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A review of lighter-than-air progress in the United States and its technological significance

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Abstract—Lighter-than-air vehicles are being studied and developed as solutions to problems in transportation and in communications and service. These vehicles include balloons, balloon-airship systems and airships. Tethered balloons of streamline form have been developed for both military (surveillance) and civil (telecommunications) applications. These are capable of flying at 4600 m altitude in 100 km/hr winds and supporting payloads up to 1678 kg. Other applications include use of natural shaped balloons for logging in forested areas and for transport of cargo from ship-to-shore. Free balloons have been flown up to 51, 812 m and 7624 kg have been carried to 34,440 m. Balloon-like remotely piloted airships are being studied and developed as high altitude geo-stationary platforms for telecommunication and surveillance. Many new and lower cost benefits would result from the successful development of this type. The carrying of heavy large-volume cargoes promises to be an important and unique application for airships which are designed to achieve precise hovering while being loaded or unloaded. Several types are being studied for this purpose. Other new applications include use of airships for airport feeder passenger transport, and as large long endurance naval patrol vehicles. Technology programs must be developed which will enable new airships to be designed and built. These would include studies in aerodynamics, materials, structures, propulsion, and operational techniques. The advancement of these new concepts is handicapped by the lack of an established industry, confidence, and the complexity and cost of development. Yet where success has been achieved, it has been worth the risk. Government support is required to achieve these goals.

Introduction

LIGHTER-THAN-AIR vehicles are seriously being considered as solutions to several contemporary and future problems in transportation and for opening new opportunities in communications and services. These new directions for the oldest branch of aeronautical science have resulted from a combination of studies to identify new uses for aerostats, new needs in transportation and communication, and from recent advances in technology. Developments which led to some of the current uses were actually initiated several years ago, but the concentration of study and activity in the past two years has produced many more new possibilities. The purpose of this paper is to examine recent events in the United States, provide a background relationship for their development, and discuss their technological significance, particularly with regard to their application and future prospects. For convenience, aerostats are discussed in the categories of balloons, balloon-airship systems and airships.

Balloon development

Tethered balloons

Balloons continue to represent a most active portion of lighter-than-air development in the United States. Of those, the tethered systems probably have experienced the most recent technological advancements. These have pursued two parallel routes—military and civil. In 1967, the Advanced Research Projects Agency (ARPA) initiated a military program to develop a stable balloon platform for supporting airborne surveillance equipment. Its orderly progress from initial requirements to the achievement of its goals is noteworthy.

This project involved the development of the Family II D-7A balloon system, capable of supporting a 340 kg payload at 3000 m altitude in 100 km/hr winds. Its development represents a considerable advance in technology achieved through a combination of wind tunnel tests, field experiments and new analytical methodology. This scientific approach was accompanied by a parallel engineering effort in development of ground facilities, winch equipment, tether cables and mooring equipment (Air Force, 1974).

Since this 5665 m^3 balloon system's initial development and first flight in 1971, further improvements have been made on its power generation system, pressurizing fans, nose mooring structure and tether cable. Improvements in the electric power generation system mounted on the balloon were aimed at increasing the efficiency of the gasoline engine at operating altitudes with the goal of achieving continuous 168 hr (1 week) endurance. This has now been demonstrated. The pressurization system for the fins and ballonet was improved through greater use of a.c. power and a more centralized location of components.

The mooring system was improved by removing most of the nose stiffening from the aerostat since its primary use was for masting the balloon between flights. A system of cables and a pneumatically supported probe replaces the rigid system in flight. A rigid cone is kept attached to the mooring mast. This change alone saved 185 kg of weight. Improvements to the tether cable were investigated through a material change program. However, none of the cables tested showed any improvement over the polyester filament now in operational use (Reed *et al.*, 1950). The improved Family II system is currently under development for export to Israel.

Civil applications based on the Family II technology have been carried out by the TCOM Corporation, a subsidiary of Westinghouse. TCOM increased the volume of the aerostat to 7080 m^3 and then to 9912 m^3 in later versions. This balloon and its associated ground equipment is shown in Fig. 1. The 9912 m^3 version is able to support 1678 kg at 4600 m operating in the same winds and weather conditions as the military Family II D-7A system. Improvements will include use of a conductive metal tether cable which functions both as an

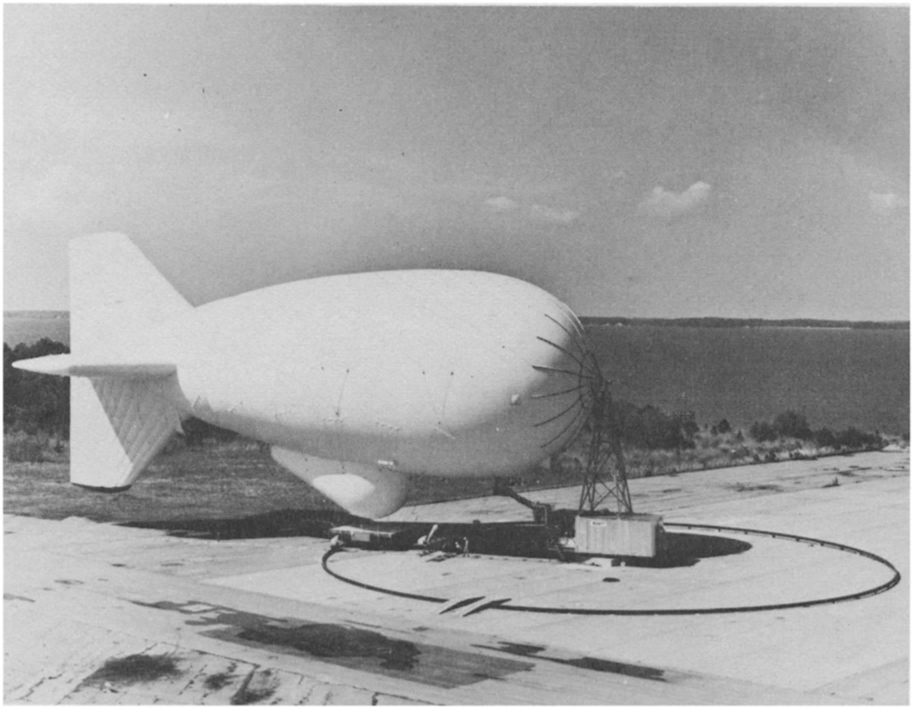

Fig. 1. TCOM Telecommunication Balloon system.

electrical power supply conduit and as a lightning ground cable. This will eliminate the need for hauling down for refueling and, of course, will allow heavier payloads to be lifted.

The TCOM balloons adopted the film-laminate method of fabric construction, developed by the Sheldahl Company, which provides a 30% weight saving over two ply balloon fabric. Figure 2 shows this construction. Balloon systems of this type are currently in use in Korea, Iran, and Nigeria as telecommunications platforms (Arnold, 1977). An assessment of progress in tethered balloon performance can be obtained by use of the following expression:

$$\text{Efficiency}\,(\eta) = \frac{W_{pl}hv}{V},$$

where W_{pl} is the payload weight, h is the operating altitude, v is the max. operating wind velocity and V is the volume.

The curve shown in Fig. 3 is an average of values of η for various balloon systems plotted against years and shows a trend toward higher efficiency. This is significant since it does not fully account for stability improvement which in most cases constitutes a weight penalty due to the use of larger tail surfaces.

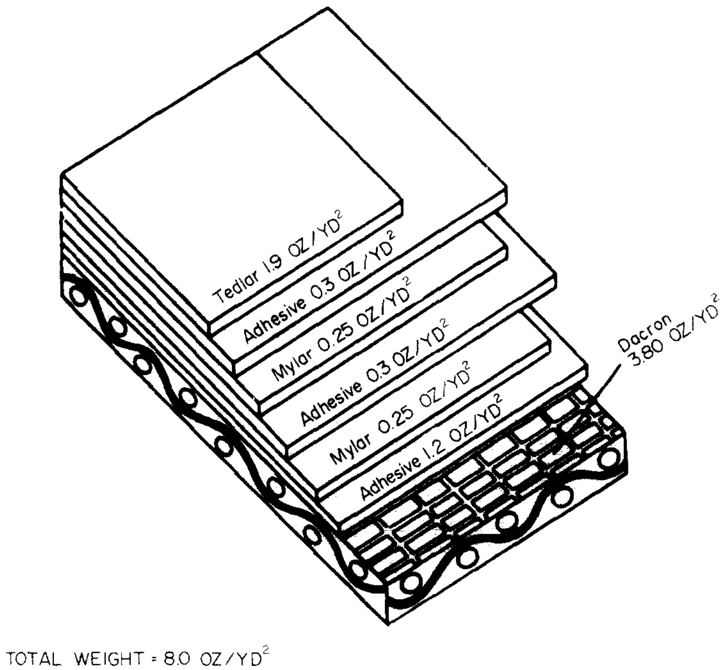

Fig. 2. Tethered balloon fabric.

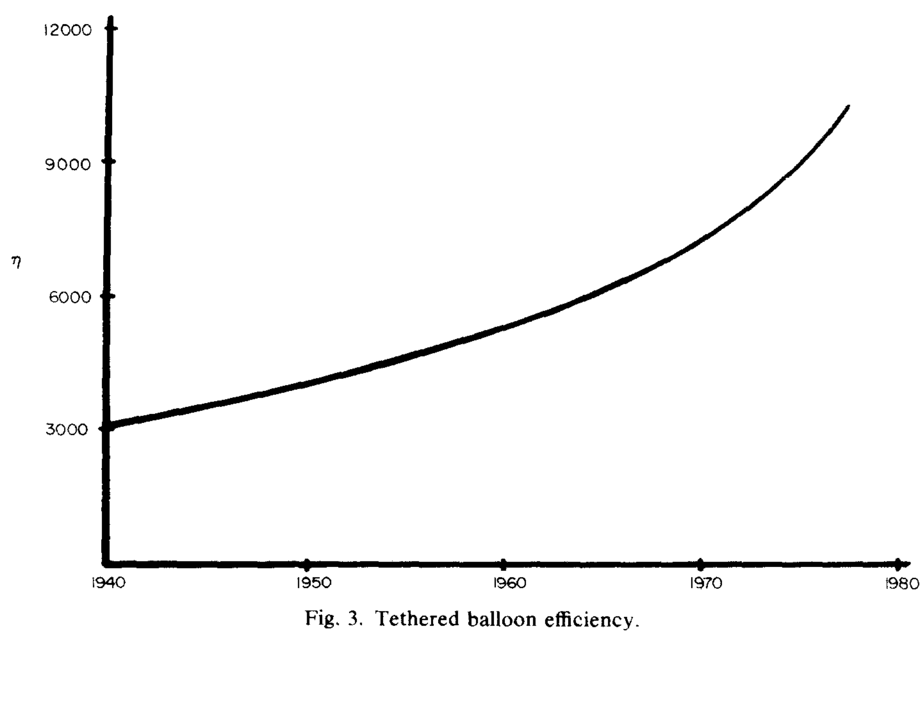

Fig. 3. Tethered balloon efficiency.

The technological advances which accompany this improvement in efficiency include:

(1) Significant reduction in inflation and mooring effort and time required by virtue of new mooring systems.

(2) Ability to reach 4500 m altitude with commercial payloads.

(3) Achievement of balloon configurations capable of stable flight in winds up to hurricane velocities.

(4) Development of improved envelope fabrics capable of gas retention over long periods and good resistance to weather effects.

(5) Development of reliable mooring and ground handling techniques.

Cargo and lumber operations

Tethered natural shaped balloons have been in use for the past few years as hoists and transports for logging operations in the Northwestern United States and Alaska. These systems eliminate much road building into forested areas, prevent damage to growing trees, and provide accessibility to difficult areas. Figure 4 shows a typical layout.

A variation of this system was employed in an experimental test program by the Defense Department in 1976 to determine its adaptability to ship cargo loading and unloading. The tests were conducted with balloons used in the logging operations. These were of 15,000 m^3 and 17,558 m^3 capacity with net lifts of 9070 and 9977 kg, respectively. The logging balloon system was adapted to the operation using standard military components. The tests simulated ship-to-shore

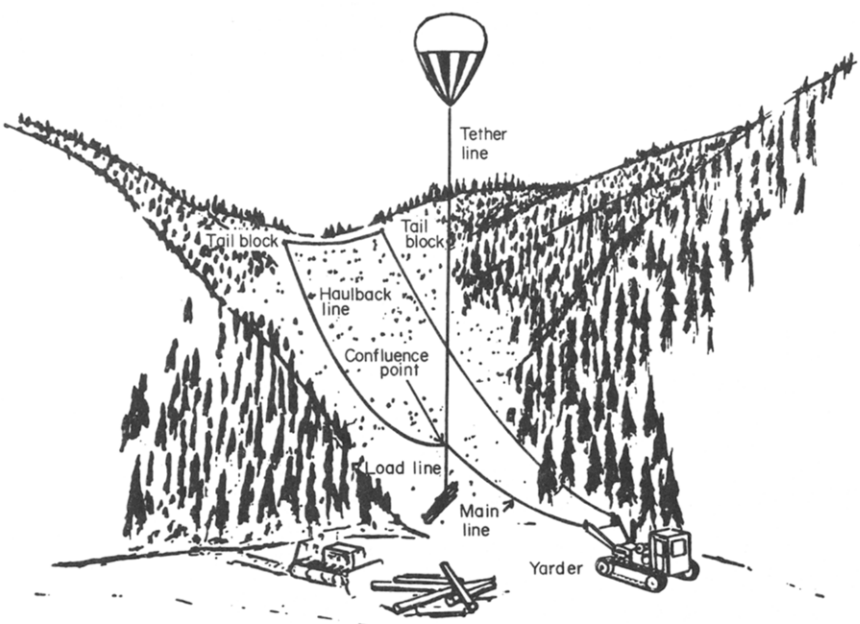

Fig. 4. Logging balloon layout.

container cargo unloading and ship-to-lighter transfers. In neither case was the operation a clear success, primarily because of extreme weather conditions which damaged one balloon and caused most of the operation to be conducted with the smaller balloon. Other factors included the difficulty of adapting a commercial system to military use, and the amount of preparation required. Despite these problems, it was concluded that the basic concept was promising and that the operational problems could be overcome (Air Force, 1976).

Just as in the case of the Family II balloon, the commercial possibilities for the system are obvious. One firm, Lightspeed Unsworth, Inc., has therefore undertaken the development of a ship-to-shore cargo handling system similar to, but improved over the military versions. This system will shortly be in service in the Arab Republic of Yemen (Lightspeed, 1977), see Fig. 5.

Free balloons

Scientific free balloons have also demonstrated increases in performance in recent years. Record loads of 7624 kg have been flown to altitudes of 34,440 m and durations up to 120 hr have been achieved while supporting 910 kg at 40,000 m. The highest balloon altitude attained in the United States to date occurred in January 1972, when 51,812 m was reached. Improved methods for control of ballast and gas release have resulted in the ability to make trans-oceanic flights from several countries to the U.S. Some of these were reported at the previous I.A.F. Congress (Shipley–Smith, 1976).

Manned ballons have also been employed recently for scientific reaserch. One such system, the ATMOSAT, is a 525 m^3 superpressure balloon constructed of Kevlar cloth and Mylar. The superpressure design allows flights at constant altitude to be achieved more easily. Experiments in air sampling have been conducted with this balloon.

Balloon-airship systems

The general success of the high altitude scientific balloon as the mainstay of research in the upper atmosphere has prompted various organizations to consider the use of similar aerostats in applications where a geo-stationary platform would be needed. Atmospheric data show that a region of relatively low wind velocites lies between the stratospheric westerlies and the tropospheric easterlies. This zone varies with the seasons but is generally located between 16,760 and 22,860 m. A number of studies and experimental programs were instituted by the DOD beginning in 1968 to determine if a propulsion system could be combined with a balloon-like vehicle, and flown in this region. Such concepts were demonstrated using propulsion modules suspended beneath conventional natural shaped free balloons. It was readily apparent that higher efficiency was required and that the aerostat must be an airship with a low drag hull or envelope (Korn, 1974).

The most recent development was sponsored by the U.S. Navy and is known as HASPA (High Altitude Superpressure Powered Aerostat). This system employs a streamlined non-rigid hull utilizing the "C" class airship envelope shape of 22,656 m^3 volume and a superpressure design approach, wherein no lifting gas (helium) is permitted to escape nor is the envelope pressure allowed to fall below the minimum required for maintenance of shape. Starting with 100% inflation, once station altitude is reached, the envelope must be capable of accommodating the pressure change which occurs during the diurnal cycle. A combination of high strength (Kevlar) yarns and Mylar film is also employed in the HASPA envelope. The yarns are used in the form of an open scrim reinforcement. The aerostat is powered by twin electric motors that drive a single stern propeller at speeds up to 46 km/hr. Thus far, a successful flight has not been achieved due to a combination of poor material performance and launch difficulties. Efforts are being continued to find solutions. The National Aeronautics and Space Administration (NASA) is also studying high altitude powered platform (HAPP) systems. These are attractive both as alternatives to satellites and as complementary systems.

An appraisal of civil applications for a HAPP vehicle shows an advantage

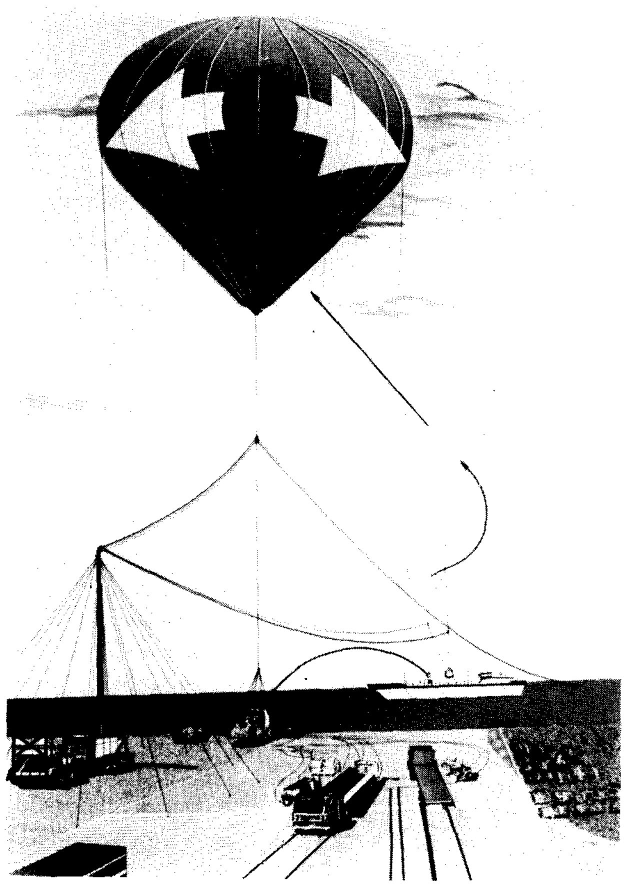

Fig. 5. Lightspeed–Unsworth ship-to-shore system.

compared to a satellite system in terms of area coverage and detail discrimination. It emphasized the fact that the Earth's surface area (on which beams may be painted) and the spectrum (frequency spread) are two limited commodities. At 21,300 m, a HAPP system would provide coverage of a 966 km diameter circle. This circle also represents a 1.2° spot beam from a geosynchronous satellite (725,000 km^2). The smaller the "paint" area, the more a given frequency can be used.

In short haul broadband communications, the terrestrial microwave spectrum is crowded in urban areas, and coaxial and fibre-optics are expensive and not viable when demands are low and scattered. The satellite footprint is too large and wasteful of the spectrum and ground stations are expensive. The HAPP system could fill the gap between geostationary satellites and terrestrial microwave systems and would free the satellites (and their spectrums) for the long haul. Thus, the HAPP satellite system could aggregate long haul traffic (from multiple microwave spot beams) and forward it to the satellite over laser links.

Other additional features include support of development of various local and regional broadband services in medical, educational, counseling and social services, teleconferencing, data and telephone trunks, and cable TV interconnects. These benefits include coverage of low density areas where demands are scattered, part time, or tentative. The telemedical field appears especially attractive for education and remote diagnosis. It would be possible to link less specialized clinics and hospitals to major hospitals, for example. A major potential market is in the area of teleconferencing, where business, government and civic groups are linked together using duplex radio with bandwidth compression. Such a system, of course, must be at least as reliable as travel itself, considering breakdown and bad weather. The potential energy conservation derived from a reduction in travel is also attractive.

In summary, it can be concluded that the HAPP system fills the gap between earth and satellite systems, provides both local and regional service, conserves the spectrum due to its small footprint, offers a platform for above cloud optical links, and reduces ground station cost. Other applications include surveillance, mapping and scientific experiments.

Airships

A number of people have advocated a reexamination of airships for various transport missions. The principal argument in many cases has been one of energy efficiency. While this may remain as an attractive reason, another more compelling one is the use of these lighter-than-air vehicles to fill requirements not being met by other types. Some of these have already been discussed in the case of balloons.

Heavy lift

Lifting and transporting heavy large-volume cargoes appears to be an important and contemporary mission. The only type of aircraft available at present that is capable of vertical lift is the helicopter. In the United States the maximum

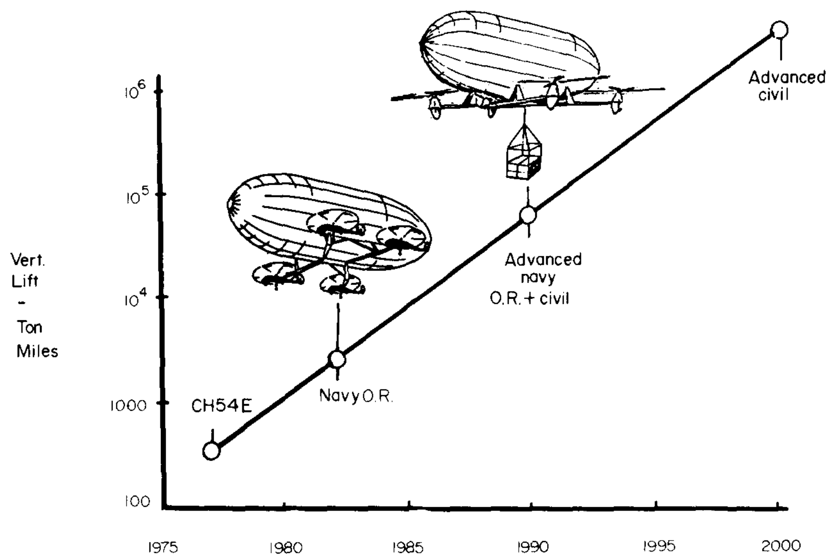

Fig. 6. Heavy-lift long term needs.

short range capacity of helicopters is presently limited to about 15 tons (metric). Studies of military and civil needs have shown that needed vertical air lift capacity could include loads up to 900 tons(m). Figure 6 illustrates the needs vs the years and indicates some of the LTA vehicles being considered as solutions.

An immediate need for heavy lift, as reflected by a Navy Operational Requirement, is caused by the trend in commerce away from handling small packages toward using shipping containers of standard sizes and types. Modern merchant vessels are equipped to carry such containers, but must rely on special port or harbor facilities for loading or unloading. It is a concern of the defense agencies that operating with such ships could be a handicap in time of war, since the containers cannot be unloaded except by cumbersome surface equipment. Airships to satisfy such requirements take on the nature of hybrid aircraft, combining aerodynamic and static lift, and using the source of dynamic lift for precision hovering control. This type is illustrated in Fig. 7.

Another aircraft being investigated by the Navy is shown in model form under test at the Lakehurst Naval Air Station (Fig. 8). This vehicle combines a spherical pressurized envelope with a rotor system which uses the balloon portion as its hub and is rotated by 4 rotor mounted engine-prop units. It is anticipated that vehicles with 46 m diameter balloons and 34 m length rotors will be capable of vertically lifting up to 45 (m) tons (All American, 1974).

Heavy lift vehicles could also be of use in the nuclear power industry, which builds its basic elements of power generating equipment in large modules. The transportation of these large units is presently limited to special railroad cars

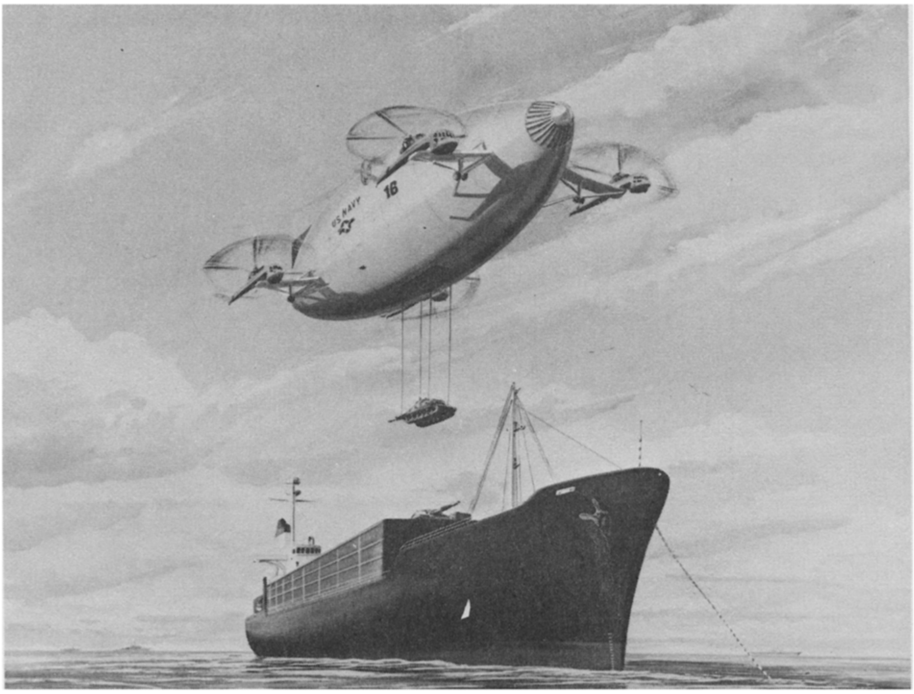

Fig. 7. Piasecki heavy lift airship concept.

and/or water-borne transport. Future requirements with regard to safety and environmental effects will tend to force the nuclear power production industry to locate at sites not very favorably situated for surface transportation. A survey made by the Grumman Aerospace Corporation showed that a sufficient market would exist to justify development of a new airship concept. Grumman determined that a 708,000 m^3 non-rigid airship hull supporting a suspended car frame structure that was mounted with gimballed engine propeller units and a control module would lift a payload of 303 tons (m). This payload would account for 60% of power components to be transported. For handling larger single items, such as steam generators or reactor vessels, two or three vehicles would be coupled together through a mid-air hook-up. The concept is shown as Fig. 9 and was described by Munier and Epps, 1976.

A non-rigid vehicle of this type could require the development of high strength fabrics and improved fabrication methods as a necessary precurser to building envelopes of such large volumes. The operational aspects would also require development and demonstration to determine overall feasibility.

Parametric system studies

Recently completed studies that were initiated by NASA in 1974 evaluated the suitability of modern airships for new applications, and identified specific applications. The first phase of this study included a review of past LTA history

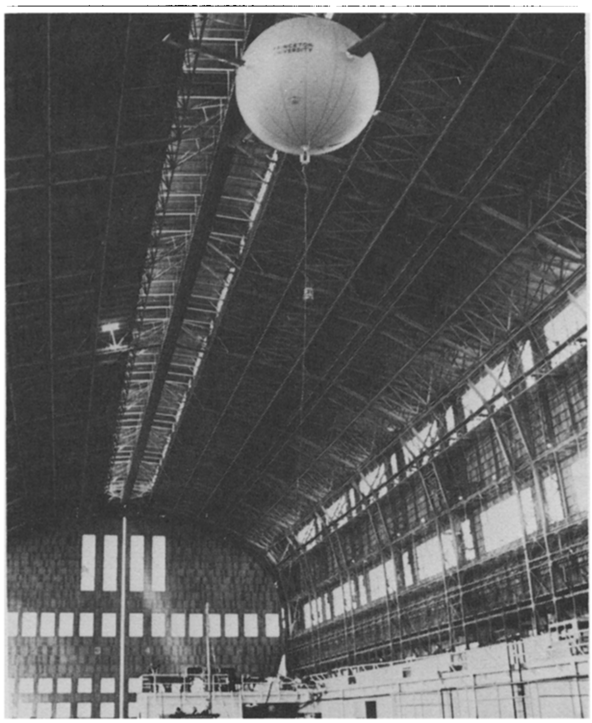

Fig. 8. All American Aerocrane research model.

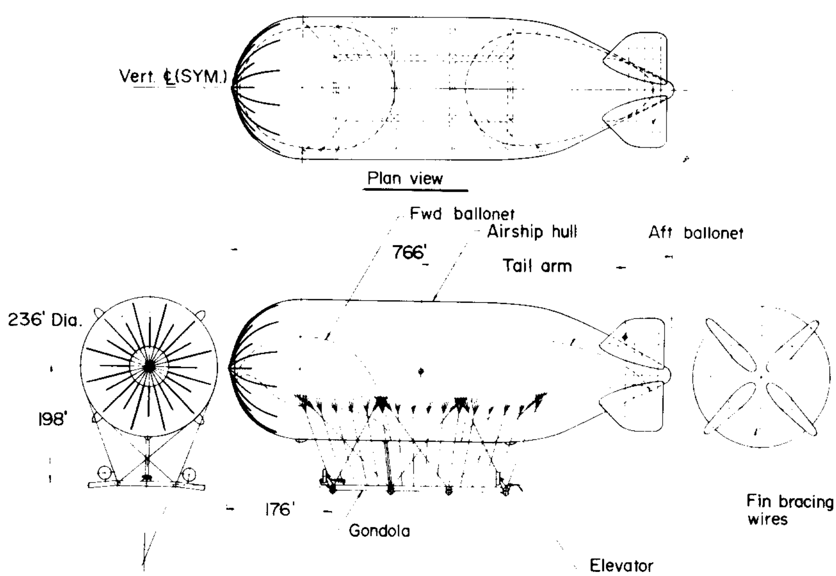

Fig. 9. Grumman heavy-lift airship concept.

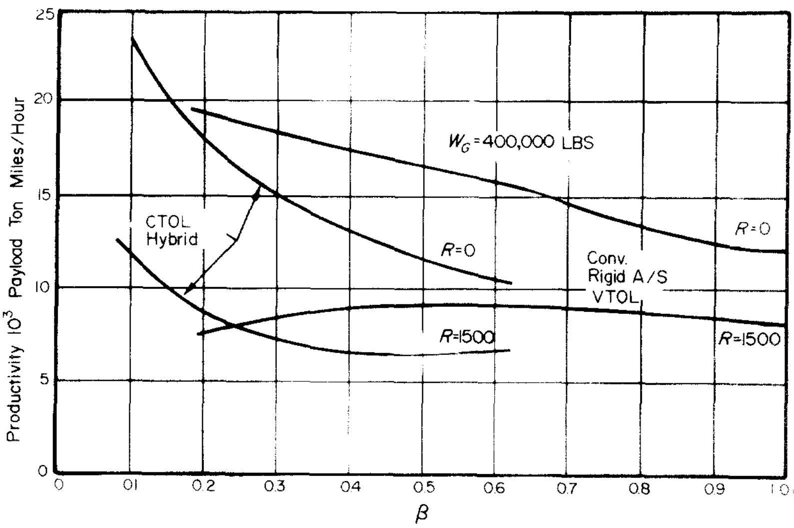

Fig. 10. Optimised productivity vs beta for 400,000 lb gross weight vehicles.

from a technical viewpoint, examined various proposed concepts for airships, and identified new and unique applications for airships.

One interesting and significant conclusion concerned the use of dynamic lift combined with lift through displacement (buoyancy). It was found that vehicles designed as conventional ellipsoidal bodies, such as airship hulls, are more efficient when flying statically heavy than are the so-called hybrids with wing shaped bodies or hulls. Figure 10 illustrates this comparison, which is based on a figure of merit depicting productivity-payload ton miles per hour. It can be seen that the true range of efficiency for the hybrids lies in the very low β range where β is the ratio of static lift/gross weight. Indeed these vehicles would be most efficient as pure heavier than air machines. The case shown is for a 200 ton gross weight vehicle. The all-buoyant airship becomes more efficient as range and weight increase (NASA, 1976).

Obviously, other figures of merit may show other conclusions. The productivity parameter happens to be of most significance for air transportation. Other NASA studies explored the case between modern airships and jet transports for passenger or cargo missions. These showed that the airship would not be directly competitive on an economic basis unless airplane operating costs increased significantly. Since this is a possibility as fuels become more scarce, the case must be reexamined periodically (Ardema, 1977).

Many comparisons are usually based on the assumption that all types are operating with similar facilities and under similar conditions, e.g. daily scheduled operations to and from airports. It now begins to appear that many special situations exist where available facilities preclude use of some types and in fact may require development of new LTA concepts.

Airport feeder airship

The NASA studies also identified other concepts. One of these was a vehicle which would serve as an airport feeder. This vehicle would carry 80 passengers, operate at a low β ratio (0.35), and be capable of roof-top or heliport type landings. It would cruise around 240 km/hr with stage lengths of 24–241 km. All metal pressure supported hull construction was envisioned. One attractive feature was a low noise level which even at take-off would not exceed 72 PNdB. Cost analysis showed the airship to have 20–30% lower fuel consumption than equivalent helicopters. Approximately 7–10 airports in the United States could merit this type of service (NASA, 1976). Figure 11 shows the concept.

Naval applications

The conventional airship assumed a favorable role when studied for Naval application under the NASA program. These Navy missions included anti-submarine surveillance and trail and convoy escort. Goodyear Aerospace Corporation, the study contractor, chose a 317,000 m^3 airship as a point design vehicle. It would have a maximum speed of 138 km/hr, a gross weight of 255 tons (m), a maximum operational altitude of 1524 m, and a useful load of 129 tons (m). It would be equipped with RPV's, piloted aircraft, and laser weapons. Its normal slow operational speed would allow endurance ranging from 1–3 weeks. Figure 12 illustrates this vehicle.

A large part of Phase II of the NASA feasibility studies was devoted to an

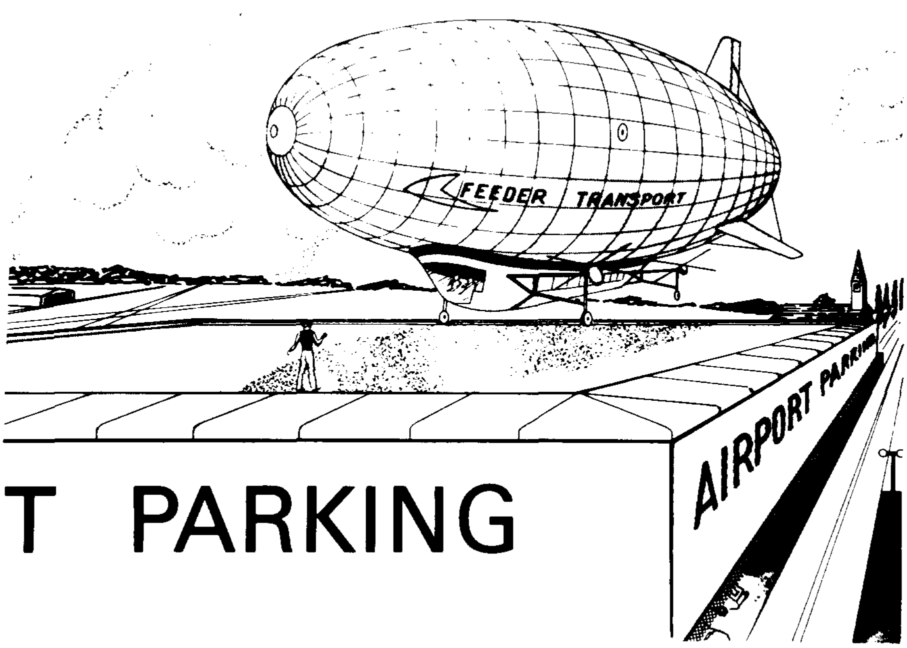

Fig. 11. Goodyear airport feeder airship concept.

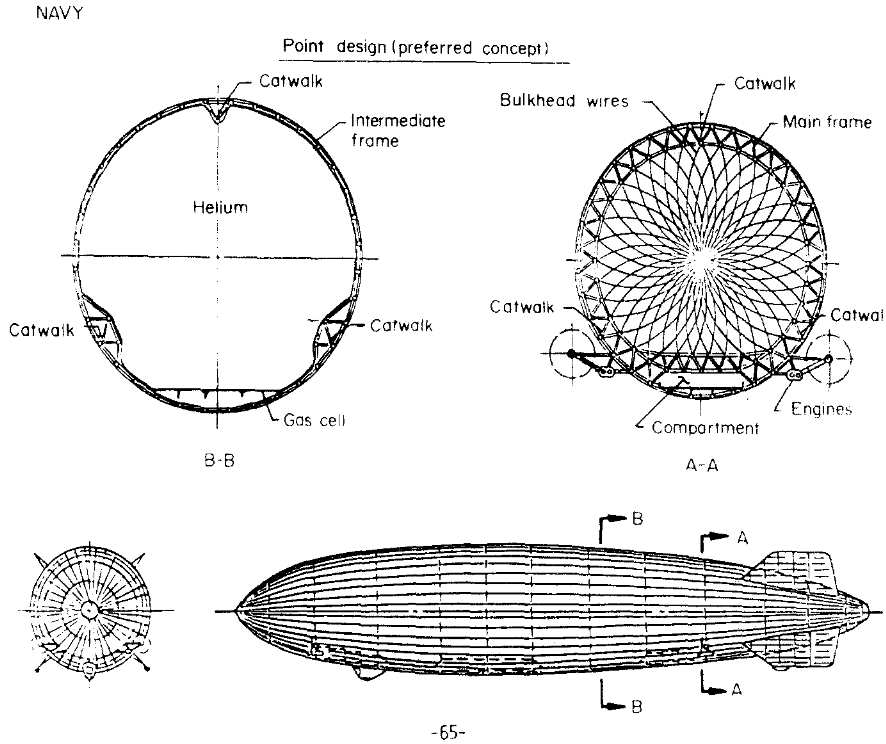

Fig. 12. Concept for navy long range patrol airship.

examination of the helicopter-airship heavy-lift hybrid in terms of control, structure and mooring. A 68 ton (m) payload, 70,800 m^3 vehicle using four CH-54 helicopters was used as a study model and proposed for initial development as a research aircraft. The military benefits of the system have already been defined, and NASA is undertaking a study to determine the civil market. The Navy Department also instituted a program of studies concurrent with the NASA effort. These included aerodynamic analyses, structures, mission analysis and assessment of new concepts.

Among the latter, the Martin–Marietta Corporation has studied a concept using a fully buoyant airship with both bow and stern thrust for control and propulsion in combination with a pressurized rigid hull. A large delta-shaped rigid design was also studied by Goodyear for high speed (250 km/hr) operation with a β ratio of 0.68.

Other applications

Private investors are also interested in the modern airship concept. For example, Lightspeed, U.S.A., is planning to develop a 63,720 m^3 cargo-passenger airship. This vehicle would combine a rigid-frame geodesic hull with a pressurized outer cover. Both framework and cover would share in carrying hull loads. Four side-of-hull mounted vectorable thrust propellers would be used in combination with a stern mounted propeller.

The Goodyear Tire and Rubber Company continues to operate its fleet of non-rigid 5750 m^3 airships for advertising with bases in Los Angeles, Houston and Miami. These airships tour the United States during the summer months. A fourth ship is engaged in a similar operation throughout Europe.

Technology needs

It is clear that lighter-than-air vehicles of various kinds offer potential and unique solutions for many present and future missions. Unfortunately, the technology base is old and has not been the subject of either continuous or recent improvements. The exceptions to this center on a few particular concepts, and the effort here is largely in the aerodynamic field. Only in the case of balloon development has there been an advance in structural materials developments. These events are in contrast with the heavier-than-air field, which experiences many basic investigations in all disciplines as well as much applied research on more or less a continuous basis. A similar program for airships would consist of the following items:

(1) *Aerodynamics*—The hybrid combinations of large rotor systems and aerostat hulls establish a need for a thorough investigation of flow fields around such vehicles. In the very preliminary results from model tests undertaken during the NASA studies, it was shown that cross flow drag was increased by the rotor induced flow (NASA, 1976). At present, analytical studies are being made in an attempt to identify optimum locations for the large prop-rotor systems. Accurate determinations of these effects will require larger scale model testing.

High altitude vehicles may possibly operate in a critical Reynold's number region where the boundary layer flow may be in the transition range. This may be a factor in choosing the size of the vehicle in order to determine predictable drag values.

(2) *Materials*—Materials for airships and balloons encompass all the normal selections from metals, plastics and composites that represent high performance and efficiency in terms of strength-weight-stiffness, etc. that are usually required for any aerospace vehicle. In addition, however, there is a need for materials which can function as gas containers or pressure supported structures, or both. These materials in many cases must be flexible to accomodate changing gas volumes and hence involve use of films, fabrics and combinations of both. The history of new materials is characterized by major failures from the hasty application of such materials to end use. Such problems can only be avoided by thorough and knowledgeable research programs.

(3) *Structures*—The major improvement in structures for airships may not be found in new structural concepts so much as in the capability to analyze large complex structural geometries. New techniques such as finite element analysis and computer programs such as NASTRAN will not only assure sound and accurate analysis, but should reduce the number of man hours of design effort

which would have to be devoted to this area. These benefits are particularly applicable to rigid airship analysis, but are useful to other types as well.

One area still in need of considerable improvement is that of structural loads. A few simple tests, in which flight path deviation and bending moment response were determined, were conducted in the 1930s and have been used as the basis for calculating the maximum bending moment on all types of airship hulls up to the present time. It has recently been proposed that power spectral density techniques coupled with current data on atmospheric turbulence would produce a much more complete and accurate picture for structural design (Witherow, 1977).

(4) *Propulsion*—The newer airship concepts are related by one common characteristic, that of a vectoring thrust system used primarily for control, but also to obtain dynamic lift. These systems have been applied in the past and are presently proposed by directly using helicopter rotor systems with aerostat hulls. While such combinations are no doubt feasible, especially through the use of a computerized fly-by-wire control system, they will suffer from the lack of optimization obtainable by designing specifically for the intended use. Both propulsive and lift efficiency would increase along with a weight reduction and an improvement in reliability.

(5) *Operations*—From the initial phase of its involvement with large airships, the U.S. Navy sought ways to ground handle and moor these vehicles with a minimum of manpower and an increase in flight readiness. This was effected through the adoption of the British high mast, followed by the Navy's own low mobile mast development used for both mooring and hangaring. The last mechanical aid in this respect was in the use of "mechanical mules", special highly maneuverable tractors equipped with constant tension winches. Four of these vehicles were sufficient to completely control the largest Navy blimps on the ground.

The new hybrid vehicles would have the capability, to a large extent, of operating in a very heavy condition and therefore would be independent of ground assisted equipment except under severe conditions. This is another factor which should reduce operating costs for modern airships.

Discussion

The arguments in favor of using LTA vehicles seem persuasive enough to warrant their development. In fact, in some cases, the rationale is better founded than that used to support many other current aeronautical programs. Yet, if this is so, one might ask why are there no new airships under development.

The differences, of course, are due to the following:

(1) There is no established industry. The general familiarity which exists among people involved with airplanes is missing in LTA. Those who must approve or support programs for technology development therefore do not have the background for judging information presented.

(2) There is a lack of confidence that promised or estimated performance can indeed be achieved. This is due in large part to an inadequate technology base.

(3) LTA aircraft are large vehicles. Their development involves engineering

and manufacturing which requires the multiple disciplines and facilities usually found in aircraft companies. This is an expensive process and it must be weighed against the benefits to be obtained from the vehicle.

All of these considerations create an atmosphere of caution and generally tends to classify LTA projects as low priority, high risk ventures. Another factor which is difficult to evaluate is that the vehicles identified as most promising represent a considerable departure from those of the past. While fundamental principles still apply, much new technology development is required.

An examination of successful examples, such as the TCOM balloon system, reveals that the risk factor was removed in the initial development through the government programs on the Family II aerostat. This seems to be a necessary ingredient in any undertaking where private venture capital is not accessible. Such support is usually based on national need. If a system can provide benefits to the nation, locally or generally, and these benefits exceed the cost of development, it is a likely candidate for support. This would seem to apply to the heavy-lift airship where the strategy of defense could be compromised by a logistics problem. It would also apply to the high altitude platform concept where benefits to communication for education, health, law and order, weather, etc. would easily compensate for development expense.

Conclusions

Lighter-than-air flight, once man's only means of leaving the surface of the earth, has never been as popular a branch of aeronautics, nor as familiar to the average person, as the airplane. Indeed, LTA development has been that of a cyclic nature rather than one of steady progress. The physical laws which govern aerostatic flight are much more bounded and limited than those circumscribing aerodynamic means—one cubic foot of air can only weigh so much. The very complexities of understanding dynamic substention also multiply the possibilities for improving its efficiency. Despite these conditions, there are times and circumstances within which the aerostatic vehicle is uniquely suited as the means—perhaps the only means—of satisfying a requirement or solving a problem.

New requirements in telecommunications, scientific research and transportation of heavy cargoes indicate a need for development of modern lighter-than-air vehicles. In the United States, studies and experiments are proceeding to explore the markets as well as to develop technology. To achieve these goals, an expansion of these programs is required in aerodynamics, structures, materials development and propulsion. Government support of this effort is required to assure success and its eventual application to civil and military use.

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