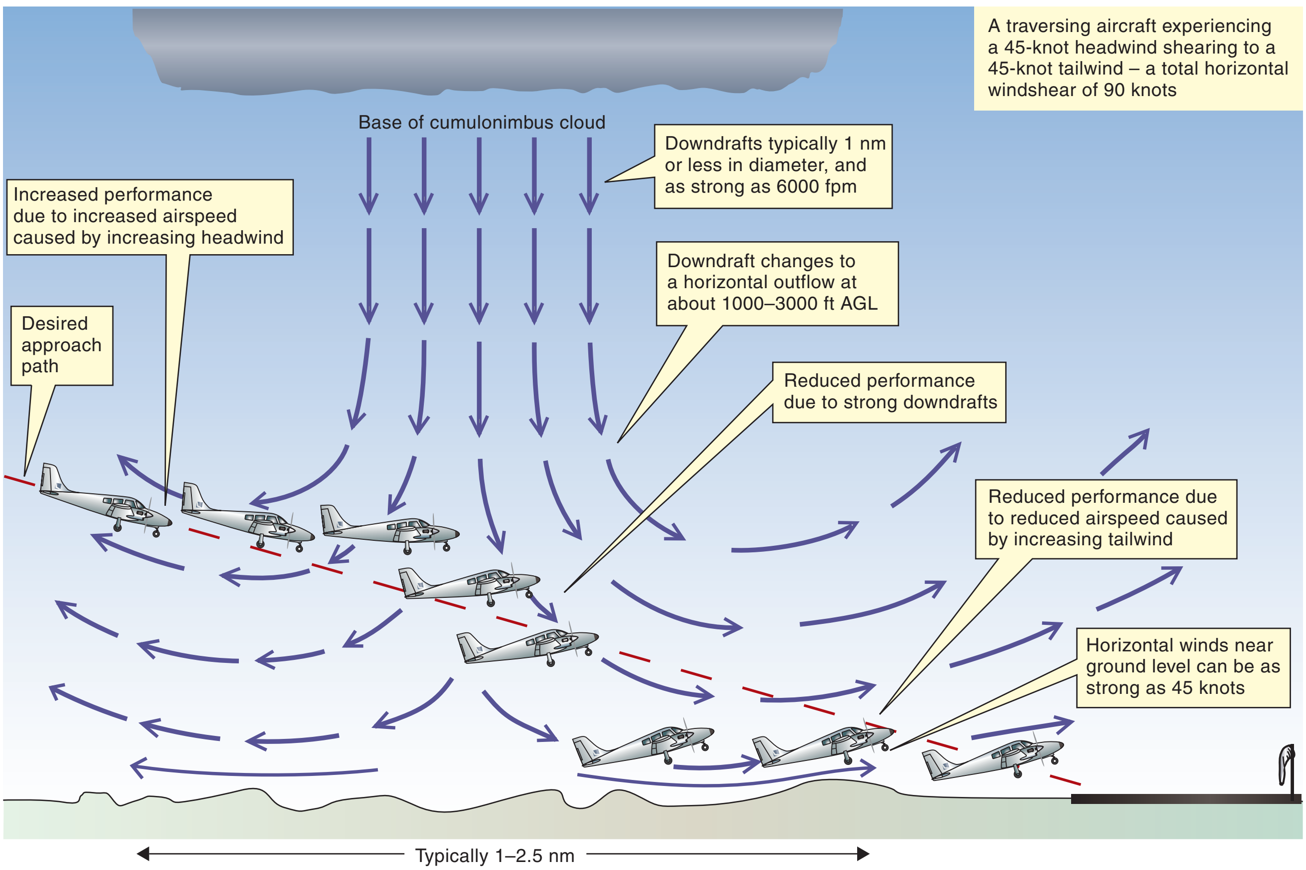


Figure 30-10 Avoid thunderstorms.

Air Masses and Frontal Weather

Air Masses

An air mass is a large parcel of air with fairly consistent properties (such as temperature and moisture content) throughout. It is usual to classify an air mass according to:

- its origin;
- its path over the earth's surface; and
- whether the air is diverging or converging.

The Origin of an Air Mass

Maritime air flowing over an ocean will absorb moisture and tend to become saturated in its lower levels; continental air flowing over a land mass will remain reasonably dry since little water is available for evaporation.

Air Mass Movement

The track of an air mass across the earth's surface determines its characteristics. Polar air flowing toward the lower latitudes will be warmed from below and so become unstable. Conversely, tropical air flowing to higher latitudes will be cooled from below and so become more stable.

Divergence or Convergence

An air mass influenced by the *divergence* of air flowing out of a high pressure system at the earth's surface will slowly sink (known as subsidence) and become warmer, drier and more stable. An air mass influenced by *convergence* as air flows into a low pressure system at the surface will be forced to rise slowly, becoming cooler, moister and less stable.

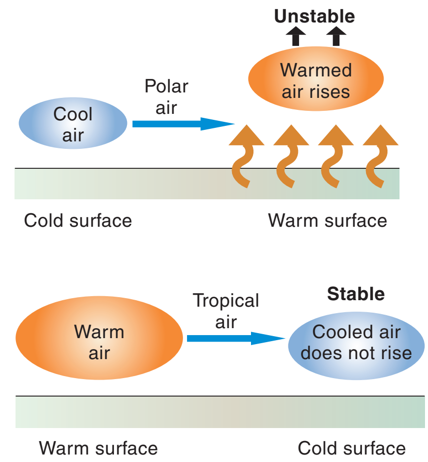


Figure 30-11
Polar air warms and becomes unstable (top) and tropical air cools and becomes stable (bottom).

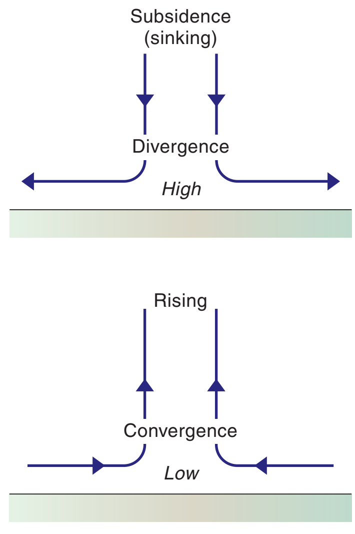


Figure 30-12
Subsiding air, resulting from divergence, is stable (top) and rising air, resulting from convergence, is unstable (bottom).

Frontal Weather

Air masses have different characteristics, depending on their origin and the type of surface over which they have been passing. Because of these differences there is usually a distinct division between adjacent air masses. These divisions are known as *fronts*, and there are two basic types—*cold fronts* and *warm fronts*. Frontal activity describes the interaction between the air masses, as one mass replaces the other. There is always a wind change when a front passes.

The Warm Front

If two air masses meet so that the warmer air replaces the cooler air at the surface, a warm front is said to exist. The boundary at the earth's surface between the two air masses is represented on a weather chart as a line with semi-circles pointed in the direction of movement.

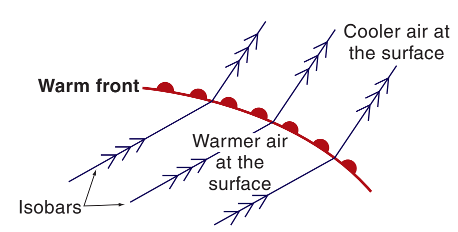


Figure 30-13
Depiction of a warm front on a weather chart.

The slope formed in a warm front as the warm air slides up over the cold air is fairly shallow and so the clouds that form in the (usually quite stable) rising warm air is likely to be stratiform. In a warm front the frontal air at altitude is actually well ahead of the line as depicted on the weather chart. The cirrus could be some 600 NM ahead of the surface front, and rain could be falling up to approximately 200 NM ahead of it. The slope of the warm front is typically 1 in 150, much flatter than a cold front, and has been exaggerated in the diagram.

A front defines the border between two different air masses. The wind changes when a front crosses over, known as frontal passage.

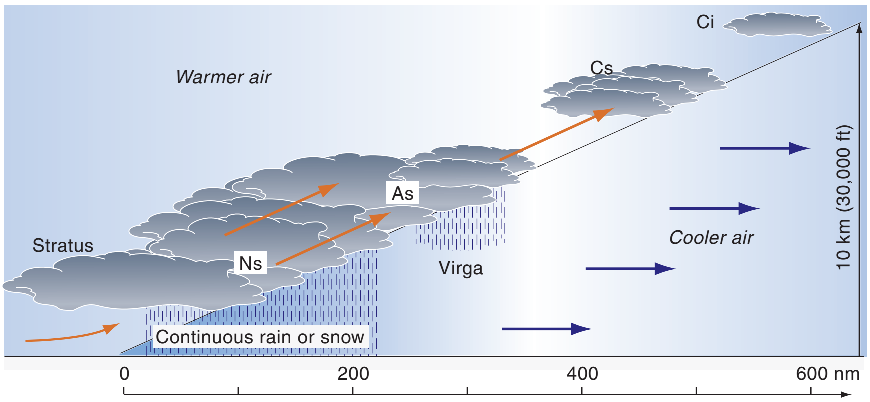


Figure 30-14 Cross-section of a warm front.

Figure 30-15 Altostratus.

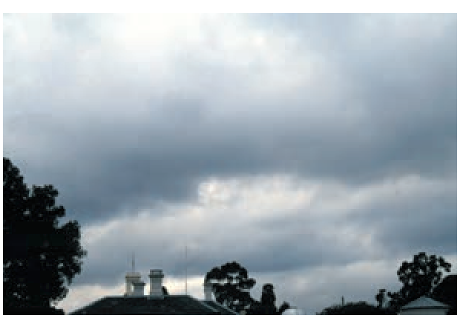


Figure 30-16 Nimbostratus indicating heavy or saturated air.

The Warm Front from the Ground

As a warm front gradually passes, an observer on the ground may first see high cirrus clouds, which will slowly be followed by a lowering base of cirrostratus, altostratus and nimbostratus. Rain may be falling from the altostratus and possibly evaporating before it reaches the ground, virga, and from the nimbostratus. The rain from the nimbostratus may be continuous until the warm front passes and may, due to its evaporation, cause fog. Also, the visibility may be quite poor.

The atmospheric pressure usually falls continuously as the warm front approaches and, as it passes, either stop falling or falls at a lower rate. The air temperature rises as the warm air moves in over the surface. The warm air holds more moisture than the cold air, and the dewpoint temperature in the warmer air is higher.

In the Northern Hemisphere, the wind direction will veer (a clockwise change of direction) as the warm front passes (counterclockwise change of direction in the Southern Hemisphere). Behind the warm front, and after it passes, there is likely to be stratus. Visibility may still be poor. Weather associated with a warm front may extend over several hundred miles.

The general characteristics of a warm front are:

- lowering stratiform clouds;
- increasing rain, with the possibility of poor visibility and fog;
- possible low-level windshear before the warm front passes;
- a falling atmospheric pressure that slows down or stops;
- a wind that veers (clockwise change of direction); and
- a temperature that rises.

The Warm Front from the Air

What a pilot sees, and in which order he or she sees it, will depend on the direction of flight. The pilot may see a gradually lowering cloud base if in the cold sector underneath the warm air and flying toward the warm front, with steady rain falling.

If the airplane is at subzero temperatures, the rain may freeze and form ice on the wings, thereby decreasing their aerodynamic qualities. The clouds may be as low as ground level (hill fog) and sometimes the lower layers of stratiform clouds can conceal cumulonimbus and thunderstorm activity. Visibility may be quite poor.

There will be a wind change either side of the front and a change of heading may be required to maintain course.

Figure 30-17 Warm, moist air and cloud.

The Cold Front

If a cooler air mass undercuts a mass of warm air and displaces it at the surface, a cold front is said to occur. The slope between the two air masses in a cold front is generally quite steep (typically 1 in 50) and the frontal weather may occupy a band of only 30 to 50 nautical miles.

The boundary between the two air masses at the surface is shown on weather charts as a line with barbs pointing in the direction of travel of the front. The cold front moves quite rapidly, with the cooler frontal air at altitude lagging behind that at the surface.

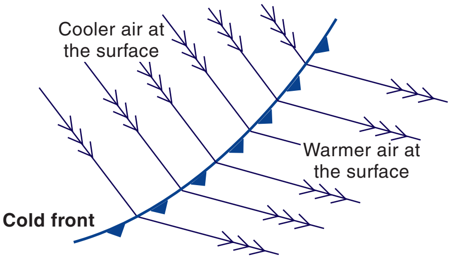


Figure 30-18
Depiction of a cold front on a weather chart.

The air that is forced to rise with the passage of a cold front is unstable and so the clouds that form are cumuliform in nature, cumulus and cumulonimbus. Severe weather hazardous to aviation, such as thunderstorm activity, squall lines, severe turbulence and windshear, may accompany the passage of a cold front.

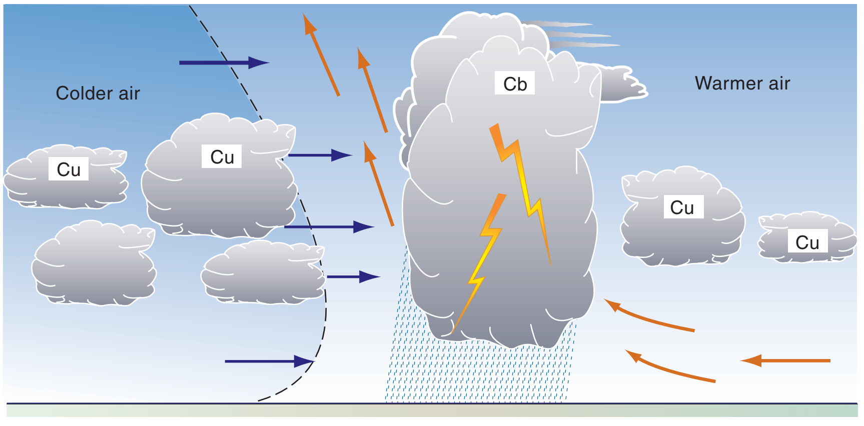


Figure 30-19 Cross-section of a cold front.

The Cold Front from the Ground

The atmospheric pressure will fall as a cold front approaches and the change in weather with its passage may be quite pronounced. There may be cumulus and possibly cumulonimbus clouds with heavy rain showers, thunderstorm activity and squalls, with a sudden drop in temperature and change in wind direction as the front passes (the direction shifting clockwise in the Northern Hemisphere, and counterclockwise in the Southern Hemisphere).

The cooler air mass contains less moisture than the warm air, and so the dewpoint temperature after the cold front has passed is lower. Once the cold front has passed, the pressure may rise rapidly. The general characteristics of a cold front are:

- cumuliform clouds—cumulus, cumulonimbus;
- a sudden drop in temperature, and a lower dewpoint temperature;
- possible low-level windshear as or just after the front passes;
- a veering of the wind direction; and
- a falling pressure that rises once the front is past.

Figure 30-20
Thickening low cloud proceding a cold front.

The Cold Front from the Air

Flying through a cold front may require diversions to avoid weather. There may be thunderstorm activity, violent winds (both horizontal and vertical) from cumulonimbus clouds, squall lines, windshear, heavy showers of rain or hail, and severe turbulence. Icing could be a problem. Visibility away from the showers and the clouds may be quite good, but it is still a good idea for a pilot to consider avoiding the strong weather activity that accompanies many cold fronts. A squall line may form ahead of the front.

The Occluded Front

Because cold fronts usually travel much faster than warm fronts, it often happens that a cold front overtakes a warm front, creating an *occlusion* (or occluded front). This may happen in the final stages of a frontal depression (which is discussed shortly). Three air masses are involved and their vertical passage, one to the other, will depend on their relative temperatures. The occluded front is depicted by a line with alternating barbs and semicircles pointing in the direction of motion of the front.

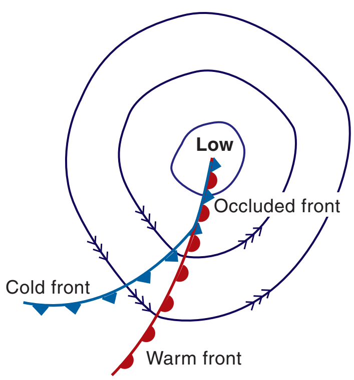


Figure 30-21
An occluded front on a weather map.

The clouds that are associated with an occluded front will depend on what clouds are associated with the individual cold and warm fronts. It is not unusual to have cumuliform clouds from the cold front as well as stratiform clouds from the warm front. Sometimes the stratiform clouds can conceal thunderstorm activity. Severe weather can occur in the early stages of an occlusion as unstable air is forced upward, but this period is often short.

Flight through an occluded front may involve encountering intense weather, as both a cold front and a warm front are involved, with a warm air mass being squeezed up between them. The wind direction will be different on either side of the front.

Depressions—Areas of Low Pressure

A *depression* or *low* is a region of low pressure at the surface, the pressure gradually rising as you move away from its center. A low is depicted on a weather chart by a series of concentric isobars joining places of equal sea level pressure, with the lowest pressure in the center. In the Northern Hemisphere, winds circulate counterclockwise around a low. Flying toward a low, an airplane will experience right drift.

Depressions generally are more intense than highs, being spread over a smaller area and with a stronger pressure gradient (change of pressure with distance). The more intense the depression, the "deeper" it is said to be. Lows move faster across the face of the earth than highs and do not last as long.

Because the pressure at the surface in the center of a depression is lower than in the surrounding areas, there will be an inflow of air, known as convergence. The air above the depression will rise and flow outward.

The three-dimensional pattern of airflow near a depression is:

- convergence (inflow) in the lower layers;
- rising air above; and
- divergence (outflow) in the upper layers.

The depression at the surface may in fact be caused by the divergence aloft removing air faster than it can be replaced by convergence at the surface.

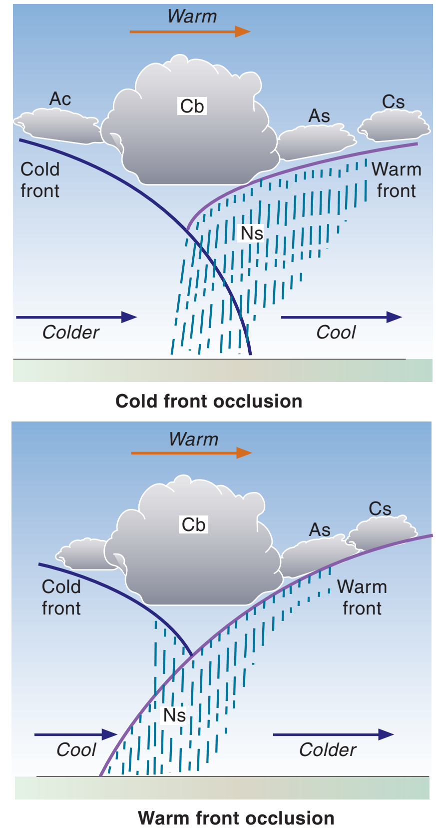


Figure 30-22
Cross-sections of occluded fronts.

Weather Associated with a Depression

In a depression, the rising air will be cooling and so clouds will tend to form. Instability in the rising air may lead to quite large vertical development of cumuliform clouds accompanied by rain showers. Visibility may be good (except in the showers), since the vertical motion will tend to carry away all the particles suspended in the air.

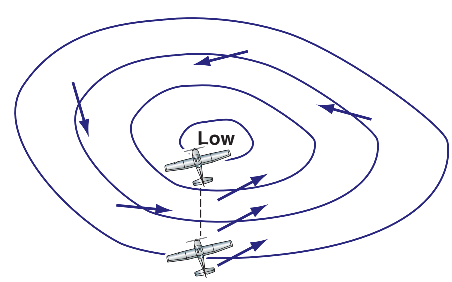


Figure 30-23
A depression or low pressure system.

Troughs of Low Pressure

A V-shaped extension of isobars from a region of low pressure is called a trough. Air will flow into it (convergence will occur) and rise. If the air is unstable, weather similar to that in a depression or a cold front will occur, cumuliform clouds, possibly with cumulonimbus and thunderstorm activity.

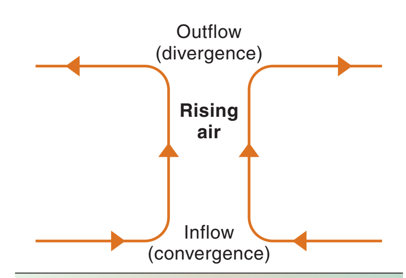


Figure 30-24
The three-dimensional flow of air near a low.

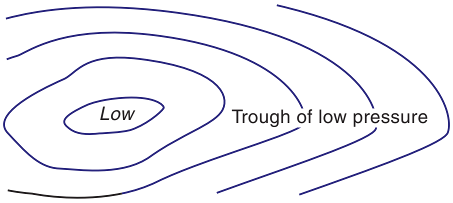


Figure 30-25 A trough.

The trough may in fact be associated with a front. Less prominent troughs, possibly more U-shaped than V-shaped, will generally have less severe weather.

The Wave or Frontal Depression

The boundary between two air masses moving (relative to one another) side by side is often distorted by the warmer air bulging into the cold air mass, with the bulge moving along like a wave. This is known as a *frontal wave*. The leading edge of the bulge of warm air is a warm front and its rear edge is a cold front.

The pressure near the tip of the wave falls sharply and so a depression forms, along with a warm front, a cold front, and possibly an occlusion. It is usual for the cold front to move faster across the surface than the warm front, but even then, the cold front moves only relatively slowly. Frontal waves can also form on a stationary front.

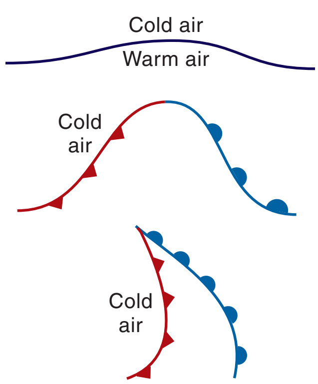


Figure 30-26
The frontal depression forming.

The Hurricane or Tropical Revolving Storm

Tropical revolving storms are intense cyclonic depressions and can be both violent and destructive. They occur over warm tropical oceans at about 10–20° latitude during certain periods of the year. In the U.S. they occur off the Pacific southwest coast, in the Gulf of Mexico, the Atlantic Ocean, and in the Caribbean Sea.

Occasionally, weak troughs in these tropical areas develop into intense depressions. Air converges in the lower levels, flows into the depression and then rises—the warm, moist air forming large cumulus and cumulonimbus clouds. The deep depression may be only quite small (200–300 NM in diameter) compared to the typical depression in temperate latitudes, but its central pressure can be extremely low.

Winds in hurricanes can exceed 100 knots, with heavy showers and thunderstorm activity becoming increasingly frequent as the center of the storm approaches. Despite the strong winds, hurricanes move quite slowly and usually only dissipate after encountering a land mass, which gradually weakens the depression through surface friction. They are then usually classified as tropical storms.

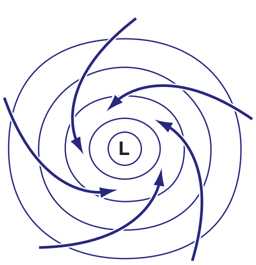


Figure 30-27
A tropical revolving storm or hurricane.

The eye of a hurricane is often only some 10 NM in diameter, with light winds and broken clouds. It is occupied by warm subsiding air, which is one reason for the extremely low pressure. Once the eye has passed, a strong wind from the opposite direction will occur. In the Northern Hemisphere, pronounced right drift caused by a strong wind from the left will mean that the eye of the hurricane is ahead (and vice versa in the Southern Hemisphere).

In addition to the term hurricane, the tropical revolving storm is also known by other names in different parts of the world—tropical cyclone in Australia and the South Pacific, and typhoon in the South China Sea.

Anticyclones— Areas of High Pressure

An *anticyclone* or *high* is an area of high pressure at the surface surrounded by roughly concentric isobars. Highs are generally greater in extent than lows, but with a weaker pressure gradient and slower moving, although they are more persistent and last longer. In the Northern Hemisphere, the wind circulates clockwise around the center of a high. Flying toward a high an aircraft will experience left drift.

The three-dimensional flow of air associated with an anticyclone is:

- an outflow of air from the high pressure area in the lower layers (divergence);
- the slow subsidence of air over a wide area from above; and
- an inflow of air in the upper layers (convergence).

The high pressure area at the surface originates when the convergence in the upper layers adds air faster than the divergence in the lower layers removes it.

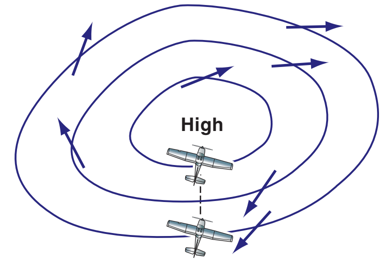


Figure 30-28
The anticyclone or "high."

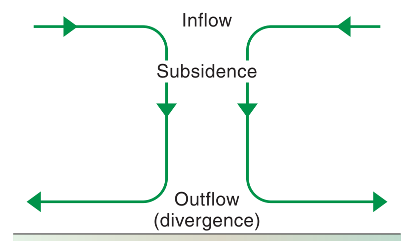


Figure 30-29
The three-dimensional flow of air near a high.

Weather Associated with a "High"

The subsiding air in a high pressure system will be warming as it descends and so any clouds will tend to disperse as the dewpoint temperature is exceeded and the relative humidity decreases. Subsiding air is stable. It is possible that the subsiding air may warm sufficiently to create an inversion, with the upper air warming to a temperature higher than that of the lower air, and possibly causing stratiform clouds to form (stratocumulus, stratus) and/or trapping smoke, haze and dust beneath it. This can happen in winter in some parts of the country, leading to rather gloomy days with poor flight visibility. In summer, heating by the sun may disperse the clouds, leading to a fine but hazy day.

If the sky remains clear at night, greater cooling of the earth's surface by radiation heat-loss may lead to the formation of fog. If the high pressure is situated entirely over land, the weather may be dry and cloudless, but with any air flowing in from the sea, extensive stratiform clouds in the lower levels can occur.

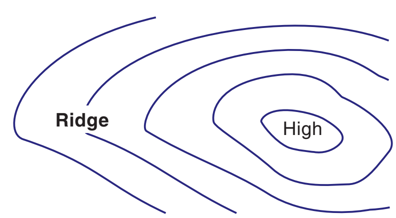


Figure 30-30 A ridge.

A Ridge of High Pressure

Isobars which extend out from a high in a U-shape indicate a ridge of high pressure (like a ridge extending from a mountain). Weather conditions associated with a ridge are, in general, similar to the weather found with anticyclones.

A Col

The area of almost constant pressure (and therefore indicated by a few widely spaced isobars) that exists between two highs and two lows is called a col. It is like a "saddle" on a mountain ridge. Light winds are often associated with cols, with fog a possibility in winter and high temperatures in summer possibly leading to showers or thunderstorms.

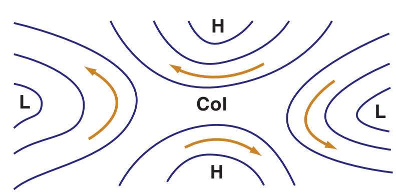


Figure 30-31 A col.

Review 30
Wind, Air Masses, and Fronts

1. What is the stratosphere?
2. What are the characteristics of the stratosphere?
3. Will stable air tend to keep rising if it is forced aloft?
4. Will unstable air tend to keep rising if it is forced aloft?
5. What is the primary cause of all changes in weather?
6. What is the Coriolis force?
7. What effect does the Coriolis force have?
8. What effect does friction have on surface winds?
9. While the winds at 2,000 feet AGL and above tend to flow parallel to the isobars, the surface winds tend to cross the isobars at an angle toward the lower pressure. Why?
10. At any level in the atmosphere, windshear can be associated with any change in:
    a. wind speed.
    b. wind direction.
    c. wind speed or wind direction.
    d. none of the above.
11. If a strong temperature inversion exists, is a strong windshear possible as you pass through the inversion layer?
12. Which of the following can windshear be associated with?
    a. Low-level temperature inversion.
    b. Jetstream.
    c. Frontal zone.
13. What sort of windshear is likely within and near a thunderstorm?
14. With a warm front, the most critical period for low-level windshear above an airport is:
    a. before the warm front passes.
    b. after the warm front passes.
15. With a cold front, the most critical period for low-level windshear above an airport is:
    a. just before or as the cold front passes.
    b. as or just after the cold front passes.
16. What is an air mass?
17. What sort of change will always occur whenever a front passes?
18. Squall lines often develop ahead of a:
    a. cold front.
    b. warm front.
19. Frontal waves normally form on which of the following?
    a. Fast moving cold fronts.
    b. Slow moving cold fronts.
    c. Stationary fronts.
20. When passing through an abrupt windshear which involves a shift from a tailwind to a headwind, what will tend to happen to your airspeed? How is a constant airspeed maintained in this circumstance?
21. When passing through an abrupt windshear which involves a shift from a headwind to a tailwind, what will tend to happen to your airspeed? How is a constant airspeed maintained in this circumstance?
22. While flying a 3° glide slope, a headwind shears to a tailwind. What will happen to your airspeed and pitch attitude? Will the tendency be to go above or below slope?
23. While flying a 3° glide slope, a tailwind shears to a headwind. What will happen to your airspeed and pitch attitude? Will the tendency be to go above or below slope?
24. Describe what power management would normally be required to maintain a constant indicated airspeed and ILS glide slope when passing through an abrupt windshear which involves a shift from a tailwind to a headwind. Compared to an approach in calm conditions, what will be the power setting in relation to the normal power setting:
    a. before the shear is encountered?
    b. when the shear is encountered?
    c. after the shear is encountered?
25. At which levels in the atmosphere can windshear occur?

Answers are given on page 791.

Visibility 31

Visibility is defined as the greatest distance that you can see and identify objects—it is a measure of how transparent the atmosphere is to the human eye.

The actual visibility is very important to pilots and strict visibility requirements are specified for visual flight operation.

Slant visibility may be quite different from *horizontal visibility*. A runway clearly visible through stratus, fog or smog from directly overhead the airport might be impossible to see when you are trying to fly the final approach.

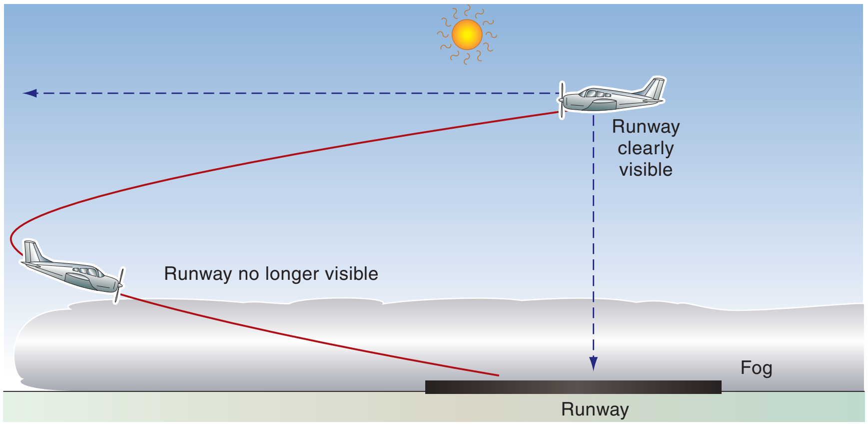


Figure 31-1 Slant visibility may be severely reduced by fog, smog or stratus.

Visibility is reduced by particles suspended in the air.

On a perfectly clear day visibility can exceed 100 NM, however this is rarely the case since there are always some particles suspended in the air, preventing all of the light from a distant object reaching your eyes.

Rising air (unstable air) may carry these particles up and blow them away, leading to good visibility; stable air that is not rising, however, will keep the particles in the lower levels, and this may result in poor visibility.

Particles that restrict visibility include:

- *minute particles* so small that even very light winds can support them;
  - *dust or smoke* causing haze;
  - liquid water or ice producing mist, fog or clouds;
- *larger particles of sand, dust or sea spray* which require stronger winds and turbulence for the air to hold them in suspension; and
- *precipitation* (rain, snow, hail), the worst visibility being associated with very heavy rain or with large numbers of small particles, such as thick drizzle or heavy, fine snow.

Unstable air that is rising may cause cumuliform clouds to form, with poor visibility in the showers falling from them, but on the other hand, good visibility with rising unstable air will carry obscuring particles away. As well as causing good visibility, the rising unstable air may cause bumpy flying conditions.

Because air is more or less transparent to incoming short wave solar radiation, the sun does not heat the air to any great extent. Rather, it passes through the air and heats the ground. Long wave radiation from the earth (or lack thereof, when the ground or water is colder than the air at low levels) is what actually results in the heating and cooling of the low-level air.

Rain or snow reduces the distance that you can see, as well as possibly obscuring the horizon and making it more difficult for you to keep the wings level or hold a steady bank angle in a turn. Poor visibility over a large area may occur in mist, fog, smog, stratus, drizzle or rain. As well as restricting visibility through the atmosphere, heavy rain may collect on the windshield and further restrict your vision or cause optical distortions, especially if the airplane is flying fast. If freezing occurs on the windshield either as ice or frost, vision may be further impaired.

Strong winds can raise dust or sand from the surface and, in some parts of the world, visibility may be reduced to just a few feet in dust and sandstorms.

Sea spray often evaporates after being blown into the atmosphere, leaving small salt particles suspended in the air that can act as condensation nuclei. The salt particles attract water and can cause condensation at relative humidities as low as 70%, restricting visibility much sooner than would otherwise be the case. Haze produced by sea salt often has a whitish appearance and may often be seen along ocean coastlines.

The position of the sun can also have a significant effect on visibility. Flying down-sun (with the sun behind you) where you can see the sunlit side of objects, the visibility may be much greater than when flying into the sun. As well as reducing visibility, flying into the sun may also cause glare. If landing into the sun is necessary because of strong surface winds or other reasons, consideration should be given to altering your time of arrival at a destination.

Remember that the onset of darkness is earlier on the ground than at altitude. Even though visibility at higher altitudes might be good, flying low in the traffic pattern and approaching to land on a darkening field may cause problems.

Inversions and Reduced Visibility

An inversion occurs when the air temperature increases with altitude.

An inversion occurs when the air temperature increases with altitude (rather than decreasing, which is the usual situation).

A temperature inversion can act as a blanket, stopping vertical convection currents —air that starts to rise meets warmer air and so will stop rising, i.e. temperature inversions are associated with a stable layer of air. Particles suspended in the lower layers will be trapped there causing a rather dirty layer of smoke, dust, or pollution, particularly in industrial areas. These small particles may act as condensation particles or nuclei,

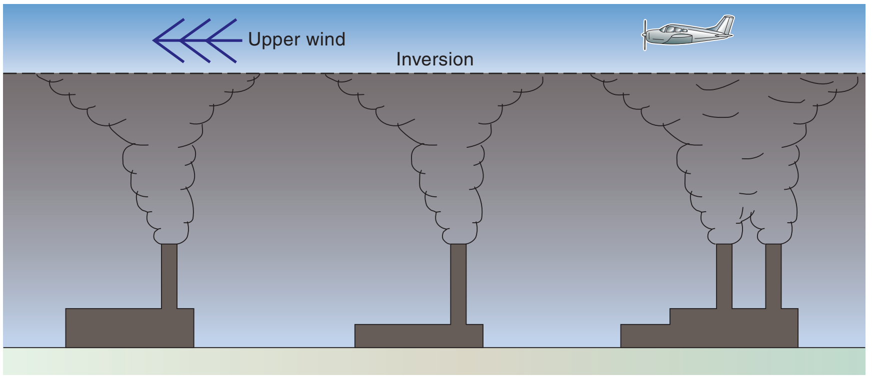


Figure 31-2 Reduced visibility and smooth flying conditions beneath the inversion, and possible windshear passing through it.

and encourage the formation of fog if the relative humidity is high—the combination of smoke and fog is known as smog. There is usually an abundance of condensation nuclei in industrial areas as a result of the combustion process (factory smoke, car exhausts, etc.), hence the poor visibility often found over these areas.

Similar poor visibility effects below inversions can be seen in rural areas if there is a lot of pollen, dust or other matter in the air.

Inversions can occur by cooling of the air in contact with the earth's surface overnight, or by subsidence associated with a high pressure system as descending air warms. The most common type of ground-based inversion is produced by terrestrial radiation on a clear, relatively still night. Terrestrial radiation often leads to poor visibility in the lower levels the following morning from fog, smoke or smog.

Flying conditions beneath a low-level inversion layer are typically smooth (due to stable air not rising), with poor visibility, haze, fog, smog or low clouds. Because there is little or no mixing of the air above and below an inversion, the effect of any upper winds may not be carried down beneath the inversion. This may cause a quite sharp windshear as an airplane climbs or descends through the inversion.

High-level inversions are common in the stratosphere, but these are so high as to only affect high-flying jets.

Condensation

Fog is simply a cloud layer reaching ground level.

Visibility can be dramatically reduced when invisible water vapor in the air condenses out as visible water droplets and forms clouds or fog. The amount of water vapor which a parcel of air can hold depends on its temperature—warm air is able to carry more water vapor than cold air. Warm air passing over a water surface, such as an ocean or a lake, is capable of absorbing much more water vapor than cooler air.

If the moist air is then cooled, say by being forced aloft and expanding or by passing over or lying over a cooling surface, it eventually reaches a point where it can no longer carry all of its invisible water vapor and is said to be *saturated*. The temperature at which saturation occurs is called the *dewpoint temperature* (or simply *dewpoint*) of that parcel of air. Any further cooling will most likely lead to the excess water vapor condensing out as visible water droplets and forming fog or clouds, a process encouraged by the presence of dust or other condensation nuclei in the air. If the air is extremely clean, with very few condensation nuclei, the actual condensation process may be delayed until the temperature falls some degrees below the dewpoint.

Air carrying a lot of water vapor, for instance warm air after passing over an ocean or large lake, will have a high dewpoint temperature compared with the relatively dry air over an arid desert. Moist air may only have to cool to a dewpoint of +25°C before becoming saturated, whereas less moist air may have to cool to +5°C before reaching saturation point. Extremely dry air may have to cool to a dewpoint temperature of -5°C before becoming saturated.

Clouds or fog form when the invisible water vapor condenses out in the air as visible water droplets.

Clouds or fog form when the invisible water vapor condenses out in the air as visible water droplets. The closeness of the actual air temperature to the dewpoint of the air, often contained in METARs, is a good indication to the pilot as to how close the air is to saturation and the possible formation of clouds or fog.

If the water vapor condenses out on contact with a surface such as the ground or an airplane that is below the dewpoint of the surrounding air, then it will form *dew* (or *frost*, if the temperature of the collecting surface is below freezing).

The reverse process to condensation may occur in the air if its temperature rises above the dewpoint, causing the water droplets to evaporate into water vapor and, consequently, the fog or clouds to disperse.

Fog

Fog is of major concern to pilots because it severely restricts vision near the ground. The condensation process that causes fog is usually associated with cooling of the air either by:

- an underlying cold ground or water surface (causing radiation or advection fog);
- the interaction of two air masses (causing frontal fog);
- the adiabatic cooling of a moist air mass moving up a slope (causing upslope fog); or
- very cold air overlying a warm water surface (causing steam fog).

The closer the *temperature/dewpoint* spread, and the faster the temperature is falling, the sooner fog will form. For instance, an airport with an actual air temperature of +6°C early on a calm, clear night, and a dewpoint temperature of +4°C (a temperature/dewpoint spread of 2°C) is likely to experience fog when the temperature falls 2°C or more from its current +6°C.

Radiation Fog

Radiation fog forms when air is cooled to below its dewpoint temperature by losing heat energy as a result of radiation. Conditions suitable for the formation of radiation fog are:

- a cloudless night, allowing the land to lose heat by radiation to the atmosphere and thereby cool, also causing the air in contact with the ground to lose heat (possibly leading to a temperature inversion);
- moist air and a small temperature/dewpoint spread (i.e. a high relative humidity) that only requires a little cooling for the air to reach its dewpoint temperature, causing the water vapor to condense onto small condensation nuclei in the air and form visible water; and
- light winds (5–7 knots) to promote mixing of the air at low level, thereby thickening the fog layer.

These conditions are commonly found with an anticyclone (or high-pressure system).

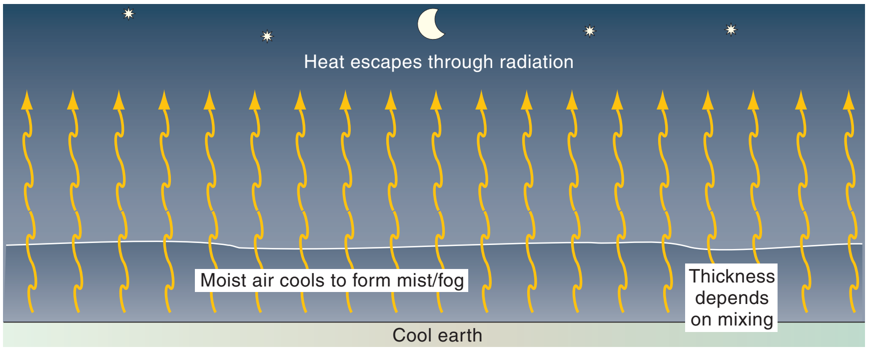


Figure 31-3 Radiation fog.

Air is a poor conductor of heat. If the wind is absolutely calm only the very thin layer of air 1–2 thick actually comes in contact with the surface will lose heat to it. This will cause dew or frost to form on the surface itself, instead of fog forming in the air above it. Dew will form at temperatures above freezing, and frost will form at and below freezing point. Dew may inhibit the formation of radiation fog by removing moisture from the air. After dawn, however, the dew may evaporate and fog may form.

If the wind is stronger than about 7 knots, the extra turbulence may cause too much mixing and, instead of radiation fog right down to the ground, a layer of *stratus* clouds may form above the surface.

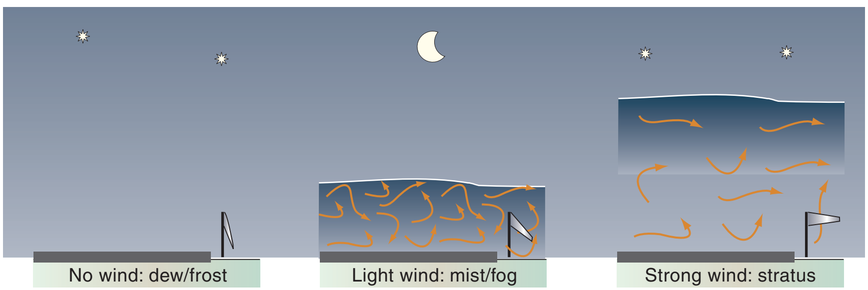


Figure 31-4 Wind strength will affect the formation of dew/frost, mist/fog or stratus clouds.

The temperature of the sea remains fairly constant throughout the year, unlike that of the land which warms and cools quite quickly on a diurnal (daily) basis. Radiation fog is therefore much more likely to form over land, which cools more quickly at night, than over the sea.

The dispersal of radiation fog depends on heating of the air.

As the earth's surface begins to warm up again some time after sunrise, the air in contact with it will also warm, causing the fog to gradually dissipate. It is common for this to occur by early or mid-morning. Possibly the fog may rise to form a low layer of stratus before the sky fully clears.

If the fog that has formed overnight is thick, however, it may act as a blanket, shutting out the sun and impeding the heating of the earth's surface after the sun has risen. As a consequence, the air in which the fog exists will not be warmed from below and the radiation fog may last throughout the day. An increasing wind speed could create sufficient turbulence to drag warmer and drier air down into the fog layer, causing it to dissipate.

Note. Haze caused by particles of dust, pollen, etc., in the air of course cannot be dissipated by the air warming—haze needs to be blown away by a wind.

Advection Fog

A warm, moist air mass flowing as a wind across a significantly colder surface will be cooled from below. If its temperature is reduced to the dewpoint temperature, then fog will form. Since the term *advection* means the horizontal flow of air, fog formed in this manner is known as advection fog, and can occur quite suddenly, day or night, if the right conditions exist, and can be more persistent than radiation fog.

For instance, a warm, moist maritime air flow over a cold land surface can lead to advection fog forming over the land. In winter, moist air from the Gulf of Mexico moving north over cold ground often causes advection fog extending well into the south-central and eastern United States.

Advection fog depends on a wind to move the relatively warm and moist air mass over a cooler surface. Unlike radiation fog, the formation of advection fog is not affected by overhead cloud layers, and can form with or without clouds obscuring the sky. Light to moderate winds will encourage mixing in the lower levels to give a thicker layer of fog, but winds stronger than about 15 knots may cause *stratus* clouds rather than fog. Advection fog can persist in much stronger winds than radiation fog.

Sea fog is advection fog, and it may be caused by:

- tropical maritime air moving toward the pole over a colder ocean or meeting a colder air mass; or by
- an air flow off a warm land surface moving over a cooler sea, affecting airports in coastal areas. Advection fog is common in coastal regions of California during summer.

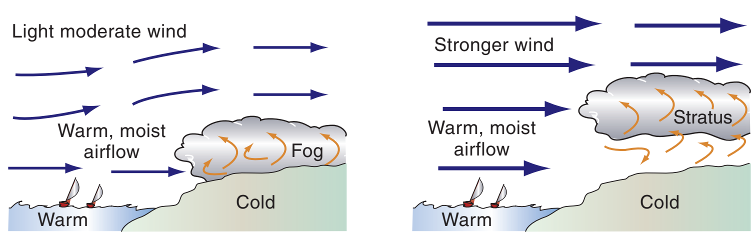


Figure 31-5 Fog or stratus caused by advection.

Upslope Fog

Both upslope fog and advection fog depend on wind to exist (but not radiation fog).

Moist air moving up a slope will cool adiabatically and, if it cools to below its dewpoint temperature, fog will form. This is known as upslope fog. It may form whether there is a cloud above or not. If the wind stops, the upslope fog will dissipate. Upslope fog is common on the eastern slopes of the Rockies and the Appalachian mountains.

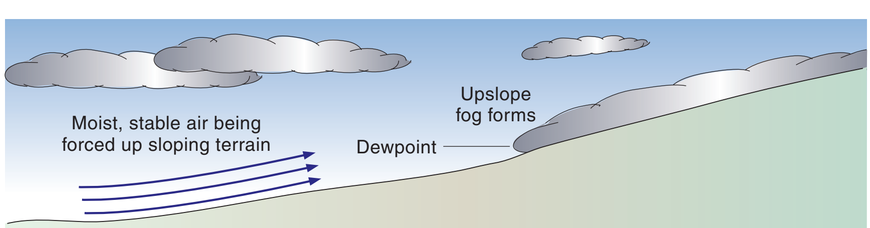


Figure 31-6 Upslope fog.

Frontal Fog

Frontal fog forms from the interaction of two air masses in one of two ways:

- as clouds that extend down to the surface during the passage of the front (forming mainly over hills and consequently called *hill fog*); or
- as air becomes saturated by the evaporation from rain that has fallen, known as *precipitation-induced fog*.

These conditions may develop in the cold air ahead of a warm front (or an occluded front), the prefrontal fog possibly being widespread.

Rain or drizzle falling from relatively warm air into cooler air may saturate it, forming precipitation-induced fog which may be thick and long-lasting over quite wide areas. Precipitation-induced fog is most likely to be associated with a warm front, but it can also be associated with a stationary front or a slow-moving cold front.

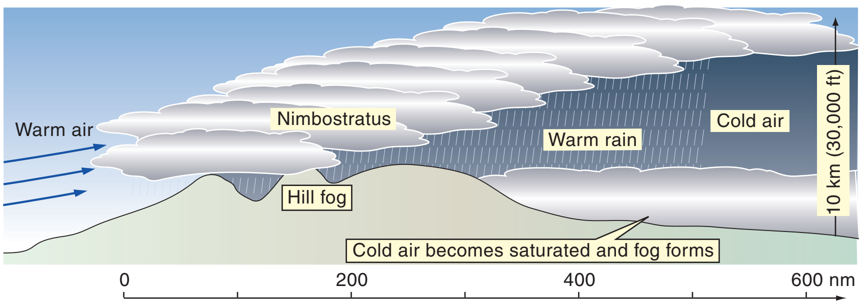


Figure 31-7 Fog associated with a warm front.

Steam Fog

Steam fog can form when cool air blows over a warm, moist surface (a warm sea or wet land), cooling the water vapor rising from the moist surface to below its dewpoint temperature and thereby causing fog. Steam fog over polar oceans is sometimes called *Arctic sea smoke.* It forms in air more than 10°C colder than water, and can be thick and widespread, causing serious visibility problems for ships.

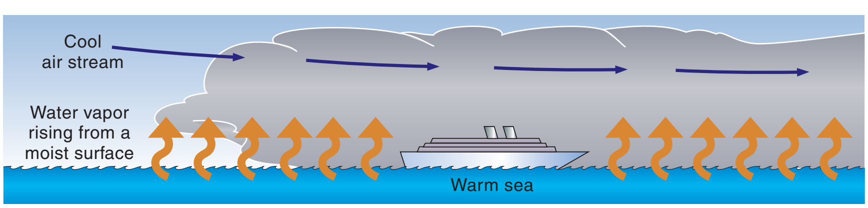


Figure 31-8 Light turbulence and a risk of icing can be present in steam fog.

Review 31

Visibility

1. Poor visibility is more likely to result with:
   a. stable air.
   b. unstable air.
2. For an inversion to exist, temperature must:
   a. increase with altitude.
   b. decrease with altitude.
3. Does air and the particles it contains tend to rise through an inversion?
4. Does the presence of an inversion increase the risk of poor visibility?
5. What happens to the air beneath an inversion?
6. Describe the likely flying conditions and visibility beneath a low-level inversion.
7. How much mixing of the air occurs above and below an inversion?
8. Is there a risk of windshear to an airplane climbing or descending through an inversion?
9. What does the amount of water vapor that a parcel of air can hold largely depend on?
10. Can warm air hold more water vapor than cold air?
11. Is water vapor visible?
12. Are the water droplets formed when water vapor condenses out of cooling air visible?
13. As a parcel of air is cooled, is it capable of holding more water vapor?
14. What is the temperature to which a parcel of air must be cooled for it to become saturated called?
15. When will water vapor condense out of air? What effect does the presence of condensation nuclei in the air have on this process?
16. When do clouds, fog, dew, or frost form?
17. When does fog form?
18. What increases the possibility of fog in industrial areas?
19. What is a mixture of smoke and fog known as?
20. In which conditions is radiation fog most likely to form?
21. Is radiation fog more likely to form over land or over the sea?
22. Does land cool faster than the sea at night?
23. How is a common type of surface-based inversion that can lead to ground fog caused?
24. Describe the conditions in which dew forms.
25. Describe the conditions in which frost forms.
26. Describe the conditions in which advection fog is formed.
27. When and where is advection fog most likely?
28. Is wind necessary for advection fog to form?
29. What is moist air flowing over a cold surface likely to form?
30. Advection fog may form on the lee side of a large lake, the side to which the wind is blowing, in what conditions?
31. What wind strength is necessary for advection fog to be lifted in order to form low stratus clouds?
32. Moist, stable air being moved over gradually rising ground by a wind may lead to the formation of which type of fog?
33. What type(s) of fog depend on a wind in order to exist?
34. Can fog be dissipated by heating of the air?
35. Can haze layers be dissipated by heating of the air?
36. How can haze be dissipated?

Answers are given on page 791.

Clouds 32

Figure 32-1 Clouds foretell much about flying conditions and trends.

A cloud is a visible aggregate of minute particles of water and/or ice in the free air. The effect of clouds on aviation, particularly on flight, is an important training topic for instrument-rated pilots.

Low stratus clouds formed in stable atmospheric conditions can sit low over the ground, possibly even on the ground as fog, and cause you to divert to an alternate destination. Towering cumulus clouds can form in unstable conditions due to moist air rising and can develop into one of the greatest hazards to an airplane: cumulonimbus clouds and thunderstorms.

The Naming of Clouds

Clouds may take on many different forms, some of which continually change. They are classified into four families according to altitude and are named individually according to their nature. It is important to have an understanding of cloud classification because the meteorological forecasts and reports use this system to give you a picture of the weather:

1. *High-level clouds* have a base above approximately 20,000 feet and are composed mainly of ice crystals in the below freezing upper atmosphere (cirrus, cirrocumulus, cirrostratus).
2. *Middle-level clouds* have a base above approximately 6,500 feet (altocumulus, altostratus, nimbostratus).
3. *Low-level clouds* have a base below approximately 6,500 feet (stratocumulus, stratus, fair weather cumulus, nimbostratus).
4. *Clouds with extensive vertical development* (towering cumulus, cumulonimbus).

Clouds are classified in four families according to altitude:
- *high-level;*
- *mid-level;*
- *low-level;*
- *those with extensive vertical development.*

Clouds are named according to the following types:

- *cirriform* (or fibrous)—consisting mainly of ice crystals;
- *cumuliform* (or heaped)—formed by unstable air rising and cooling;
- *stratiform* (or layered)—formed by the cooling of a stable layer;
- *nimbus* (or rain-bearing);
- *fractus* (fragmented);
- *castellanus* (common base with separate vertical development, often in lines);
- *lenticularis* (lens-shaped, often formed in strong winds over mountainous areas).

For example, nimbostratus means stratified clouds from which rain is falling. Altocumulus is middle-level heaped clouds. Cumulus fractus is fragmentary cumulus clouds. Cirrostratus is high-level stratified clouds consisting of ice crystals. Standing lenticular altocumulus clouds are lens-shaped middle-level clouds residing in one position, usually over a mountain range in strong winds.

Nimbostratus is a hybrid cloud in terms of classification since its base can be low level or middle level, and it can have great vertical depth. Sometimes nimbostratus is 10,000 feet or even 15,000 feet thick, making it very dark when seen from underneath and capable of causing heavy rain for many hours.

Some clouds are fine for flying through, while others are not. Know the difference.

Flying in clouds means poor visibility and the risk of icing—not a great risk in the high-level cirriform clouds consisting of ice crystals, but very great in clouds of extensive vertical development which may contain large supercooled water drops that will freeze on contact with a cold airplane.

Moisture in the Atmosphere

Clouds are formed when water vapor in the atmosphere condenses into water droplets or, in below freezing temperatures, into ice crystals. Water vapor is taken up into the atmosphere mainly by evaporation from the oceans and other bodies where water is present, or by sublimation directly from solid ice when the air overlies a frozen surface.

The Three States of Water

Water comes in three states: vapor (gas), liquid and solid. It can be found in all three forms in clouds.

Water in its vapor state is not visible, but when the water vapor condenses to form water droplets we see it as cloud, fog, mist, rain or dew. Frozen water is also visible as high-level clouds, snow, hail, ice or frost. Water exists in three states—gas (vapor), liquid (water) and solid (ice).

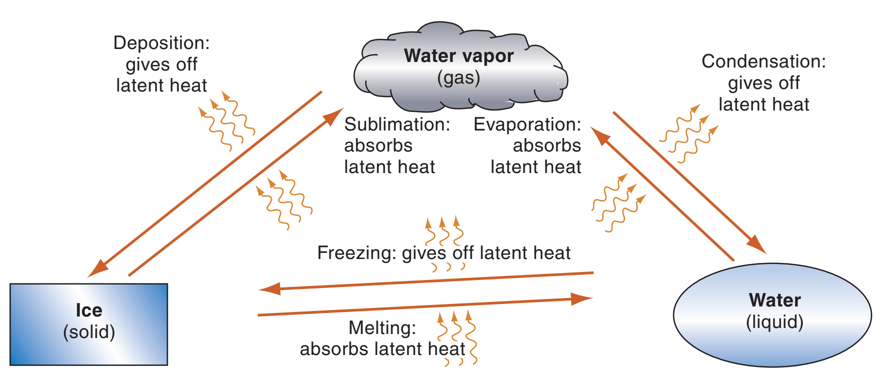


Figure 32-2 The three states of water.

Under certain conditions water can change from one state to another, absorbing heat energy if it moves to a higher energy state (from ice to water to vapor) and giving off heat energy if it moves to a lower energy state (vapor to water to ice). This heat energy is known as *latent heat* and is a vital part of any change of state. The absorption or emission of latent heat is important in meteorological processes such as cloud formation, and evaporation of rain (virga).

The three states of water, the names of the various transfer processes and the absorption or giving off of a latent heat are shown in figure 32-2.

Relative Humidity

The amount of water vapor present in the air depends on the amount of evaporation, which will be greater over wet surfaces such as oceans and flooded ground than over a desert or continent.

The actual amount of water vapor in the air, known as *humidity*, is not as important as whether the air can support that water vapor or not. When a parcel of air is supporting as much water vapor as it can, it is said to be *saturated* and have a *relative humidity* of 100%.

Air supporting less than its full capacity of water vapor is said to be *unsaturated*, and will have a relative humidity of less than 100%.

In cloud and fog, the relative humidity is 100% and the air is saturated; over a desert, relative humidity might be 20%.

Glaciation

Above a temperature of about -40° (Celsius or Fahrenheit—the two scales happen to cross at this temperature), water vapor in the free air essentially never sublimates directly into ice crystals. It nearly always goes through the liquid phase first. Whether and when the process of conversion into ice crystals starts (glaciation) depends initially on the content of the air (the aerosol). Therefore, condensation nuclei play a big role in the condensation and freezing process: liquid drops at below freezing temperatures in the free air do not freeze unless they have something to freeze on.

As the temperatures get colder, more substances become effective as freezing nuclei, and thus at colder temperatures the liquid phase may be very short lived, but it is still there. This is fundamental to the existence of supercooled clouds (liquid clouds at below freezing temperatures) which produce icing. An airplane makes a great freezing nucleus, and when one happens along into such a supercooled cloud, ice will start to deposit.

Once glaciation in a cloud starts, a struggle ensues between the creation of new liquid water by adiabatic lifting and the depletion of water by creation of ice crystals. Nature actually prefers the ice phase once it is present, because the saturation pressure over ice crystals is less than that over liquid water drops. Absent the creation of new liquid water (e.g., in a more or less quiescent stratus cloud), once glaciation starts it will go to completion in anywhere from a few minutes at warmer temperatures to probably less than a minute at cold temperatures. However, in the presence of energetic lift continuing to generate liquid water (e.g., in a wave cloud), liquid water at below freezing temperatures can remain present in the cloud (and thus the cloud can remain an aircraft icing cloud) indefinitely.

This process is fundamental to the existence of aircraft icing. If water vapor went directly to ice crystals in the free air at below freezing temperatures (sublimation), icing clouds would either not exist or at least be much rarer than they are.

Cloud Formation

Clouds are formed when air is cooled to its dewpoint temperature, and the excess water vapor condenses as liquid water or ice crystals, depending on temperature. The cooling of a parcel of air can occur by various means, such as:

- rising air cooling adiabatically as it expands; or
- air flowing over, or lying over, a cooling surface.

Dewpoint Temperature

Warm air is able to support more water vapor than cold air.

How much water vapor a particular parcel of air can support depends on the air temperature—warm air is able to support more water vapor than cold air. If the temperature of the air falls, it is capable of holding less water vapor, and so will move closer to being saturated, its relative humidity will rise. Relative humidity increases greatly with a decrease in temperature.

The temperature at which the relative humidity reaches 100%, and the excess water vapor starts to condense as water droplets, is known as the *dewpoint temperature*. The condensation process may be delayed if there are insufficient condensation nuclei in the air, or conversely, certain types of condensation nuclei may induce condensation shortly before 100% relative humidity is reached. Typical condensation nuclei are small particles of hygroscopic (water-soluble) dust, salt, or other small particles. Clouds form only when the water vapor actually condenses.

A parcel of air that has a temperature higher than its dewpoint is unsaturated and its relative humidity is less than 100%, because it is capable of holding more moisture at its current temperature. The closer the actual temperature of the parcel of air is to its dewpoint, the closer it is to being saturated. As the spread between actual air temperature and the dewpoint temperature decreases as the air temperature falls, the relative humidity increases.

At its dewpoint, the air will be fully saturated. If it becomes cooler than its dewpoint, then the excess water vapor will condense as visible water droplets (or, in freezing temperatures below the frost point, deposit as ice crystals). The actual value of the dewpoint temperature for a particular parcel of air varies, depending on the amount of water vapor it contains. If the air is moist (for instance over an ocean), the dewpoint temperature may be quite high, say +25°C; if the air is dry, the dewpoint temperature may be quite low.

If the air temperature falls to a dewpoint temperature which is above freezing, the water vapor will condense as liquid water droplets and become visible as clouds, fog, or dew; if the dewpoint temperature is below freezing, the excess water vapor may change to ice crystals (like in high-level cirriform clouds, or frost on the ground on a below freezing night).

If the air in which clouds form is unable to support the water droplets (if they become too large and heavy), then the drops will fall as precipitation (rain, hail or snow).

Adiabatic Processes

The temperature of a gas depends on the number and energy of its molecules striking the measuring surface of a thermometer. In adiabatic processes, temperature can change as a result of pressure changes, even though heat energy is neither added to nor taken from the system. Expanding a gas and decreasing its pressure causes a lowering of temperature, because fewer molecules will collide with the measuring surface.

Conversely, compressing a gas and increasing its pressure will raise its temperature because more molecules will collide with the measuring surface. Placing your finger over the outlet of a bicycle pump illustrates that compressing air increases its temperature. Also, air that has been compressed and stored at room temperature will cool when it is released to the atmosphere and allowed to expand.

A common adiabatic process that involves the expansion of a gas and its cooling is when a parcel of air rises in the atmosphere. This can be initiated by the heating of the parcel of air over warm ground, causing it to expand and become less dense than the surrounding air, hence it will rise. A parcel of air can also be forced aloft as it blows over a mountain range, or as it is lifted over a front.

Unsaturated air will cool adiabatically at about 3°C/1,000 feet as it rises and expands. This is known as the *dry adiabatic lapse rate* (DALR). Air that is 12°C at ground level will cool adiabatically to 9°C if it is forced up to 1,000 feet AGL, and to 6°C at 2,000 feet AGL, provided it does not reach saturation point.

Cooler air can support less water vapor, so, as the parcel of air rises and cools, its relative humidity will increase. At the altitude where its temperature is reduced to the dewpoint temperature (relative humidity reaches 100%), water will start to condense and form clouds.

Above this altitude, the now-saturated air will continue to cool as it rises but, because latent heat will be given off as the water vapor condenses into the lower energy liquid state, the cooling will not be as great. The rate at which saturated air cools as it rises is known as the *saturated adiabatic lapse rate* (SALR) and may be assumed to have a value of approximately half the DALR, 1.5°C/1,000 feet. Air that is, say, 5°C inside a cloud, if it is forced 1,000 feet higher, will cool adiabatically to 3.5°C.

Note. At higher levels in the cloud where there is less water vapor to condense into water (since most of this has already occurred), there will be less latent heat given off and so SALR will increase.

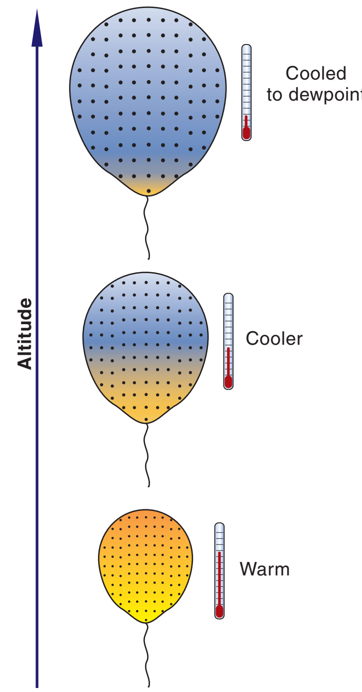


Figure 32-3
As air rises and expands, it cools adiabatically.

Which Cloud Type Forms?

The structure or type of cloud that forms depends mainly on the stability of the air before lifting occurs.

Moist air that is unstable will continue rising, forming cumulus-type clouds with significant vertical development and turbulence, whereas moist air that is stable has no tendency to continue rising and so will form stratus-type clouds with little vertical development and little or no turbulence. Some stratus-type clouds, such as nimbostratus, can however form in a thick layer. Dry air that is forced to rise, but does not cool to its dewpoint temperature, will not form clouds.

Unstable Air

As long as a parcel of air given vertical movement is warmer than its surroundings, it will continue to rise. This is known as an unstable parcel of air.

Characteristics of unstable air are:

- turbulence in the rising air;
- the formation of cumuliform clouds (heaped clouds);
- showery rain from these clouds, if there is precipitation; and
- good visibility between the showers (caused by the rising air carrying any obscuring particles away).

Stable Air

The actual environmental lapse rate varies from time to time and place to place.

If the rising parcel of air is cooler than the ambient air around it, then it will stop rising because its density will be greater than the surroundings. An atmosphere in which air tends to remain at the one level, or to sink, is called a stable atmosphere.

Characteristics of stable air are:

- the formation of stratiform clouds (layer-type) with little vertical development and steady, if any, precipitation;
- poor visibility if there are any obscuring particles; and
- possibly smooth flying conditions with little or no turbulence.

The rate of temperature change as altitude is gained in the surrounding atmosphere (in the air that is not rising) is called the *environmental lapse rate* (ELR), the ambient lapse rate or the actual lapse rate. Its relationship to DALR and SALR is the main factor in determining the levels of the bases and tops of the clouds that form. A great decrease in ambient air temperature with altitude (a high ELR) encourages warm air to keep rising (an unstable situation) and form clouds of great vertical development. A lesser ELR may indicate a stable situation. The stability in the atmosphere depends on the ambient lapse rate.

The *standard atmosphere*, which is simply a theoretical measuring stick against which the actual atmosphere at any time or place can be compared, assumes an ambient lapse rate of 2°C/1,000 feet. The actual ELR in a real atmosphere, however, may differ greatly from this—it may be 1°C per 1,000 feet gain in altitude, or it may be 2.5°C per 1,000 feet gain in altitude. In a temperature inversion, the temperature will not decrease with altitude, but will increase. The actual environmental lapse rate varies from time to time and place to place.

The type of cloud which forms depends on stability of the air.

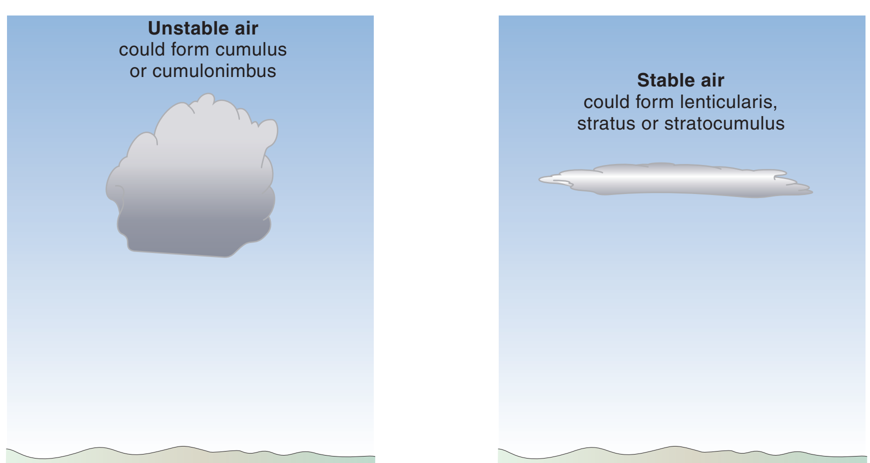


Figure 32-4 Cumuliform clouds in unstable conditions; stratiform clouds form in stable conditions.

Clouds Formed by Convection Caused by Heating

Cold air moving over or lying over a warm surface will be warmed from below, and so become less stable. It will tend to rise, causing turbulence and good visibility. If the air is moist and unstable, cumuliform clouds will develop as the air ascends and cools adiabatically to its dewpoint temperature.

$$\text{Cloud base in thousands of feet} = \frac{\text{air temperature} - \text{dewpoint}}{4.4°\text{F (or } 2.5°\text{C)}}$$

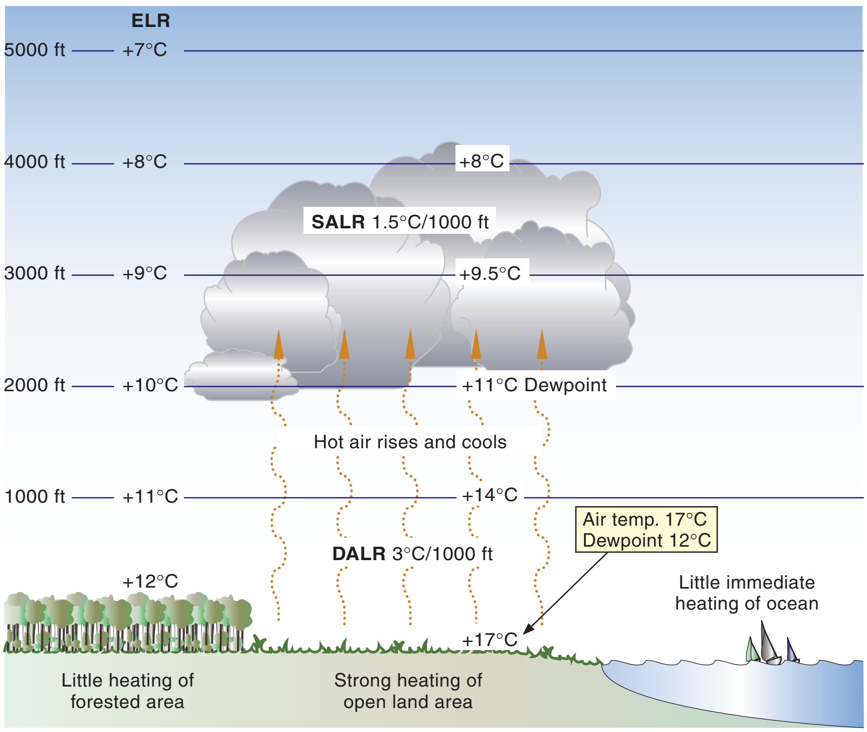


Figure 32-5 The temperature processes involved in the formation of a cumulus cloud.

The ascending unsaturated air will cool at the dry adiabatic lapse rate of 3°C/1,000 feet. The closer the air temperature is to the dewpoint, the lesser altitude it has to rise before condensing to form clouds. The dewpoint decreases at about 0.5°C/1,000 feet, which means that the *air temperature/dewpoint* spread will decrease at approximately 2.5°C/1,000 feet in rising unstable air.

For working in degrees Fahrenheit, DALR for unsaturated air is 5.4°F and dewpoint lapse rate is approximately 1°F, so they converge at approximately *4.4°F/1,000 feet* (which is the same as 2.5°C/1,000 feet).

Example 32-1

If the temperature at a given level is 17°C and the dewpsoint is 12°C, (a temperature/dewpoint spread of 5°C), then as the air rises this spread will decrease by approximately 2.5°C/1,000 feet. The temperature and dewpoint will have the same value at an altitude approximately 2,000 feet higher (5 ÷ 2.5 = 2).

The cloud base will form at a level 2,000 feet higher and the air, if it is still unstable, will continue to rise and form a heaped cumuliform cloud. Because it is now saturated, latent heat will be given off as more and more water vapor condenses into liquid water droplets. This reduces the rate at which the rising saturated air cools to the saturated adiabatic lapse rate of approximately 1.5°C/1,000 feet.

Example 32-2

What is the appropriate base MSL of clouds if the temperature at 3,000 feet MSL is 68°F and the dewpoint is 46°F?

$$\text{Cloud base in thousands of feet} = \frac{68 - 46}{4.4} = \frac{22}{4.4} = 5$$

$$\text{Therefore cloud base MSL} = 3{,}000 \text{ feet MSL} + 5{,}000 \text{ feet}$$

$$= 8{,}000 \text{ feet MSL}$$

Clouds Formed by Orographic Uplift

Air flowing over mountains rises and is cooled adiabatically. If it cools to below its dewpoint temperature, then the water vapor will condense and clouds will form. Descending on the other side of the mountains, however, the airflow will warm adiabatically and, once its temperature exceeds the dewpoint for that parcel of air, the water vapor will no longer condense. The liquid water drops will now start to vaporize, and the clouds will cease to exist below this level.

The altitude at which the cloud base forms depends on the moisture content of the parcel of air and its dewpoint temperature. The cloud base may be below the mountain tops or well above them depending on the situation. Once having started to form, the cloud may sit low over the mountain as stratiform clouds (if the air is stable), or (if the air is unstable) the clouds will be cumuliform and may rise to high levels.

An almond-shaped or lens-shaped cloud that forms as a cap over the top of a mountain is known as a *lenticular cloud*. It will remain more or less stationary while the air flows through it, possibly at speeds of 50 knots or more.

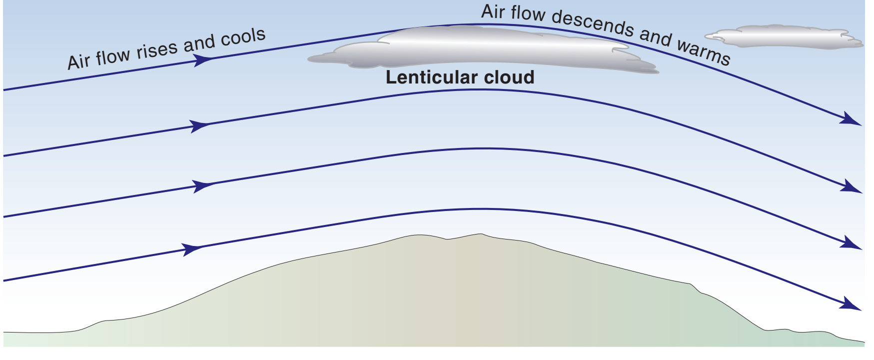


Figure 32-6 Lenticular cloud as a cap over a mountain.

Sometimes, when an airstream flows over a mountain range and there is a stable layer of air above, *standing waves* occur. This is a wavy pattern as the airflow settles back into a more steady flow and, if the air is moist, lenticular clouds may form in the crest of the lee waves, and a *rotor* or *roll cloud* may form at a low altitude. The presence of standing lenticular altocumulus clouds is a good indicator that strong *mountain wave turbulence* exists.

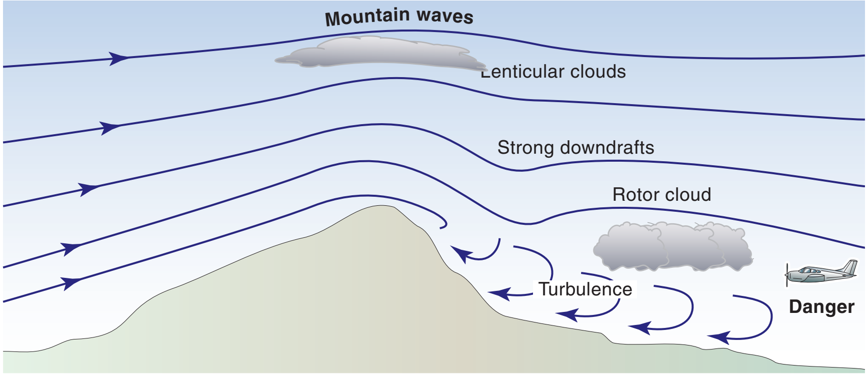


Figure 32-7 Mountain waves.

The Chinook (or Föhn) Wind Effect

If the air rising up a mountain range is moist enough to have a high dewpoint temperature and is cooled down to it before reaching the top of the mountain, then cloud will form on the windward side. If any precipitation occurs, moisture will be removed from the airflow and, as it descends on the lee side of the mountain, it will therefore be drier. The dewpoint temperature will be less and so the cloud base will be higher on the lee side of the mountain.

As the dry air beneath the cloud descends, it will warm at the dry adiabatic lapse rate of 3°C/1,000 feet, which is at a greater rate than the rising air cooled inside the cloud (saturated adiabatic lapse rate: 1.5°C/1,000 feet). The result is a warmer and drier wind on the lee side of the mountains. This noticeable effect is seen in many parts of the world, for example the Föhn (pronounced "*fern*") wind in Switzerland and southern Germany, from which this effect gets its name, the *Chinook* wind which blows down the eastern slope of the Rocky Mountains, and the Santa Ana wind which blows from the east or northeast in southern California.

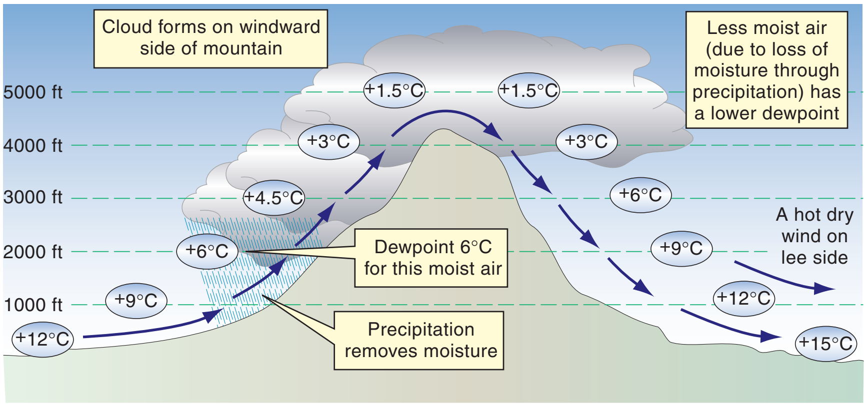


Figure 32-8 The Chinook wind effect.

Clouds Formed by Turbulence and Mixing

As air flows over the surface of the earth, frictional effects cause variations in local wind strength and direction. Eddies are set up which cause the lower levels of air to mix—the stronger the wind and the rougher the earth's surface, the larger the eddies and the stronger the mixing. The air in the rising currents will cool and, if the turbulence extends to a sufficient altitude, it may cool to the dewpoint temperature, water vapor will condense to form liquid water droplets and clouds will form.

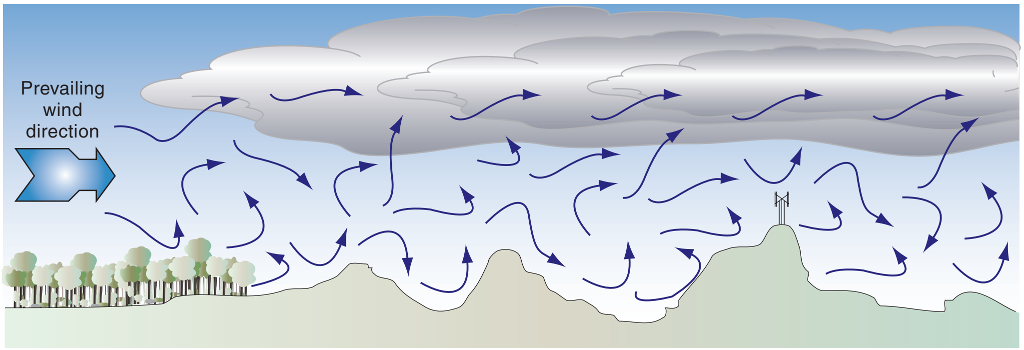


Figure 32-9 Formation of turbulence clouds.

The descending air currents in the turbulent cloud layer will warm and, if the air's dewpoint temperature is exceeded, the liquid water droplets that make up the clouds will return to the water vapor state. The air will dry out and clouds will not exist below this altitude. With turbulent mixing, stratiform clouds may form over quite a large area, possibly with an undulating base. They may be continuous stratus or broken stratocumulus.

Clouds Formed by the Widespread Ascent of an Air Mass

When two large masses of air of differing temperatures meet, the warmer and less dense air will flow over (or be undercut by) the cooler air. As the warmer air mass is forced aloft it will cool and, if the dewpoint temperature is reached, clouds will form. The boundary layer between two air masses is called a *front*.

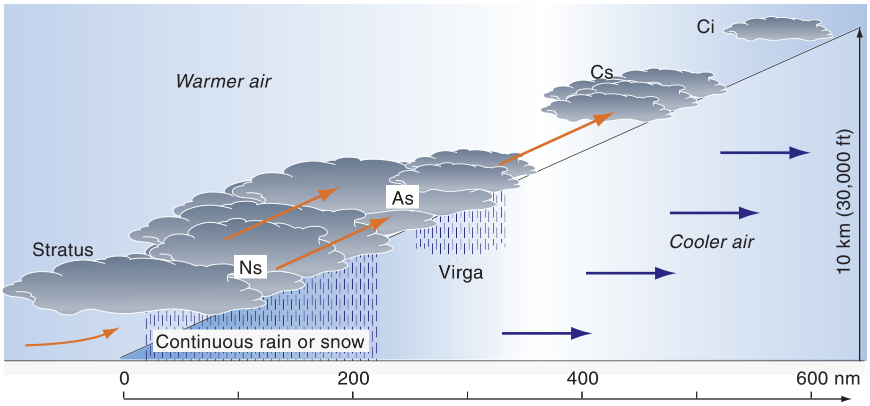


Figure 32-10 Cloud formation caused by widespread ascent.

Widespread lifting can also result from *latitudinal pinching* of an air mass as it moves to higher latitudes and has to crowd into a smaller area.

Precipitation from Clouds

Precipitation refers to falling water that finally reaches the ground, including:

- *rain* consisting of liquid water drops;
- *drizzle* consisting of fine water droplets;
- *snow* consisting of branched and star-shaped ice crystals;
- *hail* consisting of small balls of ice;
- *freezing rain or drizzle*—liquid drops or droplets which freeze on contact with a cold surface (such as the ground or an aircraft in flight); and
- *dew, frost or ice.*

Intermittent or continuous precipitation (which often starts and finishes gradually, perhaps over a long period) is usually associated with *stratiform* clouds, including fine drizzle or snow from stratus and stratocumulus, heavy continuous rain or snow from nimbostratus, and steady rain from altostratus.

Rain or snow showers are associated with *cumuliform* clouds, and very heavy rain may fall from cumulonimbus storm clouds. The strong updrafts in cumulonimbus clouds carry the water droplets up to cooler levels where the condensation process continues and the drops grow in size and weight before they fall.

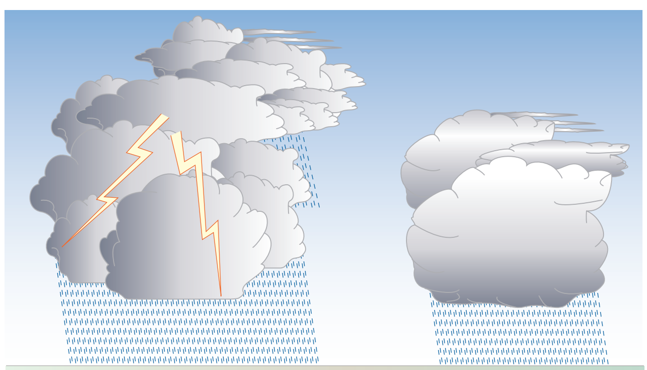


Figure 32-11 Showers fall from cumuliform clouds.

It is possible to use precipitation as a means of identifying the cloud type—rain or snow showers generally falling from cumuliform clouds, and non-showery precipitation such as steady rain, light snow or drizzle from stratiform clouds, mainly altostratus and nimbostratus.

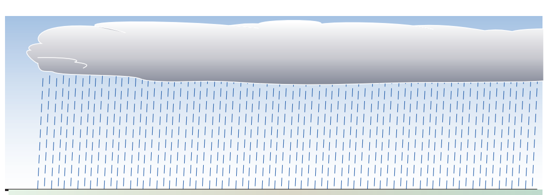


Figure 32-12
Non-showery (steady) precipitation from stratiform clouds.

For precipitation reported to be of light or greater intensity, the cloud will usually have to be at least 4,000 feet thick.

Virga is associated with microbursts.

Rain (and snow) that falls from the base of clouds but evaporates before reaching the ground (hence is not really precipitation) is called *virga*. This can occur in areas of low humidity, often over deserts. One extremely important consequence of virga is that the evaporation of the rain absorbs latent heat from the air, creating a very cool and invisible parcel of air that may sink, or even plummet, quite rapidly toward the ground. This can sometimes result in a *microburst*, a lethal form of downflow that has brought many aircraft to grief.

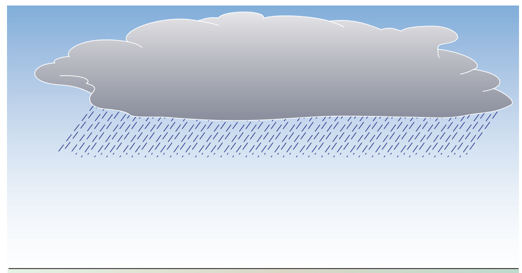


Figure 32-13 Virga.

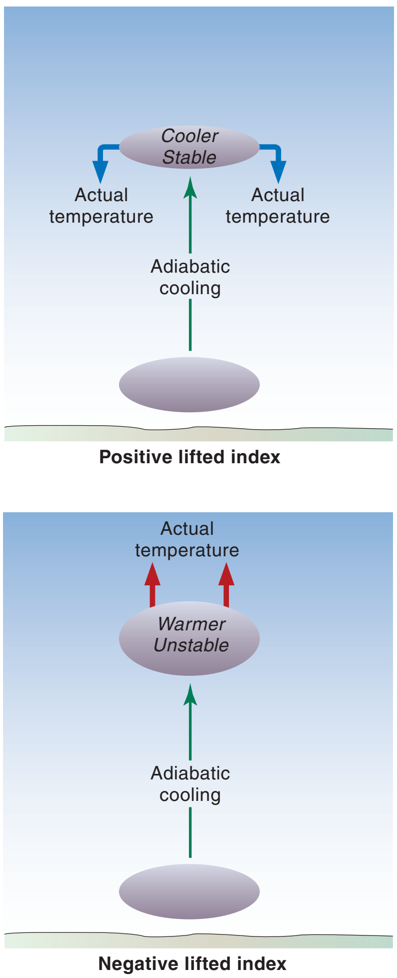


Figure 32-14
Positive and negative lifted indices.

Sometimes the only indications of a microburst are high-level virga and a ring of dust blown up on the ground. Microbursts are described on pages 708–710

Lifted Index

The lifted index of a parcel of air is a measure of its stability. The lifted index is calculated by:

theoretically lifting the parcel of air from the surface to the 500 millibar pressure level, and calculating its temperature based on it cooling adiabatically by expansion; then subtracting this calculated value from the actual temperature of the air already at the 500 millibar pressure level.

Lifted index	=	actual temperature at 500 mb level	–	theoretical temperature at 500 mb level if surface air is raised

If the "lifted" parcel of air has a temperature less than that existing in the actual air at the 500 mb pressure level, then the parcel would have no tendency to keep rising, and the lifted index would have a positive value. A positive lifted index indicates stable air.

If the "lifted" air is warmer than the environmental air, then it will tend to keep on rising, and the lifted index would have a negative value. A negative lifted index indicates unstable air.

Review 32
Clouds

1. Name the four families of clouds.
2. What clouds have their bases above approximately 20,000 feet?
3. What clouds have their bases below approximately 6,500 feet?
4. What do the suffix nimbus and the prefix nimbo, used in naming clouds, indicate?
5. Which suffix is often used to identify clouds that are broken into fragments?
6. What are clouds formed in strong winds over mountains known as?
7. What is the temperature to which air must be cooled to become saturated?
8. As a parcel of air is cooled, what happens to its relative humidity?
9. As a parcel of air is cooled to its dewpoint temperature, what change will occur to its relative humidity?
10. What does the amount of water vapor which air can hold largely depend on?
11. If air in contact with the ground cools to its dewpoint temperature, which is above freezing, what will happen to the excess water vapor?
12. If air in contact with the ground cools to its dewpoint temperature, which is below freezing, what will happen to the excess water vapor?
13. What conditions are necessary for frost to form?
14. What can delay the process of excess water condensing out of the air to form cloud or fog?
15. What sort of air is indicated by turbulence, good visibility, cumuliform clouds, and showery precipitation?
16. What sort of air is indicated by the presence of cumuliform clouds?
17. What sort of air is indicated by the presence of stratiform clouds?
18. How is atmospheric stability determined?
19. Which type of cloud is characterized by steady precipitation and little or no turbulence? Which type of air is this cloud formed in?
20. Poor visibility, stratiform clouds, and steady precipitation are more likely when the ambient lapse rate is:
    - **a.** high.
    - **b.** low.
21. The structure or the type of clouds, such as stratiform or cumuliform, is determined by:
    - **a.** the method by which the air is lifted.
    - **b.** the relative humidity of the air.
    - **c.** the prevalence of condensation nuclei.
    - **d.** the stability of the air before lifting occurs.
22. At what rate will unsaturated air being forced aloft cool?
23. At what rate will saturated air being forced aloft cool?
24. What is the ambient lapse rate in the theoretical standard atmosphere assumed to be? Can it vary from this value?
25. If an unstable air mass is forced to ascend a mountain slope, what cloud type is most likely to develop? How much, if any, vertical development will there be?
26. If a stable air mass is forced to ascend a mountain slope, what cloud type is most likely to develop? How much, if any, vertical development will there be?
27. What sort of cloud, flying conditions, and visibility can result from an unstable cold air mass moving over a warm surface?
28. What sort of cloud indicates very strong turbulence in mountain areas?
29. In a stationary group of clouds associated with a mountain wave, what sort of cloud can be the lowest?
30. Which clouds have the greatest turbulence?
31. What are high-level clouds mainly composed of ?
32. What sort of flying conditions often exist at and below the level of fair weather cumulus clouds?

33. What sort of flying conditions often exist above fair weather cumulus clouds (compared with below them)?

34. What is the presence of standing lenticular altocumulus over a mountain range a good indication of?

35. Which sort of cloud is drizzle or steady rain associated with?

36. Which sort of cloud are showers associated with?

37. What is the growth rate of raindrops enhanced by? Which sort of cloud is this associated with?

38. What is rain which evaporates before it reaches the ground called?

39. How significant is the risk of structural icing when flying in clouds of extensive vertical development? Why is this the case?

40. How significant is the risk of structural icing when flying in high-level cirriform clouds? Why is this the case?

41. For precipitation of light or greater intensity to occur, the clouds generally have to be at least:

a. 1,000 feet thick.
b. 2,000 feet thick.
c. 4,000 feet thick.
d. 10,000 feet thick.

42. What effect will evaporating rain have on the temperature?

43. Can very strong downdrafts exist beneath evaporating rain?

44. What is a very dangerous and localized down-flow of air that may be quite narrow in extent known as?

Answers are given on page 792.

Icing 33

Ice accretion on an airplane structure or within the engine induction system can significantly reduce flight safety by causing:

- *adverse aerodynamic effects*—ice buildup on the airframe structure can modify the airflow pattern around airfoils (wings and propeller blades), leading to a serious loss of lift and an increase in drag; ice/snow or frost has a thickness and/or roughness similar to medium or coarse sandpaper, and on the leading edge and upper surface of a wing it can reduce lift by as much as 30%, and increase drag also by as much as 40%;
- *a loss of engine power, or complete stoppage,* if ice blocks the engine air intake or carburetor ice forms;
- *a weight increase and a change in the CG position of the airplane,* as well as unbalancing of the various control surfaces and the propeller, perhaps causing severe vibration and/or control difficulties;
- *blockage of the pitot tube and/or static vent,* producing errors in the cockpit pressure instruments (airspeed indicator, altimeter, vertical speed indicator);
- *degradation in communications and navigation* (if ice forms on the antennas); and
- *loss of visibility* (if ice forms on the windshield).

Icing can be extremely hazardous to aircraft.

The possibility of icing conditions can be determined from weather forecasts and prognostic charts, but the most accurate information on icing conditions, both current and forecast, can be obtained from PIREPs (pilot reports), SIGMETs (weather advisories that warn of conditions that could be dangerous to all aircraft) and AIRMETs (that warn of hazards primarily for small aircraft).

PIREPs, SIGMETs and AIRMETs provide the most accurate icing information.

Structural Icing

For ice to form on the aircraft structure, two conditions must be satisfied:

- there must be visible moisture; and
- the temperature must be at or below freezing (0°C).

There must be visible moisture and near or below freezing temperatures before ice can form.

Aerodynamic cooling can lower the temperature of the airplane structure below that of the surrounding air by a few degrees, however, making it possible for ice to form on the structure even though the ambient air temperature is still a few degrees above freezing—so be on the watch for structural icing when the air temperature is below about +5°C and you are flying in visible moisture.

Temperature usually decreases in the atmosphere as you climb. The altitude where the temperature has fallen to 0°C is known as the *freezing level*, and it is possible to estimate this level, at least approximately.

The rate at which temperature falls with altitude (known as the *lapse rate*) depends on a number of variables, but the standard (average) lapse rate is a temperature decrease of 2°C for every 1,000 feet of altitude gained. For instance, if the air temperature is +8°C at 5,000 feet MSL, then you would need to climb approximately 4,000 feet for the temperature to fall to 0°C, and so the freezing level in this case is at 9,000 feet MSL.

The standard lapse rate is only an average, and the actual lapse rate may differ greatly with this. The standard lapse rate should not be used to make tactical decisions about climbing or descending in icing conditions. Rather, actual temperature information should be obtained from ATC, Flight Service, or pilot reports.

In general terms, the worst continuous icing conditions are usually found near the cloud tops above the freezing level in heavy stratified clouds or in freezing rain. Icing

Weather research flights and icing certification flights have consistently shown that the heaviest icing in stratiform clouds exists near the top of the cloud deck. This is consistent with physics, since this is where the water in the cloud has been lifted the most and consequently where the highest density of cloud liquid water would be expected.

can occur up to 5,000 feet above the freezing level, but rarely above this where the droplets in the clouds are usually already frozen. In cumuliform clouds with strong updrafts, however, large water droplets may be carried to high altitudes making structural icing a possibility up to high altitudes.

Clear Ice

Clear ice is the most dangerous form of structural icing. Liquid water drops exist in the atmosphere at temperatures well below the normal freezing point of water (0°C), possibly at -20°C or even lower. These are known as *supercooled* drops, and can occur when rain falls from air warmer than 0°C into a subzero layer of air beneath or when the rate of creation of liquid water in a subzero cloud due to adiabatic lifting exceeds the rate at which the creation of ice crystals by glaciation can occur. Supercooled drops are in an unstable state, and will freeze on contact with a subzero surface—the skin of an airplane, or the propeller blades, for example.

Clear ice can alter the aerodynamic shape of airfoils quite dramatically and reduce or destroy their effectiveness. Along with the increased weight, this creates a safety hazard.

Each drop will freeze gradually because of the latent heat released in the freezing process, which allows part of the water drop to spread backward before it freezes. The slower the freezing process, the greater the spread-back of the water before it freezes. The spread-back is greatest at temperatures just below freezing. The result is a sheet of solid, clear, glazed ice with very little air enclosed.

The surface of clear ice is smooth, usually with undulations and lumps. It is quite tenacious but, if it does break off, it could be in large chunks capable of doing damage.

A good indication to a pilot that freezing rain may exist at higher altitudes is the presence of ice pellets, formed by rain falling from warmer air and freezing on the way down through colder air. Wet snow, however, indicates subzero temperatures at some higher altitude, and warmer air at your level. The snow that formed in the subzero air above is now melting to form wet snow as it passes through your level.

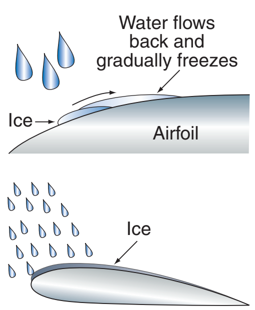


Figure 33-1
Clear ice formed from large, supercooled water drops.

Rime Ice

Rime ice occurs when tiny, supercooled liquid water droplets freeze nearly instantaneously on contact with a surface of subzero temperature. Because the drops are small, and there is little or no runback during the quick freezing process, the amount of water remaining after the initial freezing is insufficient to coalesce into a continuous sheet before freezing. The result is a mixture of tiny ice particles and trapped air, giving a rough, opaque, crystalline deposit that is fairly brittle.

Rime ice often forms on leading edges and can affect the aerodynamic qualities of an airfoil or the airflow into the engine intake. It does cause a significant increase in weight.

Mixed (or Cloudy) Ice

Cloud and rain falling from clouds may consist of drops of many sizes. A mixture of clear ice (from large drops) and rime ice (from small drops) may result. This is known as mixed ice (referred to in some countries as cloudy ice).

Frost

Frost forms when moist air comes in contact with a subzero-temperature surface. The water vapor, rather than condensing to form "liquid" water, changes directly to ice in the form of frost. This is a white crystalline coating that can usually be scraped off.

Frost can form in clear air when the airplane is parked in subzero temperatures or when the airplane flies from subzero temperatures into warmer moist air—for example, on descent, or when climbing through a temperature inversion (where temperature increases with altitude).

Although frost is not as dangerous as clear ice, it can obscure vision through a cockpit window and can possibly affect the lifting characteristics of the wings, which can be extremely serious. Although frost does not alter the basic aerodynamic shape of the wing (like clear ice does), frost can disrupt the smooth airflow over the wing, causing early separation of the airflow from the upper surface of the wing and a consequent loss of lift.

Frost remaining on the wings is especially dangerous during takeoff. It may disturb the airflow sufficiently to prevent the airplane from becoming airborne at its normal takeoff speed, or prevent it from becoming airborne at all.

Frost on the wings during takeoff may disturb the airflow sufficiently to prevent the airplane from becoming airborne at its normal takeoff speed, or prevent it from becoming airborne at all.

Structural Icing and Cloud Type

Cumulus-Type Clouds

Cumulus-type clouds nearly always consist predominantly of liquid water droplets at temperatures down to about -20°C, below which either liquid-drops or ice-crystals may predominate. Newly formed parts of the clouds will tend to contain more liquid drops than in mature parts. The risk of airframe icing is high in these clouds in the range 0°C to -20°C, and medium to high in the range -20° to -40°C, with only a small chance of structural icing below -40°C.

Since there is a lot of vertical motion in convective clouds, the composition of the clouds may vary considerably at the one level, and the risk of icing may exist throughout a wide altitude band in (and under) the clouds. Updrafts will tend to carry the water droplets higher and increase their size. If significant structural icing does occur, it may be necessary to descend into warmer air.

Stratiform Clouds

Stratiform clouds can consist entirely or predominantly of liquid water drops down to about -15°C, with a risk of structural icing. If significant icing is a possibility, it may be advisable to fly at a lower level where the temperature is above 0°C, or at a higher level where the temperature is colder than -15°C. In certain conditions, such as stratiform clouds associated with an active front or with orographic uplift, the risk of icing is increased at temperatures lower than usual; continuous upward motion of air generally means a greater retention of liquid water in the clouds. The most serious icing in stratiform clouds is generally found near the cloud tops, where the creation of liquid water by adiabatic lifting is at its maximum.

Raindrops and Drizzle

Raindrops and drizzle from any type of clouds will freeze if they meet an airplane whose surface is below 0°C, with a higher risk of clear ice forming the bigger the water droplets are. You need to be cautious when flying in rain at freezing temperatures. This could occur for instance when flying in the cool sector underlying the warmer air of a warm front from which rain is falling.

High-Level Clouds

High-level clouds, such as cirrus, with their bases above 20,000 feet, are usually composed of ice crystals which will not freeze onto the airplane, and so the risk of structural icing is only slight in these clouds.

Structural icing is most likely to accumulate rapidly on an airplane in conditions of freezing rain, for instance when flying in below-freezing air underneath the surface of a warm front from which rain is falling.

Structural icing is most likely to accumulate rapidly on an airplane in conditions of freezing rain, for instance when flying in below-freezing air underneath the surface of a warm front from which rain is falling.

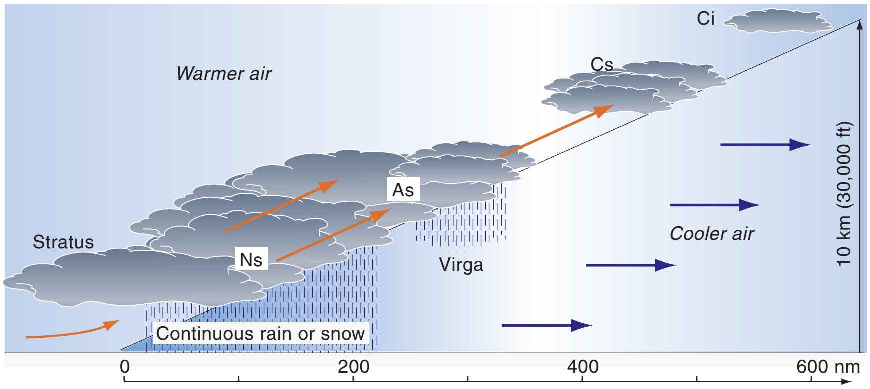


Figure 33-2
Danger area beneath a warm front.

Induction Icing

Carburetor Icing

Carburetor ice can even form on a warm day in moist air.

Ice can form in the carburetor and induction system of an engine in moist air with outside air temperatures as high as +25°C (or even higher). It will disturb or prevent the flow of air and fuel into the engine, causing it to lose power, run roughly and perhaps even stop.

Cooling occurs when the induction air expands as it passes through the venturi in the carburetor (adiabatic cooling), and occurs also as the fuel vaporizes (absorbing the latent heat of vaporization). This can easily reduce what was initially quite warm air to a temperature well below zero and, if the air is moist, ice will form.

Throttle icing is more likely to occur at lower power settings when the partially closed butterfly creates a greater venturi cooling effect, compared with high power settings when the butterfly is more open and the venturi effect is less.

Most airplanes whose engines have carburetors are fitted with a *carburetor heat* control that can direct hot air from around the engine into the carburetor, instead of the ambient air. Being hot, the air should be able to melt the ice and prevent further ice from forming. The correct method of using carburetor heat for your airplane is found in the Pilot Operating Handbook.

Engine Intake Icing

Structural icing near the engine air intake at subzero temperatures can restrict the airflow into the induction system and cause problems. Some aircraft have an alternate air system in case this occurs.

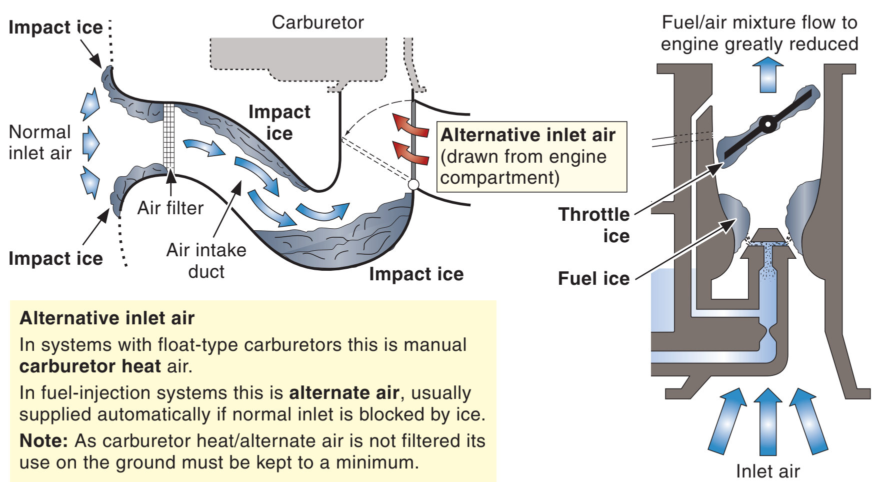


Figure 33-3
Carburetor ice.

Alternative inlet air

In systems with float-type carburetors this is manual **carburetor heat** air.

In fuel-injection systems this is **alternate air**, usually supplied automatically if normal inlet is blocked by ice.

Note: As carburetor heat/alternate air is not filtered its use on the ground must be kept to a minimum.

Instrument Icing

Icing of the pitot-static system can affect the readings of the pressure-operated flight instruments (the airspeed indicator, the altimeter, and the VSI). If the airplane has a pitot heater, then use it when appropriate.

Hints on Flying in Icing Conditions

Use all available information, such as forecasts and PIREPs, to plan your flight so that you avoid areas of icing, unless your airplane is equipped with de-icing or anti-icing equipment. Flight into known icing conditions is not authorized if the aircraft is not certified specifically to do so. Check that all the aircraft's airfoils are clean prior to takeoff. Frost, and indeed any contamination, should be removed from the wings and other lifting surfaces prior to flight if they are to produce lift efficiently.

If taxiing or taking off in below-freezing temperatures, avoid splashing water or slush onto the airplane, since it could freeze onto the structure. Always check full-and-free movement of the controls prior to commencing the takeoff roll.

Use de-icing and anti-icing equipment as recommended in icing conditions. If they are not adequate, then change course or altitude to fly out of icing conditions as quickly as possible. Consider making a 180° turn. Carry a little extra airspeed to give an added margin over what could be an increased stalling speed, and avoid abrupt maneuvers.

Be alert for incorrect readings from the pressure instruments (airspeed indicator, altimeter, vertical speed indicator) if pitot heat is not available in your airplane.

Avoid cumuliform clouds if possible, since clear ice may occur at any altitude above the freezing level. Avoid flying in or near the tops of stratiform clouds. If icing-up in stratiform clouds, either descend to warmer air above freezing, or climb out of the cloud deck or to colder air well below freezing, say -10°C or less. If descending, think carefully of the terrain below, and how far you will have to descend to fly into warmer air.

The freezing rain environment is likely to cause the highest rate of structural ice accumulation. If icing-up in freezing rain, either climbing or descending may take you into warmer or clear air. Act quickly and decisively before the build-up of ice is so great that it causes a significant deterioration in the airplane's performance.

Icing on the tail surface can cause a tail stall on approach or restrict elevator movement. If you suspect ice on the tail carry extra power on the approach and consider keeping flaps up. Recovery from a tail stall is opposite from a wing stall—the nose of the aircraft will pitch down but at a higher airspeed: increase pitch and reduce power (remember, the tail works as an inverted airfoil).

Warning!

Ice of any type on the airframe or propeller, or in the carburetor and induction system, deserves the pilot's immediate attention and removal. Wings which are contaminated by ice prior to takeoff will lengthen the takeoff run because of the higher speed needed to fly—a dangerous situation! An ice-laden airplane may even be incapable of flight. Ice or frost on the leading edge and upper forward area of the wings (where the majority of the lift is generated) is especially dangerous.

Ice of any type on the airframe or propeller, or in the carburetor and induction system, deserves the pilot's immediate attention and removal.

Most training airplanes are not fitted with airframe de-icers (removal) or anti-icers (preventive), so pilots of these airplanes should avoid flying in icing conditions (that is, in rain or moist air at any time the airframe is likely to be at subzero temperatures). If a pitot heater is fitted, use it to avoid ice forming over the pitot tube and depriving you of airspeed information.

An ice-laden airplane may be unable to fly.

Review 33
Icing

Structural Icing

1. What two conditions must be met for structural icing to occur on an airplane?
2. What sort of ice is likely to form from large, supercooled droplets striking a subzero airplane?
3. What sort of ice is likely to form from small, supercooled droplets striking a subzero airplane?
4. If the air temperature is +6°C at 1,500 feet MSL, and a standard temperature lapse rate exists, what will be the approximate freezing level (feet MSL)?
5. If the air temperature is +12°C at 1,500 feet MSL, and a standard temperature lapse rate exits, what will be the approximate freezing level (feet MSL)?
6. In which conditions is the formation of clear ice on the airplane structure most likely?
7. What does freezing rain consist of?
8. Under what conditions can freezing rain occur?
9. Rain drops falling from warm air into subzero air may remain in liquid form as supercooled water drops. What do these form? What do they form when frozen?
10. What will be the result if supercooled water drops in freezing rain strike a subzero aircraft structure?
11. How is the possibility of freezing rain at higher altitudes indicated?
12. What are ice pellets falling at ground level evidence of?
13. If you fly through rain which freezes on impact, what does this indicate about the temperature at higher altitudes?
14. If you fly through wet snow, what does this indicate about the temperature of higher altitudes? What does this indicate about the temperature at your altitude?
15. Can clear ice alter the basic aerodynamic shape of the wing?
16. Can frost cause a loss of lift from the wing? If so, how?
17. Should you remove frost, ice or any other contaminant from the wings prior to flight?
18. The risk of clear ice forming on the airplane's structure is greater when flying in which type of clouds?
19. Clouds of which height level are least likely to contribute to structural icing on an airplane?
20. In which conditions is structural icing most likely to have the highest rate of accumulation?
21. What three weather sources reflect the most accurate information on icing conditions, both current and forecast?

Induction Icing

22. Does the outside air temperature need to be below freezing for carburetor icing to occur?
23. Can ice form in the carburetor when the ambient air temperature is above freezing?
24. What happens to air entering the carburetor and induction system as it expands through the venturi?
25. What control in the cockpit is used to protect against carburetor icing?
26. Can carburetor ice form when you are flying in moist air at +10°C?

Instrument Icing

27. Which instrument(s) is/are likely to give faulty indications if ice forms over the pitot tube?
28. Which instrument(s) is/are likely to give faulty indications if ice forms over the static vents?

Answers are given on page 793.

Thunderstorms 34

A thunderstorm is one or more *cumulonimbus* clouds accompanied by sudden electrical discharges known as lightning, which cause a sharp rumbling sound known as thunder. Thunderstorms generate spectacular weather which may be accompanied by lightning, thunder, heavy rain showers, and sometimes high winds, shear, microbursts, turbulence, hail, squalls and tornadoes.

Thunderstorms are only associated with cumulonimbus clouds, and there may be several thunderstorm cells within the one cloud mass. Thunderstorms constitute a severe hazard to the aviator and must be avoided.

Figure 34-1
Cumulonimbus growing vertically.

Lightning and Thunder

Thunderstorms must be avoided!

Lightning is simply a discharge of static electricity that has built up in the cloud. The air along the path that the lightning follows experiences intense heating, causing it to expand violently. It is this expansion of air that produces the familiar clap of thunder. By definition, all thunderstorms have lightning—since it is the lightning which causes the thunder.

Thunderstorm Formation

Three conditions are necessary for a thunderstorm to develop, and they are:

1. *deep instability in the atmosphere,* so that once the air starts to rise it will continue to rise (for example, a steep unstable lapse rate with warm air in the lower levels of the atmosphere and cold air in the upper levels);
2. *a high moisture content,* so that clouds can readily form; and
3. *a trigger action* (catalyst or lifting force) to start the air rising, possibly caused by:
   - a front forcing the air aloft;
   - a mountain or other terrain forcing the air aloft, (orographic ascent);
   - strong heating of the air in contact with the earth's surface causing convective ascent;
   - heating of the lower layers of a cold polar air mass as it moves by advection to warmer latitudes, causing convective ascent and known as a cold stream thunderstorm;
   - advection of cold air in an upper layer, over warm air beneath, which will then tend to rise;
   - less dense moist air moving up and over drier and denser continental air; or
   - cooling of the tops of large clouds at night by radiation which will cause the lower warmer air to rise (for instance, thunderstorms in tropical areas at night or in the early mornings).

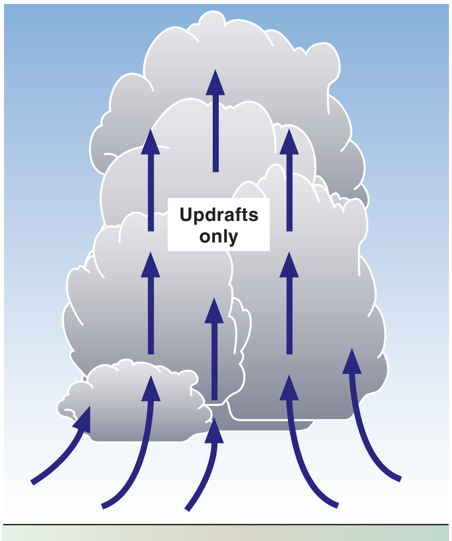


Figure 34-2 The cumulus stage in the development of a thunderstorm.

Life Cycle of a Thunderstorm

1. The Cumulus Stage

As moist air rises, it is cooled until its dewpoint temperature is reached. Then the water vapor starts to condense out as liquid droplets, forming clouds. Latent heat is given off in the condensation process, and so the rising air cools at a lesser rate, with the release of large amounts of latent heat energy driving along the formation of the storm cloud. At this early cumulus stage in the formation of a thunderstorm, there are strong, warm *updrafts* over a diameter of one or two miles, with no significant downdrafts.

Air is drawn horizontally into the cell at all levels and causes the updraft to become stronger with altitude. The temperature inside the cloud is higher than the outside environment (because of the release of latent heat during the condensation), and the cloud continues to build to greater and greater altitudes. This growth often occurs at such a rate that an airplane cannot out-climb the growing cloud.

Thunderstorms have a distinct lifecycle consisting of three stages: cumulus, mature and dissipating.

The strong, warm updrafts carry the water droplets higher and higher, to levels often much higher than the freezing level, where they may freeze or continue to exist as liquid water droplets in a supercooled state. Water condensation occurs, and the liquid droplets coalesce to form larger and larger drops.

The cumulus stage as a thunderstorm forms typically lasts 10 to 20 minutes and is characterized by continuous updrafts. If the cumulus cloud develops into a towering cumulus 25,000 feet high in only 10 minutes, then the average updraft strength exceeds 2,000 fpm.

2. The Mature Stage

The water drops eventually become too large and too heavy to be supported by the updrafts, even though the updrafts may be in excess of 6,000 fpm, and so start to fall. As the drops fall in great numbers inside the cloud, they drag air along with them causing strong *downdrafts*. Often the first lightning flashes and the first rain from the cloud base will occur at this stage.

Rain starting to fall from the base of a cumulonimbus cloud to the surface is an indication that the thunderstorm has entered the mature stage, and it is in this stage that the thunderstorm reaches its greatest intensity.

The descending air warms adiabatically, but the very cold drops of water slow down the rate at which this occurs, resulting in very *cool downdrafts* in contrast to the *warm updrafts*. Heavy rain or hail may fall from the base of the cloud at this stage, generally being heaviest for the first five minutes. The strong wind currents associated with the thunderstorm may throw the *hailstones* well out from the core of the storm, possibly several miles where they may fall in clear air.

The top of a storm cloud in this mature stage may reach as far up as the tropopause, which is perhaps 30,000 feet MSL in temperate latitudes and 50,000 feet MSL in the tropics. The storm cloud may now have the typical shape of a cumulonimbus, with the top spreading out in an *anvil* shape in the direction of the upper winds. Extremely large cumulonimbus with strong vertical development can sometimes push through the tropopause and into the stratosphere. Over the Midwestern plains, some thunderstorms reach well above 50,000 feet MSL.

The violent updrafts and downdrafts (which are very close to each other in a mature thunderstorm) cause extremely strong *windshear* and *turbulence*, which can result in structural failure of the airframe. The rapidly changing direction from which the airflow strikes the wings could also cause a stall, so intentionally flying into a mature cumulonimbus cloud is a foolhardy thing to do.

As the cold downdrafts flow out of the base of the cloud at a great rate, they change direction and begin to flow horizontally as the ground is approached. Strong windshear and turbulence will occur—and this has caused the demise of many aircraft, large and small. The outflowing cold air will undercut the inflowing warmer air and, like a mini cold front, a gusty wind and a sudden drop in temperature may precede the actual storm.

Squalls may occur at the surface—a squall being defined as a sudden increase in wind speed of at least 15 knots, with the peak being at least 20 knots and lasting more than one minute.

A *gust* is less dramatic than a squall and is defined as a brief increase in wind speed of at least 10 knots.

A *roll cloud* may also develop at the base of the main cloud where the cold downdrafts and warm updrafts pass, indicating possible extreme turbulence.

The mature stage of a thunderstorm typically lasts between 20 and 40 minutes, and is characterized by updrafts and downdrafts, and by precipitation. There is so much water falling through the cloud toward the end of the mature stage that it starts to wash out the updrafts.

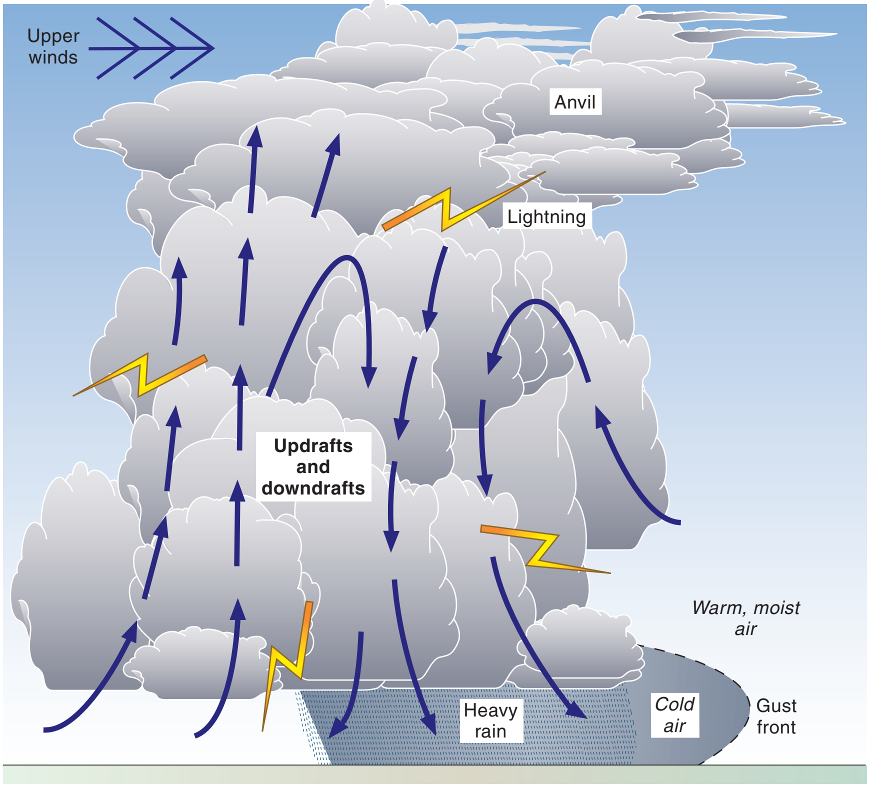


Figure 34-3 The mature stage.

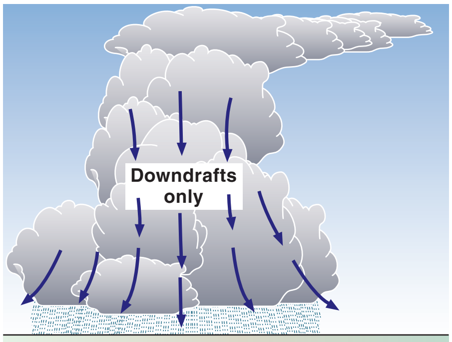


Figure 34-4 The dissipating stage.

3. The Dissipating Stage

The cold downdrafts gradually cause the warm updrafts to weaken, thereby reducing the supply of warm, moist air to the upper levels of the cloud. The cool downdrafts continue (since they are colder than the ambient air surrounding the cloud) and spread out over the whole cloud, which starts to collapse from above. The dissipating stage of a thunderstorm is characterized by *downdrafts*. Eventually the temperature inside the cloud warms to reach that of the environment, and what was once a towering cumulonimbus cloud may collapse into stratiform cloud.

Severe Thunderstorms

Sometimes severe thunderstorms develop, containing more than one storm cell, and with a prolonged mature stage of updrafts and downdrafts, with extremely strong windshears resulting. The cells within the one large storm may be at different stages in their life cycle. Strong winds aloft may cause the updrafts to slope. The rain and resulting downdrafts will be well-separated from the sloping updrafts, and so will not affect the updrafts and the moisture they are carrying up to the upper levels of the clouds. This can lead to the development of large cumulonimbus clouds and *supercell* thunderstorms.

The strong downdrafts, on approaching the ground, tend to spread out in all directions, with the forward edge in front of the cloud forming a gust front. As the gust front advances, air is forced aloft and new storm cells can form.

Embedded Thunderstorms

Embedded thunderstorms are of particular concern for instrument pilots, since they can go undetected while flying in IMC.

Sometimes cumulonimbus clouds are embedded in a general cloud layer and, unlike many isolated and scattered thunderstorms, may not be detected by pilots flying visually below the clouds or by pilots flying without weather radar.

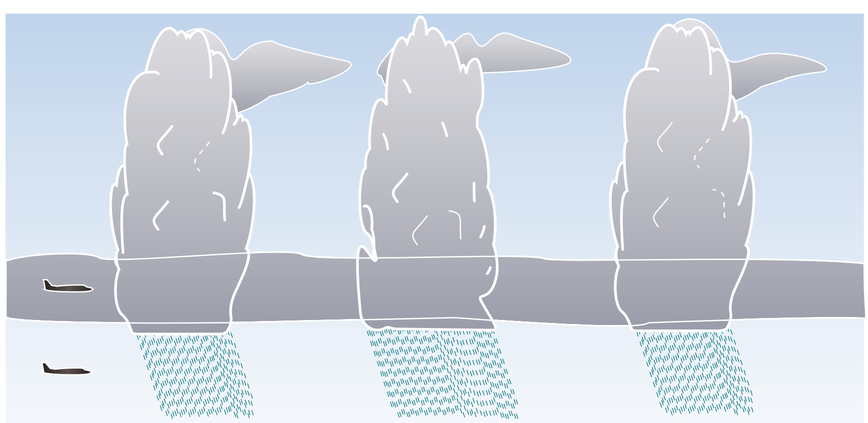


Figure 34-5 Embedded thunderstorms.

The presence of embedded thunderstorms might be indicated to a pilot flying visually beneath the cloud base by heavy rain showers. In general, however, you should not fly into or under a cloud mass containing embedded thunderstorms unless you have airborne weather radar or lightning detection equipment such as a Stormscope or Strikefinder (lightning has been associated with the severe turbulence found in thunderstorms).

Icing

With lifting and supercooled droplets, ice can occur in a much wider temperature range. Avoid flight into any known icing conditions, regardless of the temperature!

The most critical icing levels for airplanes inside a cumulonimbus cloud is from the freezing level (0°C) up to an altitude where the temperature is –15°C, the range where it is most likely to encounter supercooled water drops (freezing rain). If possible, avoid this temperature band inside clouds.

Hailstones

Large hailstones often form inside cumulonimbus clouds as water adheres to already formed hailstones and then freezes, leading to even larger hailstones. In certain conditions hailstones can grow to the size of an orange. Heavy hail can damage the skin of an airplane and damage its windshield.

Almost all cumulonimbus clouds contain hail, with most of it melting before reaching the ground where it falls as rain. Strong air currents can sometimes throw hailstones out of the storm for a distance of several miles. On cold days, with freezing level at or near ground level, hail will fall from the cloud and reach the ground before melting.

Lightning Strikes

Lightning strikes can cause damage to electrical equipment in the airplane and to the airplane skin and antennas. It can also temporarily blind the pilot, especially if flying at night in a darkened cockpit with the eyes adjusted to the darkness. A good precaution against this is to turn up the cockpit lights when in the vicinity of thunderstorms.

Lightning strikes seem to be most likely when flying in or near to cumulonimbus clouds at altitudes near the freezing level (±5°C, within about ±2,500 feet of the freezing level).

Turbulence

So that pilots and FSS can communicate efficiently regarding turbulence, certain classifications are used and should be generally understood.

- *Light turbulence* causes slight, erratic changes in attitude and/or altitude. Pilots may feel a slight pull from the seatbelt.
- *Moderate turbulence* causes some changes in attitude and/or altitude, and possibly in airspeed, but the aircraft stays in positive control at all times. Pilots will feel more pronounced pulls from the seatbelt.
- *Severe turbulence* causes large changes in attitude and/or altitude, probably with large changes in airspeed, and the aircraft may occasionally be momentarily out of control. Pilots will experience severe pulling from the seatbelt.
- *Extreme turbulence* causes violent changes in attitude and/or altitude and airspeed, with possible structural damage.

The duration of the turbulence can be described by:

- *occasional*—less than ⅓ of the time;
- *intermittent*—⅓ to ⅔ of the time;
- *continuous*—more than ⅔ of the time.

Turbulence in the vicinity of a thunderstorm that causes large changes in attitude, altitude and airspeed, with the aircraft occasionally out of control for a moment, and causing you to experience severe pulling from the seatbelt for about three quarters of the time, would be described as *continuous severe turbulence.*

Downbursts and Microbursts

Strong downdrafts that spread out near the ground are known as *downbursts*. A very strong downburst not exceeding 2 NM in diameter is called a *microburst*.

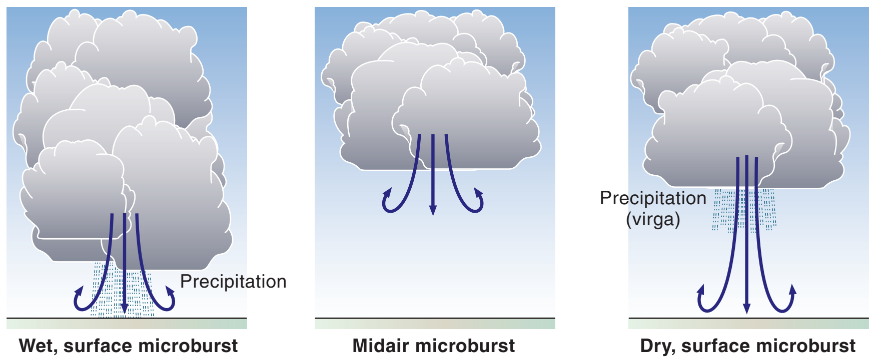


Figure 34-6 Some types of microbursts.

Airplanes may not have the performance capability or the structural strength to combat the extremely strong downdrafts, turbulence and windshear in downbursts and microbursts, and can be destroyed. You should must such weather phenomena.

Downbursts and microbursts are mainly associated with cumulonimbus clouds, but they may also occur with smaller clouds, such as cumulus, or with clouds from which virga is falling. As rain falls from high clouds and evaporates (virga), it absorbs latent heat and creates a very cold parcel of air beneath the cloud which may plummet toward the ground as a downburst or a microburst. This can sometimes be detected

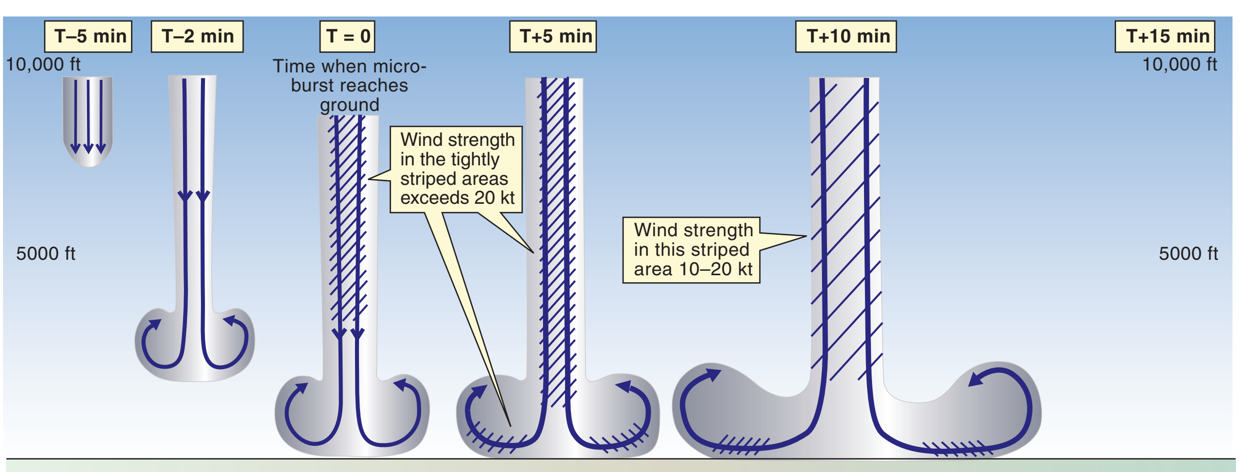


Figure 34-7 Typical life-cycle of a microburst.

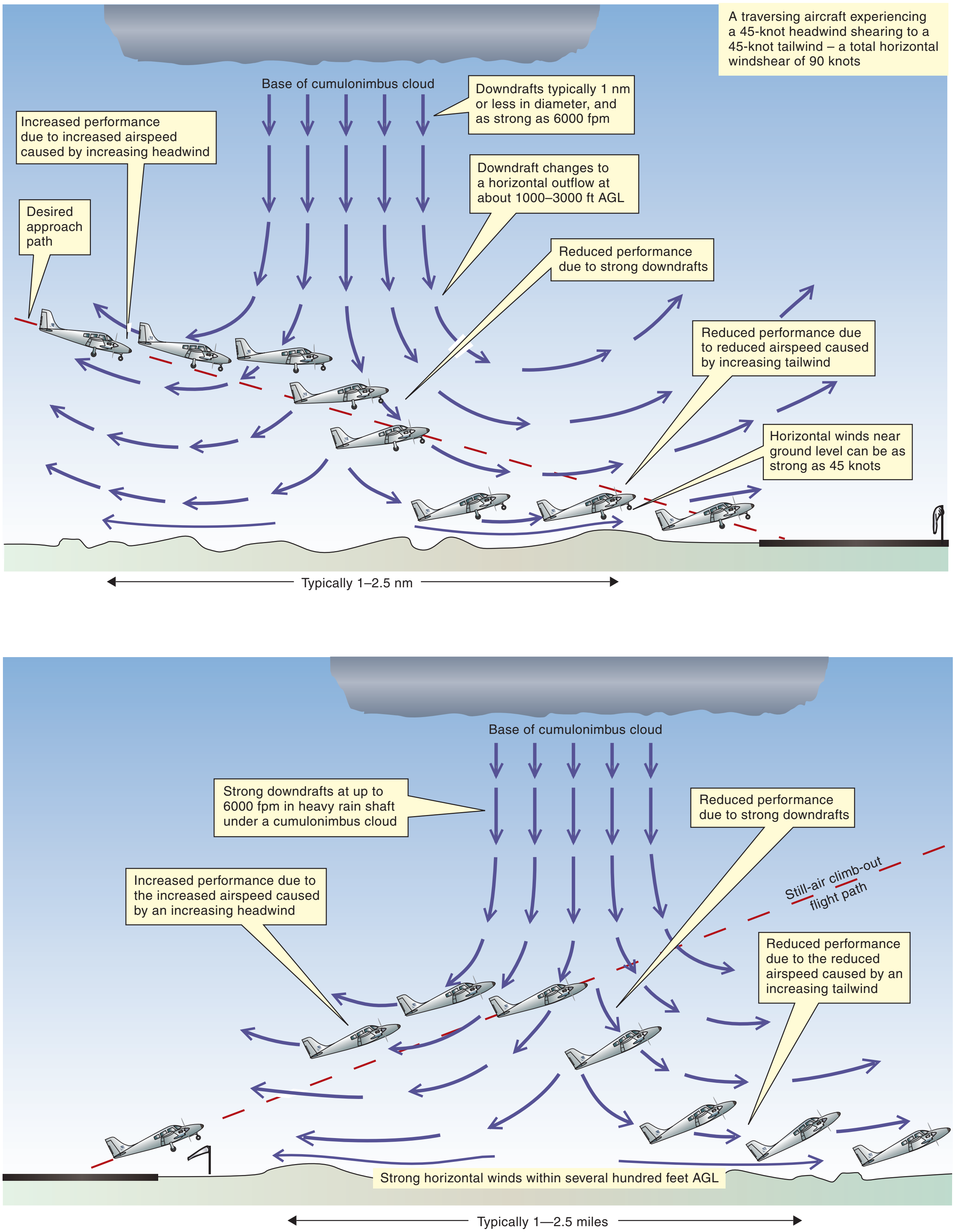


Figure 34-8 The dangers of a microburst in approach to land (top) and the dangers of a microburst following takeoff (below).

visually by a ring of dust being blown up where the microburst hits the ground and spreads out.

Microbursts and downbursts may appear very suddenly and may or may not last very long. A typical life cycle lasts about 15 minutes from when the very strong shaft of downdrafts first strikes the ground. The wind spreads out horizontally in all directions, with the horizontal winds usually increasing in strength for the first 5 minutes and peak wind strength lasting 2-4 minutes.

In extreme cases, microbursts have been known to blow hundreds of trees down in a radial pattern, and to blow trains off rails.

Even though one airplane might make an approach satisfactorily underneath a large cloud, a following aircraft may not. There are a number of accidents to illustrate this. Always be on the watch for large clouds with a bulging undersurface, for virga, or for any other indication of downbursts or microbursts.

Effects of a Microburst on Aircraft Performance

Refer to figures 34-8. An aircraft entering the area of a microburst within 1,000-3,000 feet AGL will first encounter an increasing headwind. The aircraft will initially maintain its inertial speed over the ground (its groundspeed) and the increased headwind will cause it to have a higher airspeed, therefore increased performance. It will tend to fly above the original flight path. Then the aircraft will enter the downburst shaft and will be carried earthward in the strong downward air current—a loss of performance.

As the aircraft flies out of the downburst shaft (hopefully), the situation is not greatly improved. It will fly into an area of increasing tailwind. As the aircraft tends to maintain its inertial groundspeed initially, the increasing tailwind will cause the airspeed to decay—a reduced airspeed, resulting in reduced performance. Even with the addition of full power and suitable adjustments to pitch attitude by the pilot, the airplane may struggle to maintain a safe airspeed and flight path. Traversing some small, strong microbursts safely may be beyond the performance capabilities of any aircraft.

Tornadoes and Water Spouts

A strongly growing large cumuliform cloud may "suck" air into it as an updraft. These strong updrafts may commence from just beneath the base of the cloud, or they may commence well below the cloud base from near the ground, from where they may raise objects or, if over a water surface, cause a water spout. Tornadoes and water spouts are rotating funnels of air of very small diameter. The central pressure will be much lower than in the surrounding air, creating a vortex of wind with speeds possibly exceeding 150 knots. Tornadoes and water spouts are a great hazard to aviation. Avoid them at all costs!

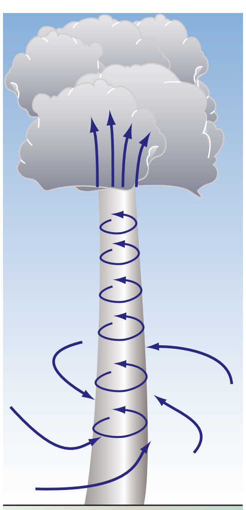


Figure 34-9
A tornado.

Thunderstorms Are Hazardous to Aviation

The dangers to aviation from a thunderstorm do not exist just inside or just under the storm cloud, but for up to 10 or 20 NM or more. Most jet transport aircraft and advanced airplanes are equipped with weather radar to enable the pilots to identify the position of storm cells and to divert around them by an appropriate distance. The visual pilot without weather radar has to use the eyes and common sense. This may be difficult if the storms are embedded and rising out of a general cloud base or out of layers of clouds that obscure the storm clouds. Frequent lightning from within a cumulonimbus cloud, the presence of rain clouds, and the presence of a roll cloud indicate a severe thunderstorm.

SIGMETs are issued whenever possible to warn pilots of known or forecast thunderstorms and other meteorological hazards.

Some obvious dangers to airplanes from thunderstorms include:

- severe windshear (which may cause large flight path deviations and handling problems, loss of airspeed, and possibly structural damage);
- severe turbulence (causing loss of control and possible structural damage);
- severe icing (possibly the dangerous clear ice that forms from large supercooled water drops striking a below-freezing surface);
- damage from hail (to the airframe and to the cockpit windows);
- reduced visibility;
- damage from lightning strikes, including electrical damage; and
- interference to radio communications and radio navigation instruments.

The most severe flying conditions, such as heavy hail and destructive winds, may be produced in a *squall line*, which is a nonfrontal band of very active thunderstorms, possibly in a long line that requires a large detour to fly around. This line of thunderstorms (sometimes more than one line) can form in the relatively warm air ahead of a cold front, and can be quite fast-moving. A squall line may contain a number of severe steady-state thunderstorms, destructive winds, heavy hail, tornadoes, and can present a most intense hazard to aircraft.

Flying Near Active Thunderstorms

Do not land or take off if there is an active thunderstorm approaching the airport. Sudden wind changes, severe turbulence and windshear are possible.

Avoid thunderstorms in flight by at least 10 NM and, in severe situations, by 20 NM. If you are passing downwind of them, you should perhaps increase this distance even further. Use your weather radar, Stormscope or Strikefinder, if available, otherwise detour visually making use of heavy rain showers, towering clouds, lightning, and roll clouds as indicators of where mature storm cells are likely to be.

Remember that embedded thunderstorms may be obscured from sight by the general cloud layers, so avoid areas where embedded cumulonimbus clouds are forecast, unless you are equipped with a serviceable weather avoidance equipment. Also avoid areas with 6/10 or more of thunderstorm coverage. Any thunderstorm with tops 35,000 feet or higher should be regarded as extremely hazardous.

Squall lines can produce the most severe flying conditions. These lines of thunderstorms are a serious hazard to aircraft.

Fasten seatbelts and shoulder harnesses, and secure any loose objects in the cockpit. Turn up the cockpit lights at night to lessen the danger of temporary blindness from nearby lightning. Do not fly under thunderstorms, because you may experience severe turbulence, strong downdrafts, microbursts, heavy hail, and windshear. High-flying aircraft should divert upwind of the tops of thunderstorms if possible, avoiding flying downwind of or under the anvil, where there may be strong turbulence. Clearing the tops by 1,000 feet or more, if the airplane has the altitude performance capability, should avoid turbulence. A good rule-of-thumb is 1,000 feet of altitude above the tops for each 10 knots of wind speed at the cloud tops.

If you cannot avoid flying through or near a thunderstorm:

- Plan a course that will take minimum time through the hazardous area.
- Establish a power setting for the recommended turbulence penetration speed (which may be near the maneuvering speed, V_A); the wing will stall before becoming overloaded, so flying at V_A reduces the risk of structural damage.
- Turn on pitot heaters (to avoid loss of airspeed indication), carburetor heat or jet-engine anti-ice (to avoid power loss) and other anti-icing equipment (to avoid airframe icing).
- Maintain your heading by keeping the wings level with ailerons, and do not make sudden changes in pitch attitude with the elevators—just hold the pitch attitude steady and allow the altitude to fluctuate in updrafts and downdrafts ("ride the waves"). Sudden changes in pitch attitude may overstress the airplane structure. It may be advisable to disconnect the autopilot, or at least its altitude-hold and speed-hold functions, to avoid the autopilot making sudden changes in pitch attitude (causing additional structural stress) and sudden changes in power (increasing the risk of a power loss).
- Avoid turns if possible, as this increases g-loading—continue heading straight ahead and avoid turning back once you have penetrated the storm, as a turn will increase stress on the airframe and also increase the stall speed. Maintaining the heading will most likely get you through the storm in the minimum time.
- Allow the airspeed to fluctuate in the turbulence, and avoid rapid power changes.
- The most critical icing band within a cloud is from the freezing level (0°C) up to an altitude where the temperature is about -15°C, which is the temperature band where supercooled water drops may exist. Avoid this temperature band in large clouds if possible.

Monitor the flight and engine instruments, avoid looking out of the cockpit too much to reduce the risk of temporary blindness from lightning. Use the weather radar effectively, occasionally tilting the antenna up or down to allow detection of thunderstorm activity at altitudes other than the one being flown.

Note. You may sometimes experience St. Elmo's fire, a spectacular static electricity discharge across the windshield, or from sharp edges or points on the airplane's structure, especially at night. St. Elmo's fire is not dangerous.

Review 34
Thunderstorms

1. What meteorological phenomenon do all thunderstorms have in common?
2. What are the requirements for the formation of a thunderstorm?
3. What does an unstable lapse rate mean?
4. Name the three stages of a typical thunderstorm.
5. What is the cumulus stage of a thunderstorm characterized by?
6. What is the growth rate of raindrops enhanced by?
7. What is the mature stage of a thunderstorm characterized by?
8. What is the dissipating stage of a thunderstorm characterized by?
9. What is rain falling from the base of a storm cloud an indication of?
10. What is an embedded thunderstorm?
11. Where are the most severe flying conditions, including heavy hail and destructive winds, often found?
12. Is hazardous windshear and turbulence possible on the outside of a thunderstorm cloud? If so, where?
13. If squalls are reported at your destination airport, you should expect:
    a. a brief increase in wind speed of at least 10 knots.
    b. heavy rain but no wind.
    c. sudden increases in wind speed.
14. If gusts are reported at your destination airport, you should expect:
    a. a brief increase in wind speed of at least 10 knots.
    b. heavy rain but no wind.
    c. sudden increases in wind speed.
15. What can airborne weather radar detect, when correctly used?
16. Do cumulonimbus clouds contain large water drops?
17. Can weather radar warn pilots of other possible instrument weather conditions, such as fog or stratiform clouds?
18. As a general rule, by what distance should you avoid severe thunderstorms?
19. For you to fly between two severe thunderstorms, how far apart (NM) should the thunderstorms be? How much separation from each storm does this distance enable you to maintain?
20. Can airborne weather radar be used to avoid all instrument weather conditions?
21. The downdraft in a microburst encounter may be as strong as:
    a. 4,000 feet per minute.
    b. 5,000 feet per minute.
    c. 6,000 feet per minute.
    d. 7,000 feet per minute.
    e. 8,000 feet per minute.
22. The downdraft from a microburst will spread out within a few hundred feet of the ground, causing horizontal winds as strong as:
    a. 5 knots.
    b. 10 knots.
    c. 45 knots.
23. How long can a typical microburst last from the time the burst strikes the ground until dissipation?
24. What is any change of wind speed and/or wind direction between two points called?
25. An aircraft faces a headwind of 45 knots as it enters a microburst. What is the aircraft likely to encounter?
26. An aircraft encounters a headwind of 45 knots near the surface as it enters a microburst. What is the total windshear across the microburst that can be expected?
27. Without a change in pitch attitude or power, what effect can entering a microburst and encountering an increasing headwind have on aircraft performance? What is the effect on airspeed and altitude?
28. In severe turbulence, will reducing the airspeed to the design maneuvering airspeed protect the wings from a potential overload?

29. Having entered a microburst, an aircraft flies from headwind conditions into a strong downdraft and then into a decreasing tailwind. What effect will this have on aircraft performance? Unless the pilot takes action, what is the likely effect on airspeed and altitude?

30. Refer to figure 34-10 (page 715). Describe the effect on performance and the cause of this effect on the airplanes in the following positions:
a. Position 2.
b. Positions 4 and 5.
c. Position 6.

31. If you unintentionally penetrate a thunderstorm, what actions should you take?

32. If you enter an area of severe turbulence, what actions should you take?

33. If you fly into severe turbulence, you should attempt to maintain a constant:
a. airspeed.
b. level flight attitude.
c. altitude.

34. Refer to figure 34-11 (page 715). Describe the effect on performance and the cause of this effect for the airplanes at the following positions:
a. Position 2.
b. Position 5.
c. Positions 7 and 8.

Answers are given on page 793.

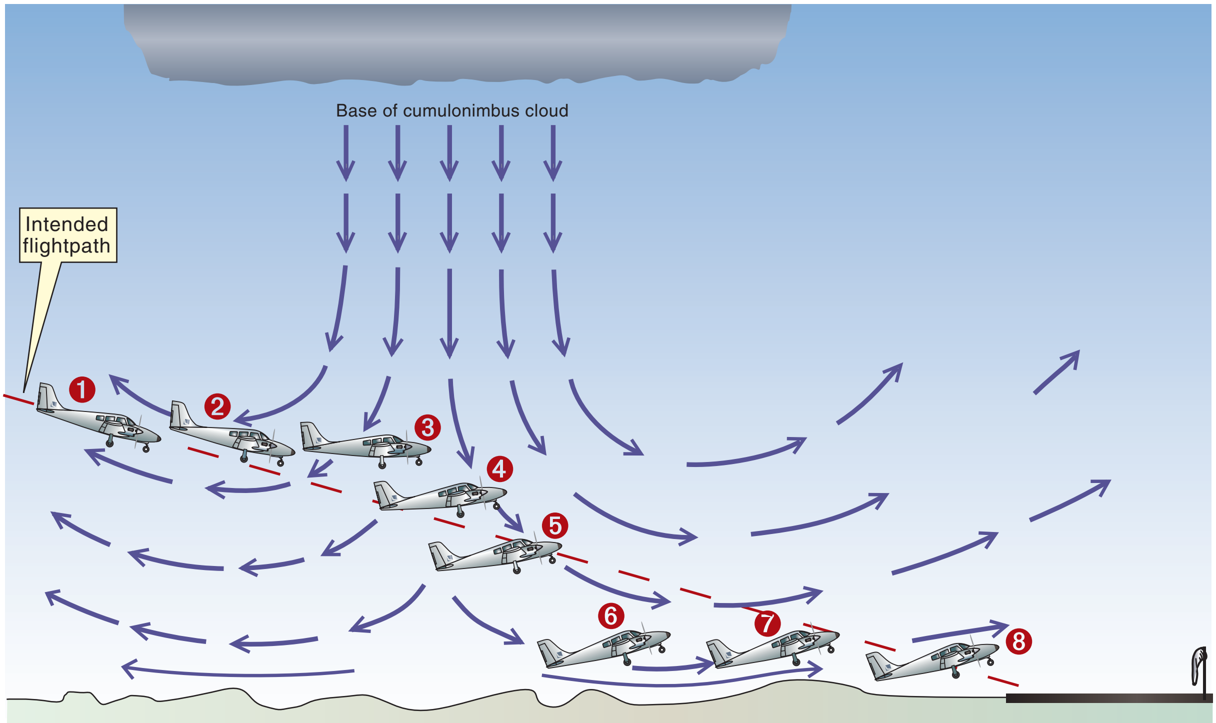


Figure 34-10 Microburst on approach.

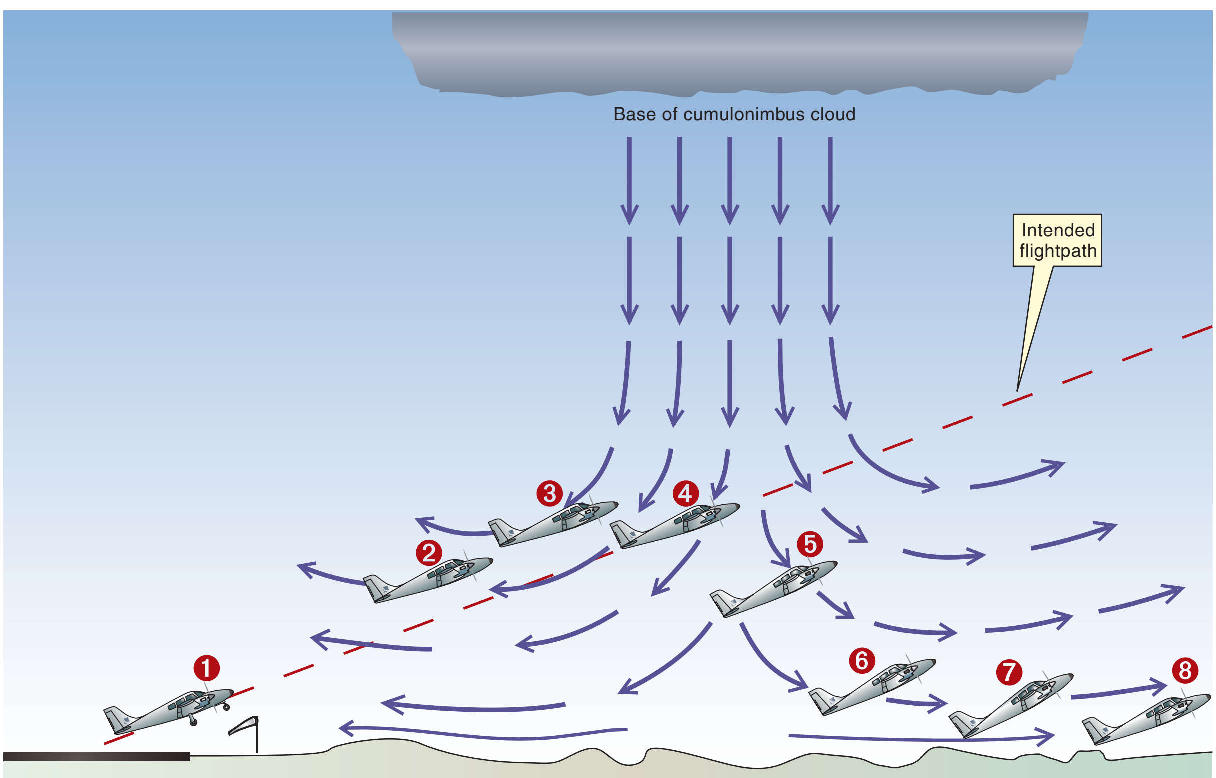


Figure 34-11 Microburst after takeoff.

High-Level Meteorology 35

High-level meteorology applies near to and above the *tropopause*, which is the border between the troposphere and the stratosphere. It varies in altitude from about 20,000 feet over the poles to 55,000 to 65,000 feet over the equator. In mid-latitudes, it is approximately 37,000 feet, and this is its assumed level in the standard atmosphere.

The tropopause is characterized by a sudden change in the temperature lapse rate, and is generally found in mid-latitudes at approximately 37,000 feet.

The tropopause is characterized by a sudden change in the temperature lapse rate, with temperature above the tropopause no longer decreasing with altitude. Temperatures and winds vary significantly near the tropopause, and knowledge of these can help you achieve an efficient and comfortable flight.

Jetstreams

The tropopause is not a continuous "sheet" from the equator to the poles, but descends in a number of steps from overhead the equator to overhead the poles. These steps are like breaks in the tropopause with intensified temperature gradients. Often the winds reach maximum values in narrow *jetstream* tubes along these breaks in the tropopause, with narrow bands of windshear and severe turbulence.

In the winter months in the Northern Hemisphere the whole system moves further

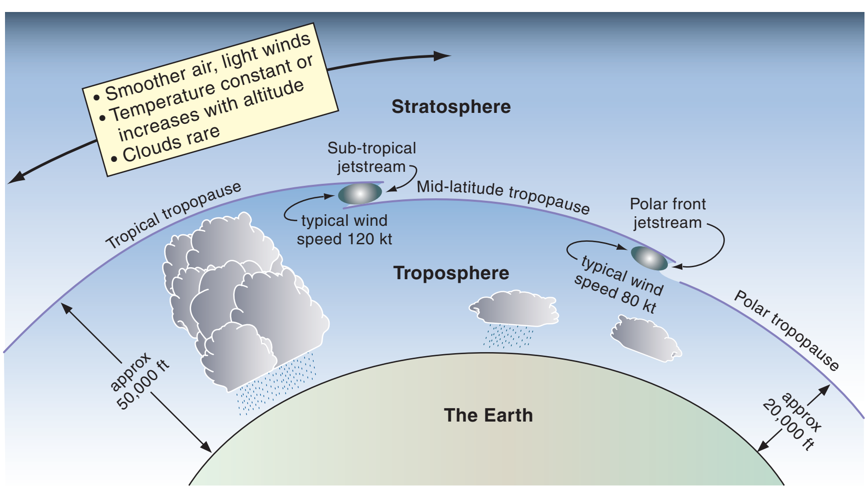


Figure 35-1 The tropopause.

south (along with the sun), and the jetstreams increase in strength. The position of the jetstream over North America varies, but it is (in general terms) further south and stronger in winter, and moves further north in summer and is somewhat weaker.

Clear air turbulence and long streaks of high-level cirrus clouds may show the presence of a jetstream.

The position of the jetstream and its associated *clear air turbulence* (CAT) can sometimes be visually identified by long streaks of high-level cirrus clouds.

Figure 35-2 High cirrus cloud.

A jetstream is typically 5,000 feet thick and is associated with a deep low-pressure trough situated in the upper atmosphere near the tropopause. It may run in a curved path for thousands of miles around the earth at high altitude basically from west to east, but its path may meander quite a bit.

The wind strength in a jetstream is 50 knots or greater, with the strongest winds existing in the "core" of the jetstream tube.

By definition, the wind strength in a jetstream is 50 knots or greater, with the strongest winds existing in the "core" of the jetstream tube. It is possible sometimes for a second and third jetstream to form.

High-flying jets often take advantage of the strong winds in the core of the jetstream when they are flying from west to east, perhaps giving them a tailwind of 100 knots or more, but avoid the jetstream when flying in the other direction.

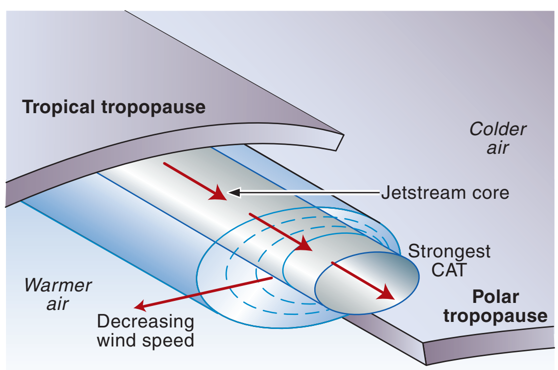


Figure 35-3 A cross-section of a jetstream.

CAT Near Jetstreams

Flying conditions can be smooth in a jetstream, but turbulence can be expected on its edges where it meets with slower moving air—so CAT is always a possibility near a jetstream. CAT is likely to be greatest on the edges of the jetstream core, especially on the cold polar side of the jetstream where there may be strong windshear, strong curvature in the airflow, and cold air moving in by advection associated with sharply curving strong upper-level troughs. A strong windshear can be expected on the low-pressure side of a jetstream core if speed at the core is greater than 110 knots.

A curving jetstream associated with a deep upper-level trough will create the greatest turbulence, especially during the winter months when the jetstream wind speeds are greater.

If encountering CAT associated with a jetstream at high altitude, it is good airmanship to report it, and also to determine from other pilot's reports if smooth flight is being achieved at other levels. You might fly out of the CAT by climbing or descending several thousand feet, or by moving some miles laterally from the jetstream.

How a Jetstream Forms

Wind velocity changes with altitude, and this is caused by uneven temperatures in the horizontal. A warm air mass alongside a cold air mass (as is the case at the polar front) will be less dense and have relatively expanded pressure levels. Even though the pressures may be the same at ground level in the two air masses (with no pressure gradient), the pressure at altitude in the warm air mass will be greater than that at the same level in the cold air mass. A pressure gradient force will exist and a wind will be initiated. In general, the higher the altitude in the troposphere, the steeper the pressure gradient and the stronger the wind.

Once the wind starts to flow, the Coriolis force turns it to the right in the Northern Hemisphere. In the situation in figure 35-4, the wind will flow out of the page (from west to east as a westerly wind), and will be stronger at higher altitudes in the troposphere. If you look at weather charts and winds-aloft forecasts, you will often see westerlies that increase with altitude.

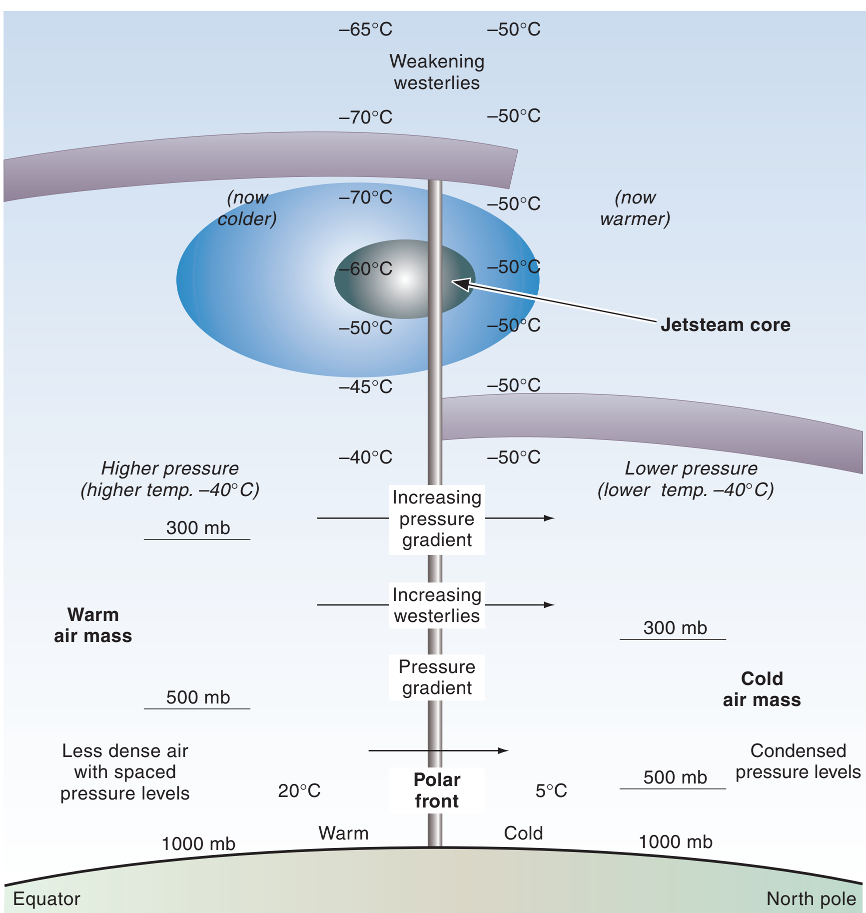


Figure 35-4 The polar front bringing cold air down from polar regions.

At the tropopause, temperature stops decreasing. Since the polar tropopause is lower than the mid-latitude tropopause, temperature above it will stop decreasing with altitude, whereas temperature will continue decreasing in the "warm" air mass until its tropopause is reached, by which time it may be significantly colder than the "cold" air mass at the same level.

As well as the temperature gradient reversing with altitude, the pressure gradient will also start to reverse, and so the westerlies will start to weaken with increasing altitude above the tropopause, and may even become easterlies at great altitudes. The westerly winds reach their maximum intensity in the break between the two tropopause sheets, often blowing in a narrow jetstream tube at speeds well in excess of 100 knots.

Clouds at High Levels

High-altitude cirriform clouds which form in the cold air at high levels usually consist of ice crystals, and so generally do not create a significant icing hazard, although you may experience continuous turbulence. Streaks of cirrus clouds may be associated with a jetstream. It is also possible for strong thunderstorms to punch their way up to high levels, even above the tropopause, creating the usual cumulonimbus problems for high-flying pilots.

Haze layers sometimes exist at high levels near the tropopause, consisting of cirrus clouds with a low density of ice crystals. They may not be visible from the ground but, when flying in them, your visibility might be greatly restricted and the ride may not be smooth. Sometimes both visibility and smoothness of ride can be improved by climbing above the haze, or by descending beneath it.

Water vapor from the exhausts of high-flying jets sometimes condenses in the cold air at high altitudes to form exhaust condensation trails, known as *contrails*.

Review 35

High-Level Meteorology

1. What is a jetstream?
2. What defines the tropopause?
3. What is the average altitude of the tropopause in mid-latitudes?
4. How does the jetstream in the summer compare to that in the winter?

Answers are given on page 794.

Weather Reports and Forecasts 36

Weather conditions vary from place to place and from time to time. It is good airmanship (common sense) that you make yourself aware of the weather that you are likely to encounter en route. You can do this by making your own observations to a limited extent but, for flights away from the local airport, you should obtain weather reports and forecasts.

Weather that has actually been observed is contained in weather *reports*. Weather that is expected to occur at some time in the future is contained in weather *forecasts* or shown graphically on *prognostic charts.*

Reports and forecasts are available before flight from *flight service stations* (FSS) and other offices by telephone, in person and through various websites. They are also available via a personal computer on the direct user access terminal (DUAT) system. When you are airborne, reports or forecasts are available from the nearest FSS, or from Flight Watch on the designated en route flight advisory service (EFAS) frequency of 122.0 MHz at the lower altitudes, hazardous in-flight weather advisory service (HIWAS), the automatic terminal information service (ATIS) and automated observing systems (AWOS and ASOS).

Figure 36-1 On-line weather services.

Obtaining a Weather Briefing

Obtaining Weather from Flight Service Stations

In the United States, the primary method of obtaining the most current aviation weather information is by calling a Flight Service Station. In most parts of the country, you can receive a briefing by dialing 1-800-WX-BRIEF, or you can look up the telephone number of an FSS under U.S. Government, Department of Transportation, Federal Aviation Administration, in a telephone book. The FAA's Airport/Facility Directory (A/FD) gives telephone numbers for weather briefings for all public-use airports. Pilots may also call National Weather Service offices for briefings.

Sometimes it is possible to visit a Flight Service Station office or a National Weather Service office for a briefing, but with the consolidation of smaller Flight Service Stations into larger automated stations, walk-in briefings are becoming uncommon. When possible, a walk-in briefing is best because it allows you to examine charts and data yourself, and not depend only on what the briefer says. Visiting the NWS website (www.nws.noaa.gov) also provides the opportunity to see the charts and data yourself.

When you call for a briefing, you can usually listen to local conditions and forecasts and then request whatever additional information you need.

Obtaining Weather by Computer

More and more pilots are obtaining weather information using personal computers, either at home or at a fixed-base operator (FBO) at an airport. This method has become the most common way of obtaining preflight weather information.

Any certificated pilot in the United States may obtain a basic weather briefing on a personal computer under the FAA's direct user access terminal (DUAT) system. These free briefings are in code, which you must learn to understand (some DUAT systems offer a "plain language" mode, but you still must learn the code). Pilots with a computer and modem can also access weather services through the internet. There are many excellent websites with aviation weather products for pilots, including the FAA site for weather at http://adds.aviationweather.noaa.gov.

Pilot Responsibility

The growing use of recorded and computer briefings means that you must assume more responsibility than in the past for obtaining needed weather data. It also means you are less likely to talk face-to-face or by telephone with a meteorologist or briefer who can help you understand the reports and forecasts.

You must learn how to read and understand coded forecasts and the various kinds of weather charts, reports and forecasts. One key to weather reports and forecasts is Aviation Weather Services, a document published by the Federal Aviation Administration and National Weather Service as FAA Advisory Circular AC 00-45. The U.S. METAR code is described in the Federal Meteorological Handbook (FMH) No. 1 "Surface Observations and Reports," while the U.S. TAF code procedures used by the National Weather Service are described in the Weather Service Operations Manual, Chapter D-31. These are available from the Federal Government Printing Office and from many FBOs and pilot-supply shops.

The "Big Picture" from TV and Newspapers

Before obtaining a specific briefing for a flight, you can get a good idea of general weather trends—the big picture—from newspaper weather forecasts and television weather programs. The Weather Channel, which is available on cable television systems across the country, broadcasts nothing but weather reports and forecasts, including segments specifically for pilots, 24 hours a day. Local television stations give detailed reports and forecasts for their viewing areas on evening news shows. These usually include moving satellite pictures, live local radar images and maps that give you a good idea of the national picture for the coming day. Many of these local weather shows are presented by knowledgeable weathercasters using sophisticated graphics, and watching them is a good way to further your weather education.

Specific Aviation Briefings

No matter how good the information you receive from a newspaper or television weather program, both common sense and the regulations require that you obtain a specific briefing for a flight to a destination away from your takeoff point. Use DUAT, the internet and/or a FSS.

When you telephone or visit a FSS, first tell the briefer you want a flight weather briefing and give the briefer the following information: you are a pilot, whether the flight will be VFR or IFR, the aircraft's N number, the aircraft type, your departure point, your proposed route, your destination, the altitude you plan to fly at, the estimated time of departure, and your estimated time en route. This information will enable the briefer to give you the information you need.

The standard briefing should follow the items specified in the FAA's Flight Service Handbook. If the briefer follows the standard format, you will receive all the needed information, but there is always a slight chance that the briefer might not give you a complete briefing. Also, if you are using a personal computer to gather weather information, you need some way to ensure that you receive all the needed data. For these reasons, you should have a form like the one shown below. If you fill in all of the blanks and complete the Pilot's Weather "Go or No-Go" Checklist, you will be assured of getting a complete briefing every time.

Pilots Weather "Go or No-Go" Checklist					
	Synopsis and area WX		Destination WX forecast		Temperature/dewpoint spread
	Adverse WX, including SIGMETs/AIRMETs		Winds & temperatures aloft forecast		Better WX area forecast
	Current en route WX		PIREPs, including top levels		Alternate airport WX forecast
	Forecast en route WX		Freezing levels		NOTAMs

Figure 36-2 The weather "Go or No-Go" checklist.

A good weather briefing should include at least the following:

- *Adverse conditions*—information about any conditions that could be a hazard to your flight, such as thunderstorms, low ceilings, poor visibility, icing.
- *Weather synopsis*—a brief statement explaining the causes of the weather. This should include the locations and movements of highs, lows, and fronts.
- *Severe weather warnings*—includes AIRMETs, SIGMETs and Convective SIGMETs, and ATC weather advisories.
- *Freezing levels*—to aid in predicting any possibility of icing conditions en route.
- *Current weather*—if you are leaving within two hours, reports of the current weather along your route should be included.
- *An en route forecast*—the briefer should summarize the expected en route conditions in a logical order; this is departure, climb-out, en route and arrival.
- *Destination terminal forecast*—this will be the forecast for one hour before your expected arrival time until an hour later.
- *Winds aloft*—a summary of the forecast winds aloft at and near your planned cruise level. The briefer can also supply the expected temperatures.
- *Notices to airmen* (NOTAMs)—current NOTAMs for your route will be provided, but you have to ask for information about military training routes, terminal flight restrictions (TFRs), GPS NOTAMs, and NOTAMs that have been published. Only Flight Service Stations, not National Weather Service offices, can supply NOTAMs.

Be sure to ask for Terminal Flight Restrictions (TFRs) and GPS NOTAMs affecting your route of flight.

Notes

1. 1. Other types of briefing: In addition to standard briefings, an FSS can offer two other kinds of briefings. When your planned departure is six or more hours away you should ask for an outlook briefing. It will include general information about expected weather trends that should help your planning. You need to ask for a more complete briefing later on, when it is closer to your takeoff time. When you need to update a previous briefing or to supplement mass-disseminated data or recorded data received by telephone or radio, you should ask for an abbreviated briefing. Tell the briefer the type of previous information you received and when you received it.
2. Updating your weather information in flight: Once you are in the air you can update weather information by contacting Flight Watch on 122.0 MHz. This is a flight service station (FSS) frequency, which is the same all over the U.S., exclusively for the exchange of weather information. The information should flow two ways. In addition to receiving updated information, you should give Flight Watch pilot weather reports, known as PIREPs. Since weather observation stations are often far apart, PIREPs are an important source of information for what is going on between stations. They give other pilots information which meteorologists usually cannot obtain from satellite photos and other sources, such as how turbulent the air is. You can also tune in to certain NDBs and VORs which broadcast continuous tape-recorded messages containing weather and NOTAM information, and hazardous in-flight weather messages (HIWAS).

Weather Reports

You should start your briefing by finding out what the current weather is along your planned route and what it has been doing the last few hours. When you have a good idea of the current conditions, you are ready to look at forecasts of what the weather is expected to be doing at the time of your flight.

On weather depiction charts:

IFR conditions are shown by a shaded area—with ceilings less than 1,000 feet AGL and/or visibility less than 3 miles.

MVFR (marginal VFR) areas are shown by contoured areas without shading—with cloud ceilings 1,000–3,000 feet AGL and/or visibility 3–5 miles.

VFR areas are shown by no contours at all—there the ceiling is above 3,000 feet AGL and visibility greater than 5 miles.

Weather Depiction Charts

If you are obtaining a walk-in briefing or if you have a personal computer with Internet access, the weather depiction chart is a good place to begin. The chart gives a broad-brush snapshot of the actual weather, showing fronts and areas of clouds and precipitation. It is a good chart for determining general weather conditions (IFR or VFR) on which to base your flight planning.

Weather depiction charts are prepared from METAR reports. They give a broad overview of flying conditions at the valid time of the chart, allowing you to determine general weather conditions quite readily, and so provide a good starting point when flight planning. More specific information, however, does need to be obtained from forecasts, prognostic charts, and the latest pilot, radar and METAR reports to augment the general information shown on weather depiction charts.

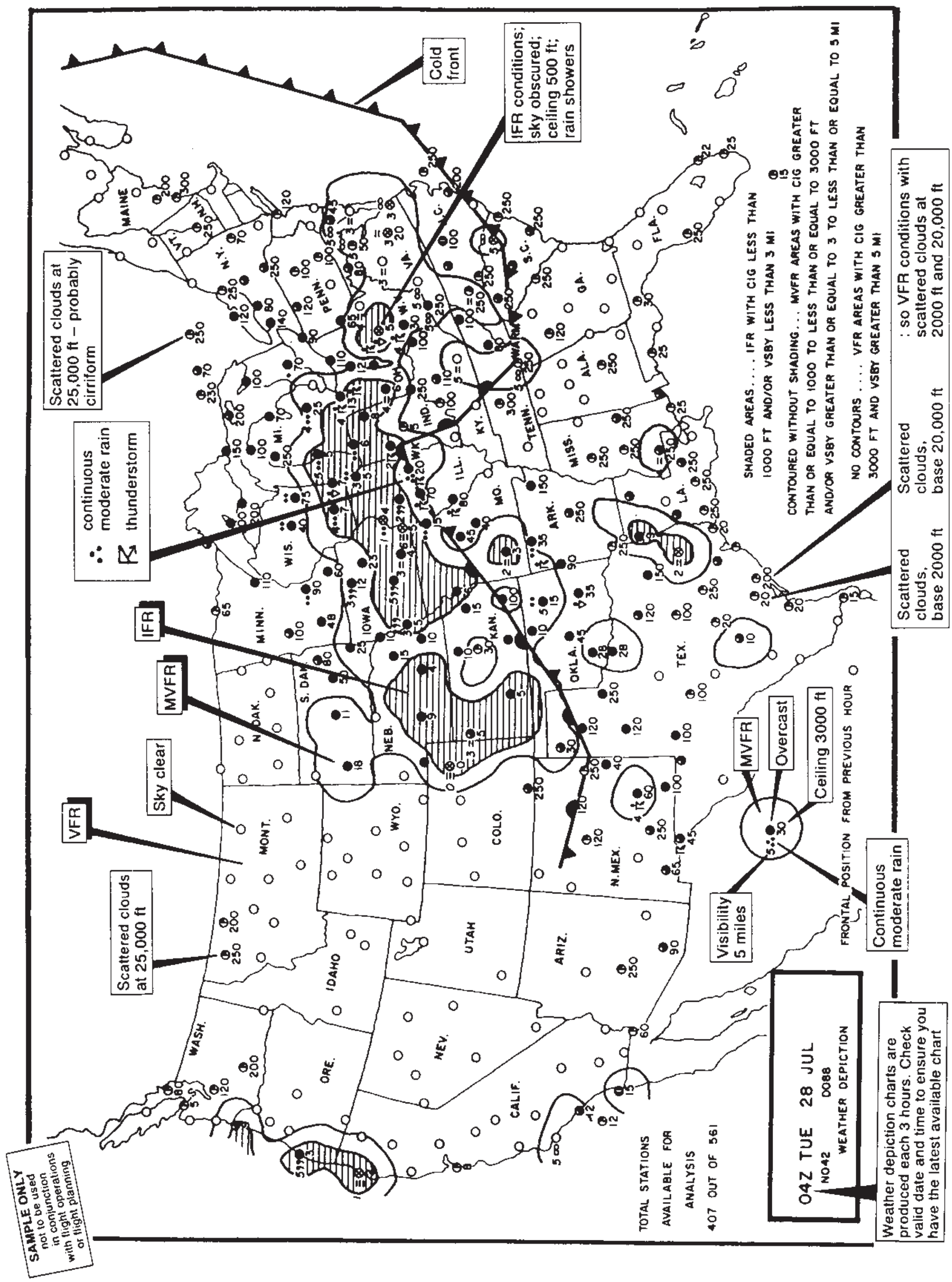


Figure 36-3 A typical weather depiction chart.

Weather depiction charts show:

- areas of IFR, marginal VFR (MVFR), and VFR conditions, as determined by cloud base and visibility;
- the position of fronts;
- sky cover, cloud height or ceiling, weather (including types of precipitation or obstructions to vision) and reduced visibilities as observed at various stations.

At each station:

- sky cover is shown in the station circle (with "M" indicating missing data);
- cloud height or ceiling above ground level (AGL) is shown under the station circle in hundreds of feet (when the total sky cover is few or scattered, the height shown on the weather depiction chart is the base of the lowest layer);
- weather and obstructions to vision symbols are shown left of the station circle;
- visibility (if 6 miles or less) is shown to the left of the symbols for weather and obstructions to vision.

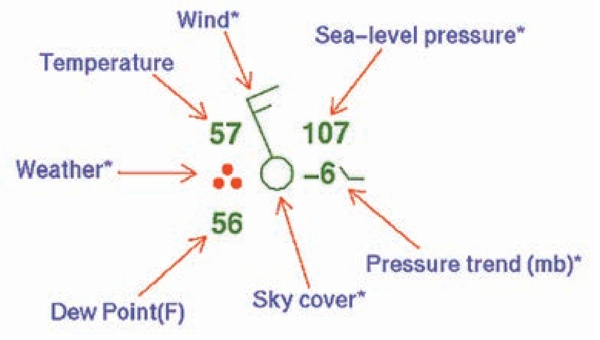


Figure 36-4 A station model.

For example, rain is indicated by small black dots to the left of the station circle—a single dot representing intermittent rain, two dots side-by-side representing continuous rain, and three dots arranged in a triangle representing continuous moderate rain. Fog is indicated by two or three horizontal lines, arranged one above the other—three lines: visibility is less than ¼ mile; two lines it is ¼ mile or greater (and a visibility value would usually be added to the left of the fog symbol).

Note. Some common weather symbols are shown in figures 36-12 and 36-13.

Surface Analysis Charts

The surface analysis chart, also known as the surface weather chart, provides an overview of the *observed* situation at the surface (ground level), and this allows you to:

- locate the position of pressure systems and fronts at ground level; and
- overview surface winds, temperatures, dewpoints, visibility problems and total sky cover at chart time.

Note. The surface analysis chart does not show cloud heights or tops (even though it shows total sky cover in the small station model circle), nor does it show the expected movement of weather pressure systems (even though it shows their position at chart time).

The National Weather Service (NWS) prepares these charts from observations taken at many weather stations, and the validity time of the chart in *coordinated universal time* (UTC, or Zulu) corresponds to the time of observation. When using surface analysis charts, you should remember that weather moves and conditions change, so what is portrayed on the chart at its validity time may have changed.

The actual chart may appear to be a bit jumbled, but the main features are shown below. The information for each station is set out in standard format, known as a *station model*. Detailed decoding information is available at Flight Service Stations and in FAA weather publications such as AC 00-45.

The closer the isobars are, the stronger the pressure gradient and so the higher the winds. If the pressure gradient is weak, sometimes dashed isobars are spaced 4 mb apart.

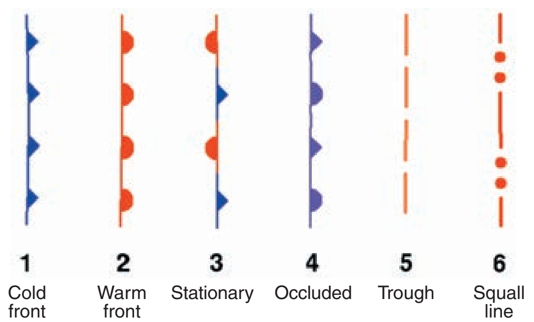


Figure 36-5 Some symbols on surface analysis charts.

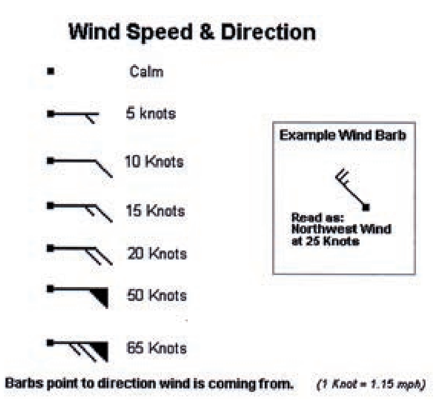


Figure 36-6 Wind speed and direction.

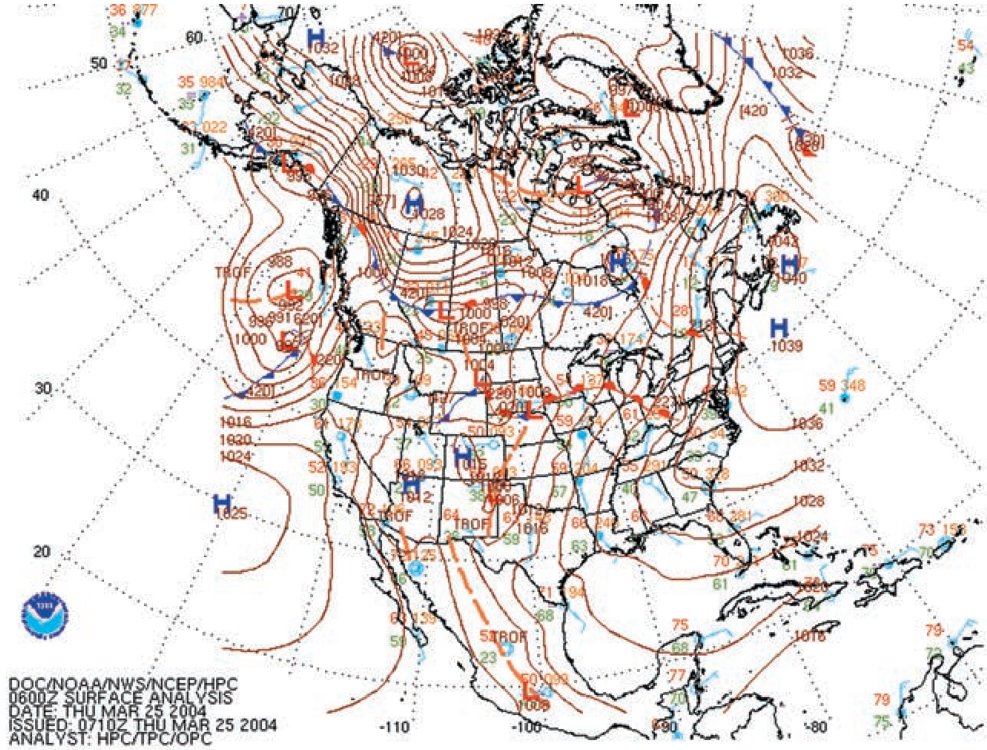


Figure 36-7 Surface analysis North American continent.

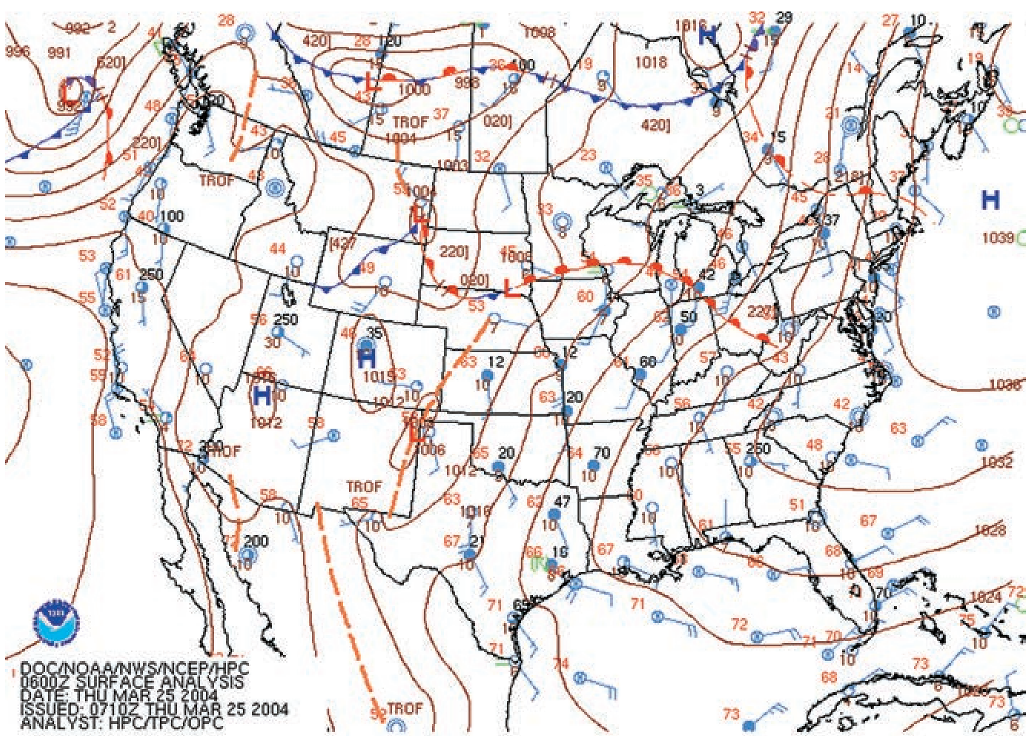


Figure 36-8 Extract from a typical surface analysis chart.

Radar Summary Charts

A radar summary chart shows areas of heavy precipitation detected by various radar stations around the country, and predicts their direction of movement. You should use the radar summary chart at the preflight planning stage, in conjunction with other charts, reports and forecasts. For instance, used in conjunction with a weather depiction chart, it can help provide a three-dimensional picture of clouds and precipitation.

Radar can detect only precipitation it cannot detect clouds, fog or icing conditions.

Heavy precipitation is often associated with thunderstorms and accompanied by the usual thunderstorm hazards, so is best avoided. Lines and cells of potentially dangerous thunderstorms, which are not shown on other charts, are shown on radar summary charts. Fog and clouds containing only small droplets are not shown.

Radar echoes may be:

- *individual cells* with individual movement indicated by an arrow with speed;
- *an area of cells* shown as a contoured area that is hatched, with movement of the area indicated by a shaft to show direction, and barbs to show speed;
- *a line of cells,* e.g. a squall line, shown as a line with the direction of movement indicated.

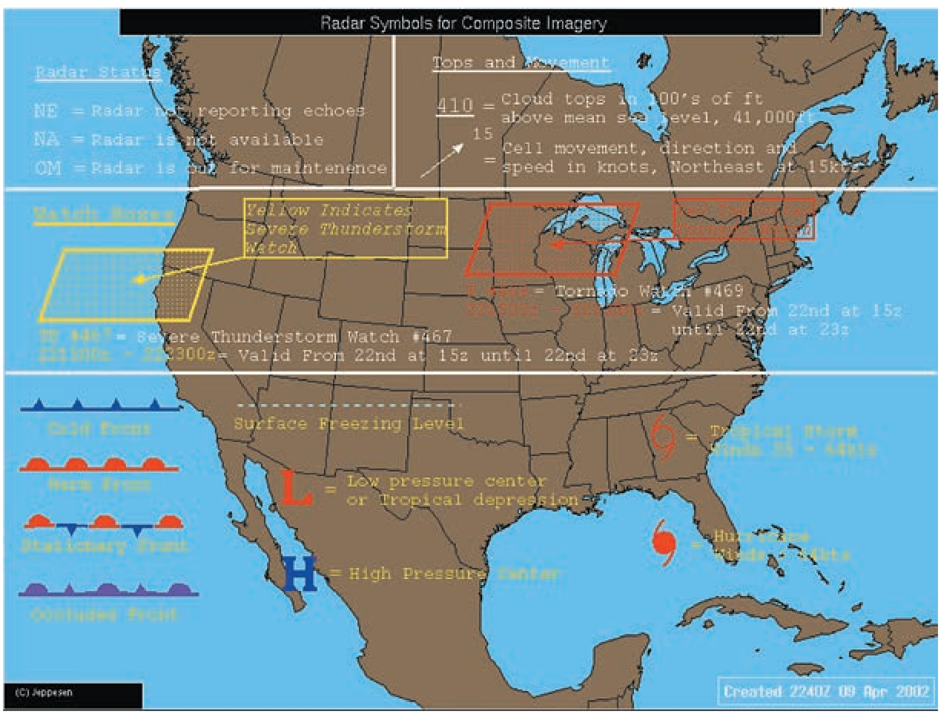


Figure 36-9 Key to radar summary charts.

Be aware that the radar summary chart can show where thunderstorms were, and where they were headed at the chart's valid time, but not where they are right now. The height of the tops and bases of the precipitation echoes is shown in hundreds of feet above and below a horizontal line (no number below the line indicates no reported echo base).

The trend of liquid precipitation is indicated by "+" for increasing, and "-" for decreasing. For instance, "RW-" means decreasing rain showers, "TRW+" means increasing thunderstorms and rain showers. Be aware that radar can detect only precipitation—it cannot detect clouds, fog or icing conditions.

Severe weather watch areas are outlined on the radar summary chart by heavy dashed lines, usually in the shape of a rectangle, labeled something like "WS821," which is severe thunderstorm watch number 821, or "WT184," which is tornado watch number 184.

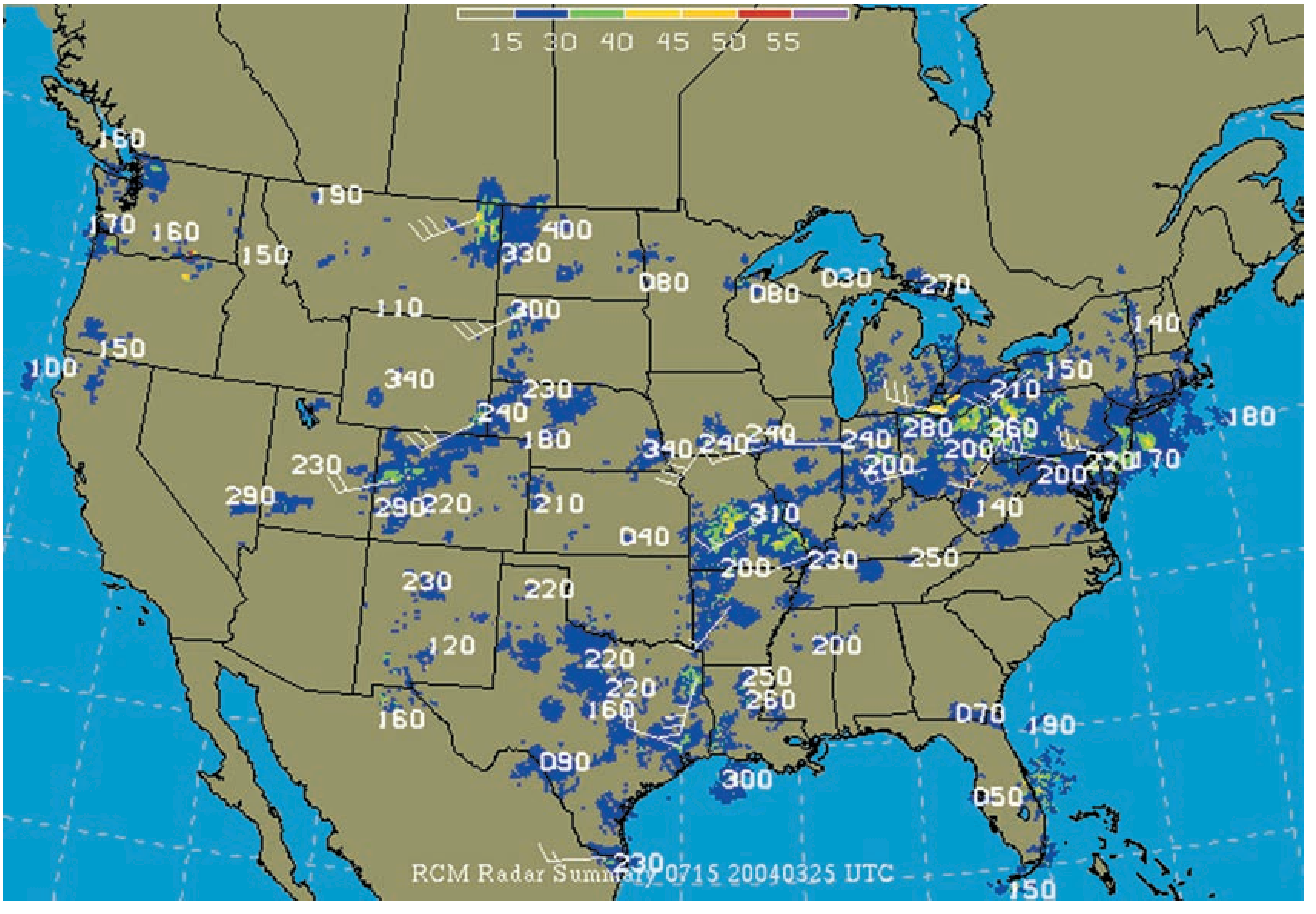


Figure 36-10 A typical radar summary chart.

Aviation Routine Weather Reports (METAR/SPECI)

Your best source of information about the current weather or past weather at a particular airport is the hourly aviation routine weather reports, known as METAR reports. The SPECI acronym roughly translates as "Aviation Selected Special Weather Report." At weather stations all over the world, observers note the weather about five or ten minutes before the end of each hour and transmit their observations. The coded reports follow a format that makes them relatively easy to translate once you understand the system.

There are a few differences, worldwide, in how the reports are coded. In the U.S., winds are reported in knots, cloud layer heights and runway visual range in feet, visibility in statute miles and altimeter settings in inches of mercury. In other parts of the world, metric measurements and hectopascals are used. Temperatures throughout the world are reported in degrees Celsius.

While the METAR code uses some non-English words for some present weather phenomena, the U.S. standard for METAR was developed in a cooperative effort. Some of the coding groups (such as GR for hail or FU for smoke) are based on French words, but many English abbreviations have been adopted. For example, the international abbreviations for *fog* and *rain* are FG and RA, respectively. A METAR observation will contain some or all of the following elements in the following order:

1.	**Type of Report**	METAR or SPECI is included in all reports, and is separated from the element following it by a space.
2.	**The Station Identifier**	This denotes where the report was taken from. Station identifiers are always given in four-letter ICAO code (KLAX, for example).
3.	**The Date and Time of the Report**	The day of the month is shown first, followed by Zulu time of the report.
4.	**Modifier**	If used, this tells if report is automated (AUTO).
5.	**Wind**	Wind is reported as the full three-digit true direction, to the nearest 10°. (Note that ATC towers and ATIS report wind as magnetic.)
6.	**Visibility**	Visibility is reported in statute miles. Runway visual range (RVR) is reported in feet.
7.	**Weather and Obstructions to Visibility**	These are reported in the format: intensity/proximity/descriptor/precipitation/obstruction to visibility/other.
8.	**Sky Conditions**	These are reported by their amount, height above ground level and type. Cloud coverage is categorized in eighths, or octas. SKC, sky clear, is just what it says. FEW is 0-2 octas coverage, SCT is 3-4 octas coverage, BKN is 5-7 octas coverage and OVC is 8 octas, or total coverage. Indefinite ceilings may be listed as VV (giving vertical visibility in feet).
9.	**Temperature and Dewpoint**	These are reported in degrees Celsius. This is sometimes found in the Remarks section of a METAR.
10.	**Altimeter Setting**	Given in inches of mercury—consists of A followed by four digits. Just add a decimal point in the middle to decode.
11.	**Remarks**	If included, these follow the altimeter setting. Some stations will note the sea level pressure (SLP) in hectopascals to the nearest tenth here. Temperature and dewpoint, coded as 9 characters, may also be listed, as well as other temperatures. Remarks are best decoded with the aid of a decoder card (see illustration).

Cloud cover:
- *SKC: Sky Clear.*
- *FEW: 0–2/8.*
- *SCT: 3/8–4/8.*
- *BKN: 5/8–7/8.*
- *OVC: 8/8.*

Note. Any information that is missing in a METAR/SPECI report will simply be left out of the report. For this reason, take care when decoding the reports.

Decode the following METAR report, using the decoder illustrated.

```
METAR KFMY 141647Z VRB05KT 10SM SKC 30/16 A3003
```

This breaks down into:

1	2	3	4	5	6	7	8	9
KFMY	141647Z	VRB05KT	10SM	SKC	30/16	A3003		

1. KFMY is Fort Myers, Florida.
2. The report was taken the 14th day of the month, at 16:47 Zulu.
3. The wind direction is variable at 5 knots.
4. The visibility is 10 miles.
5. The sky is clear.
6. The temperature is 30°C and the dewpoint is 16°C.
7. The altimeter setting is 30.03 in. Hg.

That was a nice day in Fort Myers, Florida. Next, decode a more complicated report:

```
METAR KMCO 141653Z 23006KT 10SM FEW040 27/14 A3004 RMK A02
SLP170 T02720144
```

This breaks down into:

1	2	3	4	5	6	7	8	9
KMCO	141653Z	23006KT	10SM	FEW040	27/14	A3004	RMK A02 SLP170 T02720144	

1. The report is from Orlando International Airport, Florida.
2. The day is the 14th, the time is 16:53Z.
3. The wind is from 230 degrees, at 6 knots.
4. The visibility is 10 statute miles or better.
5. There are a few clouds (0-2/8 coverage) at 4,000 feet.
6. The temperature is 27°C and the dewpoint 14°C, not close enough for you to have to worry about fog at the present time.
7. The altimeter is 30.04 in. Hg.
8. The remarks tell us that an automated observation (AWOS) that can determine precipitation (AO2) was used. We also see that the sea level pressure is 1,017.0 hPa and the temperature/dewpoint spread is a + 27.2°C and 14.4°C, respectively.

Another typical METAR/SPECI weather report is:

```
SPECI KTPA 141056Z 35003KT 6SM BR SCT250 21/18 A2998 RMK
AO2 SLP152 TO2060183
```

This decodes to: "Special weather observation for Tampa International Airport at the 14th day of the month, 10:56Z. The wind is 350 at 3 knots. There is 6 miles visibility with mist. There are scattered clouds (3/8–4/8 coverage) at 25,000 feet. The temperature is 21°C and the dewpoint is 18°C. The weather was taken by an automated observer capable of noting precipitation. The sea level pressure is 1,015.2, and the precise temperature/dewpoint spread is +20.6°C/+18.3°C."

Pilot Weather Reports (PIREPs)

Pilot reports can be your best source—sometimes the only source—of information about what is going on between weather stations. Since the reports are voluntary, PIREPs may not be available to you on every flight, but you should still ask for them.

Pilot reports (PIREPs), identified by UA or by UUA if urgent, are often appended to METARs. The form of a PIREP is UA followed by the mandatory items:

- /OV (over location);
- /TM (time);
- /FL (altitude or flight level);
- /TP (aircraft type); and then by the optional items /SK (sky cover);
- /WX (flight visibility and weather);
- /TA (temperature in degrees Celsius); /WV (wind velocity °M/kt);
- /TB (turbulence);
- /IC (icing); and
- /RM (remarks).

A typical PIREP, decoded below, is:

```
UA/OV 12 NW MDB/TM 1540/FL 120/TP BE55/SK 026 BKN 034/044
BKN-OVC/TA -11/IC MDT RIME 060-080/RM R TURBC INCRS WWD MH
270 TAS 185
```

"PIREP, 12 NM northwest of MDB, at time 1540 UTC, altitude 12,000 feet MSL, type Beech Baron, sky cover is first cloud layer base 2,600 feet MSL broken with tops at 3,400 feet MSL and second cloud layer base 4,400 feet MSL broken occasionally overcast with no reported tops, temperature minus 11 degrees Celsius, icing moderate rime between 6,000 and 8,000 feet MSL, remarks are turbulence increasing westward, magnetic heading 270, true airspeed 185 knots."

You can generally interpret the abbreviations without too much trouble. For example: FL080/SK INTMTLY BL means an airplane at 8,000 feet MSL is flying intermittently between layers; /TB MDT means turbulence moderate; /TP B727 means type Boeing 727; /SK OVC 075/085 OVC 150 means sky cover is an overcast layer with tops 7,500 feet MSL and no reported base, with a second overcast layer base 8,500 feet MSL and tops 15,000 feet MSL.

If the METAR at the place where the UA PIREP contained those last cloud details above also contained OVC009, then it is possible to calculate the thickness of the lower cloud layer. If the station elevation is say 2,300 feet MSL, then the cloud base is 3,200 feet MSL (elevation 2,300 feet MSL + ceiling 900 feet AGL). Since the pilot reported the tops of the lower layer at 7,500 feet MSL, the thickness of this layer is 4,300 feet (7,500 - 3,200).

Examples of typical PIREPs follow.

```
ONT UA/OV PDZ/TM 2109/FL 085/TP PA28/SK SCT-BKN 090/TA 05
```

"The report is from Ontario, California at 2109Z. The aircraft was over the Paradise (PDZ) VOR at 8,500 feet. It was a Piper Cherokee (or Warrior, the FAA uses the PA-

28 designation for both). The pilot reported scattered to broken clouds with tops at 9,000 feet. The temperature at 8,500 feet was +5 degrees Celsius."

```
SFO UUA/OV SFO 020030/TM 2100/FL 100/TP C130/IC MDT-SVR/RM
HAIL
```

"The aircraft was on the 020 radial from the San Francisco VOR, 30 miles out. The report was made at 2100 UTC. The airplane was at 10,000 feet. It was a C130 Lockheed Hercules. Under IC for icing, the pilot reported moderate to severe icing. Under remarks (RM), the pilot noted there was hail. While no comment is made on the weather, we can conclude that thunderstorms or violent towering cumulus clouds are around to generate the hail and, even though the pilot has not made a specific turbulence report, it probably exists—any cloud that can produce hailstones will be turbulent. The icing was probably caused by supercooled water in cloud updrafts hitting the airplane."

```
AHN UA/OV AHN/TM 2038/FL DURGD/TP CE152/SK 055 SCT-BKN 080/
TB MDT BLO 040
```

"The report is from Athens, Georgia, and the aircraft was over the Athens VOR at 2038 UTC. The DURGD under FL means the pilot reported during descent. ('During climb' is written DURGC.) Aircraft type Cessna 152. The pilot encountered a scattered to broken layer of clouds with the bases at 5,500 feet and the tops at 8,000 feet. Note that all altitudes in PIREPs are referenced to mean sea level (MSL), since the pilot will be making estimates of altitude with reference to the altimeter. The pilot also reported moderate turbulence below 4,000 feet." When reporting turbulence, use standard criteria so that other pilots derive correct information from your PIREP.

Duration:

- *occasional* is less than one-third of the time;
- *intermittent* is one-third to two-thirds of the time;
- *continuous* is more than two-thirds of the time.

Intensity:

- *light turbulence* causes slight, erratic changes in altitude and/or attitude, with the occupants feeling slight strain on their seatbelts. Rhythmic bumpiness, without appreciable changes in altitude and/or attitude, should be reported as "light chop" rather than light turbulence.
- *moderate turbulence* causes changes in altitude and/or attitude, and usually causes variations in indicated airspeed, but the aircraft remains in positive control at all times: the occupants will feel definite strains on their seatbelts and unsecured objects in the aircraft may be dislodged. Rapid bumps or jolts, without appreciable changes in altitude and/or attitude, should be reported as "moderate chop" rather than moderate turbulence.
- *severe turbulence* causes large, abrupt changes in attitude and/or altitude and usually large changes in indicated airspeed, and the aircraft may be momentarily out of control; the occupants will be forced violently against their seatbelts and unsecured objects in the aircraft will be tossed about.
- *extreme turbulence* will toss the aircraft about violently and the aircraft may be practically impossible to control—structural damage may result.

Weather Forecasts

If you visit a FSS or Weather Service Office and check over the charts and reports described above, and also look at satellite photos, you should have a good idea of what the weather was doing at the time the information was gathered. Knowing what the weather is doing now, and what it has been doing in the last few hours, makes it easier to understand the forecasts of what it should be doing later on during your flight.

You need to develop a three-dimensional picture of current weather, and then judge how this picture will change with time. To take a single example, assume you are planning a two-hour trip to another airport; the weather is forecast to be good at the destination at the time you expect to arrive, and the weather is now good at your departure point. The forecast, however, predicts that thunderstorm activity will cease at your destination about an hour before your estimated time of arrival.

Obviously, you need to know more. What is the weather likely to be along your planned route? Will the thunderstorms be moving across your planned route? If the thunderstorms are moving away from both the destination and your route, are there any indications that they are in fact moving away as predicted by the forecast? What will you do if you arrive at your destination and find that the forecast is inaccurate and the storms have not ended? Having studied the recently observed weather, it is now time to study the forecasts of what the weather is predicted to do in the hours ahead.

Low-Level Significant Weather Prognostic Charts

Prognostic charts are *forecasts*, rather than observations, and are the only charts that can give you a good overall view of the weather that is expected to occur. The low-level significant weather prog is a four-panel chart that shows the general conditions that are forecast to occur from the surface to 24,000 feet MSL (the 400 millibar (hPa) pressure level) at the valid time (VT) of the chart, the two left hand panels for 12 hours from the issuance time, and the two right hand panels for 24 hours from the issuance time. Prognostic charts are usually issued four times daily. See example in figure 36-11, page 736.

The upper panels show the *significant weather prognosis* (the forecast from the surface up to 24,000 feet):

- *forecast IFR*—enclosed by smooth lines;
- *forecast MVFR*—enclosed by scalloped lines;
- *forecast VFR areas*—not outlined;
- *forecast moderate or stronger turbulence*—enclosed by long-dashed lines, with the upper and lower limits of the forecast turbulence given in hundreds of feet above and below a line, and the intensity of the turbulence represented by a symbol;
- *forecast freezing level*—short dashed lines at 4,000 feet levels (dots when freezing level is at the surface).

The lower panels show the surface prognosis (the forecast at the surface):

- *forecast position and movement of pressure systems* (highs, lows, fronts);
- *forecast areas of precipitation and/or thunderstorms.*

Note. The method of outlining the IFR and MVFR areas differs from that on the weather depiction charts.

The low-level significant weather prognostic chart, as shown in figure 36-11, can be used to determine which areas to avoid, those with non-VFR weather, turbulence, and the possibility of icing above the freezing level.

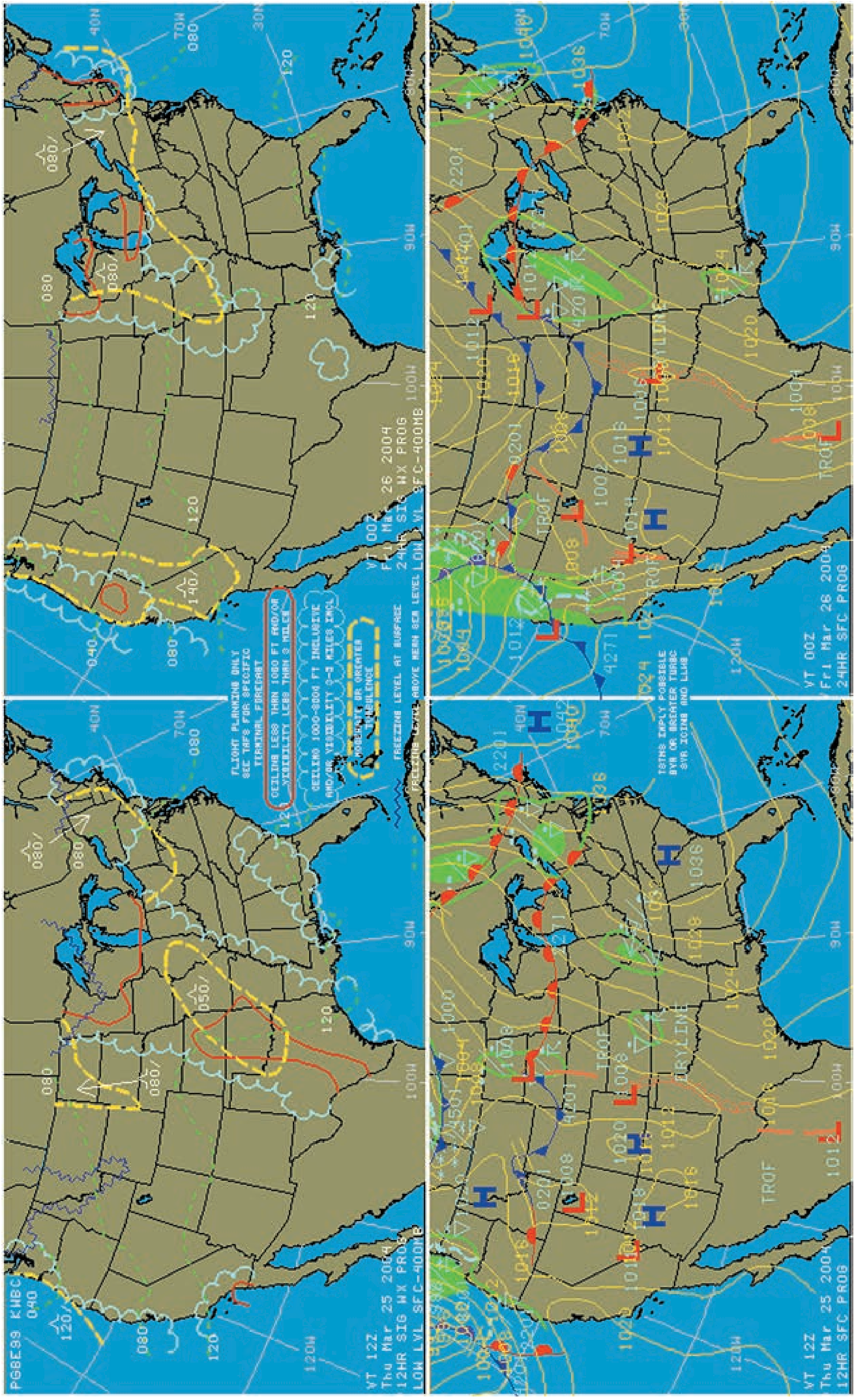


Figure 36-11 A typical low-level significant weather prognostic chart.

Note. There is also a *high-level* significant weather chart covering the airspace from 24,000 feet (400 mb) to 63,000 feet (70 mb). Small scalloped lines are used to show areas of cumulonimbus clouds. See figure 36-14.

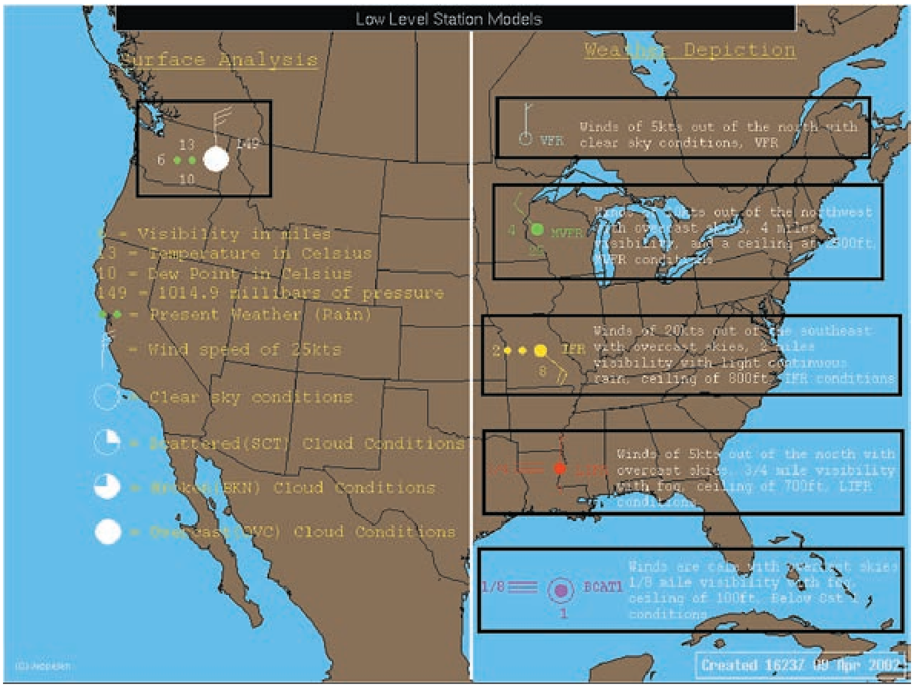


Figure 36-12 Some standard weather symbols.

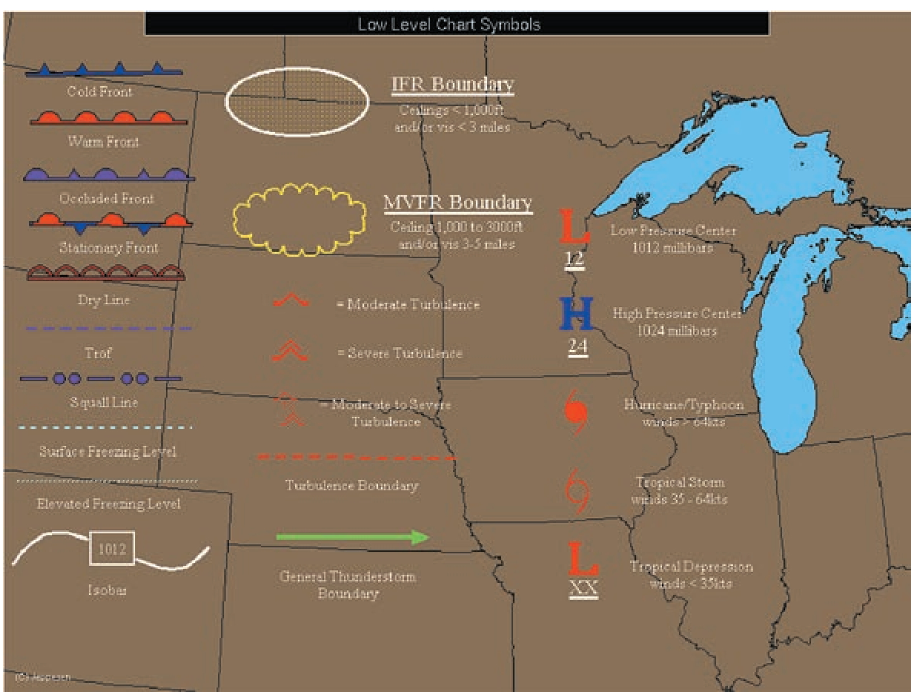


Figure 36-13 Some significant weather prognostic symbols.

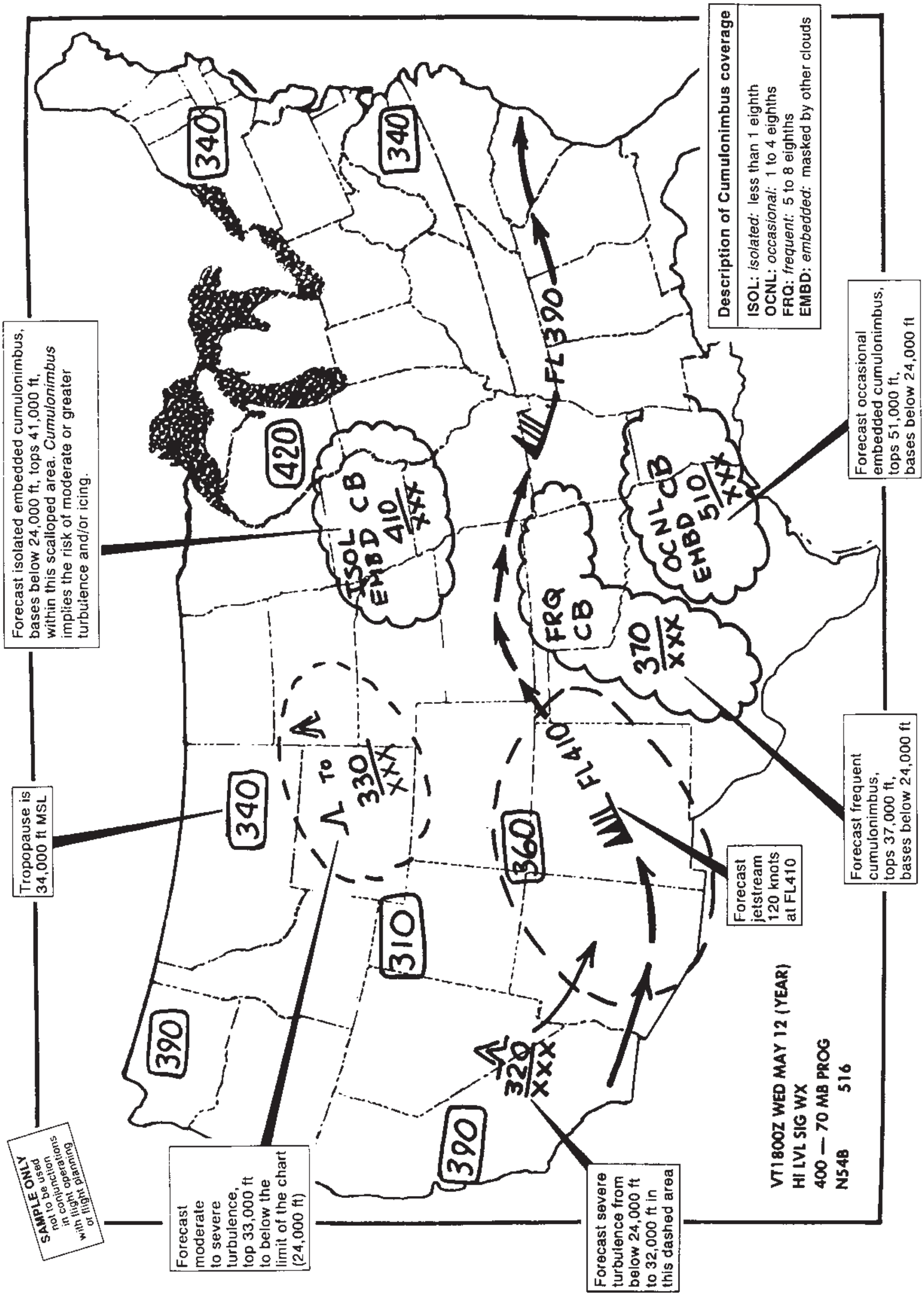


Figure 36-14 Extract of high-level significant weather prognosis panel.

Terminal Aerodrome Forecasts (TAF)

As the name indicates, terminal aerodrome forecasts (TAF) predict the weather at particular airports. They are issued four times a day and are valid for a 24-hour period. If the weather changes significantly between scheduled forecasts, amendments are issued.

Terminal aerodrome forecasts (TAF) are the ones most used by pilots.

The forecast is for cloud heights and amounts, visibility, weather and wind that would affect flying within five miles of the airport's center. If the forecast uses the term VCNTY, an abbreviation for *vicinity*, it is referring to weather expected in the area from 5 to 25 miles from the airport that could affect flying there.

The format of the terminal aerodrome forecast is essentially that of the METAR, but a few examples will illustrate the differences. There will be a date-time group, such as 141730Z, which means that the forecast was issued on the 14th day of the month at 1730Z. Forecasts are given in UTC (Zulu time), but you can translate them into local times if it makes it easier for you. Eastern daylight time (EDT) is found by subtracting 4 hours from the UTC time.

A code, much like that used for METAR weather reports, is used for the forecasts.

Next come the valid times, 141818, meaning, the 14th day, from 1800Z to 1800Z. From there on out, the forecast reads much like a METAR, except with multiple levels.

For example:

```
TAF KRSW 141730Z 141818 27008KT P6SM SCT0040 SCT200
BECMG 2122 34007KT
BECMG 0203 VRB04KT SCT150 SCT200
TEMPO 1014 BKN150
FM1400 33007KT P6SM SCT035 SCT150
TEMPO 1418 BKN150
```

"This terminal forecast is for Southwest Florida International Airport on the 14th day of the month, issued at 13:30 local time and valid from 14:00 local time until 14:00 local time on the 15th. The wind is forecast to be from 270 degrees at 8 knots, with a visibility of more than 6 miles, with a scattered layer of clouds (3-4 octas coverage) at 4,000 feet, and another scattered layer of clouds at 20,000 feet. This becomes, between 17:00 and 18:00 local time, a wind from 020 degrees, variable at 4 knots, with scattered clouds at 15,000 and 20,000 feet. Temporary changes are expected between 06:00 and 10:00 local time, when clouds are expected to be broken at 15,000 feet. From 10:00 local time, winds are forecast from 330 degrees at 7 knots, with scattered clouds at 3,500 feet. Temporary changes are forecast between 10:00 and 14:00 local time (1400-1800Z), when clouds are expected to be broken (BKN, 5/8-7/8) at 15,000 feet."

International Differences

Pilots who fly outside of the U.S. will notice that all METAR and TAF reports are not quite the same.

- International altimeter settings are given in hectopascals and noted as Q1013.
- Wind may be reported in knots, meters per second (mps) or kilometers per hour (kph). Low-level windshear that is not associated with convective activity does not get reported outside of the U.S., Canada or Mexico.
- Visibility is reported in thousands of meters, with reference to the lowest visibility in a geographic sector and a trend (for instance, 3000SWD, which means visibility of 3,000 meters to the southwest, reducing).
- Finally, in international METAR/TAF the code CAVOK means that there are no clouds below 1,500 meters (5,000 feet) or the lowest ATC sector altitude and the visibility is 10 kilometers or better.

Area Forecasts and the Convective Outlook

While TAFs provide detailed predictions for airports, they do not tell you what to expect between airports. When obtaining a weather briefing, it is a good idea to look at the forecasts for airports along and near your route for an indication of what to expect. Another forecast available to help you see the en route weather picture—area forecasts.

Area Forecasts (FA)

Area forecasts—coded "FA"—are issued three times a day (every eight hours) for six different areas of the 48 contiguous States and separately for Alaska and Hawaii. They are valid for 12 hours plus a six-hour outlook period. The outlook gives a generalized forecast.

Area forecasts are supplied in 4 sections. The first two contain:

- communication and product header section—shows where the FA was issued from, the date and time of its issue, the product name, valid times and the States the FA covers.
- *a precautionary statement section*—lets the reader know immediately if and where any IFR conditions, mountain obscurations or thunderstorm hazards exist. It also warns the reader that heights, for the most part, are given in AGL.

Then, two weather sections contain:

- *a synopsis*—a brief summary of the location and movement of weather fronts, pressure systems and circulation patterns for the eighteen-hour period; plus
- *a statement of VFR clouds and weather*—a twelve-hour forecast, in broad terms, of clouds and weather significant to VFR flights, giving a summary of the sky condition, cloud heights, visibility, weather and/or obstructions to visibility, and surface winds of 30 knots or more. It concludes with a categorical outlook valid for 6 hours.

Pilots often have more trouble deciphering area forecasts than other reports and forecasts because they use more contractions than plain English words and also because they describe the location of areas of turbulence and icing by referring to VORs—often VORs that are outside the area covered in the forecast. Practice, with a list of the most common contractions, is the only way to learn to read area forecasts. When checking the turbulence and icing parts of the forecast, look for VORs along or within 100 miles or so on either side of your planned route. If you find such a VOR listed, then you can look closer to see if your flight is likely to be affected.

A detailed explanation of a typical area forecast is shown in figure 36-15 and figure 36-16.

The Convective Outlook (AC)

The convective outlook (AC) forecasts the possibility for general, as well as severe, thunderstorm activity during the following 24 hours. An explanation of the convective outlook is given on page 744.

```
SFOC FA 101145
SYNOPSIS AND VFR CLDS/WX
SYNOPSIS VALID UNTIL 110600...CLDS/WX VALID UNTIL 110000
OTLK VALID 110000-110600   WA OR CA AND CSTL WTRS
```

AREA FORECAST (FA) VALIDITY & COVERAGE

The data originated from the San Francisco weather center, and it is an Area Forecast (FA) for the 10th of the month, effective from 1145Z (UTC). It contains a synopsis, and clouds and weather appropriate to VFR operations. The synopsis is valid until 0600Z on the 11th; the significant clouds and weather group is valid until 0000Z on the 11th.

Outlooks (in the forecasts) are valid from 0000Z, and cover a six-hour period (to 0600Z). The forecast and attached Airmets cover Washington State, Oregon, California and coastal waters.

Note: We mainly show the information for a part of Oregon in this example.

```
SEE AIRMET SIERRA FOR IFR CONDS AND MTN OBSCN.
TSTMS IMPLY SVR OR GTR TURBC SVR ICG LLWS AND IFR CONDS.
NON MSL HGTS NOTED BY AGL OR CIG
```

REFERENCE TO IMPORTANT WEATHER

Refer to Airmet Sierra (later in the briefing data) for details of IFR (Instrument Flight Rules) weather conditions and any mountain obscuration. Where thunderstorms are mentioned, this implies severe or greater turbulence, severe icing, low-level windshear and IFR conditions.

Non-mean sea level heights are appended with the terms *AGL* (above ground level) or *CIG* (ceiling).

```
SYNOPSIS...WEAK HIGH LVL TROF OVER THE SFO FA AREA. TROF XPCD
TO DRFT EWD THRU 06Z. RDG ALF BLDG ACRS THE ERN PAC.
```

THE SYNOPSIS

Synopsis of the weather situation:

There is a weak high-level trough over the San Francisco area-forecast area. The trough is expected to drift eastward through 0600Z.

A ridge (of high pressure) aloft is building across the eastern Pacific Ocean area.

```
OR CASCDS WWD
CSTL SXNS...10-20 BKN 40 BKN 100. VSBYS 3-5L-F. 18Z-20Z BCMG 15
SCT-BKN 35 BKN 80 BKN. WDLY SCT RW-. OTLK...VFR.
WILLAMETTE VLY-NRN CASCDS...15 SCT-BKN 40 BKN 100. OCNL VSBYS 3-
5L-F. 19Z-21Z BCMG 30-50 BKN 80 BKN. WDLY SCT RW-. OTLK...VFR.
```

SIGNIFICANT CLOUDS AND WEATHER

Significant clouds and weather for Oregon, Cascades westward (includes the slopes of the Cascades):

Coastal sections—broken clouds (5–7 octas—that is, 5 to 7 eighths of the sky covered), base 1,000 to 2,000 feet MSL; broken clouds, base 4,000 feet MSL up to 10,000 feet MSL. Visibility 3 to 5 miles in light drizzle *(the hyphen after the L means that the drizzle is light)* and fog.

Between 1800Z and 2000Z, clouds becoming scattered (1–4 octas) to broken, base 1,500 feet MSL; broken clouds, base 3,500 feet MSL; and again at base 8,000 feet MSL. Widely scattered light rain showers. The outlook for this region is for the weather conditions to become suitable for VFR operations.

For the Willamette valley to the northern Cascades—scattered to broken clouds, base 1,500 feet MSL; broken clouds, base 4,000 feet MSL up to 10,000 feet MSL. Occasionally, the visibility will be between 3 to 5 miles in light drizzle and fog.

Then, between 1900Z and 2100Z, the clouds will lift to become broken, base between 3,000 and 5,000 feet MSL; and also broken, base 8,000 feet MSL. Widely scattered light rain showers are forecast. The outlook for this region is also for VFR conditions.

Figure 36-15 A typical area forecast for the Washington State, Oregon, and California region.

```
AIRMET TANGO FOR TURBC VALID UNTIL 102000...WA OR
OCNL LGT ISOLD MDT TURBC BLO 150 W OF CASCDS ASSOCD WITH LGT-
MDT WLY WNDS. CONDS CONTG THRU 20Z..ENDG 02Z
```

TURBULENCE (T)

Turbulence Airmet (Tango): for Washington and Oregon, valid until 2000Z—occasional light and isolated moderate turbulence below 15,000 feet MSL West of the Cascades associated with light to moderate westerly winds; continuing thru 2000Z, ending around 0200Z.

IFR WEATHER AND MOUNTAIN OBSCURATION (S)

```
AIRMET SIERRA FOR IFR AND MTN OBSCN VALID UNTIL 102000
AIRMET IFR...OR
FROM 40SSW ONP TO 30NNE MFR TO 30S MFR TO 80WSW MFR TO 40SSW ONP
OCNL CIG BLO 10 VSBY BLO 3 FOG. CONDS ENDG 17Z-19Z.
AIRMET MTN OBSCN...WA OR CA ID MT
FROM YQL TO 50N TWF TO REO TO 20SW UKI TO 20NW FOT TO 20N TOU TO YQL
MTNS OCNL OBSCD IN CDS/PCPN F. CONDS SPRDG EWD AND CONTG BYD 20Z THRU 02Z
```

IFR Weather and Mountain Obscuration Airmet (Sierra): valid until 2000Z on the 10th.

IFR weather for Oregon—within a line joining points 40 nautical miles south-southwest of ONP VOR to 30 nm north-northeast of MFR VOR to 80 nm west-southwest of MFR VOR to 40 nm south-southwest of ONP VOR. Occasionally ceilings below 1,000 feet AGL and visibility below 3 miles in fog. These conditions to end between 1700Z and 1900Z.

Mountain obscuration data for Washington, Oregon, California, Idaho and Montana—within the specified area, mountains occasionally obscured in clouds, precipitation and fog. Conditions spreading eastward and continuing beyond 2000Z through 0200Z.

ICING AND FREEZING LEVELS (Z)

```
AIRMET ZULU FOR ICG AND FRZLVL VALID UNTIL 102000
AIRMET ICG...WA OR CA ID MT
FROM YQL TO LKT TO REO TO FOT TO 20N TOU TO YQL
LGT OCNL MDT MXD ICGICIP FRZLVL TO 160. CONDS SPRDG EWD AND CONTG
BYD 20Z THRU 02Z. FRZLVL 40-60 NW SLPG TO 70-90 SE.
FRZLVL...WA-OR..040-060 NW OF A GEG-MFR LN. 070-090 SE OF THE LN.
```

Icing and Freezing Level Airmet (Zulu): valid until 2000Z on the 10th.

Icing for Washington, Oregon, California, Idaho and Montana—within the specified area, light and occasionally moderate mixed icing in clouds and in precipitation from the freezing level up to 16,000 feet MSL. Conditions spreading eastward and continuing beyond 2000Z through 02Z.

The freezing level in this region is 4,000–6,000 feet MSL in the northwest, sloping up to 7,000–9,000 feet MSL in the southeast.

Freezing level data for Washington and Oregon—the freezing level (zero degrees Celsius) is 4,000–6,000 feet MSL northwest of a line joining GEG and MFR VORs. The freezing level is 7,000–9,000 feet MSL southeast of the line.

Figure 36-16 Explanation of area forecast for the Washington State, Oregon, and California region.

Winds and Temperatures Aloft Forecasts (FB)

Winds and temperatures aloft forecasts contain forecast upper winds in degrees true and knots, and forecast upper temperatures in degrees Celsius.

2867-21 at 18,000 feet MSL decodes as a wind from 280° true (by adding a 0 after the first two digits) at 67 knots and temperature -21°C (+/- precedes temperature up to 24,000 feet, above this all temperatures will be below zero and so no signs need be given).

- At 3,000 feet, MSL 2308 decodes as a wind from 230° true at 8 knots with no forecast temperature (usually temperature is not forecast for the 3,000 feet MSL level or for a level within 2,500 feet AGL of the station elevation—also winds aloft are not forecast for levels within 1,500 feet AGL of the station elevation).
- At 6,000 feet, 9900 decodes as winds light and variable (less than 5 knots), and for winds aloft in the 100-199 knots range, to overcome the problem that only two digits are available for wind speed the forecaster adds 50 to the direction and subtracts 100 from the speed, which you need to reverse when decoding.
- At 34,000 feet, 760850 decodes as a wind from 260° true (76 - 50 = 26) at 108 knots (100 + 08 = 108) and temperature -50°C.
- At 39,000 feet, 760559 decodes as a wind from 260° true at 105 knots and -59°C.

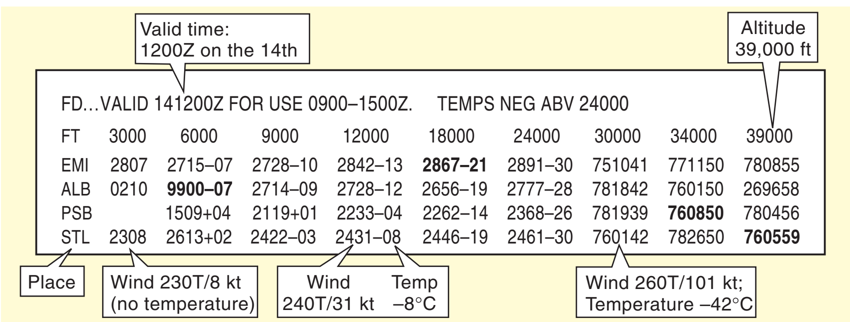


Figure 36-17 Winds and temperatures aloft forecast.

You can *interpolate* to estimate the winds and temperatures at intermediate levels. For example, if the winds and temperatures aloft forecast shows:

```
24000 ft  30000
2367-26   781938
```

You can estimate the conditions at FL270 by interpolating:

FL240 is wind	230°	at	67 knots	and temperature	-26°C
FL300 is wind	280°	at	119 knots	and temperature	-38°C
Differences:	50°		52 knots	and	12°C

Interpolating for FL270 (halfway between) gives differences of 25 in direction, 26 knots in speed, and 6°C in temperature. So the estimated values are wind from 255 degrees true (230 + 25) at 93 knots (67 + 26) and temperature -32°C (-26 - 6).

Temperatures may be asked for in the written test in °C, or as a deviation from the ISA standard (which is +15°C at MSL, decreasing at 2°C per 1,000 feet, and remaining constant at -57°C above approximately 36,000 feet).

At 24,000 feet, ISA = 15 - (2 × 24) = 15 - 48 = -33°C:

- a temperature here of, say, -35°C (2°C cooler) is ISA-2; and
- a temperature of -26°C, which is 7°C warmer, is ISA+7.

Convective Outlook Charts (AC)

The convective outlook chart is issued each morning and provides a preliminary 48-hour outlook for thunderstorm activity, tornadoes and watch areas. It is presented in two panels, the first for the time period of 24 hours, and the second for the next day. It is used for advanced planning only.

An area of forecast general thunderstorm activity is represented by a line with an arrowhead—when you face in the direction of the arrowhead, thunderstorm activity is expected to the right of that line.

Forecast severe thunderstorms may be labeled SLGT (slight risk), MDT (moderate risk) or SVR (high risk). Any tornado watches in effect at chart time are also shown.

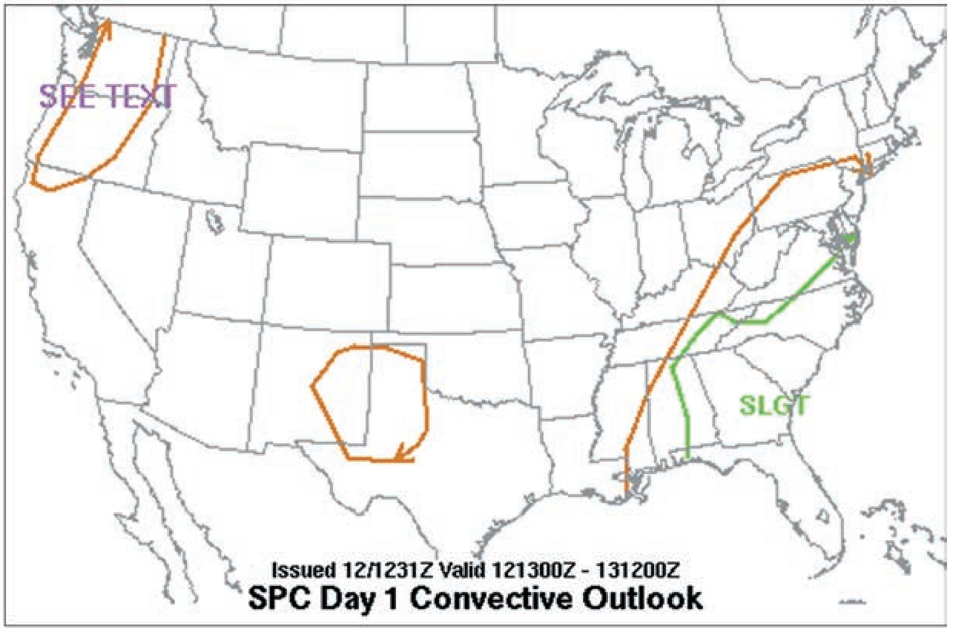


Figure 36-18 Example of a convective outlook chart.

Constant Pressure Analysis Charts

A constant pressure analysis chart shows meteorological data at a particular *pressure level* in the atmosphere, rather than at a particular altitude. They are useful for determining winds and temperatures aloft. The upper air measurements are usually taken by radiosonde instruments carried aloft by balloon, with the information then radioed back to the ground station.

In contrast to constant pressure charts, surface charts, with which you are already familiar, are based on a constant altitude, with pressure variations being plotted. They show *isobars*, which are lines joining points of equal pressure, and allow you to estimate wind direction and strength near that level in the atmosphere, based on the pattern of high and low pressure systems and the closeness of the isobars. Once you are above the friction layer (more than about 2,000 feet AGL), the wind in the northern hemisphere flows clockwise around a high pressure system and counterclockwise around a low pressure system; it generally flows parallel to the isobars, but with a component towards the center of a low and away from the center of a high. The closer the isobars, the stronger the wind.

At upper levels in the atmosphere, however, the lower air density causes the relationship between the isobars and the wind to alter, and constant pressure charts become more useful than constant altitude charts. They are just a different means of plotting the same data to better describe the same meteorological situation. The pressure systems in the upper levels may differ from those shown on surface charts, and often they have more bearing on the actual flying weather.

The various constant pressure charts relate to approximate altitudes MSL:

- 850 mb/hPa and 5,000 feet—this chart is good for forecasting poor weather which often occurs in the lower levels, such as heavy clouds, thunderstorms, rain, snow, overcast, and fronts;
- 700 mb/hPa and 10,000 feet;
- 500 mb/hPa and 18,000 feet;
- 300 mb/hPa and 30,000 feet;
- 200 mb/hPa and 39,000 feet.

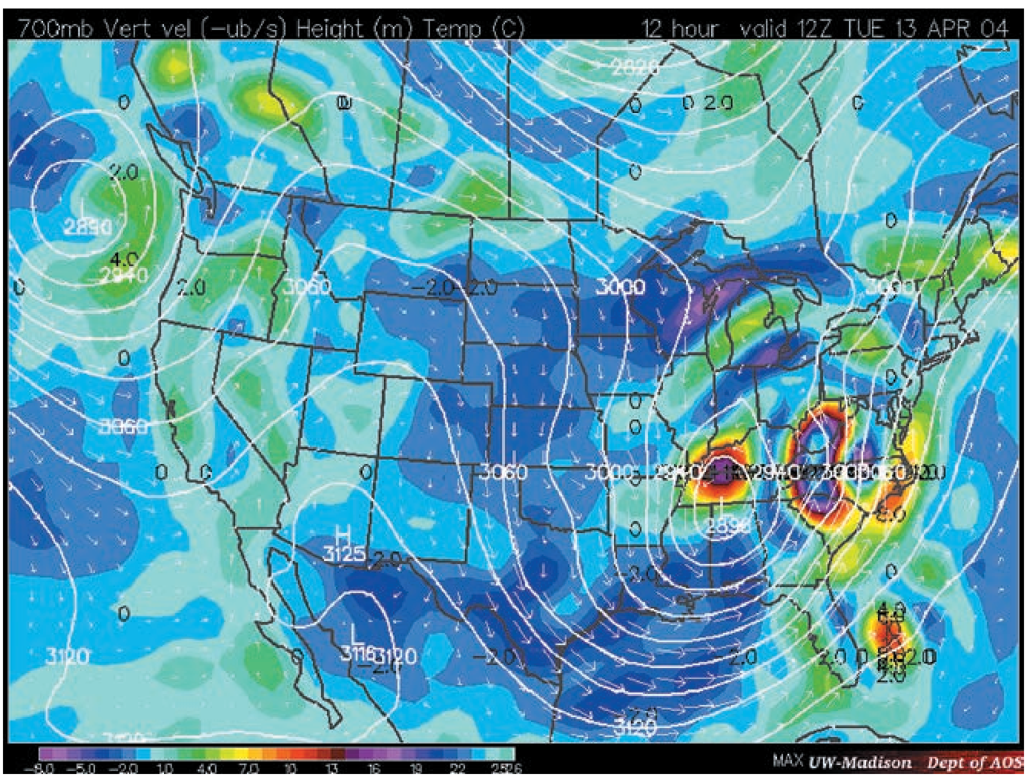


Figure 36-19 Part of a 700 mb constant pressure analysis chart (pressure alt. 10,000 feet).

If you plan on cruising at 10,000 feet MSL, you should look at the 700 mb/hPa chart especially. The 700 mb/hPa pressure level, which is equivalent to about 10,000 feet pressure altitude in the standard atmosphere, will vary in its height MSL in any real atmosphere. By plotting contour lines showing the altitudes MSL (in meters) at which the specified pressure level is found, 700 mb in this case, an upper air picture of pressure distribution is formed, in exactly the same way that variations in height are shown by contours on an ordinary survey map.

Plotted at each reporting station, at the level of the specified pressure, are:

- *height of that pressure surface* (in meters);
- *changes in this height over the past 12 hours;*
- *temperature;*
- *temperature/dewpoint spread* (useful in determining the possibility of cloud or fog formation); and
- *wind direction and speed*.

Height contours join places where the pressure level is at equal heights MSL, and these height pattern contours depict highs, lows, troughs and ridges in the upper atmosphere in a similar way to isobars on the surface charts. A *high height center* on a 700 mb/hPa constant pressure chart is analogous to a *high pressure center* at about 10,000 feet. Winds will parallel the contours, flowing clockwise around a *high* height center in the northern hemisphere and counterclockwise around a *low* above the friction layer. Fronts, if they reach as high as the specified pressure level, are depicted in the normal manner.

Isotherms are dashed lines joining places of equal temperatures, and these allow you to determine if you are flying toward warmer or cooler air. Temperatures near to and below freezing and a temperature/dewpoint spread of 5°C or less indicate a risk of structural icing.

Isotachs are short dashed lines joining places of equal wind strength. Strong wind areas are indicated by hatching. Areas with winds of 70–110 knots will be hatched, and these areas may include a clear area of stronger winds of 110–150 knots, and perhaps contain another hatched area of even stronger winds.

If the constant pressure level is high, then it has warm air beneath it. A consequence of this is that a parcel of warm air will not tend to rise through the already warm air, and so the weather in the vicinity of a *warm upper high* is likely to be typical of a high pressure system, good, although with a possibility of restricted visibility. Conversely, if the constant pressure level is low, then it has cool air beneath it. A parcel of warm air that starts to rise from the surface will tend to keep rising through the cooler air, an unstable situation, and so a *cold upper low* is an indicator of possible unstable conditions and poor flying weather.

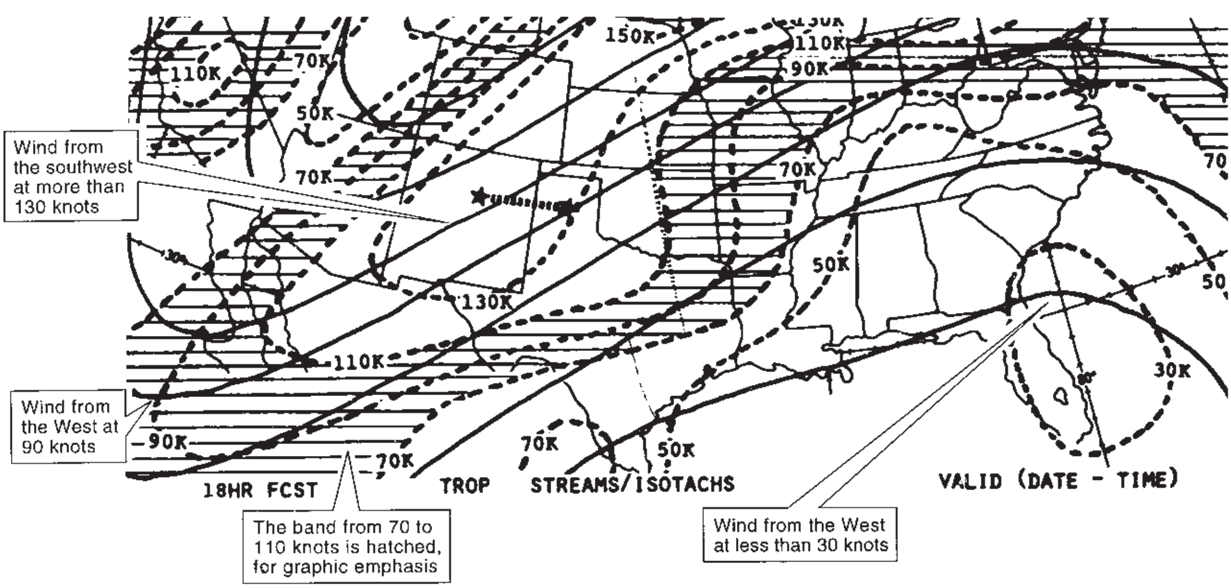


Figure 36-20 Extract from a chart showing isotachs (tropopause wind prog chart).

Other Weather Information

RADAT

Sometimes freezing level data, obtained from upper air (rawinsonde) observation stations and codified by the term RADAT. It includes:

- relative humidity at the freezing level in percent; and
- the height (in hundreds of feet above mean sea level) at which the upper air sounding passed through the 0°C isotherm (freezing level).

RADAT 86 0 55 decodes as relative humidity 86% at freezing level, and freezing level (0°C) was passed at 5,500 feet MSL.

Composite Moisture Stability Chart

The composite moisture stability chart has one panel which is an analysis of observed freezing level data from upper air observations.

Radar Weather Reports (SD)

Sometimes radar weather reports are available indicating the position and intensity of thunderstorm cells detected by a radar station. For example: `DFW 1735 LN 7TRW++/+ 75/30 160/50 170/110 12W C2520 MT470 AT 140/45` decodes as: Dallas-Ft. Worth at 1735Z, a line of very heavy thunderstorms, increasing in intensity and covering 7/10 of the sky, in the area defined by 075 bearing from DFW radar site at a distance of 30 NM, 160 bearing 50 NM, 170 bearing 110 NM, 12 NM wide band, cells moving from 250° at 20 knots, maximum tops (MT) of 47,000 feet located on 140 bearing at 45 NM.

Staying Informed in the Air

After receiving a briefing and taking off, you should remain aware that weather forecasts are just that—forecasts. They are scientific estimates of what the weather will be like at various times in the future. Forecasts can and do go wrong. Stay alert to what you see as you fly. There is no real excuse for being caught by unforecast weather changes. If the weather shows any signs of turning out to be worse than you and your airplane are prepared to deal with, then you must devise an alternative plan of action. You may have to land short of your destination or divert to an alternate airport and wait out the weather.

The *en route flight advisory service* (EFAS) is the best source of weather information en route. Call Flight Watch on 122.0 MHz (between 0600-2200 local time) with your aircraft identification and the name of the nearest VOR. This puts you in contact with someone at a Flight Service Station with immediate access to the latest weather information, including "live" weather radar. Flight Watch is an information exchange frequency for pilots and weather briefers. You can normally expect to receive actual weather and thunderstorm activity along your proposed route from Flight Watch, but not complete weather briefings. Actual destination weather and the terminal forecast will be provided on request. To assist the EFAS specialists and other pilots, you are encouraged to report good as well as bad weather, and to confirm expected conditions as well as unexpected conditions. Flight Service Stations that provide EFAS are listed in the A/FD on the inside back cover and indicated on en route charts.

Also, the National Weather Service and Federal Aviation Administration issue and broadcast various kinds of weather alerts on various NAV/COM frequencies. These are designed to warn pilots of weather that may not have been forecast when they received their briefings. These alerts include the following.

SIGMETs

SIGMETs warn of conditions that could be dangerous to all aircraft.

Convective SIGMETs

Convective SIGMETs are observations and/or forecasts that warn of conditions associated with thunderstorms, such as tornadoes or large hail, that could be dangerous to all aircraft.

AIRMETs

AIRMETs warn of hazards primarily to small aircraft. Flight Service Stations broadcast SIGMETs and AIRMETs on receipt, and at periodic intervals thereafter (15 minutes past the hour and 45 minutes past the hour for the first hour after issuance).

Hazardous In-Flight Weather Advisory Service

The hazardous in-flight weather advisory service (HIWAS) provides a continuous broadcast of in-flight weather advisories including summarized SIGMETs, AIRMETs and PIREPs. A HIWAS alert will be broadcast on all except emergency frequencies and the HIWAS message itself will be transmitted over certain VORs.

Airport Weather Broadcasts

Automatic Terminal Information Service (ATIS)

The *automatic terminal information service* (ATIS) is a continuous broadcast of recorded noncontrol information at certain airports containing weather information, runway in use and other pertinent remarks. ATIS broadcasts are updated on the receipt of any official weather, regardless of content change and reported value. The ATIS may be broadcast on a discrete VHF frequency. ATIS frequencies are published on instrument charts and in the AF/D, which also includes their hours of operation. For example, Yakima Air Terminal ATIS operates between 1400-0600Z. Time conversion is GMT-8 (-7 DT), making the hours 0600-2200 local standard time. Weather at many airports is reported by automated weather observing equipment.

Automated Weather Observing System (AWOS)

The *automated weather observing system* (AWOS) transmits data over a COM or NAVAID frequency at the airport (see A/FD).

- AWOS-A reports altimeter setting;
- AWOS-1 reports altimeter setting, wind data and usually temperature, dewpoint and density altitude;
- AWOS-2 reports the same as AWOS-1 plus visibility;
- AWOS-3 reports the same as AWOS-1 plus visibility and cloud/ceiling data.

Automated Surface Observing System (ASOS)

The *automated surface observing system* (ASOS) reports the same as AWOS-3 plus precipitation (type and intensity) and freezing rain occurrence (a future enhancement). ASOS is a more sophisticated and newer system than AWOS and as well as being transmitted on radio frequencies, the observations are fed into the weather observation system METAR reports, which are appended with A02A (facility attended) and A02 (facility unattended) in the remarks. A METAR report that comes from a completely automated site may also be notated in the remarks section with the word AUTO.

Note. Automated observing equipment has fixed sampling paths, and unlike a human observer who can take into account variations that are evident, the automated equipment may observe readings of, say, cloud base and visibility which are significantly different (better or worse) than an arriving pilot may encounter at the end of an instrument approach to the airfield.

Review 36

Weather Reports and Forecasts

Weather Briefings

1. Where are weather reports and forecasts usually obtained from?
2. What number would you call for a telephone weather briefing in most of the US?
3. Weather information may be obtained by personal computer. True or false?
4. What government book has information about weather reports and forecasts?
5. Is a pilot permitted to obtain the weather information needed for a flight solely from television programs, such on the Weather Channel?
6. What sort of briefing do you usually need before a flight?
7. What do you call a brief statement explaining the causes of the weather?
8. What sort of briefing should you request for the next day's expected weather?
9. How do you obtain weather updates in flight?
10. List ten pieces of information you should give a weather briefer.
11. What sort of briefing should you request to obtain a complete weather briefing for a planned flight?
12. If your planned departure time is 6 or more hours away, what sort of briefing should you request?
13. You have already obtained mass-disseminated weather data. What sort of briefing from an FSS should you supplement this with?

Weather Depiction Charts

14. What does a weather depiction chart show?
15. Who reports the weather shown on weather depiction charts?
16. A weather depiction chart is most valuable for determining:
- **a.** general weather conditions.
- **b.** specific cloud conditions.
- **c.** icing conditions.

17. The general weather shown on a weather depiction chart includes which of the following?
- **a.** Actual sky cover as reported.
- **b.** Forecast sky cover.
- **c.** Actual restricted visibility.
- **d.** Forecast restricted visibility.
- **e.** Actual temperature.
- **f.** Forecast temperature.
- **g.** Actual weather, including type of precipitation at weather reporting stations.
- **h.** Actual en route weather.
- **i.** Forecast en route weather.

18. What is meant by IFR conditions?
19. What is meant by VFR conditions?
20. What is meant by MVFR conditions?
21. What do the following indications represent on weather depiction charts:
- **a.** a shaded area?
- **b.** an area without contours?
- **c.** a contoured area without shading?
- **d.** a station symbol of an empty circle?
- **e.** a station symbol of a black circle?
- **f.** a station symbol of a circle including a cross?

22. The station circle on a weather depiction chart is fully black, with the number "7" beneath it. What does this indicate?
23. What does the letter "M" in the station circle on a weather depiction chart indicate?
24. The station circle on a weather depiction chart is three-quarters shaded with the number "5" beneath it. What does this indicate?
25. What does the letter "X" in the station circle on a weather depiction chart indicate?
26. The station circle on a weather depiction chart has the symbol "≡" to the left of it. What does this indicate?
27. The station circle on a weather depiction chart has the symbol "2=" to the left of it. What does this indicate?
28. What do two dots to the left of the station circle on a weather depiction chart indicate?

Refer to figure 36-3 (page 725) for questions 29 to 33.

29. Describe the following for southeast New Mexico:
  a. ceiling.
  b. cloud cover.
  c. thunderstorm activity.
  d. visibility.
  e. conditions (i.e. IFR, MVFR, or VFR).

30. What sort of front extends from New Mexico to Indiana?

31. What is the IFR weather in eastern Texas due to?

32. What is the cause of the IFR conditions along the coast of Oregon and California?

33. At what altitude will the weather for a flight from Arkansas to southeast Alabama have broken to scattered clouds?

34. Are areas where reports indicate a ceiling of greater than 3,000 feet AGL and visibility greater than 5 miles enclosed by a contour line on a weather depiction chart?

Surface Analysis Charts

35. A surface analysis chart is valid:
  a. at some time in the future.
  b. at the time the observations were taken.

36. Which of the following is shown on a surface analysis chart?
  a. The position of pressure systems and fronts at ground level.
  b. The expected direction of movement of fronts and pressure systems.
  c. Total sky cover.
  d. Cloud tops and heights.
  e. Temperature and dewpoint at various stations.
  f. Obstructions to vision.

Radar Summary Charts

37. Will radar detect a fair-weather cumulus cloud?

38. Will radar detect heavy precipitation from a cumulonimbus cloud?

39. Will radar detect icing conditions?

40. Can radar echoes determine the tops and bases of heavy precipitation?

41. Where are radar echoes, such as lines or cells of hazardous thunderstorms shown?

42. How is the movement of a cell at 20 knots to the east depicted on a radar summary chart?

43. How is the movement of an area of radar echoes at 10 knots to the northeast depicted on a radar summary chart?

44. What does the shaft show? What do the barbs show?

45. Which charts would you consider in order to form a three-dimensional picture of clouds and precipitation prior to flight?

46. On a radar summary chart, what does the following indicate:
  a. the area within the first contour?
  b. the area within the second contour?
  c. the area within the third contour?
  d. a rectangle labeled "WT762?"
  e. a rectangle labeled "WS657?"

METAR/SPECI Weather Reports

47. What are METAR reports?

48. What does the code SPECI at the beginning of a report indicate?

49. Do METAR reports use local time or UTC?

50. Decode this METAR for Bartow, Florida:

```
SPECI KBOW 141130Z 00000KT 3SM
HZ SKC 19/16 A3004
```

51. Decode the remarks "A02" in a METAR weather report.

52. Define ceiling.

53. If the station originating the following weather report has a field elevation of 1,600 feet MSL, what is the thickness of the one continuous cloud layer?

```
00000KT VV000 FG OVC040
```

54. A METAR for a particular airport that specifies BKN014 is amended by a later SPECI that specifies BKN030. What does this mean?

55. How is missing information in a METAR/SPECI report indicated?

PIREPs

56. Which letters symbolize PIREPs?

57. Which letters symbolize urgent PIREPs?

58. Specify the four mandatory items, and the letters used to symbolize each item, to be reported by a pilot making a PIREP which are necessary for the PIREP to have any significance.

59. What are the optional items that a pilot may report in a PIREP, symbolized by the following letters:

- **a.** /SK?
- **b.** /WX?
- **c.** /TA?
- **d.** /WV?
- **e.** /TB?
- **f.** /IC?
- **g.** /RM?

60. Which of the following could you observe in flight and report in a PIREP?

- **a.** Jetstream winds.
- **b.** Level of the tropopause.
- **c.** Structural icing.

61. Interpret the following extract from a PIREP:

```
SK INTMTLY BL
```

62. In PIREPs, is the level of cloud bases and tops, which are based on pilot reports, related to MSL or to AGL?

63. Interpret the PIREP:

```
UA/OV 20S ATL 1620 FL050/TP BE
18/IC MDT RIME ICE
```

64. What significant cloud coverage is reported by a pilot in the following UA? What is the thickness of the lower layer of clouds if the station elevation is 1,000 feet MSL, and the current METAR reports the ceiling as OVC008?

```
UA/OV 14 NW POR 1345/SK OVC
030/050 OVC 080
```

65. Interpret the following PIREP:

```
UA/OV MRB /TM 1835 /FL 060/TP
PA28/SK INTMTLY BL/TB MDT/RM R
TURBC INCRS WWD
```

66. How would you report turbulence that momentarily causes slight, erratic changes in altitude and/or attitude, one-third to two-thirds of the time?

67. How would you report slight, rapid and somewhat rhythmic bumpiness without appreciable changes in attitude and/or altitude, less than one-third of the time?

68. How would you report turbulence that causes changes in altitude and/or attitude more than two-thirds of the time, but the aircraft remains in positive control at all times?

Low-level Significant Weather Prognostic Charts

69. What is a forecast of future weather often referred to?

70. Which chart gives you an overall view of the weather forecast for particular times in the future?

71. Does the low-level significant weather prog chart allow you to avoid areas of non-VFR weather and to avoid altitudes where turbulence or the risk of icing exists?

72. How do you know what time the forecast shown in a particular panel of a low-level significant weather prog chart is for?

Refer to figure 36-21 (page 753) for questions 73 to 76.

73. Interpret the weather symbol depicted in the southern California area on the twelve-hour significant weather prognostic chart.

74. In which direction and at what speed is the band of weather associated with the cold front in the western states expected to move?

75. What weather is forecast for the Gulf Coast area just ahead of the cold front during the first 12 hours?

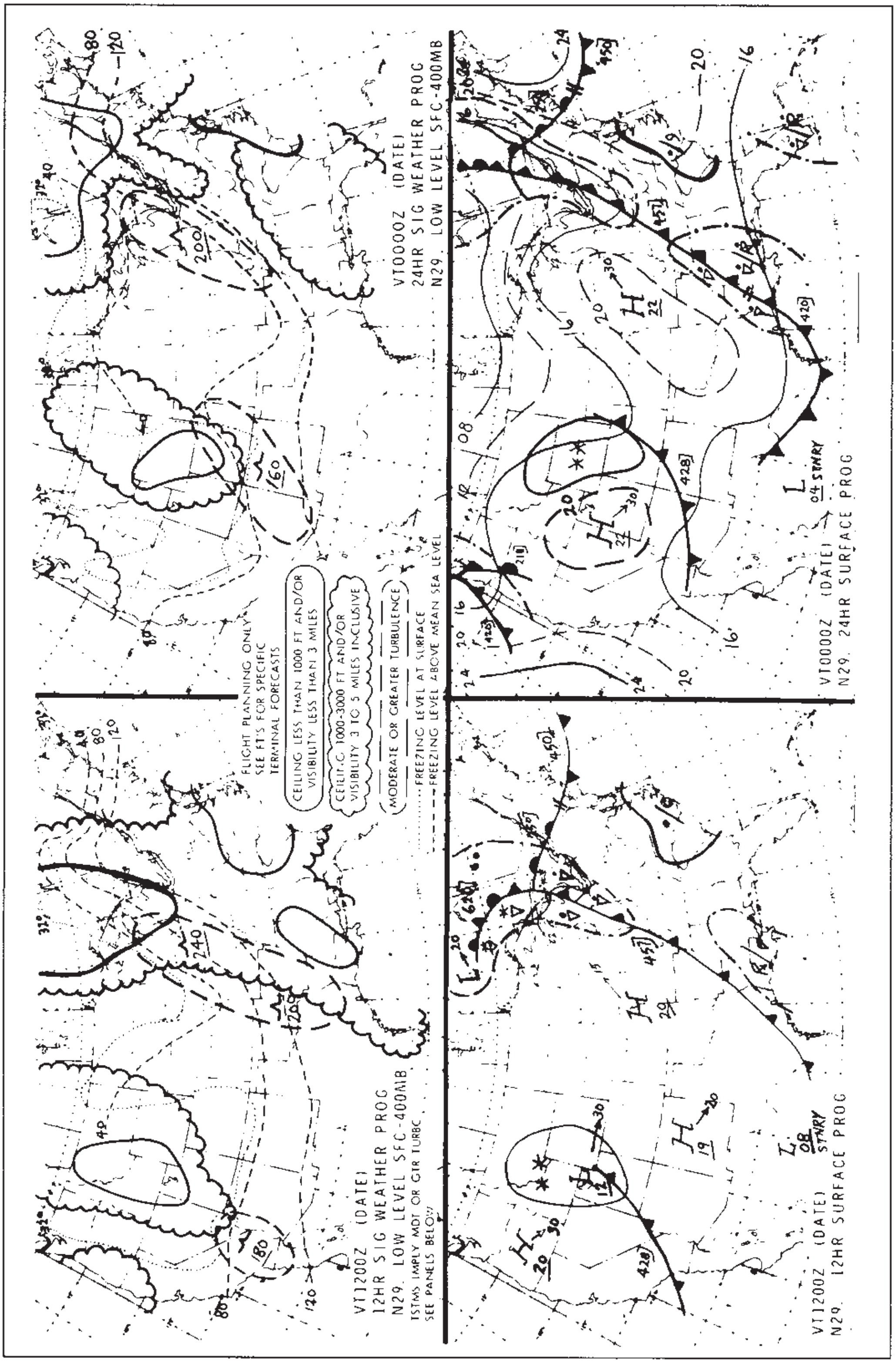


Figure 36-21 Questions 73 to 76.

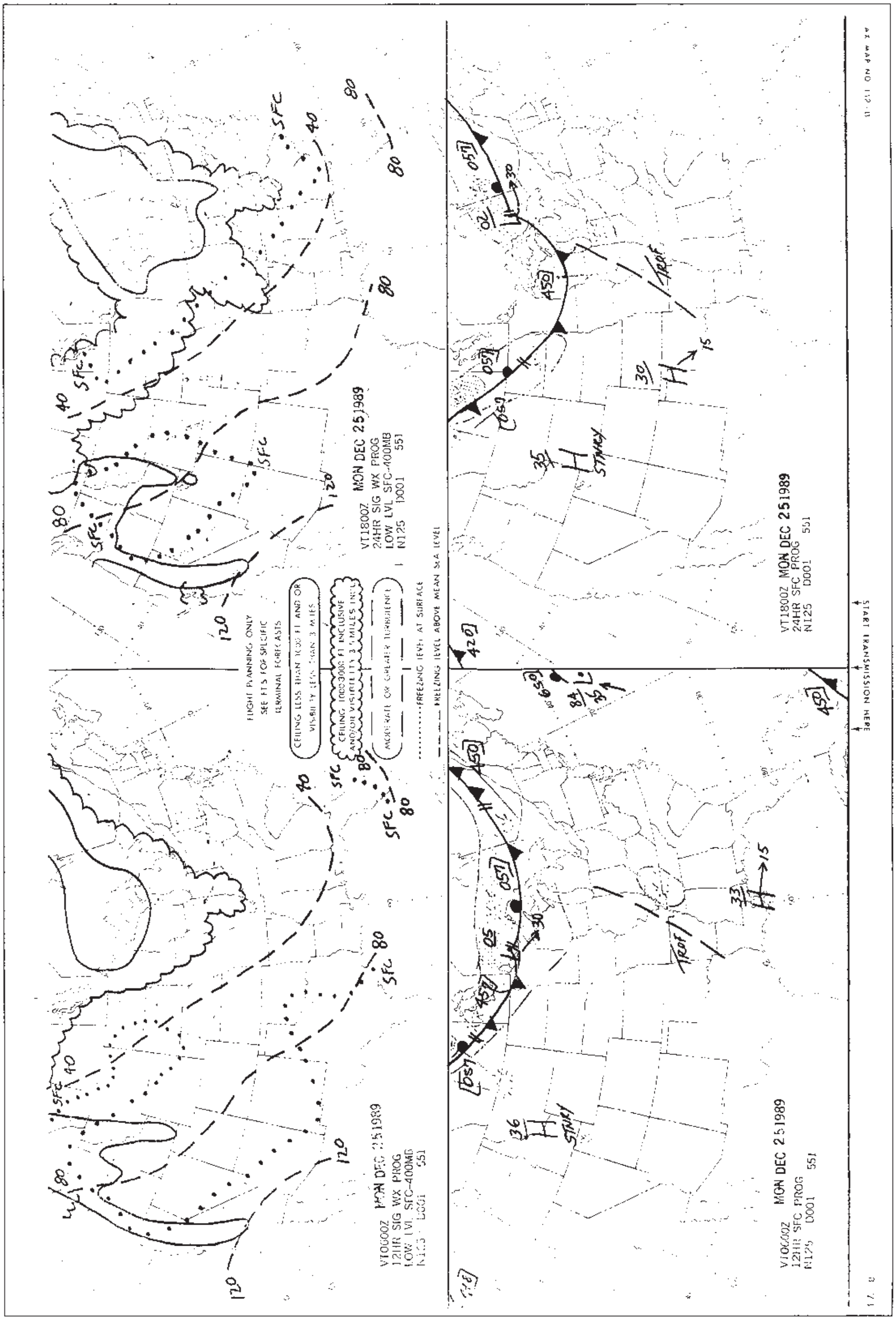


Figure 36-22 Questions 77 to 79.

76. What is the approximate freezing level over Oklahoma City?

Refer to figure 36-22 (page 754) for questions 77 to 79.

77. In the forecast for 1800 UTC for Dec. 25, is the weather over the state of Michigan expected to be VFR, MVFR, or IFR?

78. In the prog chart forecast for 1800 UTC, Dec. 25, is the weather over the state of North Dakota expected to be VFR, MVFR, or IFR?

79. What is the freezing level forecast to be over the southernmost part of California on the prog chart for 1800 UTC Dec. 25?

80. What do the following indicate on a low-level significant weather prognostic chart:

- **a.** the symbol of two dots side-by-side (••)?
- **b.** the symbol of two dots side-by-side (••) inside a shaded oval?
- **c.** the symbol of a dot above an inverted triangle (•▽)?

TAFs

81. What is the primary source of information regarding the weather expected to exist at your destination at your estimated time of arrival?

82. What area is covered by a TAF?

83. What area is considered if the term "VCNTY" is used?

84. What does a visibility entry of "P6SM" in a TAF imply about the surface visibility?

85. What does a wind entry of "VRB" in a TAF imply?

86. What does the term "TEMPO" in a TAF mean?

87. What does the term "VV000" in a terminal forecast mean?

88. What does the term "PROB40" in a terminal forecast (TAF) mean?

89. What does the term squalls mean?

Area Forecasts and the Convective Outlook

90. Where is information regarding frontal movement, turbulence, and icing conditions for a specific area found?

91. Where are forecast weather conditions for a given area the size of several states contained?

92. In an FA, what is contained in the A Statement of VFR Clouds and Weather section?

93. What does the Synopsis section of an FA contain?

94. Which weather forecast describes the prospects for an area coverage of severe or general thunderstorm activity during the following 24 hours?

Winds and Temperatures Aloft Forecast

95. On a winds and temperatures aloft forecast, which units are used for the following:

- **a.** wind direction?
- **b.** wind strength?
- **c.** temperature?

96. On a winds and temperatures aloft forecast, what do the following decode as:

- **a.** "9900+03" at 6,000 feet MSL?
- **b.** 2745-20 at 18,000 feet MSL?
- **c.** "1608" at 3,000 feet MSL?

97. When is temperature omitted on a winds and temperatures aloft forecast?

98. When is the wind group omitted for one of the usual forecast levels on a winds and temperatures aloft forecast?

99. What does "841558" at 39,000 feet decode as on a winds and temperatures aloft forecast?

100. How would you encode a wind from 290 degrees true at 60 knots and a temperature of minus 40 degrees Celsius at FL300 in a winds and temperatures aloft forecast?

101. How would you encode a wind from 170 degrees true at 140 knots and a temperature of minus 45 degrees Celsius at FL300 in a winds and temperatures aloft forecast?

102. How would you encode a wind from 340 degrees true at 8 knots and a temperature of minus 9 degrees Celsius at 9,000 feet MSL in a winds and temperatures aloft forecast?

103. Planning for a flight at FL270, the winds and temperatures aloft forecast predicts:

```
24000    30000
2891-30  751041
```

What approximate wind direction, speed, and temperature (in °C and also as a deviation from standard) can you expect?

104. Planning for a flight at FL270, the winds and temperatures aloft forecast predicts:

```
24000    30000
2368-26  781939
```

What approximate wind direction, speed, and temperature (in °C and also as a deviation from standard) can you expect?

Convective Outlook Charts

105. What is a convective outlook chart?

106. What does a single-hatched area on a convective outlook chart mean?

107. What do the letters "MDT" on a convective outlook chart mean?

108. What do the letters "SLGT" on a convective outlook chart mean?

109. What does a crosshatched area on a convective outlook chart mean?

110. What does a line with an arrowhead plotted on a convective outlook chart represent?

Constant Pressure Analysis Charts

111. What do constant pressure charts show?

112. What are constant pressure charts useful for?

113. What is the most relevant constant pressure chart for a flight at 5,000 feet MSL?

114. What is the most relevant constant pressure chart for a flight at 18,000 feet MSL?

115. What does an upper high indicate?

116. What does an upper low indicate?

117. Are clouds more likely to form if the temperature/dewpoint spread is wide or small?

118. When should you be on the watch for structural icing?

119. State five pieces of information shown on constant pressure charts.

Other Weather Information

120. A panel of which chart includes an analysis of observed freezing level data from upper air observations?

121. What does "MT 460 AT 140/55" mean in a RAREP (radar weather report)?

122. What does "RADAT 67055" mean?

Staying Informed in the Air

123. What are SIGMETs warnings of?

124. What is the quickest means of obtaining a relevant SIGMET in flight?

125. AIRMETs contain information most relevant to pilots which sort of aircraft?

126. How often does FSS broadcast current AIRMETs?

127. Where would a widespread sandstorm which lowered visibility to less than 3 miles be reported?

128. Where would a sustained surface wind of 30 knots or more be reported?

129. What is the best source of weather information en route?

Answers are given on page 794.

Appendices

Appendix 1
Abbreviations

Note. Refer also to the Pilot/Controller Glossary in the Aeronautical Information Manual, the Index to the Federal Aviation Regulations, or www.datwiki.net for more terms and definitions.

α: symbol for angle of attack
ρ: symbol for air density
AC: severe weather outlook chart
ACLT: actual calculated landing time
AD: Airworthiness Directive
ADC: air data computer
ADF: automatic direction finder
ADR: advisory route
ADS-B: automatic dependent surveillance Broadcast
A/FD: Airport/Facility Directory
AFM: Approved Flight Manual
agl or AGL: above ground level
AH: artificial horizon (see AI)
AHRS: attitude heading reference system
AI: attitude indicator
AIM: Aeronautical Information Manual
AIRMET: Aeronautical Meteorological Information
ALS: approach lighting system
ALT: altitude; altimeter
ALTN: alternate airport
AMA: area minimum altitude (Jeppesen charts)
A&P: airframe and powerplant
A/P: autopilot
APG: adverse pressure gradient
APP: approach
APT: airport
APV: approach with vertical guidance
ARSR: air route surveillance radar
ARTCC: air route traffic control center
ASD: accelerate-stop distance
ASI: airspeed indicator
ASOS: automated surface observing system
ASR: airport surveillance radar
ATA: actual time of arrival
ATC: Air Traffic Control
ATCO: Air Taxi and Commercial Operators
ATCRBS: air traffic control radar beacon system
ATD: actual time of departure
ATIS: automatic terminal information service
ATP: airline transport pilot
AVASI: abbreviated VASI
AVGAS: aviation gasoline
AWOS: automated weather observing system
AWW: severe weather forecast alerts
BDC: bottom-dead-center
BHP: brake horsepower
C: Celsius temperature scale
CA: closing angle
CAS: calibrated airspeed
CAT: clear air turbulence
C_D: coefficient of drag
CDI: course deviation indicator
CFI: certified flight instructor
CG: center of gravity
CHT: cylinder head temperature
C_L: coefficient of lift
CO: carbon monoxide
CO_2: carbon dioxide
COP: changeover point
CP: center of pressure
CRS: course
CRT: cathode ray tube
CST: Central Standard Time
CTAF: common traffic advisory frequency
CW: continuous wave radio transmissions
CWA: center weather advisory
D: drag
DA: density altitude
DA(H): decision altitude (height)
DALR: dry adiabatic lapse rate
DC: direct current
DH: decision height
DME: distance measuring equipment
DP: departure procedure
DR: dead (deduced) reckoning
DUAT: direct user access terminal (for weather data)
EAT: expected approach time
EDT: Eastern Daylight Time
EET: estimated elapsed time
EFAS: en route flight advisory service (callsign Flight Watch—operating on 122.0 MHz)
EGT: exhaust gas temperature
ELEV: elevation ELR environmental lapse rate (of ambient air)
ELT: emergency locator transmitter
ELR: environmental lapse rate
EST: Eastern Standard Time
ETA: estimated time of arrival
ETD: estimated time of departure
ETE: estimated time en route
ETI: estimated time interval
F: Fahrenheit temperature scale
FA: area forecasts
FAA: Federal Aviation Administration
FAF: final approach fix

FB: winds and temperatures aloft forecast
FBO: fixed base operator
FCU: fuel control unit
FL: flight level (hundreds of feet, e.g. FL210 is 21,000 feet)
FPA: flight path angle
fpm or FPM: feet per minute
FSS: Flight Service Station
ft or FT: feet (distance or altitude)
ft/min: feet per minute
g: acceleration due to gravity
GCA: ground controlled approach
GLS: GNSS landing system
GNSS: global navigation satellite system
GP: glide path
GPS: global positioning system
gph: gallons per hour
GPS: global positioning system
GS: groundspeed; glide slope
GW: gross weight
HAA: height above airport
HAT: height above touchdown
HDG: heading
HF: high frequency (radio transmissions)
HI: heading indicator
HIRL: high intensity runway lights
HIWAS: hazardous in-flight weather advisory service
HP: horsepower
HSI: horizontal situation indicator
HWC: headwind correction
Hz: Hertz (cycles per second)
IAF: initial approach fix
IAP: instrument approach procedure
IAS: indicated airspeed
ICAO: International Civil Aviation Organization
IFR: instrument flight rules
ILS: instrument landing system
IMC: instrument meteorological conditions
in. Hg or Hg: inches of mercury (unit of pressure)
in-lb: inch-pounds
IOAT: indicated outside air temperature
IR: instrument rating
ISA: international standard atmosphere
KCAS: knots calibrated airspeed
kg-mm: kilogram-millimeters
kHz: kilohertz (1,000 cycles per second)
KIAS: knots indicated airspeed
km: kilometer (1,000 meters)
kt: knots
KTAS: knots true airspeed
L: lift
LAAS: local area augmentation system
lb: pounds
lb-in: pound-inches
L/D: lift/drag ratio
LF: low frequency (radio transmissions)
L-W: lift-weight couple
LDA: landing distance available, localizer type directional aid
LIFR: low IFR (used on some meteorological charts)
LIRL: low intensity runway lights
LLWAS: low-level windshear alert system
LNAV: lateral (or horizontal) navigation
LOM: locator outer marker
LoP: line of position
LPV: localizer performance with vertical guidance
LW: landing weight
m or M: meters (distance)
M: degrees magnetic
MAA: maximum authorized altitude
MAC: mean aerodynamic chord (in weight and balance)
MALS: medium intensity approach light system
MAP: missed approach point
MAYDAY: (repeated three times) international distress radio signal
mb: millibars (unit of pressure)
MC: magnetic compass; magnetic course
MCA: minimum crossing altitude
MCP: maximum continuous power
MDA: minimum descent altitude (MSL) (for nonprecision instrument approach)
MEA: minimum en route altitude
MEF: maximum elevation figure
METAR: aviation routine weather forecast
METO: maximum except takeoff power
MF: medium frequency (radio transmissions)
MFD: multi-function display
MH: magnetic heading
MHA: maximum holding altitude
MHz: megahertz (million cycles per second)
MIRL: medium intensity runway lights
MLW: maximum certificated landing weight
MM: middle marker (beacon on ILS)
MOA: Military Operations Area
MOCA: minimum obstruction clearance altitude
MORA: minimum off route altitude (Jeppesen charts)
MRA: minimum reception altitude
MSA: minimum safe altitude
msl or MSL: mean sea level

MST: Mountain Standard Time
MTA: military training area
MTOW: maximum certificated takeoff weight
MTR: Military Training Route
MULTICOM: a self-announce radio frequency
MVA: minimum vectoring altitude
MVFR: marginal VFR
MZFW: maximum zero fuel weight
NACO: National Aeronautical Charting Office
NDB: nondirectional radio beacon
NM: nautical mile(s)
NOTAM: Notice To Airmen
NTSB: National Transportation Safety Board
NWS: National Weather Service
OAT: outside air temperature
OBI: omni bearing indicator (on VOR cockpit instrument)
OBS: omni bearing selector (on VOR cockpit instrument)
OFT: outer fix time
OM: outer marker (beacon on ILS)
OMNI: VHF omnidirectional radio range (same as VOR)
PA: pressure altitude
PAN-PAN: (repeated three times) international urgency radio signal
PAPI: precision approach path indicator
PAR: precision approach radar
PATWAS: pilots automatic telephone weather answering service
PCL: pilot controlled lighting
PDT: Pacific Daylight Time
P-factor: asymmetric propeller blade effect
PFD: primary flight display
PIREP: pilot weather report
PL: position line
POH: Pilots Operating Handbook
PPI: plan position indicator
PRV: pressure relief valve
PST: Pacific Standard Time
PVASI: pulsating visual approach slope indicator
RADAT: freezing level data
RAIL: runway alignment indicator lights
RB: relative bearing
RBI: relative bearing indicator
RCLS: runway centerline light system
RCO: remote communications outlet
REIL: runway end identifier lights
RMI: radio magnetic indicator
RNAV: area navigation
RNP: required navigation performance
RoC: rate of climb
RPM: revolutions per minute
RVR: runway visual range
RWY: runway
SAE: Society of Automotive Engineers
SALR: saturated adiabatic lapse rate
SALS: short approach lighting system
SAR: specific air range; search and rescue
SD: radar weather reports
SDF: simplified directional facility (similar to a localizer)
SFL: sequenced flashing lights
SGR: specific ground range
SIAP: standard instrument approach procedure
SIGMET: significant meteorological advisory alert
SM: statute mile(s)
SSR: secondary surveillance radar
SSV: standard service volume
STAR: standard terminal arrival route
SVFR: Special Visual Flight Rules
T: thrust
T: degrees true
TACAN: tactical air navigation
TAF: terminal aerodrome forecast
TAS: true airspeed
TC: true course; turn coordinator
TCAS: traffic alerting and collision avoidance system
TCH: threshold crossing height
T/D: thrust-drag couple
TDC: top-dead-center
TDZE: touchdown zone elevation
TDZL: touchdown zone lights
TE: tracking error
TEC: tower en route control (routes)
TH: true heading
TOSS: takeoff safety speed
TOW: takeoff weight
TPA: traffic pattern altitude
TR: track
TRSA: Terminal Radar Service Area
TTS: time to the station
T-VASI: T-form VASI
UNICOM: aeronautical advisory radio communications unit (non-government)
UTC: coordinated universal time or Z Zulu time (ATC reference to UTC)
V_A: design maneuvering speed
V_B: turbulence penetration speed
VASI: visual approach slope indicator
VDP: visual descent point
V_F: design flap speed

V_{FE}: maximum flaps-extended speed
VFR: visual flight rules
VHF: very high frequency
V_{LE}: maximum landing gear extended speed
V_{LO}: maximum speed, landing gear operating
VMC: visual meteorological conditions
VNAV: vertical navigation
V_{NE}: never-exceed speed
V_{NO}: normal-operating limit speed
VNR: VFR not recommended
VOR: VHF omnidirectional radio range
VORTAC: co-located and integrated VOR and TACAN* (*used for distance measuring)
V_{RA}: rough-air speed
V_S: stall speed
V_{S0}: stall speed in landing configuration
V_{S1}: stall speed clean
VSI: vertical speed indicator
V_{TURB}: turbulence penetration speed
V_X: best angle-of-climb speed
V_Y: best rate-of-climb speed
W: weight
WA: AIRMET
WAAS: Wide Area Augmentation System
WAC: World Aeronautical Charts
WCA: wind correction angle
WS: SIGMET
WSFO: National Weather Service Forecast Office
WSO: National Weather Service Office
W/V: wind velocity
WX: weather
Z: Zulu (ATC reference to UTC)
ZFW: zero fuel weight

Appendix 2

Answers to Review Questions

Review 1: Airmanship

1. **D**–Detect a change, **E**–Estimate the need to react, **C**–Choose an outcome, **I**–Identify actions, **D**–Do the necessary action, **E**–Evaluate the effect.
2. Example applying the DECIDE model to a specific flight situation: A pilot takes off in excellent VFR conditions and anticipates good weather for the duration of the flight. While enroute, the pilot double checks the weather and discovers that the weather has deteriorated and the destination has gone IFR. The pilot uses the DECIDE model to make a safe decision. The pilot Detects a change—deteriorating weather. Estimates the need to react—file IFR or plan a diversion. Chooses an outcome—remain VFR. Identifies actions—land short of the original destination and wait for weather to improve. Does the necessary action—lands VFR at an alternate airport. Evaluates the effect—the flight ends safely.
3. The five hazardous attitudes and their antidotes include:
   - **a.** Antiauthority (don't tell me!). The antidote to antiauthority is: Follow the rules; they are usually right.
   - **b.** Impulsivity (do something, quickly!). The antidote is: Not so fast. Think first.
   - **c.** Invulnerability (it won't happen to me). The antidote is: It could happen to me.
   - **d.** Macho (I can do it). The antidote is: Taking chances is foolish.
   - **e.** Resignation (what's the use?). The antidote to this attitude is: I'm not helpless. I can make a difference.
4. The steps of the ACTION model include: **A**–Anticipate and assess the possible scenarios; **C**–Consider actions and outcomes; **T**–Time—if available, immediate decision or nominate decision point (go/no-go point) and criteria; **I**–Implement decision—make a control input, transmission etc; **O**–Observe the result and correct—fine tune; **N**–Nominate the next milestone, decision point or potential hazard.
5. Example applying ACTION to a specific flight situation: While flying daytime VFR, a pilot sees smoke in the cockpit. The pilot must act quickly—deferring action is not an option. The pilot employs the ACTION model. The pilot Anticipates that smoke and fire in the airplane could be catastrophic. The pilot Considers the action of turning off the airplane's electrical system. The pilot determines that the situation can only get worse with Time, so action is warranted without delay. The pilot Implements the decision and turns off the Master Switch. The pilot waits to Observe if turning of the Master Switch has stopped the smoke. After a few moments the pilot detects no additional smoke. The pilot Nominates the next milestone to be a precautionary landing and decides not to turn the electrical system back on. The pilot remains in VFR conditions and lands at a nontowered airport where radio communications are not required.
6. The Five P Check (5Ps) is a practical application for pilots to maintain Situational Awareness. The 5P's consist of "the Plan, the Plane, the Pilot, the Passengers, and the Programming." Each of these areas consists of a set of challenges and opportunities that face a single pilot. Each can substantially increase or decrease the risk of successfully completing the flight based on the pilot's ability to make informed and timely decisions.
7. The 5P's are used to evaluate the pilot's current situation at key decision points during the flight, or when an emergency arises. These decision points include, preflight, pre-takeoff, hourly or at the midpoint of the flight, pre-descent, and just prior to the final approach fix or for VFR operations, just prior to entering the traffic pattern.

Review 2: The Human in the Cockpit

Am I Fit to Fly?

1. 8 hours.
2. Hypothermia is when a person suffers from an abnormally low temperature.
3. DECIDE, which stands for: Detect, Estimate, Choose, Identify, Do, Evaluate. The six-step process is a logical way to make decisions while flying or flight planning.
4. Know your personal limits; use all available resources, avoid hazardous attitudes, learn to modify your behavior, and develop methods to assess risk.

Respiration

5. Hypoxia is a state of oxygen deficiency in the body.
6. Hyperventilation is overbreathing.

7. Hyperventilation causes low carbon dioxide levels in the blood.
8. Stress.
9. Tingling sensations in the hands and feet.
10. Because of the possibility of carbon monoxide poisoning.
11. Answer c.

Balance

12. Spatial disorientation is a state of temporary confusion resulting from misleading information being sent to the brain by various sensory organs.
13. The flight instruments.
14. Answer c.

Vision

15. Cones are concentrated around the central section of the retina. Rods are concentrated in the outer parts of the foveal area.
16. False. Cones are most effective in the day.
17. No. They only see in black-and-white.
18. Rods.
19. Using successive eye movements.
20. True.
21. Yes.
22. False. They are most clearly seen in your peripheral vision.
23. Answer c.
24. There will be no apparent relative motion between your aircraft and the other aircraft.
25. Yes.
26. 30 minutes.
27. The other aircraft is crossing to the left.
28. The illusion that the correct approach path is too steep and that the runway is shorter than it is.
29. The illusion that you are higher than you really are, resulting in the airplane flying into the runway.

Review 3: Aviation Regulations

Definitions and Pilot Qualifications

1. Night is defined as starting at the end of evening civil twilight and ending at the beginning of morning civil twilight.
2. Authorization to proceed under specified traffic conditions in Class A, B, C, D and E airspace.
3. **a.** A category of aircraft;
   b. A class of aircraft.
4. An airworthiness certificate remains valid provided the aircraft is maintained and operated according to the regulations.
5. Part 1.1.
6. Maximum landing gear extended speed.
7. Maximum flap extended speed.
8. Stalling speed or minimum steady flight speed in the landing configuration.

Part 61—Pilot Certification

9. A current pilot certificate, a current medical certificate, and photo ID.
10. No.
11. July 31, 5 years later, if the pilot was younger than 40 on the date of the examination.
12. During an airlift for a charitable organization, when the FAA has been notified and a donation made to the charitable organization.
13. You must have made 3 takeoffs and 3 landings within the preceding 90 days in an aircraft of the same category and class, or type. For tailwheel airplanes, the landings must be to a full stop.
14. 1929.
15. Three.

Part 91—General Operating and Flight Rules

16. The pilot in command.
17. The pilot in command.
18. Yes, the pilot in command may deviate from the regulations to the extent required to meet the emergency. A written report of the deviation should be sent to the FAA on request.
19. In the current, FAA-approved flight manual, approved manual material, markings, and placards, or any combination thereof.
20. Airworthiness certificate, registration certificate, operating limitations (Flight Manual, POH, placards, etc.), and weight-and-balance information (in the Flight Manual, POH, or separate). These can be remembered using the mnemonic “AROW.”
21. 0.04% by weight.
22. Yes.
23. No.
24. During takeoffs and landings.
25. Airplane.
26. An aircraft in distress.
27. No (it only has right-of-way over other engine-driven aircraft).
28. The aircraft on the left shall give way.

29. The airplane.
30. Both should turn right.
31. The airship.
32. An aircraft at the lower altitude, but it shall not take advantage of this rule to cut in front of or to overtake another.
33. Yes.
34. The right.
35. 250 KIAS.
36. 250 KIAS.
37. 200 KIAS.
38. 500 feet.
39. An altitude allowing, if a power unit fails, an emergency landing without undue hazard to persons or property on the surface.
40. When requested by ATC.
41. Exercise extreme caution.
42. Return to the starting point on the airport.
43. Exercise extreme caution, then on seeing flashing red (only) abandon the approach because the airport is unsafe and the ATC message is "do not land."
44. Left.
45. As soon as possible after departure.
46. Yes.
47. Two-way radio communications and an altitude-encoding transponder.
48. Class B and C.
49. **a.** Flight fuel plus 30 minutes at normal cruise speed;
    b. Flight fuel plus 45 minutes at normal cruise speed.
    c. Flight fuel plus for alternate, plus 45 minutes.
50. Class B, C, D or E surface areas, except at the airports listed in Part 91, Appendix D, Section 3.
51. Visibility 1 SM and clear of clouds.
52. 6,500 feet MSL.
53. When the ELT has been used for more than 1 hour cumulative, or 50% of the battery's useful life.
54. During the period from sunset until sunrise.
55. That flight time in excess of 30 minutes at those altitudes.
56. Class A, Class B (and within 30 miles of the Class B primary airport), and Class C.
57. 1,500 feet AGL and 3 statute miles.
58. 1,359.6 hours.
59. Yes (note that the reverse does not apply).
60. In the maintenance records.
61. Yes, but only to protect the wreckage from further damage.
62. No.
63. 10 days.
64. Yes.

IFR Operations

65. To operate under IFR, an operational check of the aircraft VOR equipment must have been accomplished within the preceding 30 days.
66. The maximum tolerance between the two indicators when set to identical radials of a VOR is plus or minus 4 degrees.
67. Date; place; bearing error; and signature.
68. The maximum tolerance allowed for an operational VOR equipment check when using a VOT is plus or minus 4 degrees.
69. Within ETA±1 hour, forecast ceiling 2,000 feet, forecast visibility 3 miles.
70. Yes. Ceiling must be at least 2,000 feet above airport elevation.
71. Yes.
72. Yes.
73. No. Ceiling exceeds 2,000 feet height above airport elevation (HAA), visibility exceeds 3 miles.
74. Yes. The IFR destination must be served by an IAP.
75. No. Ceiling must be at least 2,000 feet, and visibility must be at least 3 miles—this airport just makes it!
76. Yes. Fuel to destination, fuel to alternate, plus 45 minutes at normal cruising speed.
77. No. Fuel to destination, plus 45 minutes at normal cruising speed.
78. Yes.
79. Yes.
80. Yes.
81. No.
82. Yes, the improvement is more than 1 hour after your ETA.
83. Yes, the improvement is required at least 1 hour before your ETA.
84. **a.** Ceiling: 800 feet HAA (height above airport elevation), Visibility: 2 SM;
    b. Ceiling: 600 feet HAA, Visibility: 2 SM;
    c. Ceiling: 800 feet HAA, Visibility: 2 SM;
    d. Ceiling: 600 feet HAA, Visibility: 2 SM.
85. Answer a.
86. An airport without an authorized instrument approach procedure may be included on an IFR flight plan as an alternate if the current weather forecast indicates that the ceiling and visibility at the ETA will allow descent from the MEA followed by an approach and landing, all under basic VFR.

87. You are restricted to the landing minimums for the approach to be used.
88. Yes.
89. Yes.
90. Yes.
91. No.
92. Yes.
93. No.
94. No.
95. No.
96. Yes.
97. Answer c.
98. Yes.
99. Yes.
100. Minimum obstruction clearance altitude.
101. Yes.
102. No.
103. No, the MOCA is lower than the MEA.
104. Minimum crossing altitude.
105. At the intersection.
106. 3 minutes before your ETA at the intersection.
107. You should plan to maintain a clearance of at least 2,000 feet above the highest obstacle within a horizontal distance of 4 NM of the course to be flown.
108. You should plan to maintain a clearance height of at least 1,000 feet above the highest obstacle within a horizontal distance of 4 nautical miles of the course to be flown.
109. Yes.
110. No.
111. No.
112. No.
113. The landing minimum is specified as visibility.
114. The missed approach procedure.
115. Standard takeoff minimums for a one- or two-engine airplane carrying people for 14 CFR Part 135 operations are visibility 1 SM. For flights operating under Part 91, the standard takeoff minimums are none.
116. 1/2 SM.
117. 1 SM.
118. No.
119. Yes.
120. Yes.
121. Squawk 7600, continue the flight under VFR, and land as soon as possible.
122. You should depart the Holding fix at the EFC time of 1620Z and complete the approach.
123. Squawk 7600, continue flight on the last assigned route, and fly the last assigned altitude or the MEA, whichever is higher.

Review 4: Forces Acting on an Airplane

4 Forces in Flight

1. Lift.
2. Thrust.
3. Drag.
4. 10 times.
5. Lift = weight; thrust = drag.

Airfoil Lift

6. An airfoil.
7. Streamline flow.
8. At the separation point.
9. Static pressure in the air is exerted in all directions.
10. Dynamic pressure.
11. Static pressure + dynamic pressure.
12. It will decrease.
13. Dynamic pressure.
14. The mean camber line.
15. The lifting ability of the wing.
16. True.
17. Relative airflow is parallel to the flight path of the airplane and flows in the opposite direction.
18. The angle between the wing chord line and the relative airflow.
19. It will increase.
20. Answer b.
21. Distribution of positive and negative pressure on the wing.
22. It moves forward on the wing.
23. True.
24. Frost will disrupt the smooth flow of air over the wing, adversely affecting its lifting ability.

Drag

25. Drag is the component of relative airflow which is parallel to the relative airflow.
26. True.
27. The two basic groups of drag are induced drag, which comes about in the production of lift, and parasite drag which is not associated with the production of lift.

28. False. As airspeed increases, drag caused by skin friction increases.
29. To reduce form drag, separation of the boundary layer airflow from the wing surface should be delayed by streamlining.
30. True.
31. At high angles of attack and low airspeeds.
32. At medium speed where the parasite drag and induced drag are equal.
33. Because of the greater parasite drag.
34. True.
35. The lift/drag ratio describes the aerodynamic efficiency of the wing.

Wing Flaps

36. It increases the camber of the wing.
37. Drag.
38. No, flaps decrease the lift/drag ratio.
39. True.
40. False. With flaps extended, the nose attitude of the airplane is lower.
41. True.

Thrust from the Propeller

42. Thrust.
43. False. At high altitudes, when the air is less dense, a propeller will be less efficient.
44. To ensure that it operates at its most efficient angle of attack along its full length.
45. True.
46. True.
47. Answer a.
48. P-factor causes the airplane to yaw left at high angles of attack of the wing.
49. Because of the propeller torque reaction.
50. Torque effect is greatest in a single-engine airplane at high power and low airspeed.
51. By applying right rudder.

Review 5: Stability and Control

Stability

1. Yes.
2. A nose-down pitching moment.
3. A nose-up pitching moment.
4. It would pitch down.
5. The center of pressure is behind the CG.
6. A downward force.
7. These will cause the nose to drop.
8. Answer b.
9. Pitching.
10. Yawing.
11. The horizontal stabilizer.
12. Yes.
13. False. An airplane loaded with the CG too far aft will be unstable at all speeds, and if stalled will be difficult to recover.
14. No (a forward CG location will cause an airplane to be more stable at all speeds).
15. With a large vertical stabilizer.
16. Answer b.
17. Lateral stability.
18. Roll.

Control

19. The elevators.
20. The pitching plane.
21. Lateral axis.
22. Up.
23. **a.** The airplane will be excessively stable, which may make it difficult to flare on landing;
    b. The airplane will be excessively unstable, which may make it difficult to fly smoothly.
24. The ailerons.
25. The longitudinal axis.
26. Left.
27. True.
28. False. One aileron will rise by an amount greater than the other aileron is lowered.
29. Yes.
30. The vertical (normal) axis.
31. It will tend to yaw the nose away from the turn.
32. By the use of differential ailerons, or by Frise-type ailerons.
33. Rudder.
34. Yes, lift increases. This leads to a roll.
35. Yes.
36. Yes.
37. Yes.
38. To reduce the control pressures (or "stick load") on the pilot.
39. Servo tab, horn balance, and inset hinge.
40. Answer a.
41. Answer b.
42. To prevent control-surface flutter in flight.

Review 6: Aerodynamics of Flight

Straight-and-Level Flight

1. Answer b.
2. Zero.
3. It must be increased.
4. High angles of attack and a high nose attitude.
5. This is achieved by decreasing the angle of attack or decreasing airspeed.
6. It disrupts the smooth airflow over the wings, decreasing the lifting ability.

Climb and Descent

7. Yes.
8. Answer a.
9. 350 FPM.
10. Answer c.
11. 600 FPM.
12. Answer b.
13. The vertical speed indicator.
14. True.
15. The altitude at which the climb performance of an airplane falls to zero.
16. Answer b.
17. Answer b.
18. Lift and drag.
19. It will decrease the rate and angle of decent.
20. False. The descent becomes steeper.
21. False. Flying faster than the correct descent speed will steepen the descent angle through the air.
22. No, it will glide the same distance.
23. Airspeed must be lowered.
24. 6 minutes (wind does not affect rate of climb or descent).
25. 8,000 feet.
26. 528 feet.

Turning and Load Factor

27. Load factor is the ratio of lift to weight.
28. Centripetal force.
29. Centripetal force is provided by the horizontal component of lift.
30. False. The pilot must apply power to overcome the increased induced drag.
31. Answer a.
32. **a.** Load factor is 2;
    b. 2 times.
33. Approximately 3,960 pounds (3,300 × 1.2).
34. Approximately 9,180 pounds (5,400 × 1.7).

Stalling and Spinning

35. Control buffet.
36. 16°.
37. Answer b.
38. Answer d (stall IAS is not affected by air density).
39. False. It will stall at the same angle of attack.
40. The inner section.
41. No, power-on stall speed is less than the power-off stall speed.
42. It must be stalled.
43. Answer a.
44. Frost and ice on the wing may delay the takeoff to a higher airspeed than normal.

Takeoff Performance

45. Yes.
46. 10 knots.
47. Answer a.
48. **a.** 25 knots;
    b. 22 knots.
49. **a.** It increases takeoff distance;
    b. It increases takeoff distance;
    c. It decreases takeoff distance.
50. Takeoff distance is measured from the start point on the runway to the point where the airplane reaches 50 feet above the runway.
51. Flaps 50%.
52. 10,000 feet.
53. 3,400 pounds.
54. 1,067 feet.
55. 2,494 feet.
56. 1,395 × 20% = 1,674 feet.
57. 1,829 × 80% = 3,292 feet.
58. 3,376 – 10% for 12 knot headwind = 3,039 feet.

Landing Performance

59. 2,900 pounds.
60. 75 KIAS.
61. Flaps 100% and power at idle.
62. 1,070 feet.
63. 2,275 feet.
64. 2,490 feet.
65. 1,195 – 20% for headwind = 956 feet.
66. 2,348 + 30% for 6 knot headwind = 3,052 feet.
67. 1,188 + 20% = 1,426 feet.
68. 1,240 + 60% = 1,984 feet.

Wake Turbulence

69. **a.** Wingtip vortices;
b. Wake turbulence.

70. Down and outward.

71. Answer c.

72. Below its flight path.

73. By maneuvering your airplane above and upwind of its flight path.

74. By being airborne prior to reaching the jet's flight path until able to turn clear of its wake.

75. Beyond its touchdown point.

76. You should make sure you are slightly above the path of the jet.

77. Answer c.

Ground Effect

78. Ground effect is the result of the interference of the surface of the earth with the air-flow patterns about an airplane.

79. Answer b.

80. Answer a.

81. When within 1 wingspan height above the ground.

82. Answer a.

83. Answer b.

Windshear

84. Any change in the wind speed and/or the wind direction as you move from one point to another.

85. The effect of a windshear that causes an airplane to fly above the desired flight path and/or to increase its speed.

86. This term describes the overall influence of the windshear on the airplane when the initial effect of a windshear is reversed as the airplane travels further along its flight path (say on approach to land).

87. Yes.

88. Answer a.

89. Answer a.

Review 7: Airframe

1. The spar.

2. The vertical stabilizer, the rudder, the horizontal stabilizer, and the elevator.

3. Ribs.

4. Monoplanes.

5. Semi-monocoque.

6. Yes.

7. Oil.

8. False. The oleo strut will extend further in flight than on the ground.

9. To avoid rapid wearing of the seals during taxiing and ground maneuvers as the strut telescopes in and out.

10. A torque link.

11. A shimmy-damper.

12. Creep.

13. Castoring.

14. Answer a.

15. Answer b.

16. Answer b.

17. No.

18. Yes.

19. Answer c.

Review 8: Engine

The Engine

1. Intake (or induction), compression, power (or expansion), and exhaust.

2. No.

3. No.

4. No.

5. Yes.

6. Valve overlap.

7. By a high-voltage spark just prior to top-dead-center and the commencement of the power stroke.

8. Yes.

9. True.

10. No.

11. Answer b.

12. There is a broken magneto ground wire.

13. Answer c.

14. By impulse coupling.

Carburetor and Fuel Injection

15. The principle of a simple carburetor is to decrease the pressure as air flows through a venturi throat and draw fuel into the passing airstream.

16. The ratio between the weight of the fuel and the weight of the air entering the carburetor.

17. With the mixture control.

18. Excess fuel.

19. Excess air.

20. An idling jet.

21. The fuel/air ratio which provides the most power for any given throttle setting.

22. By using the mixture control, which is usually a red colored knob.
23. Fouling of the spark plugs.
24. Answer a.
25. True.
26. Answer c.
27. Answer c.
28. Answer b.
29. Preignition.
30. The expansion of air as it accelerates through the carburetor venturi causes it to drop in temperature, and if it contains moisture carburetor ice can form.
31. Carburetor heat.
32. A loss of power (indicated by a decrease in RPM).
33. Yes.
34. It will increase the ground roll.
35. Yes.
36. True.
37. Answer c.
38. The fuel/air mixture may become excessively lean.
39. Detonation is an explosive combustion of the fuel/air mixture in the cylinders.
40. By using a lower than specified grade of fuel and/or excessively high engine temperatures. Detonation may also be caused by the mixture being too lean.
41. Preignition.
42. Answer c.
43. Because the hot air source is unfiltered.
44. Answer a.

The Oil System

45. Oil lowers friction between moving parts and so prevents high temperatures, and what heat is formed can to some extent be carried away by circulating oil.
46. False—oil grades may not be mixed.
47. With the oil filter.
48. You may observe a high oil temperature and/or a low oil pressure.
49. It is forced through an oil filter bypass valve.
50. True.

The Cooling System

51. To increase the exposed surface area in order to allow better cooling.
52. Answer c.
53. Reduce rate of climb and increase airspeed.
54. Answer b.

Engine Operation

55. Only prior to startup.
56. Oil pressure.
57. 30 seconds.
58. Yes.
59. **a.** RPM;
    b. Manifold pressure and RPM.
60. True.
61. True.
62. Increase RPM first, then manifold pressure.
63. Decrease manifold pressure first, followed by RPM.
64. **a.** The throttle;
    b. The manifold pressure gauge.
65. Answer b.
66. **a.** RPM will stay the same;
    b. MP will decrease by about 1 in. Hg per 1,000 ft.
67. True.
68. Answer b.
69. Answer a.
70. It means reducing the amount of fuel to match the reduced weight of air.
71. Answer b.
72. In a carbureted engine, moving the mixture to idle cut-off clears the induction manifold and engine cylinders of fuel. With a fuel-injected engine, this clears fuel lines and cylinders of fuel. Not answer a—stopping the engine by removing the spark ignition would leave fuel in the fuel lines and engine. Not answer c—this would only turn off aircraft electrical services such as lighting, or radios, but would have no effect at all on the engine or engine ignition.
73. The oil temperature gauge.
74. **a.** You should suspect a serious loss of oil;
    b. You should consider an immediate landing.
75. Answer b.

Review 9: Systems

The Fuel System

1. To provide fuel at the required pressure, to purge the fuel lines of any vapor, to prime a fuel-injected engine for start-up, and to supply fuel if the engine-driven fuel pump fails.
2. The next higher octane aviation gas.
3. Because it could lead to detonation and engine damage.
4. No.

5. Prior to the first flight of the day and after each fueling.
6. False. Water tends to collect at the lowest points in the fuel system.
7. By color and smell.
8. Green.
9. Blue.
10. Answer c.
11. AVGAS equipment decals are colored red.
12. Jet fuel equipment decals are colored black.
13. Air being drawn into the fuel lines and causing a vapor lock.

The Electrical System

14. The alternator or generator.
15. The battery.
16. Answer c.
17. To provide electrical power for start-up and to act as an emergency source of electrical power.
18. A center-zero ammeter measures current in and out of the battery.
19. A left-zero ammeter measures only the battery of the alternator.
20. True.
21. Excessive electrical current.
22. 3 hours.
23. Typically, answers e, g, and i. The ASI, altimeter and VSI are pitot-static instruments and are not typically electrically powered (although there may be an electrical pitot heater to avoid icing). The gyroscopic instruments (AI, TC and HI) may be electrically powered or powered from the vacuum system—a typical arrangement is a vacuum-powered AI and HI with an electrical TC. The fuel quantity gauges and oil temperature gauge (if installed) will probably be electrically powered. The RPM gauge (tachometer) is self-powered directly off the engine. (Check the POH for your airplane.)

The Vacuum System

24. Answer b.
25. By the vacuum relief valve.
26. True.

Review 10: Flight Instruments

Pressure Instruments

1. The static vent.
2. Total pressure.
3. As a precaution against ice forming in the pitot tube.
4. The rate of change of static pressure.
5. Pitot and static pressures.
6. The airspeed indicator only.
7. No.
8. Yes.
9. The airspeed indicator, the altimeter, and the VSI.
10. The same altitude.
11. **a.** The yellow or amber arc;
b. The green arc;
c. The white arc.
12. The red radial line.
13. Lower limit of the white arc.
14. The low-speed end of the white arc.
15. The low-speed end of the green arc.
16. Yes.
17. False. The maximum flaps-extended speed corresponds to the high-speed end of the white arc.
18. Yes.
19. 165 to 208 mph.
20. 60 to 100 mph.
21. 100 mph.
22. 29.92 in. Hg/1,013.2 hPa.
23. The height of the airplane above the 30.05 in. Hg pressure level.
24. The height of the airplane above mean sea level.
25. Field elevation (approximately).
26. The vertical distance of the aircraft above the surface.
27. The pressure altitude corrected for non-standard temperature.
28. The correct local altimeter setting.
29. The local altimeter setting is set in the pressure window. This is done so the altimeter will read height above sea level.
30. **a.** 10,500 feet;
b. 14,500 feet;
c. 9,500 feet.
31. Answer b.
32. 150 feet higher.
33. Indicated altitude will increase by approx. 60 feet.
34. 6,100 feet.

35. A pressure altitude of 23,000 feet.
36. False. The airplane will be lower than the indicated altitude.
37. The indicated altitude to be less than the true altitude.
38. Standard atmospheric conditions must exist.
39. In warmer than standard temperature.
40. False. The altimeter will indicate a lower altitude than actually flown when the air temperature is higher than standard.
41. It will increase.
42. A transponder.

Gyroscopic Instruments

43. Yes.
44. Below it.
45. Turn information.
46. Turn and roll information.
47. No.
48. 3° per second.
49. The magnetic compass.
50. The AI, the HI, and the turn coordinator.
51. Coordination ball.
52. Answer b.
53. To guard against a simultaneous loss of all gyroscopic instruments.
54. The attitude indicator.
55. The turn coordinator (or turn indicator).
56. Answer c.

Magnetic Compass

57. The geographic or true north and south poles.
58. The magnetic north and south poles.
59. Magnetic variation.
60. No, it varies.
61. 10° east variation.
62. **a.** MH 080 (variation east—magnetic least);
    b. MH 086;
    c. MH 095.
63. The isogonic lines.
64. An agonic line.
65. MH 180.
66. MH 225.
67. The earth's magnetic poles being positioned away from the true geographic poles.
68. Magnetic fields within a particular airplane distorting the lines of magnetic force.
69. Airplane heading.
70. Answer a.
71. The magnetic heading of the airplane.
72. Answer b.
73. Acceleration errors occur on easterly or westerly headings, and do not occur on northerly or southerly headings.
74. You should undershoot this heading on the magnetic compass, and roll out wings-level when the compass initially indicates 320, because the compass will lag behind the actual turn.
75. You should overshoot this heading on the magnetic compass, and roll out wings-level when the compass initially indicates 140, because the compass will be ahead of the actual turn.
76. Latitude.
77. Because of the greater magnetic dip.
78. Answer c.
79. Only in unaccelerated flight.
80. Answer c.

Review 11: Weight and Balance

Weight and Balance

1. Maximum takeoff weight.
2. True.
3. True.
4. airframe, powerplant, permanently installed equipment, unusable fuel, unusable oil (unless it is specifically stated that full oil is included), hydraulic fluid.
5. **a.** 6 pounds;
   b. 156 pounds
6. 18.4 gallons.
7. False. If the CG is located at the rear limit, the airplane be less stable longitudinally.
8. True.
9. Answer b.
10. 17,600 lb-in.
11. Answer b.

12. 273 lb (2,400 – 2,127), 45.5 gal.

Empty weight	1,432 lb
Front seat	320
Rear seat	340
Baggage	20
Oil	15
ZFW	2,127 *
MTOW	2,400
Fuel	273 lb

*This is the zero fuel weight for these conditions. Note that it is not a limiting weight.

13. 43 lb.

Basic empty weight (incl. oil)	2,015 lb
Front seat	369
Rear seat	267
Fuel (36 gal @ 6 lb/gal)	216
ZFW	2,867
Max allowed TOW	2,910
Therefore, max. baggage is:	43 lb

14. Answer b.

	Weight (lb)	Arm (in)	Moment (lb-in)
Empty weight	1,495.0	101.4	151,593.0
Pilot and passenger	380.0	64.0	24,320.0
Full fuel (30 gal usable)	180.0	96.0	17,280.0
Total	2,055.0	94.1	193,193.0

Weight-and-Balance Calculations

15. **a.** 80.8;

b. Using the center of gravity moment envelope 1,999 lb and 80.8 inches lie just within the envelope in the utility category.

Item	Weight (lb)	Moment (mom/1,000)
Empty weight	1,350	51.5
Pilot and front passenger	310	11.5
Rear passengers	96	7.0
Fuel (38 gal)	228	11.0
Oil (8 quarts)	15	–0.2
Gross weight	1,999	80.8

16. **a.** 79.2, 38.9 inches aft of datum. The weight and moment index of the oil is given in the graph at Note 2;

b. Using the center of gravity moment envelope, 2,033 lb and 79.2 lie within the envelope in the normal category.

$$\text{CG Position} = \frac{\text{total moment}}{\text{total weight}}$$

$$= \frac{79{,}200}{2{,}033}$$

$$= 38.9 \text{ inches aft of datum}$$

Item	Weight (lb)	Moment (mom/1,000)
Empty weight	1,350	51.5
Pilot and front passenger	380	14.2
Fuel (48 gal = 288 lb)	288	13.7
Oil (8 qt)	15	–0.2
Gross weight	2,033	79.2

17. Answer c.

- fill in the table as far as possible;
- calculate weight and moments as far as possible—without the fuel, since it is an unknown quantity;
- add up the actual weights and, from the known maximum gross weight (2,300 lb shown on CG envelope for the normal category), calculate the maximum possible fuel from a weight point of view (no balance as yet), and check that it does not exceed fuel tank limits (48 gal = 288 lb);
- add the fuel weight and moment to table, find new totals, and check they lie inside the CG envelope; and
- convert pounds of fuel to gallons (1 gal = 6 lb).

Item	Weight (Lb)	Moment (Mom/1,000)
Empty weight	1350	51.5
Pilot and front passenger	340	12.5
Rear passengers	310	22.5
Baggage	45	4.0
Oil (8 qt)	15	–0.2
ZFW	2060	90.3
Maximum fuel (2300 – 2060)	240	11.5
Maximum gross weight (from CG envelope)	2300	101.8 OK

18. 45 lb.

Note. The empty weight and moment is stated in figure 11-21 (page 302).

Item	Weight (lb)	Moment (mom/1,000)
Empty weight	1350	51.5
Front seats (200 +187)	387	330 (170 + 160)
Rear seats (140 + 153)	293	355 (169 + 186)
Fuel (35 gal)	210	158
Gross weight (no baggage)	2905	2397
Baggage	45	63
Gross weight (with baggage)	2950	2460
Maximum weight	2950 OK	2422-2499 OK

19. **a.** Weight is 2,927 lb;

b. CG is 83.39 inches aft of datum. To calculate the CG position:

$$\text{Mom}/100 = 2{,}441$$

$$\text{Moment} = 244{,}100 \text{ lb-in}$$

$$= 2{,}927 \text{ lb} \times \text{CG arm}$$

$$\text{CG arm} = \frac{79{,}200}{2{,}033}$$

$$= 89.3 \text{ inches aft of datum}$$

Note. "Determine weight and balance" means: "calculate the weight, calculate the moments, and also calculate the position of the CG."

Weight and balance is within limits (i.e. within the range 2399–2483 at the very close weight of 2930 lb.

Item	Weight (lb)	Mom/100
Empty weight	2015	1554
Front seats (200 + 150)	350	298 (170 + 128)
Rear seats (200 + 125)	325	393 (242 + 151)
Baggage	27	38
Fuel (35 gal)	210	158
Gross weight	2927 OK	2441 OK

20. The weight is within limits (right on maximum), but the CG is out of limits (because the mom/100 lies outside the allowable range at that weight—2422–2499 is the CG range at 2950 lb).

Item	Weight (lb)	Mom/100
Empty weight	2015	1554
Front seats (215 + 200)	415	353 (183 + 170)
Rear seats	110	133
Baggage	32	45
Fuel (mains 44 gal aux 19 gal)	264 114	198 107
Gross weight	2950 OK (max wt)	2390 NOT OK

Weight Shift Calculations

21. Answer b. Drain 9 gallons of fuel. You need to reduce gross weight by (3,004 – 2,950) = 54 lb = $^{54}/_{6}$ gal = 9 gal. Shifting fuel changes the CG, but not the weight. Balance is not the problem, but weight is, so answer c is not correct.

Item	Weight (lb)	Mom/100
Empty weight	2015	1554
Front seats (225 + 200)	425	362 (192 + 170)
Rear (150 + 150)	300	364 (182 + 182)
Fuel (mains 44 gal)	264	198
Gross weight	3004 NOT OK, max wt 2950 lb	2478

Answer a and answer b are correct from the weight point of view, since draining 9 or more gallons of fuel will bring the weight within limits. So now we need to check the balance. Try the 9 gal first, since the less we have to drain the better, and if this doesn't work, try the balance after draining 12 gal. In these workings, we have shown how the weight values (and associated mom/100) have been subdivided and necessary interpolations made. With practice, you will be able to do this without having to lay out your workings in this way. Remember, you can always use weight arm to derive the moment.

Item	Weight (lb)	Mom/100
Empty weight	2015	1554
Front seats (225 + 200)	425	362 (192 + 170)
Rear seats (150 + 150)	300	364 (182 + 182)
Fuel (mains 35 gal)	210	158
Gross weight	2959 OK	2438 OK 2422-2499 is allowable range

22. Answer a.

This question is best solved by following the tabulation method shown in example 11-9 on page 293. The following is the sequence of steps:

- deduct the front passenger and derive the new gross weight and moment;
- deduct the rear passenger and derive the new gross weight and moment;
- add rear passenger (204 lb) to front seat and derive final gross weight and moment;
- check that weight and moment are within limits; and
- calculate original and new CG locations and determine the CG movement; and
- original CG = 84.01 in. aft of datum (226,000/2,690). New CG = 81.00 in. aft of datum (203,300/2,510). CG movement 84.01 − 81.00 = 3.01 inches forward (say 3 inches).

Item	Wt (lb)	Arm (in)	Mom/100
Gross weight	2690	84.01	2260
Front seat (OUT)	−180		−153
New GW	2510	–	2107
Rear seat (OUT)	−204		−247
New GW	2306	–	1860
Front seat (IN)	+204		+173
Final GW	2510	81.00	2033

Both GW and moment (mom/100) are within limits.

23. **a.** Yes, you can carry 100 lb but must move one passenger to front seat. As loaded initially, CG is outside aft limits of 2,393 mom/100 (by interpolation). So, 1 passenger must move from rear seat to front seat (rear arm 121, front arm 85). CG limits for 2,815 lb are 2,271 – 2,393 mom/100, so the new CG location is well within;

b. Final CG is at 82.84 inches aft of datum.

$$\text{CG Location} = 2{,}332 \text{ index units}$$

$$= \frac{233{,}200 \text{ lb-in}}{2{,}815}$$

$$= 82.84 \text{ inches aft of datum}$$

Item	Weight (lb)	Mom/100
Empty weight	2015	1554
Pilot (front seat)	180	153
2 × rear seat @ 170 lb	340	412
Baggage	100	140
Minimum fuel (30 gal)	180	135
Gross weight	2815	2394 CG outside aft limit
1 × rear passenger OUT	−170	−206 to move CG fwd
New GW	2645	2188
1 × passenger to front	+170	+144
Final GW	2815	2332 OK

24. Answer a; Burning 35 gallons will reduce gross weight by 210 lb, which will reduce the mom/100 by 158 (find this on table, or work it out as 210 lb arm 75 in. = 15,750 lb-in = 157.5 mom/100, say 158). New gross weight = 2,890 – 210 = 2,680 lb. New mom/100 = 2,452 – 158 = 2,294, but allowable limits are 2,123 to 2,287. Therefore, weight is OK, but mom/100 is too great, which means CG is aft of limits.

25. **a.** Yes, takeoff is permitted and no ballast is required;
b. Landing weight is 2,699 lb and CG is 82.25 inches aft of datum:

$$\text{CG at landing} = \frac{222{,}000 \text{ lb-in}}{2{,}669}$$
$$= 82.25 \text{ inches aft of datum}$$

Item	Wt (lb)	Mom/100
Empty weight	2015	1554
Front seat	300	256
Rear seat	180	218
Baggage	60	84
ZFW	2555	2112 OK (1990 limit)
Fuel (mains 44 gal aux 15 gal)	264 90	198 85
Planned TOW	2909 OK	2395 OK (2377 limit)
Burn-off (aux 15 gal) mains 20 gal	–90	–85
	2819	2310 OK
	–120	–90
Landing weight	2699	2220 OK (2144 limit)

Review 12: Charts

Aeronautical Charts

1. Yes.
2. A parallel of latitude that joins all points of the same latitude with the exception of the equator.
3. True.
4. The prime meridian.
5. The Greenwich Observatory just outside London, England.
6. True.
7. False. Meridians of longitude are great circles.
8. Angular position east or west of the prime meridian.
9. 1 NM.
10. 60 NM.
11. Scale is the ratio of chart length to earth distance.

VFR Charts

12. 1,434 feet (434 + 1,000 because of being in a congested area).
13. 2,873 feet MSL.
14. 122.8, the CTAFs.
15. 122.8 MHz.
16. Airport/Facility Directory (check A/FD contents).
17. **a.** Yes;
b. Yes;
c. No, it is further west;
d. No, it has a more westerly longitude.
18. **a.** N47°33´ W116°12´;
b. 2,223 feet MSL;
c. It has some lighting;
d. Hard;
e. 5,500 feet;
f. This airport does not have a control tower;
g. 122.8 MHz;
h. NAV-COM.
19. **a.** N47°54 W116°43´;
b. 2,350 feet MSL;
c. No;
d. Hard;
e. 4,200 feet;
f. 122.7 MHz;
g. Parachuting;
h. A/FD (airport/facility directory).
20. **a.** Sandpoint;
b. North;
c. Yes;
d. No;
e. SANDPOE NDB;
f. 264 kHz;
g. Automatic direction finder (ADF);
h. Morse code ident SZT (dit-dit-dit dah-dit-dit-dit dah).
21. **a.** N47°47´ W116°49´;
b. North;
c. This airport does not have a control tower;
d. 2,318 feet MSL;
e. It has some lighting;
f. Hard;
g. 7,400 feet;

h. NAV-COM;
i. 135.075 MHz;
j. NAV-COM;
k. Class E;
l. 6,500 feet MSL.

22. a. 299°M (316°T – 17°E variation);
b. 30 NM.

23. A visual checkpoint to identify position for initial call up.

24. Answer a.

Review 13: Airports and Airport Operations

Airports

1. 090° and 270° magnetic.
2. a. A closed runway;
b. B;
c. Taxiing and takeoff.
3. The weather in the control zone is below basic VFR minimums (i.e. visibility less than 3 miles and/or ceiling less than 1,000 feet).
4. By clicking the NAV-COM microphone 7 times within 5 seconds.
5. By blue omnidirectional lights.
6. Green.
7. You are slightly high on glide slope.
8. You are below glide slope.
9. A pulsating red light.

Airport Operations

10. a. Right-hand traffic and Runway 18;
b. The traffic patterns are left-hand for Runway 22, and right-hand for Runway 4. Runway 22 and Runway 4 are not available for use.
11. Observe the traffic flow, enter the traffic pattern, and look for a light signal from the tower. Squawk transponder code 7600.
12. You are cleared for takeoff.
13. a. You should exercise extreme caution;
b. The airport is not safe and you should not land there;
c. You should give way to other aircraft and continue circling.
14. LNK.
15. 1,214 feet MSL.
16. 3,414 feet MSL; 2,200 feet AGL.
17. a. A hard surface;
b. 12,901 feet;
c. 200 feet.
18. 118.5 MHz.
19. 118.05 MHz.
20. Monitor the airport traffic, and announce your position and intentions on frequency 118.5 MHz.
21. 1800Z (1200 local + 6 hours).
22. 1200Z to 0600Z.
23. 124.8 MHz.
24. On initial contact with ground control.
25. a. Right;
b. South.
26. True.
27. West.

Review 14: Visual Navigation Fundamentals

Navigation

1. Nautical miles.
2. Knot (= 1 NM per hour).
3. Foot.
4. Foot.
5. 6,076 feet.
6. Yes.
7. The speed of the airplane relative to the air mass.
8. Heading and true airspeed.
9. By a single-headed arrow.
10. a. The movement of an air mass relative to the ground;
b. By convention, the direction that the wind blows from;
c. The speed of an airplane relative to the ground;
d. The direction in which an airplane points;
e. The airplane's direction of travel over the ground;
f. The angle between the direction an airplane is pointing (its heading) and the direction in which it is traveling over the ground (its ground track);
g. The difference between desired course and the ground track.
11. The drift angle.
12. Answer a.
13. Tracking error.
14. Answer b.
15. A: HDG/TAS;
B: TR/GS; and
D: drift.

16. Answer b.
17. The physical north pole and the physical south pole (otherwise known as true north and true south.)

Time

18. **a.** 291015, 11291015;
    b. 191517, 07191517;
    c. 011700, 04011700.
19. **a.** 15°;
    b. 142.5° (142°30').
20. 2000 UTC, 1500 EST.
21. 1100Z; 0400 PDT.
22. 1030 MST.
23. 1545Z.
24. 10 hours.
25. 1930 UTC, 1230 MST.
26. False. You would expect to lose one day.
27. American Air Almanac (a publication not required by pilots).
28. True.
29. Latitude and date.
30. One hour.

Review 15: Global Positioning System (GPS)

1. 24.
2. 12 hours.
3. 11,000 NM.
4. 4.
5. Availability and continuity of service.
6. Clear/acquisition (C/A), standard positioning service (SPS).
7. Selective availability (S/A).
8. Range from a satellite is determine by the receiver measuring the period between the time of transmission and the time of reception of the satellite signal.
9. Barometric aiding.
10. The three operating modes normally provided by a GPS receiver are navigation with RAIM, navigation (two and three dimensional) without RAIM, and loss of navigation or DR.
11. By data received from the satellites.
12. By appropriate software modeling in the receiver.
13. All data entered into the GPS, either manually or automatically, from a current data base should be checked against the relevant and current navigation chart. It should also be checked to ensure that it remains current for the duration of the flight.

Review 16: Radar and ADS-B

1. Radar vectoring.
2. Answer b.
3. A transponder.
4. Air traffic control radar beacon system (ATCRBS).
5. Ground track.
6. Yes.
7. Yes.
8. Yes.
9. No.
10. Mode C.
11. You should press the ident button once firmly.
12. **a.** 7700;
    b. 7600;
    c. 1200.
13. In the Airport/Facility Directory (A/FD).
14. By the letters ASR in the communications area on the chart.
15. By the letter (R) following the particular frequency in the communications area on the chart.
16. An Airport Surveillance Radar approach.
17. **a.** 300 fpm;
    b. 450 fpm.
18. **a.** 95 NM;
    b. 55 NM;
    c. 61 NM.
19. When to commence descent to the MDA, the airplane's position each mile on final from the runway, and arrival at the MAP.
20. A particular surveillance approach must have been previously authorized and established by the FAA for a particular runway for it to be available. It must have an approach chart and/or published minimums.
21. At standard-rate unless otherwise advised. After, turns are made at half standard-rate unless otherwise advised.

Review 17: The VOR

1. VHF omni-directional range.
2. VHF.
3. DME.
4. Approximately 67 NM.
5. The magnetic bearing from a VOR ground station.
6. MH 070.
7. MH 230.
8. By its Morse code ident or voice ident.
9. At least ±2°.

10. The NAV/COM.
11. Course deviation indicator (CDI).
12. Omni bearing selector (OBI).
13. In the Airport/Facility Directory.
14. **a.** 2°;
    b. 4°;
    c. 6°;
    d. 8°;
    e. 10° or more.
15. 090 radial.
16. 270 radial.
17. 274 radial (094-TO).
18. 092 radial.
19. Right.
20. Left.
21. No, the VOR cockpit display is not heading sensitive.
22. VOR indication (i) corresponds to airplane B; VOR indication (ii) corresponds to airplane C; VOR indication (iii) corresponds to airplane D.
23. Illustration a.
24. Illustration d.
25. 4° between the two indicated bearings to a VOR.
26. Set the designated radial on the OBI. The CDI must be within 4° of the radial. The flag should show FROM.
27. Between 334- FROM and 346-FROM, or between 154-TO and 166-TO.
28. In the Airport/Facility Directory and on the A/G Voice Communication panel of the En route Low Altitude Chart.
29. Yes, since they are within ±4° of 360-FROM and 180-TO.
30. By either a Morse code identification or, in some cases, by a recorded voice identification.
31. No.
32. If a VOR is undergoing maintenance, its identification is removed. It may transmit navigation signals.
33. About once every 10 seconds.
34. The VOR must not be used for navigation. The DME may be used for navigation.
35. For a distance of 22 NM (25 SM) from the VOR.
36. One NAV/COM set is required. "MRA 6,000" indicates that adequate VOR coverage is not assured below 6,000 feet MSL.
37. It would take 27 minutes. The approximate distance is 81 NM.
38. 10° or greater.
39. At least 100 NM.
40. No further apart than 200 NM.
41. Answer d.
42. This should cause a bearing change of between 10° and 12°.
43. 5°.
44. 5 NM (5° = 5 NM at 60 DME).
45. 2.5 NM (5° = 5 NM at 60 DME = 2.5 NM at 30 DME).
46. 3 NM (3 dots = 6° = 6 NM at 60 DME = 3 NM at 30 DME).
47. You will be diverging from the radial.
48. A remote indicating compass and ADF/VOR needles.
49. A remote indicating compass and a VOR indicator.
50. The aircraft is located northeast of the VORTAC.
51. **a.** An HSI;
    b. A VOR indicator;
    c. 5 NM (2.5 dots = 5° which, at 60 NM, = 5 NM);
    d. R-345 radial (2.5 dots = 5° before the selected R-350 FROM);
    e. 165 (345-FROM to center the CDI = 165-TO);
    f. 4°;
    g. 174 (aircraft is 2 dots = 4° to the right of the selected R-170);
    h. 354 (174-FROM to center the CDI = 354-TO).
52. Answer d.
53. Answer b.
54. Answer d.
55. Answer a.
56. Answer d.
57. Answer c.

Review 18: Airspace

1. By a blue, solid line surrounding the primary airport.
2. A private pilot certificate, or a student pilot certificate which has the appropriate logbook endorsements.
3. 3 SM and clear of clouds.
4. By thick magenta, solid lines.
5. 10 NM.
6. Two-way radio communications equipment and a 4096-code transponder with an encoding altimeter (mode C).
7. Approach control.
8. 200 KIAS.

9. 3 SM and a distance from clouds of 500 feet below clouds, 1,000 feet above clouds, and 2,000 feet horizontally from clouds.
10. Class E.
11. Visibility 3 SM and distance from clouds 500 feet below clouds, 1,000 feet above clouds, 2,000 feet horizontally from clouds.
12. 14,500 feet MSL but is often designated lower.
13. **a.** 700 feet AGL;
    b. 1,200 feet AGL.
14. Visibility 1 mile and clear of clouds (since the airspace around the airport is Class G below 700 feet).
15. Class G airspace from surface to 699 feet, Class E airspace starting at 700 feet.
16. Class E airspace.
17. Low altitude high-speed military training, under IFR, above 1,500 feet AGL but with some sectors possibly below 1,500 feet AGL.
18. Class B.
19. 61 feet MSL.
20. Visual checkpoint for initial radio call prior to entering the San Jose Class C airspace.
21. 30 NM (see 30 NM arc and Part 91).
22. No SVFR is not permitted. It is indicated on the chart by "NO SVFR."
23. Flight visibility 3 SM, and distance from clouds 500 feet below, 1,000 feet above, and 2,000 feet horizontal.
24. Flight visibility 1 SM and clear of clouds.
25. Flight visibility 5 SM, and distance from clouds 1,000 feet below, 1,000 feet above, and 1 SM horizontal.
26. Flight visibility 3 SM, and distance from clouds 500 feet below, 1,000 feet above, 2,000 feet horizontal.
27. In a flight visibility of 1 SM and clear of clouds, if flown within H mile of the runway.
28. By magenta lines with hachuring.
29. Exercise extreme caution when military activity is being conducted.

Review 19: Flight Planning

1. Meteorological forecasts and NOTAMs.
2. In the Airport/Facility Directory.
3. True.
4. **a.** 2,000 feet AGL;
   b. 2,000 feet AGL.
5. False. When planning to fly more than 3,000 feet AGL, you should you base your VFR cruise altitude on magnetic course.
6. False. VOR radials are based on magnetic north.
7. Answer a.
8. Answer b.
9. **a.** 5,500 feet MSL;
   b. 4,500 feet MSL or 6,500 feet MSL;
   c. 5,500 feet MSL;
   d. 4,500 feet MSL or 6,500 feet MSL.
10. In hours and minutes.
11. The initial cruising altitude.
12. The name of destination airport if no stopover for more than 1 hour is anticipated.
13. The amount of usable fuel on board expressed in time.
14. The pilot must close the flight plan with the nearest FSS or other FAA facility on landing.

Cruise Altitude and Power Setting

15. TAS 157 knots or 181 mph.
16. TAS 159 knots or 183 mph (interpolate between the TAS values for 8,000 and 10,000 feet).
17. 20.1 in. Hg.
18. Answer a.
19. **a.** 11.5 gph;
    b. 163 KTAS.
20. **a.** 111.5 gph;
    b. 163 KTAS.
21. Answer c.
22. 36.2 gallons (fuel flow 11.5 gph, 500 NM @ 159 KTAS = 500/159 hour = 3.14 hours @ 11.5 gph = 36.2 gallons).
23. 32.1 gallons (10.9 gph, TAS 163 knots, headwind 10 knots = GS 153 knots for 450 NM = 2.94 hours @ 10.9 gph = 32.1 gal).
24. 73.3 gallons (fuel flow 11.5 gph, TAS 157 knots for 1,000 NM = 1,000/157 hours = 6.37 hours @ 11.5 gph = 73.24, say 73.3 gal).

Review 20: Introduction to Instrument Flight

1. By believing the flight instruments.
2. A sloping cloud layer may cause a false horizon.
3. A false horizon.
4. By avoiding bright white light in the cockpit.
5. **a.** The illusion of tumbling backward;
   b. The illusion of being in a nose-up attitude;
   c. The illusion of being in a nose-up attitude;
   d. Spatial disorientation.

Review 21: IFR Departure

Takeoff Minimums

1. Visibility only.

2. Visibility 1 SM. This is equivalent to an RVR of 5,000 feet.

3. Automatic terminal information service.

4. The ATIS is updated upon receipt of any official weather.

5. The absence of sky condition and visibility on an ATIs broadcast implies a ceiling of more than 5,000 feet above ground level and unrestricted visibility.

6. Standard takeoff minimums require a climb gradient of 200 feet/NM or better.

7. The required rate of climb is 200 feet per minute.

8. The required rate of climb is 300 feet per minute.

9. To achieve the same climb gradient taking off with a tailwind, compared with no-wind or a headwind, will require a higher rate of climb.

10. Takeoff minimums not standard and/or special IFR departure procedures are published.

11. Check the front of the approach plate booklet.

12. The airplane must climb at 200 feet/NM or better to remain well above the obstacle-clear surface which climbs at 152 feet/NM.

13. 480 feet per minute.

14. Nonstandard takeoff minimums may contain a cloud ceiling requirement as well as a visibility requirement.

15. Yes.

16. During an IFR departure in visual conditions, you should climb on the centerline.

17. After takeoff, you should change from tower control frequency to departure control on request.

18. You should climb to the assigned altitude at the optimum rate of climb. For the last 1,000 feet, you should reduce to between 500 feet per minute and 1,500 feet per minute.

DPs

19. "NO DP."

20. Answer a.

21. Pilot nav DPs and vector DPs.

22. Yes.

23. Departing aircraft will normally be routed to the fixing aid via a DP or by radar vectors.

24. **a.** No (see chart);
b. Begins at the runway and then via waypoints to STAAV;
c. This leads from STAAV to BEATTY VOR;
d. The required minimum climb gradient is 348 feet/NM to 7,000 feet MSL. The rate of climb needed is 696 fpm;
e. MCA 7,000 feet;
f. 7,000 feet (see route description);
g. 125.9 (shown on the DP chart);
h. NIPZO WP;
i. 84 NM.

25. 490 fpm (2.3 NM per minute × 210 feet per NM).

26. Yes.

ATC Clearances

27. An abbreviated clearance.

28. Destination or fix, DP/transition if appropriate, and altitude.

29. You should advise ATC of your intentions as soon as possible, but no later than 30 minutes.

30. 7,000 feet only.

31. 7,000 feet or below (but above minimum IFR altitude).

32. No.

33. Yes.

Review 22: En Route

Radar Service

1. Yes.

2. Radar flight-following is not terminated. You should turn to intercept the airway on your own initiative.

En Route Clearances

3. Yes.

4. Yes.

5. Yes.

6. "Radar contact."

7. Request verification.

8. Answer d.

9. Answer c.

10. Prior to transitioning from VFR to IFR, close the VFR portion of your plan with FSS and request an IFR clearance.

Radio Reports

11. No.

12. Yes.

13. By solid triangles.

14. No.

15. Yes.

16. Yes.
17. Yes.
18. No.
19. Yes.
20. You are required to report time and altitude.
21. Yes.
22. Yes.
23. Mode C should be selected at all times, unless otherwise requested by ATC.
24. Yes.
25. Yes.
26. Speed reduction (5% of TAS or 10 knots), moderate turbulence.
27. Advise ATC of revised estimate 0502Z, since it differs by more than 3 minutes from previously advised estimate (GS 120 for next 40 NM = 20 minutes).
28. Yes.
29. No.
30. Yes.
31. No.
32. Yes.

Flying the Airways

33. The protected airspace either side of an airway is at least 4 NM.
34. Yes.
35. Approximately 40° right.
36. For FAA — a white "H" in a black circle in the top RH corner of the NAVAID data box. For Jeppesen — the service will be shown immediately above the NAVAID data box.
37. This indicates no voice is transmitted on the frequency.
38. You should call (FSS name) Flight Watch. You should use 122.0. You need to give aircraft identification and the name of the nearest VOR.
39. Yes (rear cover).

High Altitude Flying and Oxygen

40. A lack of oxygen is known as hypoxia. No, symptoms of hypoxia are not easily recognized before reactions are affected. You should use oxygen to combat hypoxia.
41. Too much air being breathed into the lungs is known as hyperventilation. The remedy is to slow your breathing rate.
42. Required minimum crew must be using supplemental oxygen; passengers do not require oxygen — only above 15,000 feet (14 CFR 91, see chapter 3).

VFR-on-Top

43. No.
44. Yes.
45. "IFR to VFR-on-top."
46. Yes, provided VFR criteria are met.
47. Yes.
48. Yes.
49. Yes.
50. Answer b.
51. When flying VFR-on-top, you use VFR cruising altitudes.
52. Answer d.
53. Answer b.
54. Answer b.
55. Both VFR and IFR rules apply.
56. Yes, VFR-on-top are prohibited in Class A airspace.
57. Your correct altitude is 16,000 feet MSL. The next higher suitable altitude is 16,500 feet MSL.
58. No, VFR-on-top is not permitted in Class A airspace (above 18,000 feet MSL).
59. Yes.
60. Yes.
61. Yes, except in Class A airspace (above 18,000 feet MSL).
62. Yes.
63. VFR-on-top flights must be above the MEA.
64. Class A airspace (18,000 feet MSL).

DME Failure

65. Answer c.
66. Yes.
67. No.

En Route Diversions

68. En route flight advisory service.
69. 122.0.
70. 0600–2200 local time.
71. Fuel remaining, less transit and approach fuel, less reserves.
72. In this situation, you should advise ATC "minimum fuel." This is not a declaration of an emergency.

Radio Communications Failure

73. Squawk 7600. Continue under VFR and land as soon as practicable.
74. Squawk 7600. Follow the route as cleared. You should climb to and maintain 9,000 feet.

Canceling an IFR Flight Plan

75. Yes.

76. Yes.

77. In VFR conditions outside Class A airspace.

En Route Charts (a)

78. Minimum en route altitude.

79. Yes.

80. Yes.

81. No.

82. No.

83. No.

84. No.

85. Minimum obstruction clearance altitude.

86. Yes.

87. No.

88. An acceptable navigation signal coverage at the MOCA is assured only to a distance of 22 NM, or 25 SM, from the VOR.

89. No, the MOCA is lower than the MEA.

90. Minimum reception altitude (MRA).

91. If no MCA is specified, the lowest altitude at which you may cross the fix is 7,000 feet MSL. The climb should be initiated immediately after passing the fix at the latest.

92. In the case of operations within a designated mountainous area, no person may operate an aircraft under IFR below 2,000 feet above the highest obstacle. This is within a horizontal distance of 4 NM from the course flown.

93. Yes, the MEA assures acceptable navigation signal coverage. Yes, the MEA meets obstruction clearance requirements.

94. You would change VOR frequencies at the midway point.

95. It is shown with the distance to each VOR.

96. A predetermined geographical position defined by either navigation aids or latitude and longitude.

97. Yes.

98. Class A airspace begins at 18,000 feet MSL. No, this is not depicted on en route low-altitude charts.

99. Maximum speed below 10,000 feet is 250 KIAS.

100. Maximum speed within 4 NM of the primary airport of a Class C airspace area is 200 KIAS.

101. Yes.

102. Class E airspace.

103. Transition area extensions associated with an airport with an instrument approach procedure in a Class D airspace area commence at 700 feet AGL (and extending upward).

104. Transition areas associated with the airways route structure commence at 1,200 feet AGL. They extend up to the overlying airspace.

105. Airspace beneath a transition area and down to the surface is uncontrolled airspace (Class G).

106. Military operations areas (MOAs).

107. Class E airspace.

108. No.

109. A mode-C equipped transponder is required for all flights above 10,000 feet MSL, as well as all flights in Class B and Class C airspace.

110. At and above FL 240.

111. Class C airspace usually has one stepped tier. Class C airspace extends upward to a designated altitude.

112. Class D airspace at an airport is indicated by a boxed "D" beside the airport name. Class D airspace usually extends upward to 2,500 feet AGL—expressed as an MSL altitude.

113. Two-way communications, a Mode C transponder, and an operable VOR for IFR flights.

114. Prior to entering the Class D airspace.

115. An advisory service.

116. In the applicable A/FD booklet, and on the FAA IFR en route chart in the A/G Voice Communication legend—time is given in UTC (Z).

117. Yes.

En Route Charts (b)

118. Yes, if they serve an ATC function such as defining an intersection.

119. 121.5 and 122.2.

120. Hazardous In-Flight Weather Advisory Service.

121. Class G airspace below 14,500 feet MSL.

122. 30 NM east of Daisetta.

123. De Ridder FSS.

124. 121.5, 122.2 and 122.3.

125. Montgomery County.

126. Talk to—yes, receive from—no.

127. On the VOR frequency 116.9 with voice selected.

128. 121.5, 122.2 and VOR 116.9.

129. Mode C transponder required.

130. Because the back course serves an ATC function (defining the MARSA intersection), whereas the front course serves no such function.

131. Class D (boxed-D symbol).

132. The VOR changeover point is at the halfway point (otherwise it would be designated on the chart).

133. The VOR changeover point is 34 NM from BPT VORTAC.

134. The MEA is 2,300 feet MSL.

135. The MEA is 2,000 feet MSL.

136. The MEA is 2,500 feet MSL. Yes, adequate obstruction clearance is assured at this attitude. Yes, adequate navigational signal coverage is assured at this altitude.

137. The symbol "*1800" means 1,800 feet MSL is the MOCA. Yes, adequate obstruction clearance is assured at this altitude. No, adequate navigation signal coverage is not assured at this altitude.

138. 133.8 MHz and 124.7 MHz.

139. On the standard frequency 122.0 MHz at low altitude (up to 18,000 feet MSL).

140. HIWAS is available on 114.5 MHz. You would select this on your NAV/COM. Note: HIWAS is no longer depicted with a black square, but instead with a circled H.

141. Pilot controlled lighting.

142. Houston Center, 124.7 MHz.

Review 23: Instrument Approaches

Arrivals

1. This means you may delay the commencement of the descent.

2. You should remain VFR and advise ATC.

3. 160 ±10 knots, but exactly 160 is better.

4. You should look approximately 60° right.

5. You should look approximately 40° right.

6. Radar flight-following will be provided. You are not required to give position reports.

7. Standard Terminal Arrival Route.

8. STARs are established to simplify clearance delivery procedures.

9. To accept a STAR, you need at least a textual description of it in the cockpit.

10. Yes.

11. "No STAR."

12. **a.** The actual arrival begins at DINGO;
b. The Stanfield transition begins at TFD;
c. The Phoenix transition begins at PXR VORTAC;
d. No (see top of chart);
e. ATIS frequency 123.8.

13. No, you need an approach clearance.

Instrument Approach Charts

14. IAF.

15. Yes.

16. Aircraft approach categories are based on 1.3 times the stall speed in the landing configuration at maximum gross landing weight.

17. The "T" indicates takeoff minimums are not standard and/or departure procedures are published. You should consult the alternate takeoff procedures.

18. Special alternate minimums apply.

19. Minimum Safe Altitude.

20. 1,000 feet obstacle clearance within a 25 mile radius of the navigation facility.

21. No.

22. When established on a segment of a published route or instrument approach procedure.

23. You should intercept the localizer.

24. You should maintain heading and query ATC.

25. You should commence final approach without a procedure turn.

26. Aircraft speed.

27. Category A (since 1.3 × V_{S0} 52 = 67 knots).

28. Category B (since 1.3 × V_{S0} 77 = 100 knots).

29. A straight-in landing may be made if the pilot has the runway in sight in sufficient time to make a normal approach for landing, and has been cleared to land.

30. Category C.

31. The maximum speed should not be greater than 250 knots.

32. No.

33. No.

34. Timing on the outbound leg should commence at wings-level after completion of the turn outbound.

RVR

35. Minimums for an ILS approach, with all components operative, normally establish a visibility requirement of RVR 2,400 feet or visibility ½ SM.

36. Answer c.

37. Yes.

38. The visibility requirement should be a ground visibility of ½ statute mile.

Sidestep Maneuver

39. You should commence this maneuver as soon as the runway environment is in sight.

Missed Approaches

40. You should track to the MAP before commencing the turn.

41. You should commence a missed approach, make a climbing turn toward the landing runway and continue the turn until on the missed approach course.

Equipment Requirements

42. **a.** ILS;

b. ILS, DME;

c. VOR;

d. ADF;

e. Approved RNAV receiver;

f. IFR-approved GPS and supporting ground-based NAVAIDs as identified on the approach plate.

Visual Illusions on Approach

43. Haze creates the illusion that the runway is further away, suggesting a lower-than-normal approach.

44. You should rely on the flight instruments.

45. A runway that is larger than usual will appear to be closer than it really is.

46. A runway that is smaller than usual will appear to be further away than it really is.

47. A narrow runway will give the pilot on the correct approach slope an impression of being high on slope.

48. A wide runway will give the pilot on the correct approach slope an impression of being low on slope.

49. When on approach to land on an upsloping runway without slope guidance, the tendency is to approach on a flight path that is too shallow.

50. When on approach to land on a downsloping runway without slope guidance, the tendency is to approach on a flight path that is too steep.

Riverside ILS Rwy 9 Chart

51. The minimum safe altitude is 5,200 feet within 25 NM of RAL.

52. This ATIS can be received on frequency 128.8 MHz.

53. Ontario approach control frequency is 135.4.

54. Riverside control tower frequency is 121.0. It is not manned continuously.

55. Ground control frequency is 121.7.

56. Appropriate NAVAID selections would be: VOR frequency and ident—VOR 115.7 SLI; ILS frequency and ident—ILS 110.9 I-RAL.

57. The minimum altitude is 3,000 feet.

58. Yes.

59. No.

60. Once you have intercepted the localizer, you may descend to 2,500 feet prior to EXPAM.

61. The FAF is at EXPAM INT.

62. 29.4 NM.

63. No.

64. The glide-slope angle is 3°. The threshold crossing height of the glide path is 39 feet.

65. TDZE 794 feet MSL.

66. Decision height is 994 feet MSL which is 200 feet HAT. 1.3VS0 gives 78 knots. This places the aircraft in Category A.

67. The visibility required to continue with the landing is ½ SM.

68. The minimum becomes MDA 1,300 feet MSL, which is 506 feet HAT. You can recognize the MAP by timing from the FAF.

69. Yes, you will need a second NAV/COM. You may cross AGNES at or above 1,300 feet MSL. You may then descend to an MDA of 1,200 feet MSL. Visibility required to land is ½ statute mile.

70. With the NAV-1 on the localizer and the NAV-2 on the PDZ VOR radial 031.

71. You may continue.

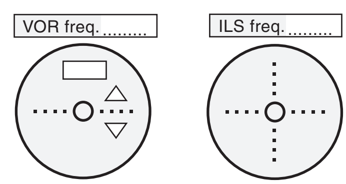
72. You must make a missed approach.

73. Direct entry.

74. By making an appropriate holding pattern entry.

75. You should squawk 7600 with your transponder. You should commence approach at 0915 (see chapter 3).

76.



77. No.

78. 4 (SLI VORTAC, POM VORTAC, PIRRO intercept and EXPAM INT).

79. When Riverside Tower is not operating, the runway/approach lighting is pilot-activated.

80. COM, 121.0 MHz. Medium Intensity Approach Lighting System, with RAIL/SFL.

81. Circling minimums (MDA 1,300 feet MSL, visibility 1 SM).

82. 2,851 feet.

83. No (no ASR/PAR mentioned in communications area of chart).

Review 24: Visual Maneuvering

1. A straight-in procedure aligns the airplane within ±30° of the landing runway.

2. An instrument approach procedure that is not straight-in will be followed by a circling or circle-to-land maneuver.

3. A circle-to-land maneuver procedure may be initiated once the pilot is visual at or above the circling MDA.
4. Answer b.
5. Answer b.
6. Yes, if you have the runway (which must be suitable, of course) in sight and sufficient room to make a normal approach.
7. Obstruction clearance in the circling area is 300 feet.
8. If the highest obstacle in the circling area is 450 feet HAA, you would expect the circling MDA to be 750 feet HAA.
9. If the circling MDA is 950 feet HAA, you would expect the highest obstacle in the circling area to be 650 feet HAA.
10. The circling area for an airplane that maneuvers at 90 knots or less is defined by 1.3 NM radii from the runway end.
11. The circling area for an airplane that maneuvers at 120 knots or less is defined by 1.5 NM radii from the runway end.
12. Your circling MDA is that for airplanes maneuvering at less than 120 knots. This is Category B ($1.3V_{S0}$ = 104 knots).
13. Your circling MDA is that for airplanes maneuvering at less than 90 knots. This is Category A ($1.3V_{S0}$ = 85 knots).
14. No.
15. Answer b.
16. Yes.
17. A contact approach or a visual approach.
18. You must have the airport in sight or a preceding aircraft to follow, and be able to proceed to the airport in VFR conditions.
19. Yes.
20. No.
21. Answer a.
22. VFR conditions.
23. One mile visibility and clear of clouds.
24. Yes.
25. No.
26. Yes.
27. Answer b.
28. Wingtip vortices.
29. Behind heavy aircraft flying at high angles of attack.
30. Yes.
31. Answer e.
32. If possible, you should try to land beyond the touchdown point of a preceding heavy jet airliner.
33. You would expect a sudden loss of airspeed.
34. Hydroplaning may occur at high speeds on a wet and slushy runway.
35. During hydroplaning, the tire is separated from the runway surface.
36. Hydroplaning dramatically decreases a pilot's ability to achieve directional control and good braking on the runway.
37. This indicates that the ground visibility is less than 3 miles and/or the ceiling is less than 1,000 feet.
38. Activate the airport rotating beacon.

Review 25: The VOR Instrument Approach

1. After crossing the SYI VOR the pilot should reset the OBS to the outbound radial of 332°. Unless the inbound course to the VOR happened to be 332° the pilot will now have to make an intercept of that radial. If the airplane is higher than 2,800 feet (the procedure turn altitude) a descent should begin as soon as the 332° radial has been intercepted.
2. The procedure turn altitude of 2,800 feet is only a safe altitude when within 10 nm of the SYI. If the pilot has DME, the distance outbound should be monitored to ensure the airplane remains within the 10 NM mile area. If there is no DME timing the outbound leg is necessary. The rule of thumb is to go outbound one minute if the final approach fix is not at the airport, or two minutes if it is. Pilots need to use caution and consider the wind when timing the legs.
3. The minimum altitude for the VOR RWY 18 approach at SYI is 2,800 feet. If the aircraft arrives over the VOR at a high altitude, the pilot should descend down to 2,800 while outbound and even while in the procedure turn. The line under the altitude of 2,800 feet on the chart's profile view indicates that a pilot can be higher, but not lower than 2,800 feet.
4. If the pilot does not remember to switch the OBS from the outbound to the inbound course, they will experience reverse needle sensing when they are attempting to intercept the final approach course. This could be distracting and delay the intercept. It is very important to make the intercept quickly because the pilot cannot start the final descent until on the final approach course—any delay could mean the pilot cannot get down to the MDA before reaching the Missed Approach Point, and that could trigger an unnecessary missed approach. During the proce-

dure turn, the pilot is flying a heading, not tracking a radial, so this is the best time to make the switch to the inbound course.

5. When flying the VOR RWY 18 approach at SYI, and without DME the pilot will know when the aircraft has arrived at the Missed Approach point when the Ambiguity Indicator switches through the OFF or NAV position and to the FROM indication.
6. Instrument approaches do not have to be aligned exactly with the runway centerline to be considered "straight-in." The approach has no straight-in minimums and becomes a circling only approach when the angle between the final approach course and runway centerline exceeds 30°. The actual location of the VOR at Shelbyville is just to the East of the runway. The final approach course is offset from the runway centerline here but the course crosses the runway threshold in line with the position of the VOR antenna.
7. The pilot should not adjust the OBS at all in this situation. During the missed approach from the VOR RWY 18 approach at SYI, the pilot will make a right climbing turn from the MDA to 2,800 feet. The pilot should roll out of that turn on a heading of approximately 332°, which is the outbound heading of the holding pattern. The OBS should still be set to 152° as that was what was used to determine the final approach course before the missed approach. By leaving the OBS at 152°, the pilot will be able to determine when the outbound leg of the holding pattern begins by noting when the ambiguity indicator moves from FROM to OFF to TO. Then when the outbound leg has been flown, the pilot makes a right turn to intercept the inbound course and the OBS is already set and reverse needle sensing is avoided.

Review 26: GPS Approaches

1. LNAV is the GPS provided Lateral Navigation used to provide a course to the runway on a non-precision approach. VNAV or Vertical Navigation is an electronic vertical path to the runway. The system is unlike an ILS glideslope, because it is only advisory information, but does provide the pilot with a constant rate of descent to the minimum altitude of the approach.
2. WAAS is the Wide Area Augmentation System. WAAS couples GPS with ground stations to increase the accuracy of the GPS signals. The increased accuracy makes it possible for GPS approaches to have lower minimums and provide VNAV. LAAS is the Local Area Augmentation System couples with GPS to provide signal accuracy that is equal to an ILS glideslope. WAAS, as the name implies, covers a wide area and many airports. The LAAS is more accurate because it is specific to a particular airport or even a particular runway.
3. Required Navigation Performance is a set of accuracy criteria for aircraft flying through the nation's airspace. As traffic congestion increases, there will be the need to fly airplanes closer together while maintaining safety. To do this navigation aids must provide extreme precision.
4. GLS is the Global Navigation Satellite System's precision approach. The GLS approach uses the LAAS together with GPS signals to provide an approach that equals or improves the accuracy of the current Instrument Landing System (ILS).
5. 980 feet and 1 mile visibility.
6. The pilot would need to fly a Circle to Land approach. The MDA for that circle is 1,080 feet. The pilot should plan to stay close to the airport, because the visibility minimum if one mile. If the visibility was indeed just one mile and the pilot allowed the airplane to fly a pattern larger than a mile, the pilot would lose sight of the airport and this would force a missed approach.
7. NA means, Not Authorized. To have LNAV/VNAV capability, the approach must have access to WAAS. The NA indicates that this approach does not use WAAS and therefore does not have an electronic rate of descent indication. To have a GLS capability, an approach must have access to LAAS. The NA means that this approach does not have access to LAAS and therefore is not a precision approach with electronic glideslope. Both the LNAV/VNAV and GLS lines on this approach chart are "place holders" for when WAAS and LAAS capability becomes available.
8. Letters appear in the title of a GPS approach when there are two or more approach procedures to the same runway. The letters assigned to the approach procedures start at the end of the alphabet and work backwards: Z, Y, X, etc.

Review 27: Instrument Landing System (ILS)

ILS Specifications

1. Approximately 200 feet HAT.
2. Immediately you reach the DH.
3. Outer compass locator.
4. Middle compass locator.
5. I-TFR in Morse code is dit-dit dah dit-dit-dah-dit dit-dah-dit. You would expect to hear the code identifier TF—dah dit-dit-dah-dit.

6. A flashing blue marker light and continuous dashes (dah-dah-dah-dah-dah).
7. A flashing amber light and alternate dots and dashes (dit-dah-dit-dah-dit-dah-dit-dah).
8. A flashing white light and rapid dots (dit-dit-dit-dit-dit-dit-dit-dit).
9. Approximately 70 feet.
10. Approximately 14 feet.
11. Approximately 355 feet.
12. Approximately 215 feet.
13. 140 feet high, and 710 feet right of the localizer.
14. Runway visual range.
15. ½ SM or RVR 2,400 feet.

HSI and ILS

16. The better technique is to set the inbound localizer course, so that it is a command instrument.
17. You will have reverse sensing, and the HSI will act as a noncommand instrument (a poor technique).
18. Yes.
19. Answer e.
20. Answer a.
21. Answer d.
22. Answer b.
23. **a.** Positions 9 and 6;
    b. Positions 5 and 13;
    c. Position 12;
    d. Position 2;
    e. Positions 8 and 3;
    f. Position 4;
    g. Positions 7 and 11;
    h. Position 1;
    i. Positions 7 and 11.

Unusable ILS Components

24. Answer a.
25. A compass locator, precision radar (PAR), surveillance radar (ASR), DME, VOR, or a nondirectional fix authorized on the instrument approach chart.
26. A compass locator, or precision radar (PAR).
27. A localizer approach.
28. The minimum is raised.
29. **a.** 6,839 feet MSL;
    b. 200 feet HAT;
    c. 6,980 feet MSL;
    d. This is the localizer minimum, known as the minimum descent altitude.
30. Yes (but recheck minimums without a glide slope).

Flying the Approach

31. Maintain the assigned heading and query ATC.
32. Request a holding pattern or radar vectors.
33. No greater than ±2°.
34. Groundspeed.
35. Yes. You would expect to decrease the rate of descent to stay on slope (because of the lower groundspeed).
36. Your initial correction should be to adjust power.
37. Your groundspeed will increase. To stay on the ILS glide slope, the rate of descent should be increased.
38. At the decision height on the glide slope.

Lighting, and Precision Instrument Runway Markings

39. 3°.
40. Top bar red, bottom bar white.
41. Top bar white, bottom bar white.
42. Top bar red, bottom bar red.
43. Top bar red, middle bar red, bottom bar white.
44. Top bar red, middle bar white, bottom bar white.
45. Top bar white, middle bar white, bottom bar white.
46. Top bar red, middle bar red, bottom bar red.
47. The pilot of along-bodied airplane should treat the top two bars of a three-bar VASI as a two-bar VASI and neglect the bottom bar.
48. Top bar red, middle bar white, bottom bar white.
49. You should fly level until you intercept the slope, then descend.
50. Yes.
51. 10° left or right of the extended centerline out to a distance of 4 NM from the runway threshold.
52. **a.** Amber;
    b. Green;
    c. Red.
53. This means that you are on slope. Usual slope is 3°.
54. This means that you are below slope. Your slope is likely to be 2.8°.
55. This means that you are well below slope. Your slope is likely to be below 2.5°.
56. This means that you are above slope. Your slope is likely to be 3.2°.
57. This means that you are well above slope. Your slope is likely to be above 3.5°
58. Runway end identifier lights. REIL are synchronized flashing white lights specifically installed at an airport to enable you to identify the runway end on approach in reduced visibility.

59. **a.** 500 feet;
b. 1,000 feet;
c. 500 feet.

60. By arrows leading to the threshold mark.
61. Answers a and b (taxiing and takeoff).
62. Yes.
63. Yes.

Simultaneous Approaches

64. The tower frequency.
65. Simultaneous approaches can only be made when there is at least 4,300 feet between the centerlines of the parallel runways.

The Sidestep Maneuver

66. As soon as you are visual and have the runway environment in sight.
67. The sidestep maneuver may only be performed when the landing parallel runway is displaced not more than 1,200 feet from the runway on which the precision approach aid is aligned.

LDA, SDF and ILS Approaches

68. Approximately 5°.
69. Yes.
70. No.
71. No.
72. No, the SDF is less precise than the LDA.
73. The width of an SDF course is either 6° or 12°.
74. No.
75. No.
76. An instrument landing system (ILS).
77. No.

Review 28: Holding Patterns, Procedure Turns, and DME Arcs

1. Answer b.
2. Four minutes.
3. In strong head/tailwind conditions on the outbound leg of a holding pattern, the timing should be adjusted by two seconds per knot of the estimated head/tailwind component.
4. With an estimated fifteen-knot tailwind component on the outbound leg of a holding pattern, it is reasonable to adjust the timing by reducing the 60 seconds by half, and flying outbound for 30 seconds.
5. Triple the wind correction angle.
6. 15° right.
7. Refer to figure 28-8 (page 622) for the sector 1 entry; refer to figure 28-9 (page 622) for the sector 2 entry; and refer to figure 28-10 (page 622) for the sector 3 entry.
8. A Sector 1 entry is also known as a parallel entry.
9. A Sector 2 entry is also known as a teardrop entry.
10. A Sector 3 entry is also known as a direct entry.
11. Refer to figure 28-20 (page 628).
12. The correct procedure is to join holding pattern A (because the holding fix is always at the end of the inbound leg) using a direct entry, with an initial turn after passing the fix left to MH 266.
13. The correct procedure is to join holding pattern B (because the holding fix is always at the end of the inbound leg) using a parallel entry, with an initial turn after passing the fix right to MH 268.
14. Abeam the fix.
15. When the wings are level after turning outbound.
16. The recommended maximum speed is 175 KIAS.
17. The recommended maximum speed for propeller-driven aircraft is 175 KIAS. The recommended maximum speed for jets is 265 KIAS.
18. The recommended maximum speed for a jet in a holding pattern below 14,000 feet MSL is 230 KIAS (210 where published). The lowest holding altitude that provides adequate protection is known as the minimum holding altitude (MHA).
19. Abeam the fix.
20. Abeam the fix.
21. **a.** Right turns;
b. 090-TO the fix;
c. Direct entry;
d. Right;
e. MH 270.

22. **a.** Left turns;
b. 180-TO the fix;
c. Direct entry;
d. Left;
e. MH 360.

23. **a.** Right turns;
b. 360-TO;
c. Teardrop entry;
d. Right;
e. MH 150 (the outbound heading).

24. **a.** Left turns;
b. 270-TO;
c. Parallel entry;
d. Right;
e. MH 090

25. **a.** Right;
b. 360-TO;
c. Direct entry;
d. Right;
e. MH 180.

26. **a.** Left turns;
b. 180-TO;
c. Teardrop entry;
d. Left;
e. MH 030.

27. **a.** Right turns;
b. 090-TO;
c. Direct entry;
d. Right;
e. MH 270.

28. **a.** Right turns;
b. 050-TO;
c. Direct entry;
d. Right;
e. MH 230.

29. **a.** Left turns;
b. 220-TO;
c. Teardrop entry;
d. Right;
e. MH 070.

30. **a.** Left turns;
b. 320-TO;
c. Parallel entry;
d. Right;
e. MH 140.

31. On the outbound leg.

32. The holding maneuver must be executed within the one minute time limitation or the published leg length. The maneuver is considered complete when established inbound.

33. Yes.

34. Yes.

35. No.

36. The pilot should leave the final approach fix inbound at the assigned time. Yes, the holding pattern can be adjusted to achieve this.

37. No—the pilot must be in contact with ATC, which may be center or approach control, before switching to the tower.

38. For a timed approach from a holding fix with only one missed approach procedure available, the reported ceiling and visibility minimums must be equal to or greater than the prescribed circling minimums for the instrument approach procedure.

39. A procedure turn is a common maneuver used for course reversal.

40. Yes.

41. A procedure turn should normally be completed within 10 NM of the procedure turn fix, or as otherwise published on the instrument approach chart.

42. The bearing pointer should be on the right wingtip.

43. The bearing pointer should be ahead of the right wingtip.

44. The bearing pointer should be behind of the right wingtip.

45. For each 1/2 NM you have drifted outside a DME arc, a suitable heading change is approximately 10° to 20° toward the arc.

46. Yes, course reversal or positioning to commence an instrument approach can sometimes be achieved by entering an appropriate holding pattern.

47. Squawk 7600 with the transponder. You should depart the holding fix at 1245. Yes, in IFR conditions, you should continue on the cleared route.

Review 29: Normal Instrument Flight on a Partial Panel

1. The altimeter, ASI, and VSI.

2. **a.** The altimeter;
b. The altimeter;
c. The ASI;
d. The ASI;
e. The HI;
f. The turn coordinator.

3. Climbing turn to the right, AI has failed—right turn (turn coordinator and HI, not supported by AI), climb (altimeter VSI and ASI, not supported by AI), coordinated (ball).

4. Straight-and-level flight, airspeed decreasing (perhaps iced-up pitot tube)—wings level (AI, turn coordinator and HI), level flight (AI, altimeter and VSI), coordinated, pitot system has failed (ASI indication not supported by other instruments).

5. The HI, magnetic compass, and turn coordinator.

6. The magnetic compass.

7. The ASI, altimeter, and VSI.

8. The ASI, altimeter, and VSI.

9. The ASI.

10. The AI, HI, and turn coordinator.

11. The AI and HI.

12. Descending right turn—right turn (AI, turn coordinator and HI), nose down (AI), pitot-static system failed since there is no increase on the ASI, altimeter and VSI.
13. Level turn to the right, ASI has malfunctioned—right turn (AI, turn coordinator and HI), level (AI, altimeter and VSI), ASI reading not supported by other instruments.
14. Reaching approximate level attitude is indicated by the ASI and altimeter stopping their movement.
15. Straight-and-level flight, with a malfunctioning vacuum system (AI and HI unreliable)—wings level (turn coordinator, not supported by AI that shows a bank to the right, and not supported by the HI that shows a turn to the left), level flight (AI, altimeter and VSI).
16. Climbing right turn, with a malfunctioning turn coordinator—bank to the right (AI and HI, not supported by turn coordinator), climb (AI, altimeter and VSI).
17. Climbing right turn with a faulty static system—right bank (AI, turn coordinator and HI), nose high (AI with no support, but fixed indications on the altimeter and the VSI along with a decreasing airspeed are consistent with a climb with a blocked static system)—therefore lower the nose and level the wings with reference to the AI.
18. The ASI and altimeter.
19. The HI.
20. The magnetic compass.

Review 30: Winds, Air Masses, and Fronts

1. The atmospheric layer above the tropopause.
2. A low moisture content, little vertical movement, and small changes in temperature with an increase in altitude.
3. No.
4. Yes.
5. Variations in solar heating of the earth's surface.
6. An apparent force resulting from the passage of the air over the rotating earth.
7. It acts at a right angle to the wind and deflects it to the right in the northern hemisphere until it is flowing parallel to the isobars.
8. It causes surface winds to weaken in strength and to flow across the isobars.
9. Because they are slower and therefore less affected by the Coriolis force.
10. Answer c.
11. Yes.
12. Answers a, b and c.
13. Strong windshear.
14. Answer a.
15. Answer b.
16. An extensive body of air with fairly uniform temperature and moisture content horizontally.
17. A wind change will always occur.
18. Answer a.
19. Answers b and c.
20. Airspeed will tend to increase. To maintain a constant airspeed, power will initially have to be decreased for a brief period.
21. Airspeed will tend to decrease. To maintain a constant airspeed, power will initially have to be increased for a brief period.
22. Airspeed and pitch attitude will decrease. There will be a tendency to go below slope.
23. Airspeed and pitch attitude will increase. There will be a tendency to go above slope.
24. **a.** The power setting will be lower than normal;
    b. The power setting will be lower than normal (a further decrease);
    c. The power setting will be higher than normal.
25. Windshear can occur at any level.

Review 31: Visibility

1. Answer a.
2. Answer a.
3. No.
4. Yes.
5. The air beneath an inversion is held down by the inversion. This forms a stable layer.
6. Likely conditions are smooth with poor visibility.
7. There is little mixing of air above and below an inversion.
8. Yes.
9. On air temperature.
10. Yes.
11. No, water vapor is invisible.
12. Yes.
13. No—as a parcel of air is cooled, it is capable of holding less water vapor.
14. Its dewpoint.
15. When it is at or below its dewpoint. This process is encouraged by the presence of condensation nuclei in the air.

16. When water vapor condenses. (The lack of condensation nuclei in clean air sometimes delays the condensation process until the air temperature is below the dewpoint.)
17. When the air is cooled to its dewpoint temperature or below.
18. The prevalence of condensation nuclei as a result of the combustion process.
19. Smog.
20. On a clear night when the temperature/dewpoint spread is small and the wind is light.
21. Radiation fog is more likely to form over land than over the sea.
22. Yes.
23. A common type of surface-based inversion that can lead to ground fog is caused by ground radiation on clear, cool nights with light winds.
24. The temperature of the collecting surface must be below the dewpoint of the surrounding air, and the dewpoint must be above freezing.
25. The temperature of the collecting surface must be below the dewpoint of the surrounding air, and the dewpoint must be below freezing.
26. When moist air is carried over a cooler surface.
27. In winter and in coastal areas.
28. Yes.
29. Fog.
30. If the lake is colder than the air.
31. Winds stronger than about 15 knots.
32. Upslope fog.
33. Advection fog and upslope fog.
34. Yes.
35. No.
36. By a wind blowing it away.

Review 32: Clouds

1. High-level clouds, middle-level clouds, low-level clouds, and clouds with extensive vertical development.
2. High-level clouds.
3. Low-level clouds.
4. That the clouds are rain-bearing.
5. Fractus.
6. Lenticular (lenticularis).
7. The dewpoint temperature.
8. It rises.
9. It will rise to 100%.
10. Its temperature.
11. Excess water vapor will condense out and form dew.
12. Excess water vapor will condense out and form frost.
13. The dewpoint must be below freezing, and the collecting surface must be below freezing.
14. Insufficient condensation nuclei in the air.
15. Unstable air.
16. Unstable air.
17. Stable air.
18. From the value of the ambient lapse rate.
19. This is a characteristic of stratiform cloud. This type of cloud is formed in stable air.
20. Answer b.
21. Answer d.
22. A rate of 3°C per 1,000 feet.
23. A rate of 1.5°C per 1,000 feet.
24. This is assumed to be 2°C/1,000 feet. Yes, it can vary significantly from this value.
25. The cloud type most likely to develop is cumuliform cloud. There will be extensive vertical development.
26. The cloud type most likely to develop is stratiform cloud. There will be little vertical development.
27. Cumuliform clouds, turbulent flying conditions, and good visibility.
28. Standing lenticular altocumulus clouds.
29. A rotor cloud.
30. Cumulonimbus clouds.
31. Ice crystals.
32. Turbulent conditions.
33. Often smoother conditions.
34. Strong turbulence.
35. Stratiform cloud.
36. Cumuliform cloud.
37. The growth rate is enhanced by updrafts. This is most likely in cumulonimbus clouds.
38. Virga.
39. There is a great risk. This is the case because clouds of extensive vertical development may contain large supercooled water drops.
40. There is little risk. This is the case because high-level cirriform clouds consist mainly of ice crystals.
41. Answer c.
42. Evaporating rain will cause the temperature to decrease.
43. Yes.
44. Microburst.

Review 33: Icing

Structural Icing

1. Visible moisture and a temperature at or below freezing.
2. Clear ice.
3. Rime ice.
4. Approximately 4,500 feet MSL.
5. Approximately 7,500 feet MSL.
6. When flying through freezing rain.
7. Supercooled water drops.
8. When rain falls into a layer of air that is below 0°C.
9. These can form freezing rain. They may freeze to form ice pellets.
10. They will spread out on impact, join together and freeze to form clear ice (clear ice is very dangerous).
11. By ice pellets.
12. Freezing rain at a higher level.
13. This indicates that temperatures at some higher altitude are above the freezing temperature of 0°C.
14. Flying through wet snow indicates that temperatures at some higher altitude are below the freezing temperature of 0°C. This also indicates that the temperature at your altitude is above 0°C.
15. Yes.
16. Yes. Frost can cause a loss of lift by causing early airflow separation from the wing.
17. Yes.
18. Cumuliform cloud.
19. High-level cloud.
20. In freezing rain.
21. PIREPs, SIGMETs, and AIRMETs.

Induction Icing

22. No.
23. Yes.
24. It cools.
25. Carburetor heat control.
26. Yes.

Instrument Icing

27. The ASI only.
28. The ASI, altimeter, and VSI.

Review 34: Thunderstorms

1. Lightning.
2. Moist air, an unstable ambient lapse rate, and a lifting action in the atmosphere.
3. The lapse rate is high and that rising air will tend to keep rising.
4. Cumulus stage, mature stage, and dissipating stage.
5. Updrafts.
6. Updrafts.
7. Updrafts and downdrafts.
8. Downdrafts.
9. Downdrafts have developed, and that the mature stage in its life cycle has commenced.
10. Thunderstorms that grow out of a massive cloud layer that possibly obscures them.
11. In squall lines, which should be avoided.
12. Yes. Hazardous windshear and turbulence may occur beneath, within, and on all sides of a thunderstorm cloud.
13. Answer c.
14. Answer a.
15. Large water drops in some cumulonimbus clouds, giving pilots warning of possible turbulence, windshear, hail, icing and instrument weather conditions.
16. Yes.
17. No.
18. At least 20 NM.
19. They should be separated by at least 40 NM. You can maintain a separation from each of at least 20 NM.
20. No.
21. Answer c.
22. Answer c.
23. 15 minutes.
24. Windshear.
25. A downdraft followed by a 45 knot tailwind as it exits the microburst.
26. A total windshear of 90 knots can be expected.
27. This can effect an increase in performance. The aircraft is likely to gain airspeed and altitude.
28. Yes.
29. There will be a decrease in performance. The aircraft is likely to lose airspeed and altitude.
30. **a.** Position 2 will experience an increase in performance due to increasing headwind;
    b. Positions 4 and 5 will experience a decrease in performance due to a strong downdraft;
    c. Position 6 will experience a decrease in performance due to increasing tailwind.

31. You should set the power for the recommended turbulence penetration airspeed, maintain heading, and maintain attitude (pitch and bank).
32. You should attempt to hold the wings level with the ailerons and hold a constant pitch attitude even if the altitude varies.
33. Answer b.
34. **a.** Position 2 will experience an increase in performance due to increasing headwind;
 b. Position 5 will experience a decrease in performance. This is due to a strong downdraft;
 c. Positions 7 and 8 will experience a decrease in performance. This is due to increasing tailwind.

Review 35: High-Level Meteorology

1. A wind of 50 knots or greater.
2. An abrupt change in temperature lapse rate.
3. 37,000 feet.
4. The jetstream is generally weaker and further north in the summer compared to in the winter.

Review 36: Weather Reports and Forecasts

Weather Briefings

1. From a Flight Service Station (FSS); they may also be obtained from a National Weather Service office.
2. 1-800-WX-BRIEF.
3. True.
4. Aviation Weather Services (FAA Advisory Circular AC 00-45).
5. No.
6. A standard briefing.
7. Synopsis.
8. Outlook.
9. By calling Flight Watch on frequency 122.0 MHz.
10. The fact that you are a pilot; VFR or IFR; N-number of aircraft; aircraft type; departure point; the route; destinations; en route altitude; time of departure; and time en route.
11. A standard briefing.
12. An outlook briefing.
13. An abbreviated briefing from an FSS.

Weather Depiction Charts

14. Actual weather as reported.
15. Weather reporting stations.
16. Answer a.
17. Answers a, c and g.
18. Ceiling less than 1,000 feet and/or visibility less than 3 miles.
19. Ceiling greater than 3,000 feet and/or visibility greater than 5 miles.
20. Ceiling is at or between 1,000 feet AGL and 3,000 feet AGL, and/or the visibility is at or between 3 miles and 5 miles.
21. **a.** IFR conditions;
 b. VFR conditions;
 c. MVFR conditions;
 d. Sky clear;
 e. Sky overcast;
 f. Sky obscured or partially obscured.
22. The reported sky cover is overcast with a ceiling of 700 feet above ground level.
23. Missing data.
24. Sky coverage is broken, which means a sky coverage of from six tenths to nine tenths, with a base of 500 feet AGL.
25. Sky obscured or partially obscured.
26. Thick fog (visibility less than G mile).
27. Light fog with visibility 2 miles.
28. Continuous rain.
29. **a.** The ceiling in southeast New Mexico in the contoured area without shading is 6,000 feet;
 b. The sky is overcast;
 c. There are thunderstorms;
 d. Visibility is 4 miles;
 e. Conditions are MVFR.
30. A stationary front.
31. Fog.
32. Low ceilings of 300 feet with fog and drizzle.
33. At 25,000 feet.
34. No.

Surface Analysis Charts

35. Answer b.
36. Answers a, c, e and f.

Radar Summary Charts

37. No.
38. Yes.
39. No.
40. Yes.
41. On radar summary charts.
42. By a single arrow.

43. By a shaft and barbs.
44. The shaft shows the direction. The barbs show speed.
45. The radar summary chart and the weather depiction chart.
46. **a.** Conditions that are weak to moderate;
   b. Conditions that are strong to very strong;
   c. Conditions that are intense to extreme;
   d. Tornado watch number 762;
   e. Severe thunderstorm watch number 657.

METAR/SPECI Weather Reports

47. Scheduled hourly observations of the weather.
48. Unscheduled special observations indicating a significant change in one or more elements of the weather.
49. UTC (coordinated universal time).
50. Special report for Bartow, 14th day of the month at 11:30Z. Wind is calm with 3 statute miles visibility and haze. The sky is clear and the altimeter setting is 30.04 in. Hg.
51. Automated weather observation system capable of detecting precipitation used.
52. The lowest layer of clouds or obscuring phenomena aloft that is reported as broken or overcast.
53. 2,400 feet thick (ceiling is indefinite, indicated by "VV000," so the sky cover extends from the surface at 1,600 feet MSL to the top of the overcast layer at 4,000 feet MSL).
54. The ceiling has improved by 1,600 feet (3,000 – 1,400).
55. Information missing in a METAR/SPECI report will be omitted completely.

PIREPs

56. "UA."
57. "UUA."
58. Over location (/OV); time (/TM); flight level or altitude (/FL); and aircraft type (/TP).
59. **a.** /SK—sky cover;
   b. /WX—flight visibility and weather;
   c. /TA—temperature in degrees Celsius;
   d. /WV—wind velocity;
   e. /TB—turbulence;
   f. /IC—icing;
   g. /RM—remarks.
60. Answer c.
61. Intermittently between layers.
62. MSL.
63. 20 NM south of Atlanta at 1620Z, a pilot flying at 5,000 feet MSL in a Beech 18 reported moderate rime ice.
64. The pilot report mentions the top of the lower overcast layer at 3,000 feet MSL (OVC 030), and then a second overcast layer with base 5,000 feet MSL and tops 8,000 feet MSL (050 OVC 080). Base of the lower overcast layer is 800 feet AGL (OVC008), which is 1,800 feet MSL, giving a thickness of 1,200 feet (3,000 – 1,800).
65. PIREP/overhead MRB/time 1835 UTC/altitude 6,000 feet MSL/aircraft type PA28/sky cover—intermittently between layers/turbulence: moderate/remarks: rain and turbulence increasing westward.
66. "Intermittent light turbulence."
67. "Occasional light chop."
68. "Continuous moderate turbulence."

Low-level Significant Weather Prognostic Charts

69. Prog.
70. Low-level significant weather prog chart.
71. Yes.
72. By the VT—valid time—in the lower left corner of the chart.
73. Moderate turbulence from the surface to 18,000 feet.
74. In a direction toward the east at a speed of 30 knots.
75. Marginal VFR (outlined by scalloped lines) with some areas of IFR (outlined by smooth lines) as shown in upper chart, and some associated thunderstorms and showers shown in lower chart.
76. 10,000 feet MSL (by interpolation between 8,000 and 12,000).
77. IFR.
78. MVFR.
79. 12,000 feet or higher.
80. **a.** Continuous rain;
   b. Continuous rain covering more than half the area;
   c. Rain shower,

TAFs

81. The terminal forecast (TAF).
82. Out to 5 NM.
83. An area from 5 NM out to 25 NM.
84. The surface visibility is more than 6 statute miles.
85. The wind is expected to be variable in direction and less than 3 knots.

86. The following conditions are expected to be temporary during the time mentioned in the forecast.
87. Vertical visibility zero—used to describe an indefinite ceiling.
88. Conditions are forecast to occur with a probability of 40%.
89. A sudden increase in wind speed of at least 15 knots to a sustained speed of 20 knots or more for a period of at least 1 minute.

Area Forecasts and the Convective Outlook

90. In an area forecast (FA).
91. In an area forecast.
92. A twelve-hour forecast that identifies and locates weather significant to VFR flights.
93. A summary of location and movement of fronts in a given area.
94. A convective outlook (AC).

Winds and Temperatures Aloft Forecast

95. **a.** Degrees true;
    b. Knots;
    c. Degrees Celsius.
96. **a.** Wind light and variable, temperature +3°C;
    b. A wind from 270 degrees true at 45 knots and temperature –20°C;
    c. A wind from 160 degrees true at 8 knots and no reported temperature.
97. When the level is within 2,500 feet of station elevation.
98. When it is within 1,500 feet of station elevation.
99. A wind from 340 degrees true at 115 knots and temperature –58°C.
100. 296040.
101. 674045.
102. 3408–09.
103. Wind from 265 degrees true at 100 knots, and temperature –36°C or ISA+3 (since at FL270, ISA = 15 – (2 × 27) = 15 – 54 = –39°, and –36° is 3° warmer or ISA+3).
104. Wind from 255 degrees true at 93 knots and temperature –33°C (or ISA+6).

Convective Outlook Charts

105. A preliminary forty-eight-hour outlook chart that shows forecast areas of thunderstorm activity, tornadoes, and watch areas.
106. There is a forecast risk of severe thunderstorms.
107. There is a moderate risk of severe thunderstorm activity in that area.
108. There is a slight risk of severe thunderstorm activity in that area.
109. There is a forecast risk of tornadoes.
110. An area of forecast general thunderstorm activity to the right of the line when you face in the direction of the arrow.

Constant Pressure Analysis Charts

111. Meteorological data collected at a particular pressure level in the atmosphere.
112. Quickly determining the winds and temperatures aloft.
113. The chart for 850 mb/hPa.
114. The chart for 500 mb/hPa.
115. A stable atmosphere with probable good flying conditions, with the risk of poor visibility.
116. An unstable atmosphere with possible poor flying conditions.
117. When there is a small temperature/dewpoint spread.
118. If there is a small temperature/dewpoint spread, and the temperature is below about +5°C.
119. Height of pressure surface; changes in this height over last 12 hours; temperature; temperature/dewpoint spread; and wind direction and speed.

Other Weather Information

120. The composite moisture stability (CMS) chart.
121. Maximum tops of thunderstorm cells is 46,000 feet, located on a bearing of 140°M from the station at 55 NM.
122. Relative humidity of 67%, and a freezing level (0°C) at 5,500 feet MSL.

Staying Informed in the Air

123. Warnings of weather that is potentially hazardous to all aircraft.
124. Contacting the nearest FSS.
125. Light aircraft.
126. FSS will broadcast current AIRMETs on receipt, and then at H+15 and H+45, during the first hour after issuance.
127. In a SIGMET.
128. In an AIRMET.
129. Flight Watch (on 122.0 MHz).

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The Pilot's Manual

Access to Flight

Integrated Private and Instrument Curriculum

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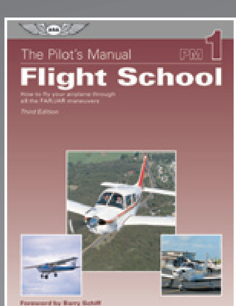

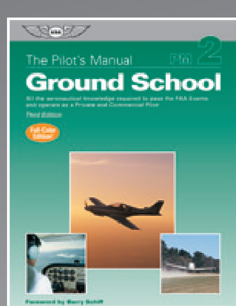

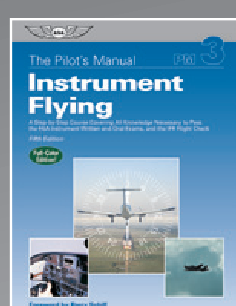

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