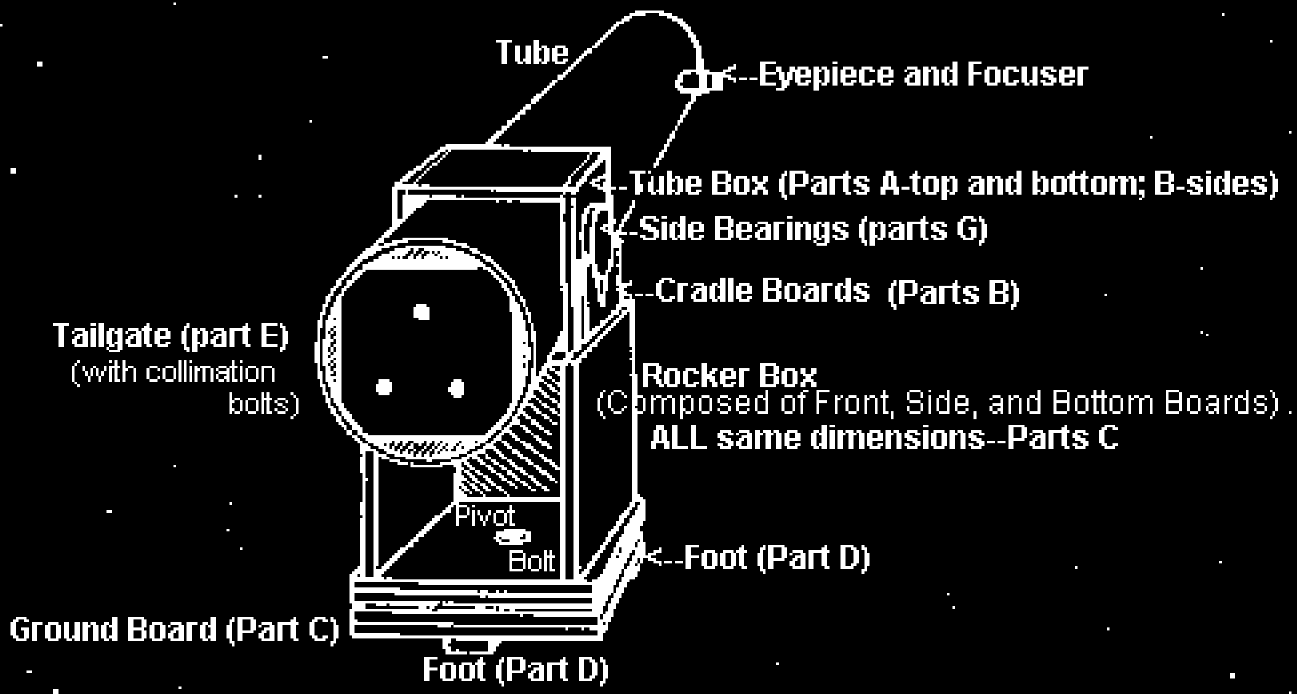
The San Francisco

SIDEWALK ASTRONOMERS

BRING YOU :

Complete Plans for

Building a Dobsonian Telescope



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This manual was created using Acrobat 4.0 you need to download the latest free reader to view this manual properly! Older readers will give you strange results.

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The San Francisco Sidewalk Astronomers

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Plans for Building a Dobsonian Telescope

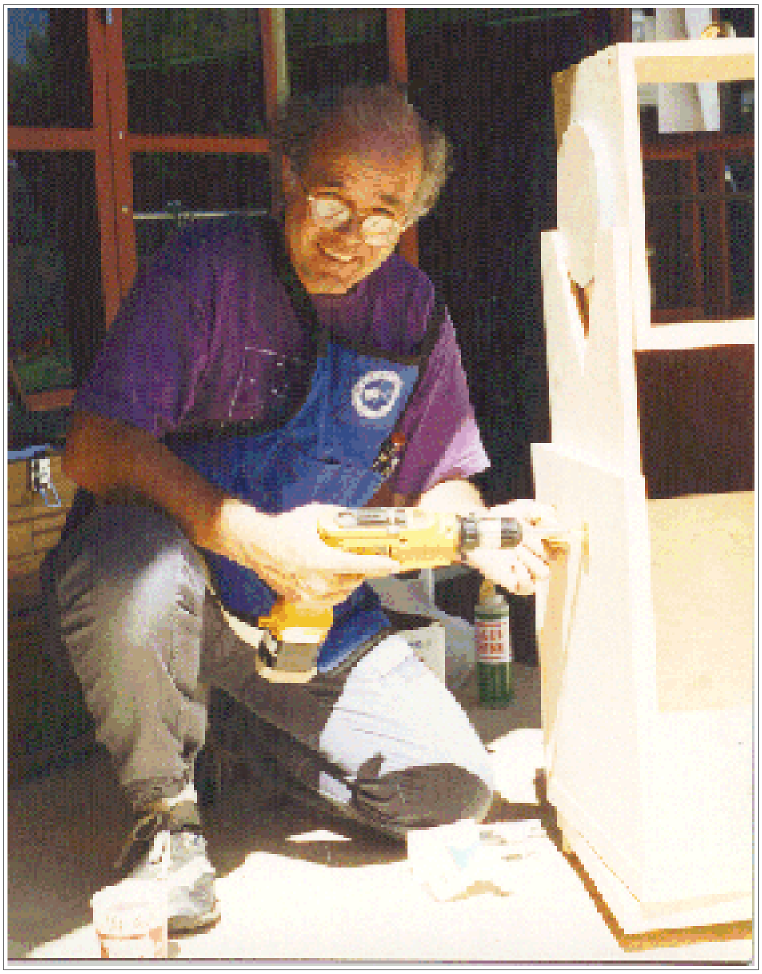
brought to you by: The San Francisco Sidewalk Astronomers

Yes, it "looks like a cannon," but the above is really a ten-inch (measured by the diameter of the objective) Newtonian telescope that almost *anybody* can build. Here you will find plans to build this telescope, or a smaller one--either a six-inch, or an eight-inch--of identical design. These plans are only slightly modified from the plans *The Sidewalk Astronomers* have been sending to interested parties for a mere $2.00 via snail-mail. I have kept as close to this design as possible: One, because this is--hands down--the cheapest and easiest way to make a quality telescope; and two, because I walk in the shadow of John Dobson, who invented many of these designs which have revolutionized amateur and professional astronomy alike... Besides, *Los Angeles Sidewalk Astronomer*, Pam Reid, did most of the work by writing and typing the procedures, as well as gathering the drawings--which, by the way, were done by Earl Jungians (from photographs of John at work by Molly Lusignan). Most of my "work" consisted of scanning and re-typing Pam's work... though I do interject my two-cents here and there.

In the category of "the left hand not knowing what the right hand is doing," another Webpage, supported by NASA's ***Telescopes in Education Project,*** also have these plans online. Here you will find the original plans--images and text scanned together, without my minor meddling--which includes, by the way: the Six-inch plans, the Sun Telescope construction tips page, a Links page, and a real person to E-mail your questions to. Regardless, it is a beautiful page, and I recommend you check it out; especially if you have any problems printing the plans from this page.

If you would like to grind, polish and figure your own mirror, I suggest Victor's Telescope Making page as well as the late Sam Brown's book , **All About Telescopes**, which may be ordered from Orion Telescope and Binocular Center.

--Ray Cash-Le Pennec



Introduction

The plans you will find on these pages, are, by and large, the result of years of trial and error on the part of John Dobson, one of the founders of The San Francisco Sidewalk Astronomers and a prolific telescope maker. John has, quite literally, helped thousands of people make telescopes of this design! Only in the past few years have commercial telescope manufacturers adopted the *Dobsonian* approach to make affordable, alt-azimuth Newtonian telescopes... However, the three top manufacturers (henceforth referred to as: "The Big Three"), Celestron, Meade, and Orion, continue to fall short mechanically of the simple designs found on these pages. All of The Big Three, for example, use *Melamine*; a kind of coated particle board, which is heavy, not durable, in short; not as strong or light as plywood, which, of course, *we* recommend. All of The Big Three have undersized pivot bolts, do not use *Teflon* as bearing surfaces (there is no substitute!), and have shoddy mirror cells (tailgates). The list goes on... They do look "pretty," especially in photos; I'll give them that. If you happen to own one of these scopes; you might well peruse these pages to find ways to tinker and fix up your mass-produced Dob: you can only *improve* what you got! It ain't rocket science!

The designs you find on these pages are also open to improvement by *you*: the builder. Not only will you discover the ins and outs of Newtonian / Dobsonian telescope design, but you are encouraged to come up with your own modifications. We include plans to make your own Primary Mirror Cell (we call it a "Tailgate"), Secondary Diagonal Mirror Holder and "Spider," and Eyepiece Holder/Focuser. These are items even the most seasoned TM (telescope-maker) usually buys from small telescope part manufacturers: you may opt to do the same (although John's designs are perfectly functional--some ingenious--and *very* inexpensive to fabricate). Contact your local astronomy club, there are usually at least a handful of TM's that can help you out. Also, check my Sources page for materials and accessories you will need, or, might want, to purchase.

I think you will find these plans pretty clear, simple, and straightforward. If not, let me know.

Have fun!

Some not-too-technical advice before you begin...

This Webpage contains complete instructions for constructing a Sidewalk (Dobsonian) telescope using a six, eight, or ten inch (diameter) purchased objective mirror. If you are interested in grinding and polishing your own mirror, we suggest you pick up John Dobson's video (listed under "Sources" below) as a start. Also, Victor's Telescope Making Page has step by step instructions for mirror making. **All About Telescopes**, by Sam Brown (found at Orion Telescope and Binocular Center) also has good instructions on this art.

How much is this going to cost? Well... an 8" f/7 mirror from Coulter with diagonal costs $219.95, plus $15.00 for shipping. If you can build an 8" scope for twice the cost of this, consider yourself lucky! You *can* buy a "Big Three" scope for only a little more; you can also buy used for less... Something else must be motivating you to "build your own." This Webpage is for you... and your daughter and/or son!

You will need to purchase one objective ("primary") mirror and one diagonal flat, ("secondary) mirror, in order to build the telescope. Mirrors may be purchased from mail-order telescope supply houses. Coulter Optical is an excellent, dependable source for good-quality, inexpensive mirrors, so we have included their address in the "Sources" list below. Orion Telescope and Binocular Center also sell mirrors, as well as alot of other stuff.

REMEMBER! TELESCOPE MIRRORS ARE POWERFUL CONCENTRATORS OF LIGHT.

Sunlight reflected off the face of a telescope mirror can cause BLINDNESS or **START A FIRE!** Always handle your mirror indoors or in the shade! The telescope described in these plans is for **NIGHT USE ONLY. NEVER** set up your telescope in a location where it may be reached by sunlight, and:

NEVER LOOK AT THE SUN THROUGH YOUR TELESCOPE!

The plywood cutout patterns on the next few pages are for the construction of telescopes with six, eight, and ten inch objective mirrors, but you can use the same design for smaller telescopes (4.5", for example) or larger telescopes with objective mirrors of up to 15" in diameter. Just remember that the tube of your telescope needs to be at least 1-1/2" wider than the diameter of the objective mirror. Then increase (or decrease) the tube box and rocker dimensions proportionately. THE DIAMETER OF YOUR TUBE DETERMINES ALL OTHER DIMENSIONS.

For telescopes with mirror diameters 16" and larger, a different tube box design and mirror support system is necessary. (Again, John Dobson's telescope-making video listed in "Sources" shows the construction of a 16" telescope with this modified tube box and support system). A more popular method of construction nowadays for large Dobs is the truss design, which allows the telescope to be "broken down" for transport and storage. See my Vanity Page for examples I have built; recommendations, and resources.

Objective and Diagonal Mirrors

What we describe as a Sidewalk Telescope, or Dobsonian Telescope, is a simple Newtonian reflecting telescope in a sturdy, wooden, alt-azimuth mount or rocker. The telescope consists of a concave (actually *parabolic*) objective (or Primary) mirror, which is mounted in the bottom of the tube. This objective gathers light from the object under observation and brings the light to a focus; forming an image of the object in what is called the *focal plane* or image plane, at the upper end of the tube.

A small, flat, front-surface mirror called the diagonal (or secondary) mirror is mounted inside the telescope tube near the front end. This mirror is mounted at a 45 degree angle to the tube's axis hence its name. It deflects light from the objective to the side of the tube where the image may be more easily examined with an eyepiece.

The size of the diagonal mirror is dependent on the size and focal ratio of the objective mirror. So, when you order your mirrors, make sure to ask your supplier to tell you the correct size diagonal mirror to order. Specify that you will be using a low-profile focuser. To determine more accurately the size of the diagonal, peruse the following email correspondence:

balzaccom@aol.com (Paul Balzac) writes:

>By the way, I tried to find the equation you mentioned in the archives, but
>couldn't. Anyone help?

The equation is found in Richard Berry's **Build Your Own Telescope**, pgs 26-28. However, there are a couple of errors on those pages: "E" on page 27 should be changed to "D" (this makes more sense with the drawing). Also, in the final example he uses, the "6" and "8" are transposed; switch them around, in other words.

But to cut to the chase, the formula is:

d = df +([D-df]/F) X Lde

Where **"d"** is the minor axis of the diagonal,

"df" is the focal length of your primary multiplied by: the result of the amount of fully illuminated field you want divided by 57.3 (radians in a degree). In other words,
F X (x/57.3) where **"F"** is focal length and **"x"** is the amount of fully illuminated field you desire. *("df," is, in fact, the amount of fully illuminated field).*

"D" is the diameter of your primary,

"F" is the focal length of your primary,

"Lde" is the distance between the diagonal and the field stop of your eyepiece.

A self-serving example: I recieved my 8" f/7.06 mirror from Coulter yesterday. The common rule of thumb is to have a half (.5) degree of "fully illuminated field" for visual use. (But I will also plug in a .25 fully illuminated field, just to see how much smaller my diagonal will be...). The telescope will use a 10.5" outside diameter Sonotube, have a low profile focuser (say 2.125 inches high), and I will add 3/4 of an inch to be sure all my eyepieces will focus with a variety of eyeballs: So my "Lde" will be: 8.125 inches: 5.25 (radius of 10" tube) + 2.125 + .75.

"df" is then,
for a .5 degree fully illuminated field: 56.5 X (.5/57.3) = .493
for a .25degree fully illuminated field: 56.5 X (.25/57.3) = .247

So lets plug these numbers in:

The formula, again is: **d = df +([D-df]/F) X Lde** (be sure to multiply BEFORE you add)

.493 + .133 X 8.125 = 1.57 inches. So, a 1.57" minor axis diagonal will fully illuminate a half a degree at the eyepiece.

.247 + .137 X 8.125 = 1.36 inches. So, if I want only a .25 degree fully illuminated field to produce more contrast on the planets... I would go with a diagonal this size.

Diagonal mirrors do not come in the above sizes, of course; but one can round off--in either direction--your preference!

--Ray

A Word About Focal Length and Focal Ratio

The focal ratio of the mirror you select determines how long your telescope will be. A 10" objective mirror with an f/7 focal ratio will give you a telescope with a 70" focal length. (Multiply the "f-number" by the diameter of the objective mirror to get the focal length.) Your tube will need to be cut to the length of the focal length, so you would have a 70" long tube. An 8" objective mirror with an f/7 focal ratio would have a 56" focal length, and a 56" long tube.

(John Dobson recommends a focal ratio around f/6 or f/7)

FOCAL RATIO (f-number) x MIRROR DIAMETER = FOCAL LENGTH = LENGTH OF TUBE

When you get your mirror, the focal ratio may be exactly what you ordered, or it may be a little more, or a little less. So don't cut your tube till you receive your mirror. To measure your focal length exactly, have a friend help you: Take your mirror, a tape measure, and a piece of paper outside on any clear night and catch the light of a bright star or the Moon with your mirror and reflect it back in that direction. Using that piece of paper find where the star, or Moon forms the smallest image. Measure that distance as accurately as you can. (Instead of a piece of paper, it is often easier to reflect onto a fixed surface, such as a garage door jamb or header). Write this measurement down! This determines the length of your telescope tube, as well as where you cut a hole for your focuser. **The key thing to remember is that you want this formed image (called the *focal plane*), to hover in the same plane as the field stop of your eyepiece.** If you opt for a commercial focuser, you will undoubtedly have to cut your focuser hole in a different place than these plans call for! Do you have your eyepiece(s) yet? If that's a "yes," good: Look into your eyepiece and put your pinky finger in the other end--slowly and carefully--can you see where your finger comes into a magnified focus? Usually there is a black ring (called a *field stop*) at this point around the inside of the eyepiece; and usually this corresponds to where--on the outside of the eyepiece--the chrome barrel ends and the rest of the eyepiece body begins. This means this is where the eyepiece "bottoms out" when inserted into a commercial focuser. But, you don't want your commercial focuser to bottom out when focusing! Individual eyes and eyepieces are different! Always allow at least 3/4" "**in travel**" for your commercial focuser, when doing the arithmetic to determine where to cut your focuser hole! More is said on this subject in "Section A" of these plans online.

TUBE DIAMETER

The telescope tube should be about 2 inches wider in diameter than your objective:

A ten-inch diameter objective mirror requires a twelve-inch diameter tube.

An eight-inch diameter objective mirror requires a ten-inch diameter tube.

A six-inch diameter objective mirror requires an eight inch diameter tube.

Materials List

- **Cardboard tube ("Sonotube") (1):**Construction, specifically concrete construction supply houses usually carry these tubes, which are used for forming concrete columns. Get the supply house to cut your tube rough, that is, longer than you need by, let's say, six inches or so. To "finish cut" your tube square: Tape several 8-1/2" x 11" pieces of paper together end for end--enough to wrap around the circumference of the tube, and do just that... Make the ends come together squarely; and mark the edge you want to cut. Proceed with a hand saw or Jigsaw...
- **Exterior grade plywood:** 4' x 8' x 3/4" thick. For an eight or ten inch telescope, one sheet will be plenty. An alternative to "exterior grade plywood" would be "shop grade"; not much more expensive, a MUCH smoother finish is possible.
- (Optional) **Six-Eight feet of Douglas Fir 2"X 2"**: Cut these into small lengths and glue to inside of Rocker Box and Tube Box corners--this will strengthen these joints considerably.
- **Paint and painting supplies:** Flat black for inside the tube; any dark color is fine for the outside

of the tube. White is not recommended--it takes longer for a white tube to cool down to ambient (outside temperature).

- **Sheet Metal Screws:** Panhead, size #8, 3/4" long. Get at least a dozen.
- **Nails**: Assorted sizes. Hot-dipped galvanized box nails work well.
- **Machine Bolts (3):** Three bolts, 1" long; 3/8" in diameter.
- **Lag Screw with matching washer (1):** One lag screw, 3" long; 1/2" in diameter.
- **Record (1):** One phonograph record 33-1/3 LP rpm size (A "used" record is fine.) Or visit your local cabinetmaker for some free "scrap" Plastic Laminate ("Formica" is a brand of Plastic Laminate)--you won't need much--just enough to cover the bottom of your Rocker Box (see Section "C" of these plans) and line the outside edges of your Altitude Bearings. Do not use "gloss" Plastic Laminate, however--just the rougher surfaced stuff. You may also want to contact http://www.crazyedoptical.com/ for inexpensive "kits" of Plastic Laminate and Teflon.
- **Chrome-plated Brass Tubing:** Washbasin drainline trap 1-1/2" outside diameter: We 'll need two pieces: one about 1-1/2" long, for the eyepiece holder, and one about 6" long, for the aligning tube. (Available from a plumber's scrap bin.)
- **Cedar Shim Shingles:** Three pieces, about 1-1/2" to 2" wide. Shingles break easily, so it's a good idea to keep a few extra shingles on hand.
- **Wooden Dowel:** One piece, about 3" long. Usually sold as "closet pole" or "hand rail stock" Approximately 1-3/4" in diameter.
- **Cardboard "Mailing" Tube:** One piece, 1-1/2" inside diameter, about 2" long (Grocery stores have this tube in the produce department used for dispensing plastic bags.)
- **Thumbtacks (3)**
- **Leather Scrap:** Three small pieces about 1/2" square. Old belt leather works fine.
- **Sticker or Decal (1):** About 1/2" in diameter. I like to use "hole reinforcements" stickers, for three-ring notebook paper. A "gold star" also works well. Visit your stationary store.
- **Masonite:** One rectangle of 1/8" thick Masonite board about 3" x 4" (1/4" thick is also O.K.) with a 1-1/2" hole drilled in the center; **and** three pieces about 1" square.
- **Teflon:** 7 pieces, approximately 1" x 1" square, and 1/4" thick. Three pieces will be used for the lower Rocker Box bearings and four for the Cradle Board bearings.Try a local electronics surplus house; otherwise call Crazy Ed Optical, under "Sources."
- **Furring nails (4)** If you can't find furring nails, don't fret; I like to use rubber furniture glides (the kind you just nail in--this serves the same purpose as the furring nails: namely preventing our primary mirror from falling forward.
- **Glue:** White glue works fine. In addition, I like to use 100% black silicone glue on selected parts (like focuser construction and diagonal mirror to diagonal holder adhesion.
- **Telescope Objective Mirror (1):** See above "A word concerning focal ratio.." and "Sources" below.
- **Cardboard:** The back of a cardboard breakfast cereal box works nicely.
- **Telescope Diagonal Mirror (1):** Order when primary f/ratio is decided upon.
- **Eyepiece (1):** Eyepieces may be purchased from telescope supply houses (see "Sources"), or you

can salvage one out of an old pair of 7 x 35 binoculars (binoculars should be labeled "fully coated optics").

Tools Needed

- Hammer
- Saw (Table Saw, and/or Jigsaw is/are helpful but not essential).
- Drill and 1/4", 7/16",1/2",and 3/32" Drill Bits, in particular.
- Tape Measure
- Compass
- Screwdrivers
- Nail Set
- Crescent (adjustable end) Wrench
- Awl
- Hole Cutter or 1-1/2" diameter doorhandle drill bit.
- Carpenter's Framing Square (helpful but not essential); Combination Square

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SOURCES:

Sources for "Ready Made" Telescope Mirrors and Telescope Eyepieces:

- **Coulter Optical, Inc** -- now part of: Murnaghan Instruments

  1781 Primrose Ln.

  W. Palm Beach, FL

  We recommend Coulter's mirrors: quality products at **very** reasonable prices. Call or write for catalog and price list.
- **Orion Telescope and Binocular Center**

  2540 - 17th Avenue, P. O. Box 1158

  Santa Cruz, CA 95061-1158

  In California (800) 443-1001

  Outside California (800) 447-1001

  Call toll free number for free color catalog.

- **Paul Rini** sells *very* inexpensive eyepieces at $17.50 apiece plus $4 shipping.

  P. O. Box 224 Main St.

Maple Shade, NJ 08052-0224

- You may also check the "previously owned" market at: http://www.astromart.com/.

Other Accessories, and Miscellaneous Parts:

- http://www.crazyedoptical.com/ is a great source for *Teflon* and hard to find parts to "gussy up" your scope.
- The ATM Resource List. The *definitive*, up-to-date list for the Amateur Telescope Maker. If you can't find it here, I can't help you!

If you want to make your own mirror, may we suggest:

- **John Dobson's Telescope-Building Video**

This 90 minute, full color video is John Dobson's personal guide to making astronomical telescopes 8 inch to 16 inch apertures and larger. Especially strong in the mirror making department and for large (read 16" Dobsonians). Free color flier available on request.

Price per tape: $39.95

Shipping per tape: $3.50

CA residents add $3.40 sales tax.

Total per tape (except CA) $43.45

Total per tape (CA only) $46.85

Make check or money order payable to: Dobson Astro Initiatives

Remember to include your shipping address!

Mail to: Dobson Astro Initiatives

P. O. Box 460915

San Francisco, CA 94146-0915

Sources for Mirror Kits and other Mirror Making Supplies:

Willmann-Bell; P.O. Box 35025; Richmond, VA 23235

(804) 320-7016

$1 Catalog

Newport Glass Works, LTD; 2044-D Placienta Ave; Costa Mesa, CA 92627

(714) 642-9980

If you can't print--for whatever reason--from these pages, I suggest you contact the Los Angeles Sidewalk Astronomers: last I heard, they are still sending out hard copies for $2.00 from this address:

The Sidewalk Astronomers
1946 Vedanta Place
Hollywood, CA. 90068

If you are requesting these plans be mailed to another country, the price may be higher.

The plans on this Webpage are much improved from the ones the LA folks send out--I recommend you try to print the plans from these pages.

I do not send any plans through the mail, nor do I have any control over those that do (concerning promptness--or anything else, that is)!

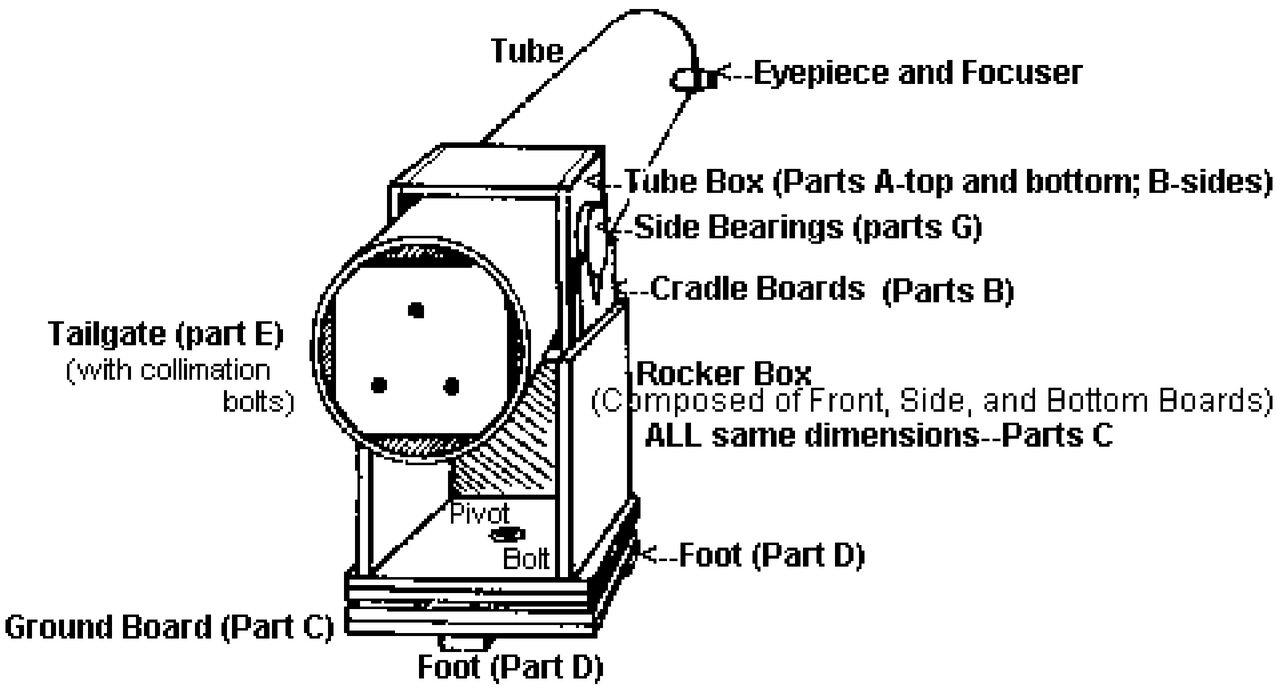
To join **The Sidewalk Astronomers** and receive our quarterly newsletter, send $15 to:

The Sidewalk Astronomers

1946 Vedanta Place

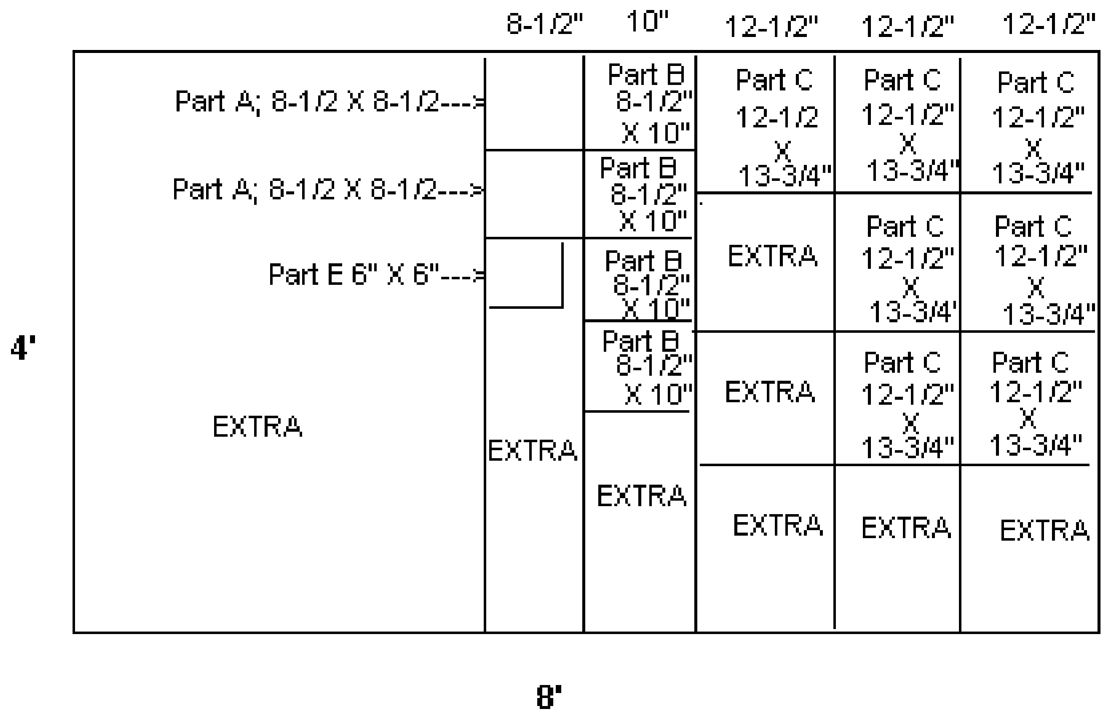
Hollywood, CA 90068

Six-inch Telescope Overview with Plywood Cut Pattern



3/4" thick plywood cut to these sizes:	**Parts A** (2 pieces--top and bottom of Tube Box) 8-1/2"x 8-1/2"	**Parts B** (4 pieces) (sides-tube box; Cradle Boards) 8-1/2"x 10"	**Parts C** (7 pieces--(Rocker Box, Ground Board) 12-1/2"x 13-3/4"
Parts D (3 pieces--Feet) 1-1/2"x 1-1/2"	**Part E** (1piece--tailgate) 6"x 6"	**Parts F** (4 pieces) 1"x 4" (Mirror Blocks--*not shown*)	**Parts G** (2 pieces--5" diameter circles; Altitude Bearings) Not shown below--cut from "extra."

PLYWOOD CUT PATTERN FOR A TELESCOPE WITH A 6" MIRROR:



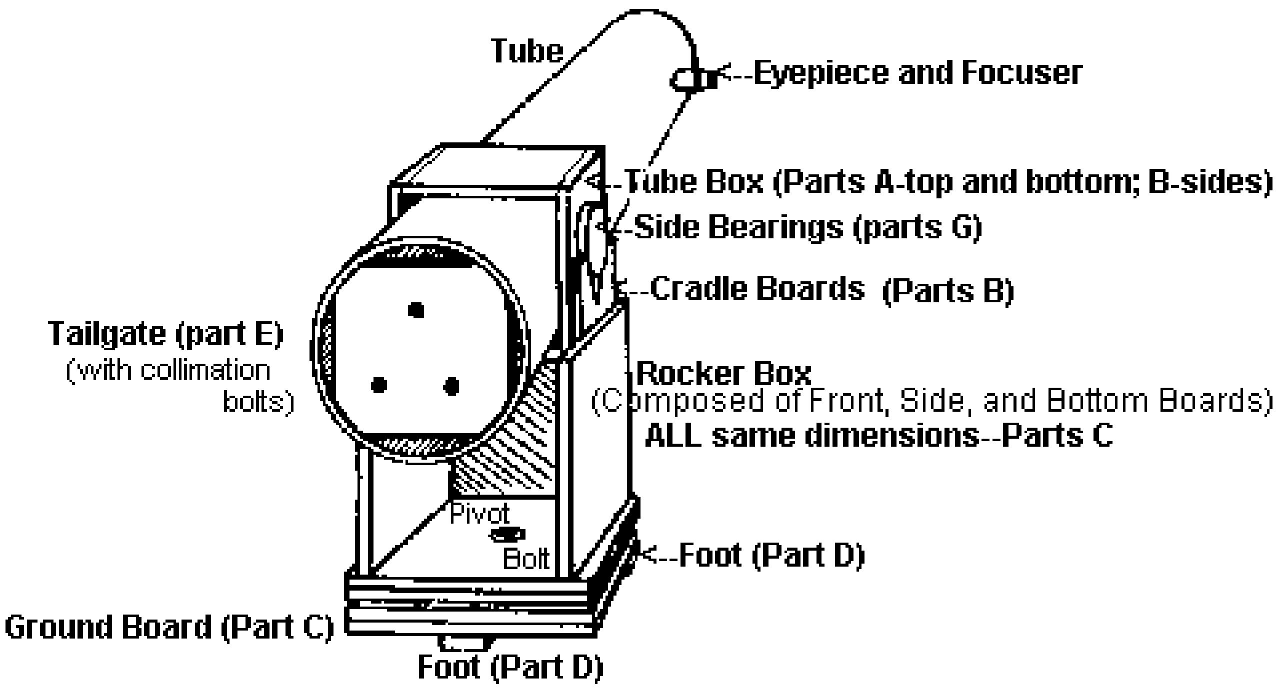
Notes:

You can make your job easier by having the lumberyard pre-cut your plywood on their panel saw. Most stores give you two free cuts and charge (50 cents?) for each additional cut. (They can only do the vertical cuts above.) Then cut the pre-cut pieces into the necessary sizes at home. Note that for a six-inch scope, you will be using less than a half-sheet of plywood; perhaps you and a friend can make two?

Make sure you tell the salesperson cutting the wood for you that these sizes are for the finished (cut) pieces of wood. Allowance will have to be made before cutting for the width of the saw blade ! ! ! (You lose about 1/8" of an inch for each cut, usually.) The wood sizes given should be the actual sizes of the cut pieces of wood.

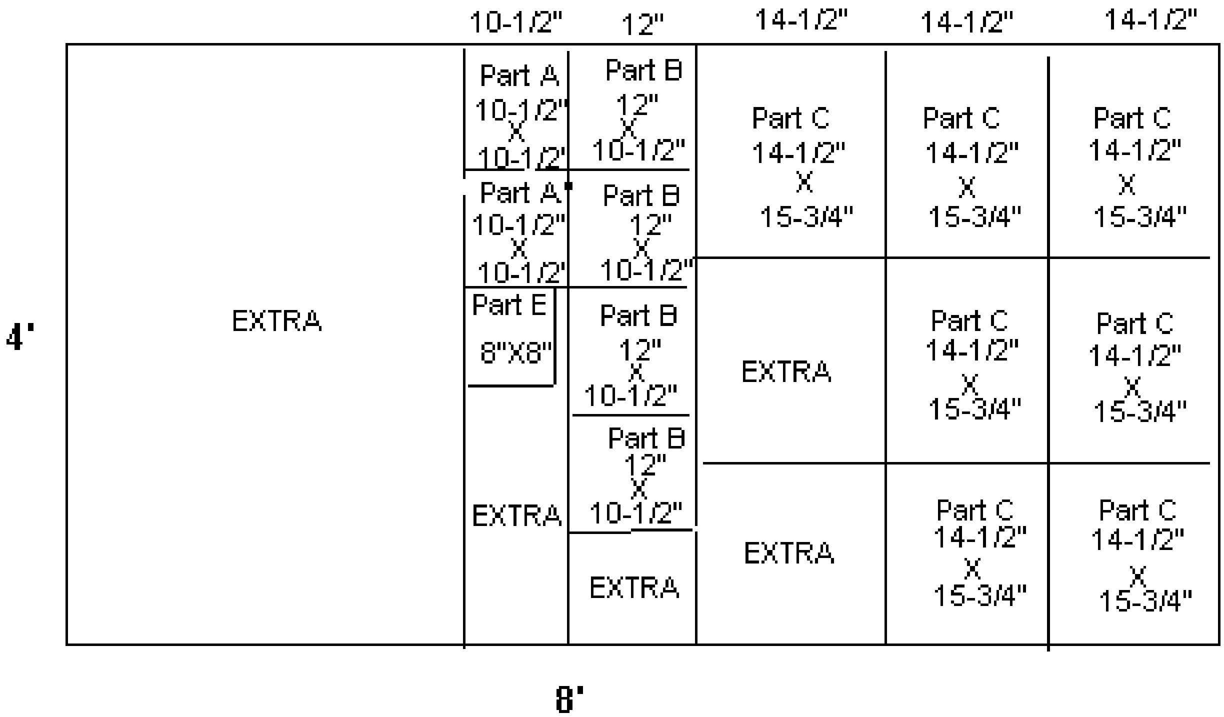
Refer to the above drawing and plywood "cut pattern" throughout the following step-by-step instructions. Label all pieces (in pencil, chalk, or crayon) as they are cut! We will build our telescope from the "inside out," beginning with the tube.

Eight-inch Telescope Overview with Plywood Cut Pattern



3/4" thick plywood cut to these sizes:	**Parts A** (2 pieces--top and bottom of Tube Box) 10-1/2"x 10-1/2"	**Parts B** (4 pieces) (sides-tube box; Cradle Boards) 10-1/2"x 12"	**Parts C** (7 pieces--(Rocker Box, Ground Board) 14-1/2"x 15-3/4"
Parts D (3 pieces--Feet) 2"x 2"	**Part E** (1piece--tailgate) 8"x 8"	**Parts F** (4 pieces) 1"x 4" (Mirror Blocks--*not shown*)	**Parts G** (2 pieces--6" diameter circles; Altitude Bearings) Not shown below--cut from "extra."

PLYWOOD CUT PATTERN FOR A TELESCOPE WITH AN 8" MIRROR:



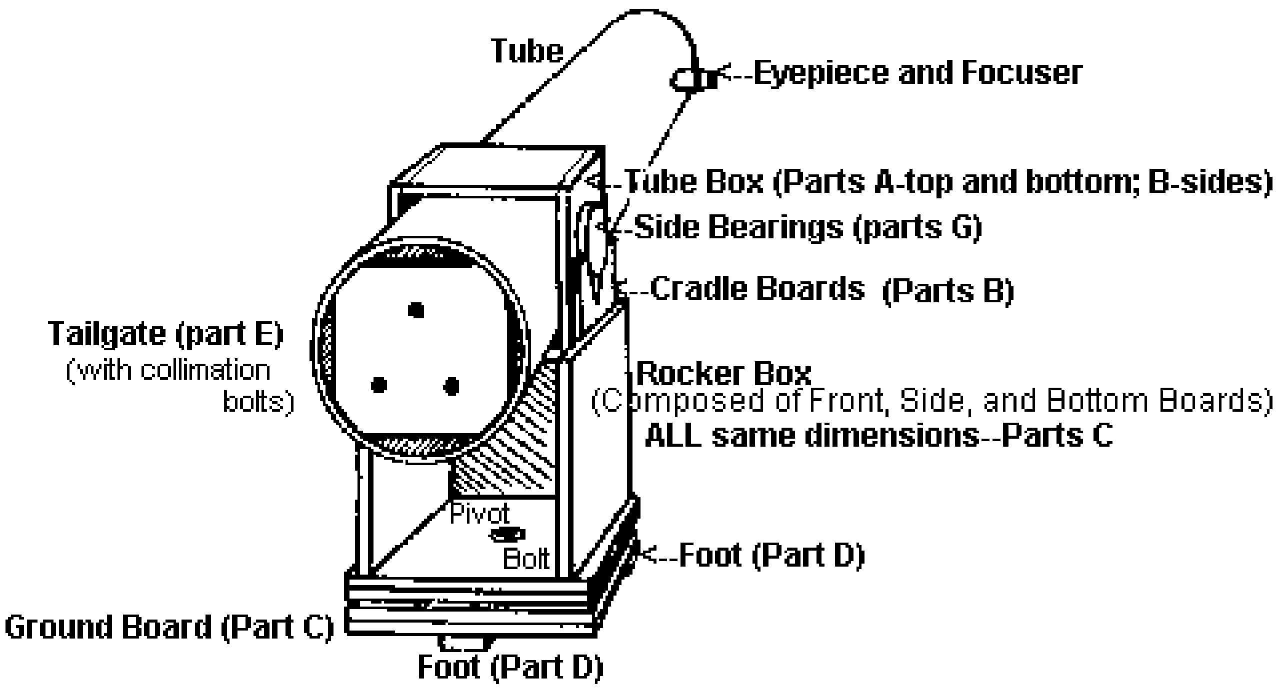
Notes:

You can make your job easier by having the lumberyard pre-cut your plywood on their panel saw. Most stores give you two free cuts and charge 25c for each additional cut. (They can only do the vertical cuts above.) Then cut the pre-cut pieces into the necessary sizes at home.

Make sure you tell the salesperson cutting the wood for you that these sizes are for the finished (cut) pieces of wood. Allowance will have to be made before cutting for the width of the saw blade ! ! ! (You lose about 1/8" of an inch for each cut, usually.) The wood sizes given should be the actual sizes of the cut pieces of wood.

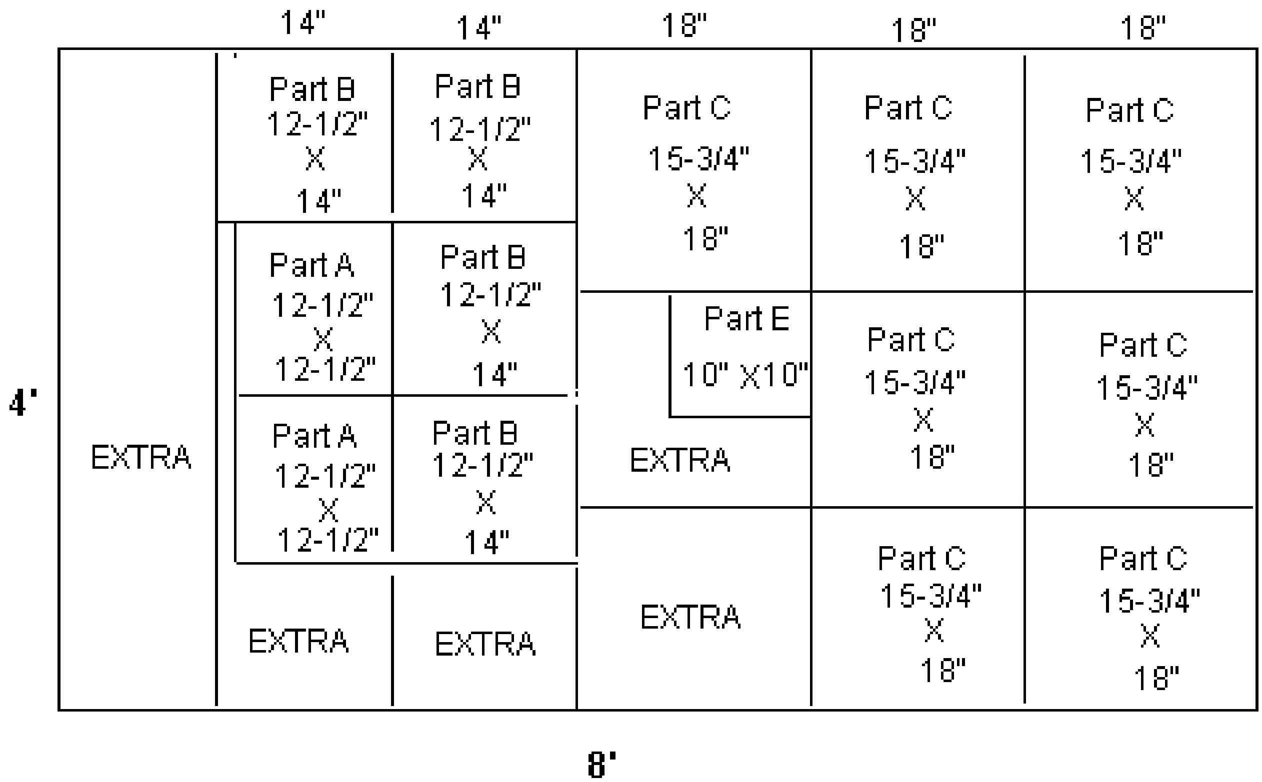
Refer to the above drawing and plywood "cut pattern" throughout the following step-by-step instructions. Label all pieces (in pencil, chalk, or crayon) as they are cut! We will build our telescope from the "inside out," beginning with the tube.

Ten-inch Telescope Overview with Plywood Cut Pattern



3/4" *thick plywood cut to these sizes:*	**Parts A** (2 pieces--top and bottom of Tube Box) 12-1/2" x 12-1/2"	**Parts B** (4 pieces--sides of Tube box, Cradle Boards) 12-1/2" x 14"	**Parts C** (7 pieces-Rocker Box, Ground Board) 15-3/4" x 18"
Parts D (3 pieces--Feet) 2" x 2"	**Part E** (1 piece) 10" x 10" (Tailgate)	**Parts F** (4 pieces) 1" x 4" (Mirror Blocks--*not shown*)	**Parts G** (2 pieces--Altitude Bearings--6" diameter circles). Not shown below--cut from "extra."

PLYWOOD CUT PATTERN FOR A TELESCOPE WITH A 10" MIRROR:



Notes:

You can make your job easier by having the lumberyard pre-cut your plywood on their panel saw. Most stores give you two free cuts and charge a nominal fee (50 cents?) for each additional cut. (They can only do the vertical cuts above). Then cut the pre-cut pieces into the necessary sizes at home.

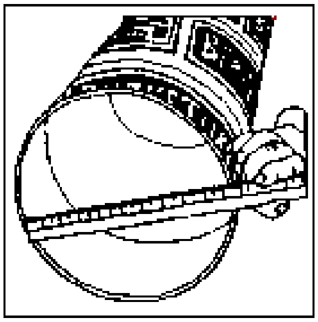
Make sure you tell the salesperson cutting the wood for you that these sizes are for the finished (cut) pieces of wood. Allowance will have to be made before cutting for the width of the saw blade ! ! ! (You lose about 1/8" of an inch for each cut, usually.) The wood sizes given should be the actual sizes of the cut pieces of wood.

Refer to the above drawing and plywood "cut pattern" throughout the following step-by-step instructions. Label all pieces (in pencil, chalk, or crayon) as they are cut! We will build our telescope from the "inside out," beginning with the tube.

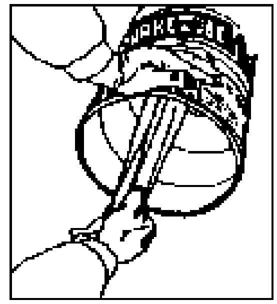
Section"A" of Making a Dobsonian Telescope

(Preparing the Tube; Making the "Spider" and Eyepiece Holder-Focuser)

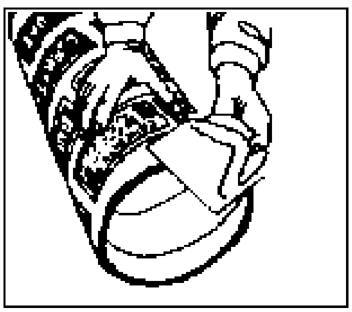
PREPARING THE TUBE



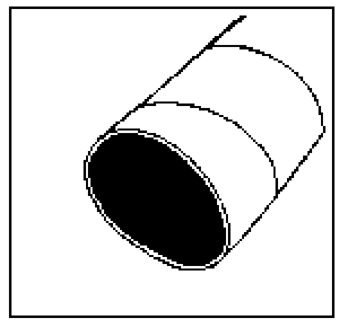
The diameter of the telescope tube should be about 2" larger in diameter than the diameter of the objective mirror



The plastic liner may be carefully peeled out of the inside of the tube.Slow, careful peeling helps keep the liner in one piece and makes it easier to remove.

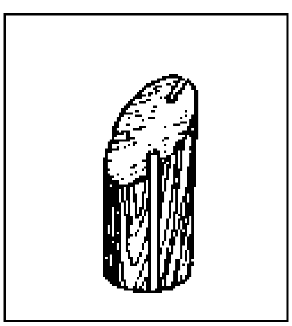


Some tubes are waxed outside. If you plan to paint the outside of the tube, a light sanding will remove some of the wax and make painting easier.



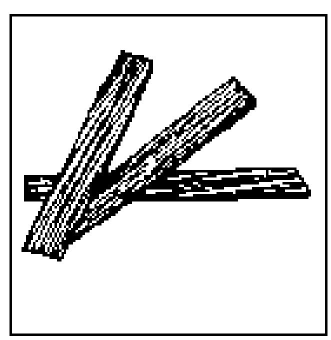
The inside of the tube may be painted black. Tape your paint brush on a broomstick handle if your tube is longer than your arm reach.

MAKING THE SECONDARY MIRROR MOUNT ("SPIDER")



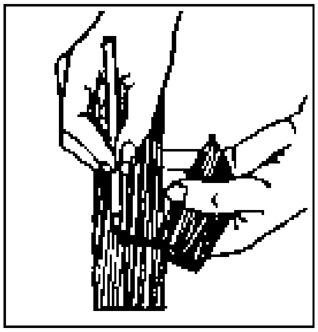
Dowel (closet pole, or handrail stock) with one end cut at a 45 degree angle. Three grooves should be cut (with a thin blade) at equal (120 degree) intervals (about 1/4" deep) as shown.

Note: How does one cut a cylinder at 45 degrees? Cut a strip of paper long enough to wrap around your "closet pole." cut both ends (of the paper strip) at 45 degrees so that you make a trapezoidal

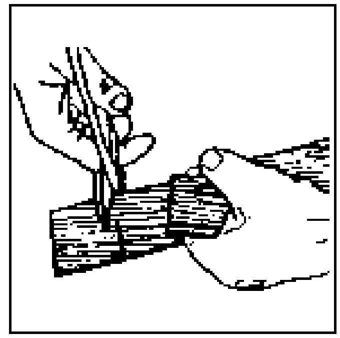


We will need three pieces of cedar shingle, each about 1 1/4" wide.

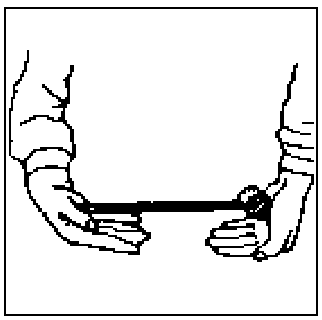
shape... wrap this piece of paper around the dowel so that the ends come together (trail and error cutting may be required here). The paper will **not** lay flat! Now trace the outline the edge of the paper makes. Cut close with a hand saw. Sand or file to line.



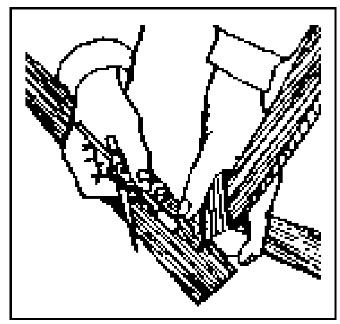
Marking the thin ends of the shingles where they fit snugly into the grooves in the dowel.



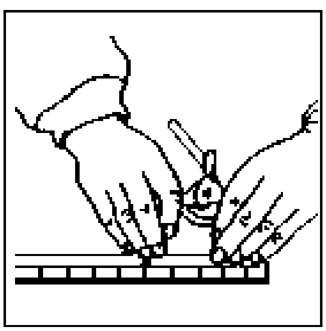
If the shingles are cut slightly concave (so they won't rock back and forth in the dowel and will fit snugly) they won't have to be glued in. Replacement will then be easy. If you do decide to glue them in, use black, 100% silicone adhesive.



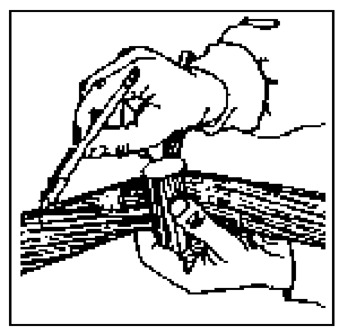
Shoving a shingle into the groove in the dowel.



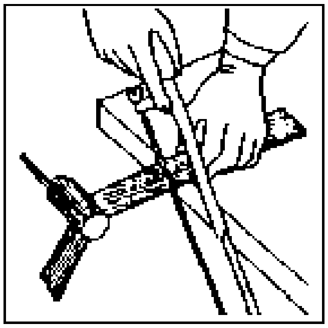
Doing the same with the other two shingles.



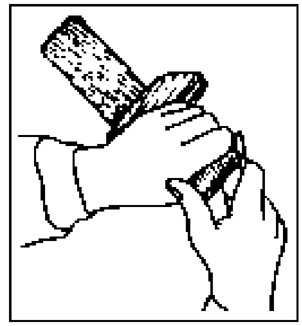
The compass should be set to the radius of the *inside* of the telescope tube.



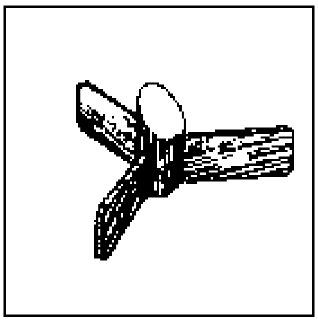
Placing the point of the compass at the center of the dowel, mark all three shingles.



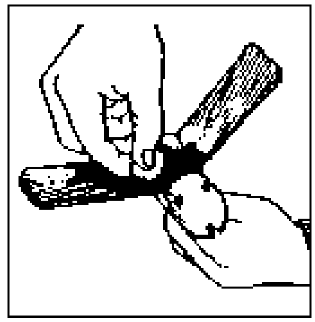
Sawing off the ends of the shingles at the marks.



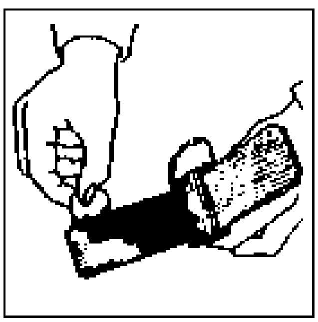
Beveling the corners so the shingles won't split when the position of the spider is adjusted in the tube.



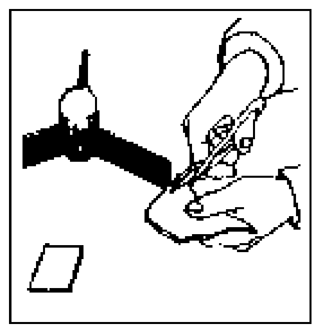
All corners beveled...



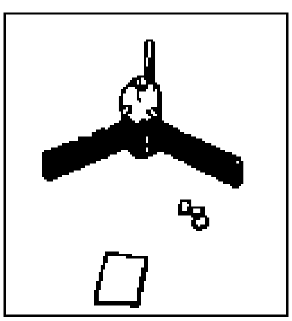
We may paint the spider black, or simply blacken the surfaces facing the eyepiece tube.



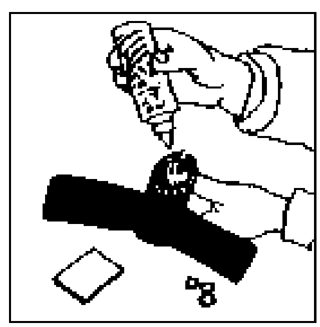
The slant-cut end should be left unpainted (to accept glue). If spray paint is used, be sure to cover the slant-cut end with masking tape while spraying



Cutting leather scrap. We will need three pieces about 1/2" square.

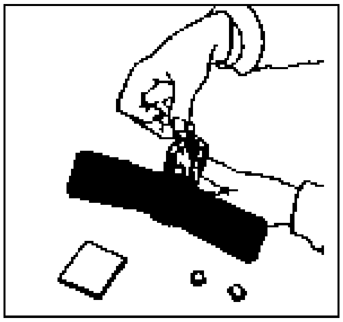


The secondary mirror (flat front-surface mirror). This mirror is also called a "diagonal." (Secondary mirrors are *usually* elliptical in shape; not rectangular like the one above).

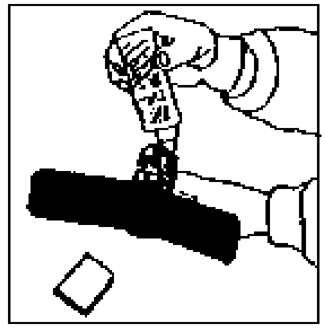


Applying glue at three points on the slant cut end of the dowel. (If masking tape was used, remove it first!). Leather pieces should be glued directly to the wood. *An alternative to leather and white glue is to use three dabs of 100% silicone adhesive--you might want to drill three small, shallow holes in the "slant cut" to accept the silicone better.*

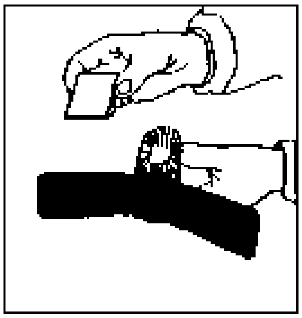
COMPLETING THE SPIDER



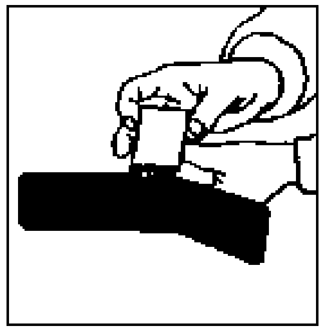
Leather pieces should be spaced evenly between the grooves. Be sure the leather gets good and wet with the glue.



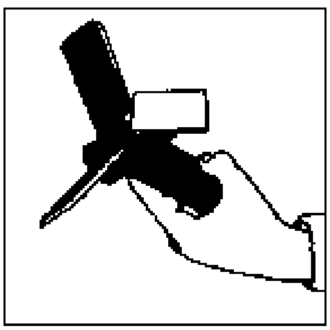
After the leather pads are glued to the dowel, we apply glue to the tops of the leather pads...



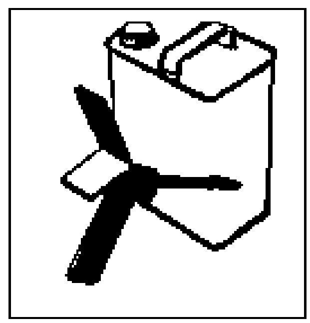
...and glue the mirror onto the pads.



Make sure the mirror is evenly centered over the dowel.



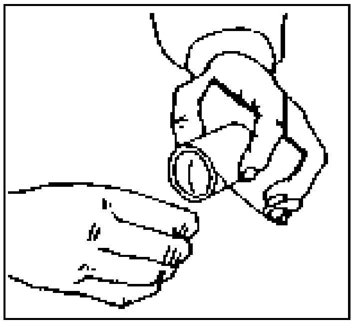
The mirror should be kept level while the glue dries.



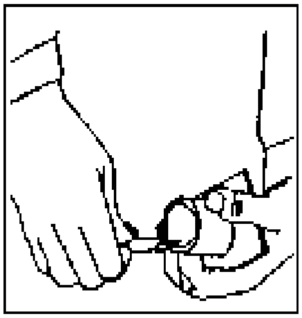
Propping up the spider while the glue sets.

MAKING AND INSTALLING THE EYEPIECE TUBE

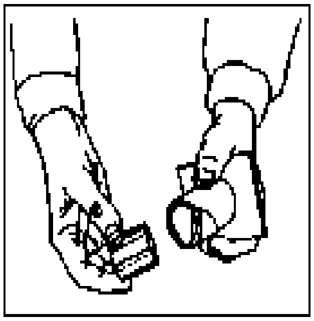
NOTE: Above, a close-up photo of my **Dobsonian Sun scope**: An inexpensive alternative to constructing an eyepiece tube from a cardboard tube and masonite (below) is to order--and attach--a ***2-inch to 1-1/4-inch adapter*** from a telescope mail order house like Lumicon, Orion, or Crazy Ed Optical. This $20 item is used in expensive, low-profile focusers to adapt from eyepieces with a 2" barrel to ones with the more common 1-1/4". You will have to drill a couple of holes through the metal (usually aluminum) to accept the small through bolts, and shim the flat bottom equally in two places (since you are attaching the thing to a cylindrical surface)... It adds a little more weight "up top," requires two hands to focus (one to operate the knurled stop screw, and one to push-pull focus); but you will end up with a sturdier, low-profile focuser than the one described below. Be sure to drill only an 1-1/4" hole in the tube, instead of the 1-1/2" hole as per the instructions below.

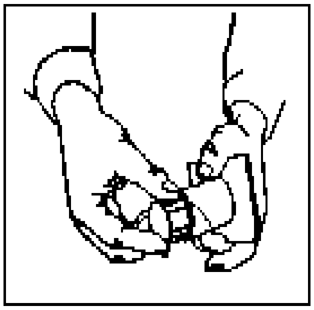


Gluing the cardboard eyepiece to a 3" x 4" piece of Masonite with a 1 1/2" hole cut in its center. Make sure to get the cardboard wet with the glue.

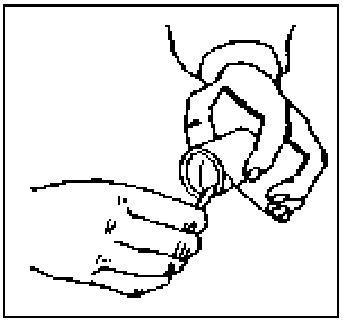


Beveling the inner edge of the tube with a pen knife so that the brass will fit in easily.

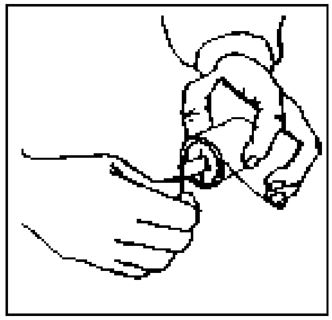




The brass tube should fit snugly inside the cardboard tube... ...and slide back and forth fairly easily.

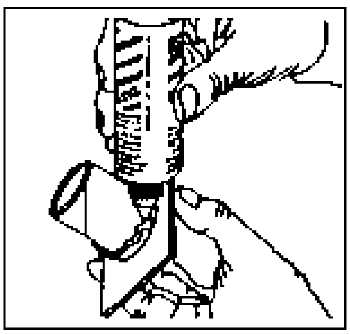


If the fit is too tight, we may peel out a thin layer of the cardboard on the inside of the eyepiece tube.

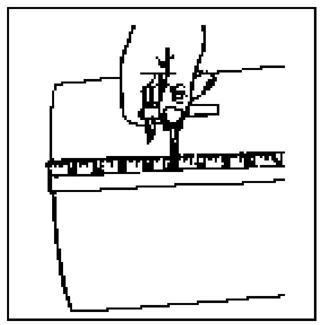


If the fit is too loose, we may glue in a strip of cardboard lengthwise down the inside of the eyepiece tube and let the end of the strip hang down over the end of the tube. (The strip should be glued down over the lip of the tube.)

Gary Morris (glmorris@jps.net) came up with an elegant solution to attain the correct amout of "focusing friction": He simply uses a hose clamp (see photo at left)... He writes that it is a onetime affair to tighten the hose clamp around the cardboard focusing tube just enough to provide the necessary friction around the sink drain tube.(This would replace the need to "peel" or "glue in a strip of cardboard" in the two previous steps)



Running a thin bead of glue (100% silicone glue works well here) around the cardboard tube where it meets the Masonite.



Finding the location for the eyepiece hole. See note—below:

Note: Cut the telescope tube the same length as the focal length of your mirror. Then cut the eyepiece hole back from the front end of the telescope tube by the radius of the tube. That is, for a 10" diameter tube, cut the eyepiece hole 5" from the front end; for a 12" diameter tube, cut the eyepiece hole 6" from the front end. These distances are for mirrors about 1" thick. If you have a thick mirror (i. e. 2"+) the hole should be moved up toward the front end of the tube an extra 1" to compensate. (i. e., a 12" tube with a 2" thick mirror would put the hole 5" from the front end; a 10" tube with a 2" thick mirror would put the hole 4" from the front end.

A more important Note: Now, the above *note* ONLY works if you make the homemade focuser AND follow all the details of tailgate construction, use Sonotube, etc in these plans. If you don't, you will have to do some simple arithmetic. Folks: it is extremely easy to drill your focuser hole in the wrong place! Please read the following email and my response:

> I just built a Dob with an 8" f/6 primary mirror, 48" length tube and
> centered the focuser 5" from the end of the tube. I can see the moon really
> clearly, but when I look at distant stars, I can see their light, but in the
> eyepiece, I can only see the primary mirror--the star doesn't come into
> focus. I have a Crayford R&P focuser and a zoom eyepiece (7-20MM).

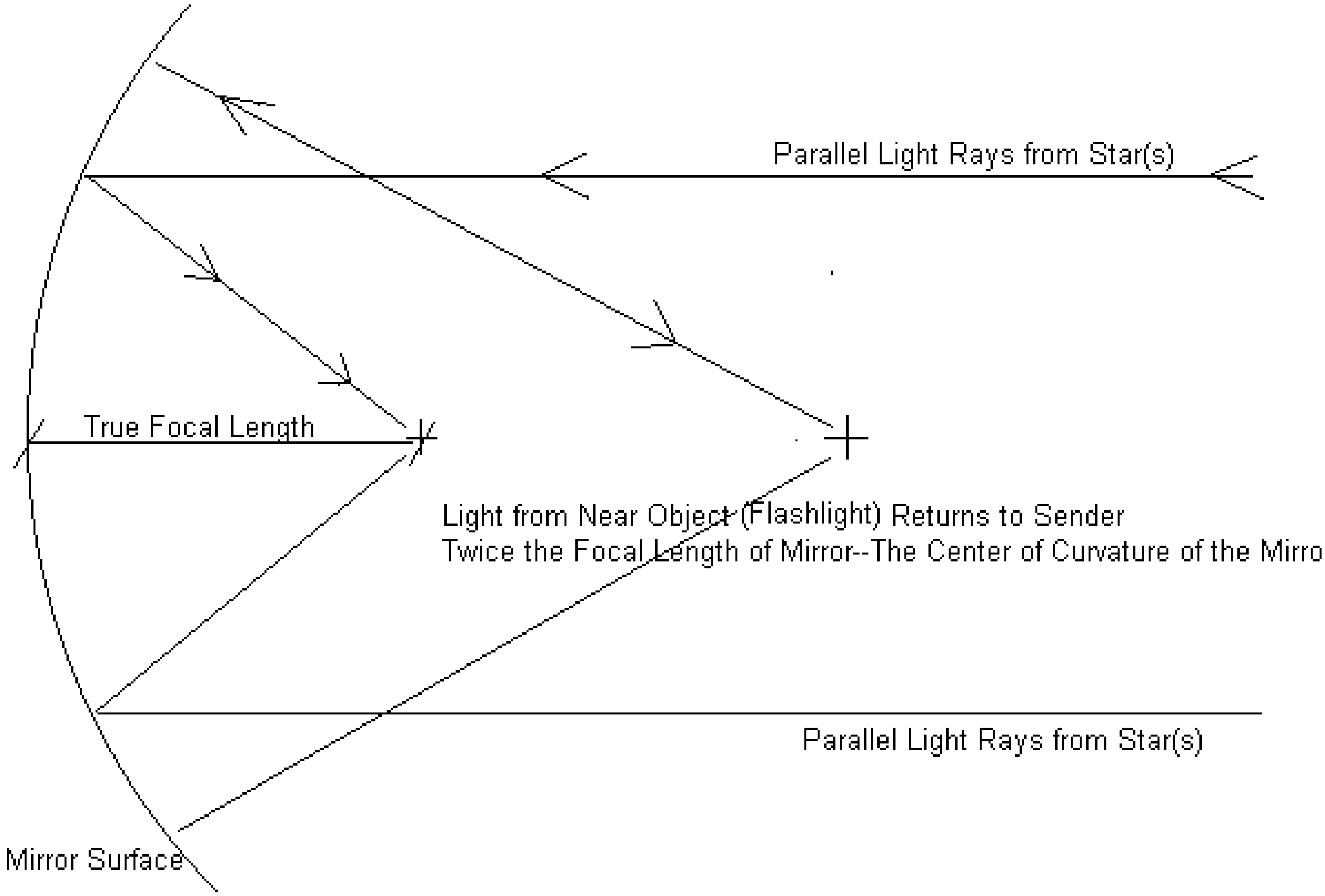
Hi Daj,

This is a most common problem. I must rewrite that section on the plans!

You did what the plans told you to do; however, you used a commercial focuser, which does not have as much "in travel" as the homemade one in the plans. You need to re-position your diagonal closer to the main mirror and re-drill your focuser hole.

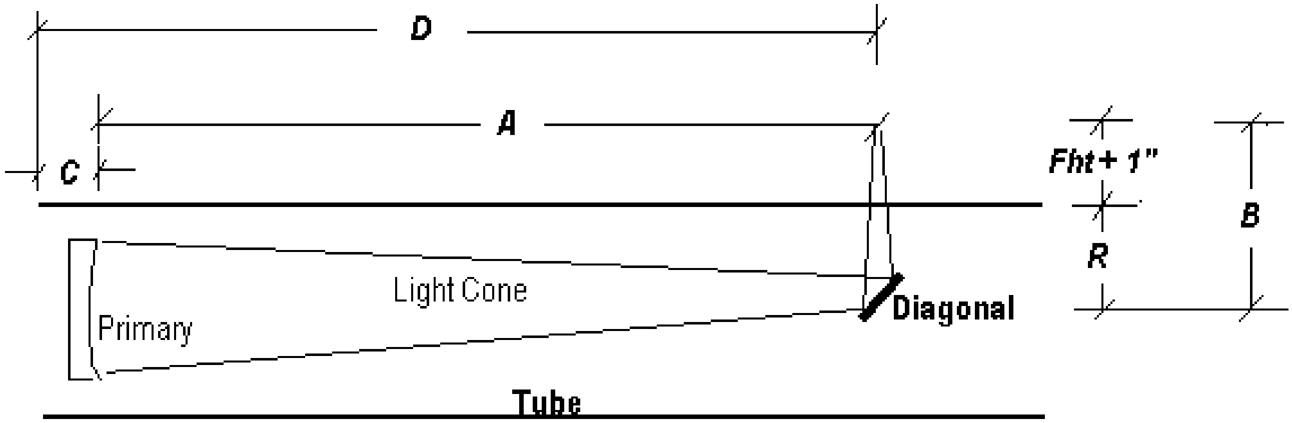
Here's how to figure out where EXACTLY:

Number One: Find out the exact focal length of your primary mirror (even if it is *supposed* to be 48"--for example--this may vary by an inch or more in either direction). To do this, the safest way is to bring your primary indoors, prop it up at the end of the hall, and then, with a piece of paper and a flashlight, start at about TWICE the distance of the (supposed) focal length, shine the flashlight at the primary and look for a formed image on the piece of paper (that you are holding in your other hand). IMPORTANT: The flashlight filament and piece of paper MUST be in the same plane, facing the mirror. Focus the image on the filament. Mark your floor with a piece of tape, or something. Measure carefully the distance from the face of your mirror to your mark. DIVIDE BY TWO. This is the focal length of your mirror. Write it down!



You can, of course, double check this dimension (the True Focal Length), outside at night, using the Moon or bright Jupiter as a target--don't forget to bring a friend and a tape measure to help you! And catch the image of Jupiter or the Moon bouncing back in the same direction!

Now, your telescope, when set up properly, will have a celestial image formed at the *field stop* of your eyepiece(s). Look at your eyepiece(s). Specifically, look down the "wrong end," the open end. Usually you can find a small black ring encircling the inside of your eyepiece, usually this ring corresponds to where the chrome barrel ends on the *outside* of the eyepiece, and where the eyepiece bottoms out when inserting into focuser. Find it? Now, look into your eyepiece (normally now, through the right end) and place a pinky finger in the wrong end at the field stop. See how your finger is magnified? Understand the dynamics of the telescope-to-eyepiece relationship better now? I am not familiar with zoom eyepieces; do determine where the field stop is--or its average place in relation to the outside of the eyepiece is, though. What I am trying to say is: the field stop *generally* corresponds to where the eyepiece bottoms out in the focuser, but maybe not in the case of a zoom eyepiece.



Refer to the above diagram, fill in your own values, if you will:

A + B = your true focal length

C = back of telescope tube to face of mirror

D = back of telescope tube to center of focuser hole

R = radius of tube

Fht + 1" = your focuser height (fully racked in) plus one inch.

(A and/or D is what we are going to determine).

Okay: it is just simple arithmetic to determine where to drill your focuser hole and place your diagonal directly below it:

Fht + 1": Let's say you have a commercial focuser, which, when racked all the way in is 1-5/8" high (sitting 1-5/8" above the tube). First of all, you do not want your focuser racked all the way in; you need some "play"; not all eyes focus the same; not all eyepieces focus the same. Add one inch to this minimalist equation (2-5/8", in other words). You want the telescopic image to hover 2-5/8" above your tube, in other words, before being magnified by an eyepiece.

You know all the other factors: The TRUE focal length of your mirror, where the mirror face is sitting in relation to the back of your tube, and the radius of your tube.

So, as an example, let's say the true focal length of your mirror is 48".

And your mirror face is sitting 2" from the back of your tube (assuming you have 3/4" plywood tailgate + 1/4" masonite collimation pads + a 1" thick mirror = 2")

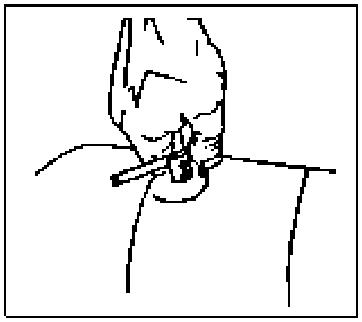
And the radius of your tube is 5".

So: add 5" + 2-5/8" = 7-5/8"

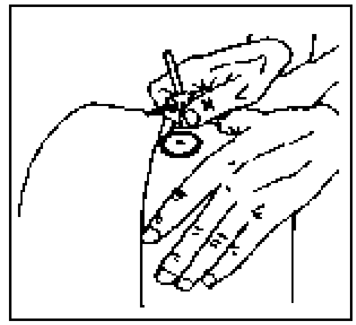
Subtract 7-5/8" from 48" = 40-3/8" This will be the distance from the face of your mirror to your focuser hole, and the diagonal.

If you add the 2" (the face of mirror to back of tube dimension), you can measure from the back of the tube 42-3/8"

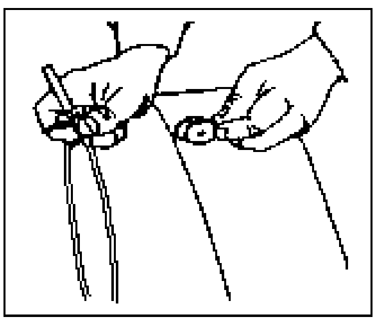
I drilled my focuser hole in the wrong place on my first homebuilt telescope; it is simple enough to fix. Did you save the piece you drilled out? Good. you can use "Bondo" (automotive body filler) to patch it back in--use masking tape to hold it in until the Bondo sets up (about ten minutes). Simply rotate your tube and redrill hole--of course you will have to reposition your diagonal, too.



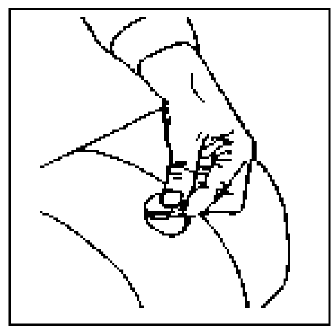
The distance we have measured is for the center of the hole. We may cut the hole to the outside diameter of the cardboard eyepiece tube.



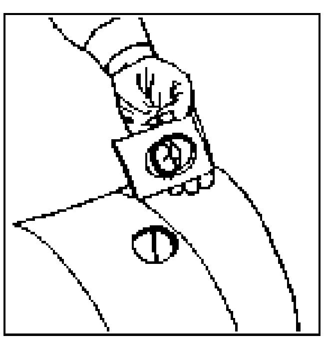
If a hole-cutter is unavailable, a mat knife may be used.



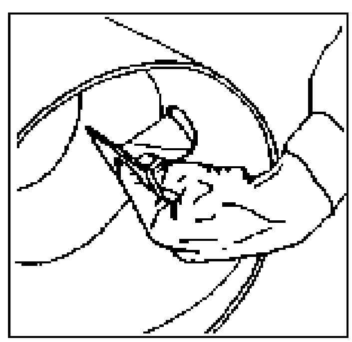
We may peel off layers of cardboard as we gradually cut through the tube.



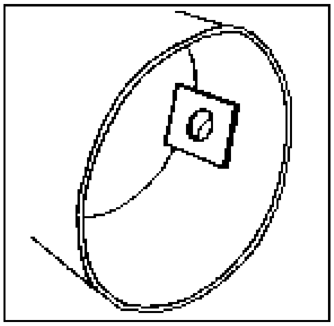
Mission accomplished! **Hint:** *Save this piece, just in case you made a boo-boo here! It will be much easier to patch up, if necessary, with this piece still around!*



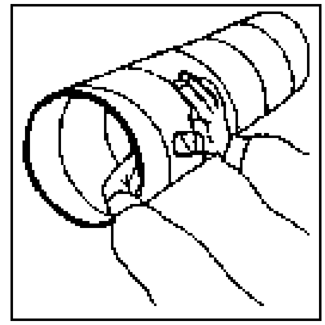
We are ready to install the eyepiece tube.



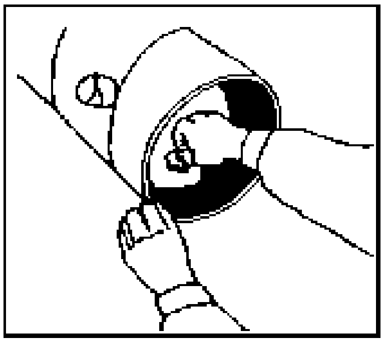
The cardboard eyepiece tube should fit snugly through the hole. If it is too tight, file or pare the hole a little bigger.



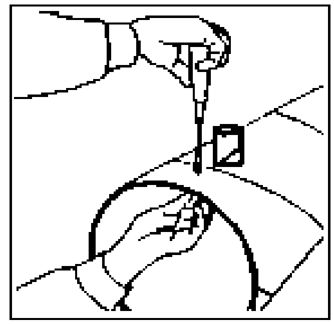
Eyepiece tube in place.



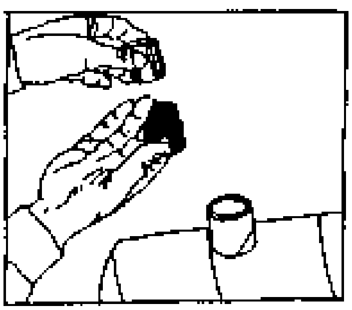
View from the outside of the telescope tube.



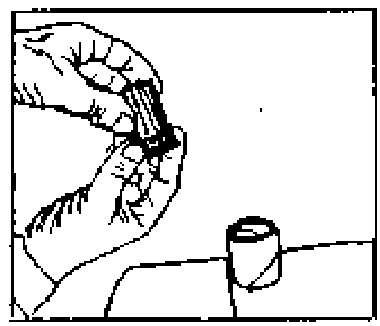
If we have not already painted the inside of the telescope tube, we now need to paint at least the section visible through the eyepiece tube black .



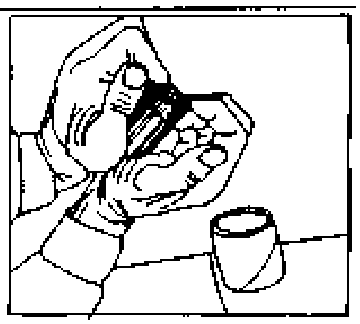
Two sheet metal screws (one on either side of the eyepiece tube) may be used to draw the Masonite rectangle snugly up against the inside of the telescope tube wall.



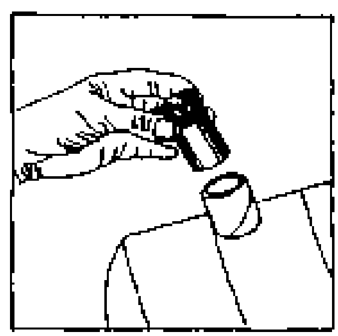
Fitting the eyepiece inside the brass tube. You can purchase an eyepiece, or salvage the eyepieces out of an old pair of binoculars.



If the eyepiece is too small to fit snugly in the brass tube, wrap it in a layer of two of corrugated cardboard.



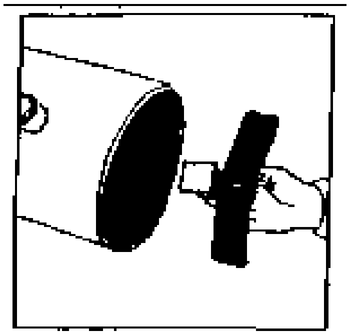
Adjust the amount of cardboard as needed so that the fit of the eyepiece in the brass tube is snug.



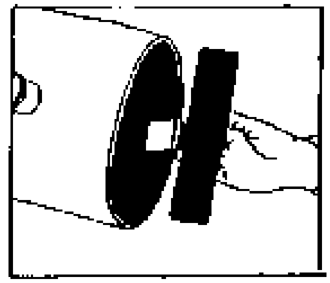
The eyepiece is ready for use!

Please Note: It is very easy to whack your eyepiece holder as you move your telescope tube around: Be especially mindful of doorjambs and car loading/unloading!

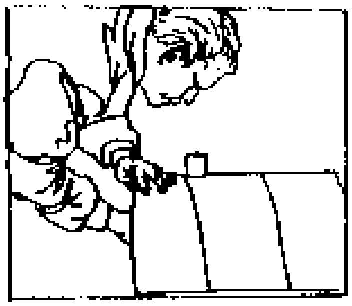
INSTALLATION & ADJUSTMENT OF THE SPIDER



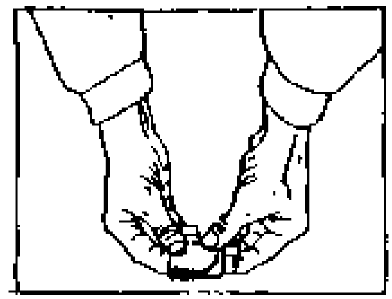
Trying out the fit of the spider in the telescope tube.



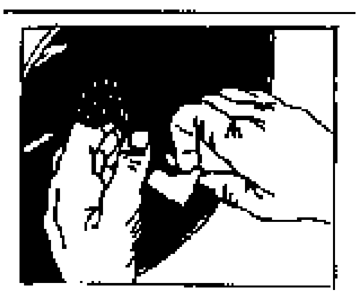
Adjust the spider so that the diagonal mirror is in front of the eyepiece hole. (The diagonal mirror should be facing the hole).



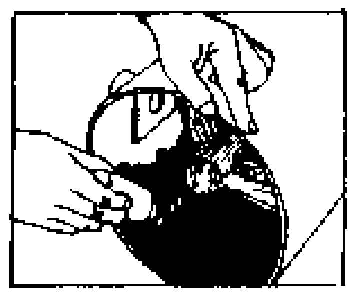
When we look through the eyepiece hole we should be able to see the reflection of the (open) bottom end of the telescope tube in the diagonal mirror.



If the fit of the spider is too loose, we may tighten the fit with cardboard folded to the necessary thickness...



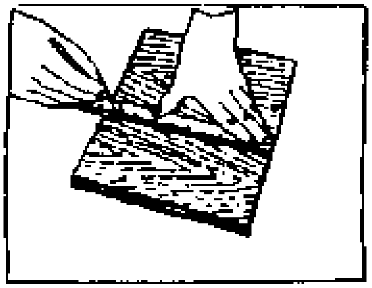
Fitting cardboard under one shingle (the shingle opposite the eyepiece hole). Readjust the spider as needed after fitting the cardboard.



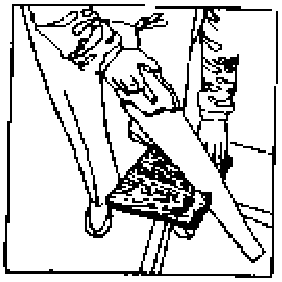
When installed, the whole objective mirror will need to be visible in the diagonal when we look into the eyepiece hole. Do not glue the spider to the tube until final adjustments are made on the alignment.

Section "B" of Making a Dobsonian Telescope

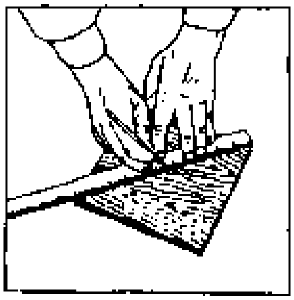
MAKING THE TAILGATE



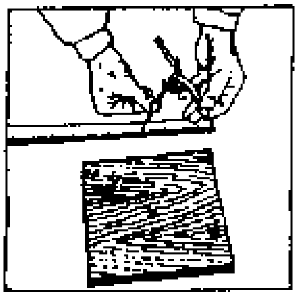
The tailgate should be a square with the same width as the objective mirror. (e. g. a 10" mirror in a 12" tube gets a 10" square tailgate--you will soon "lop off" the corners.)



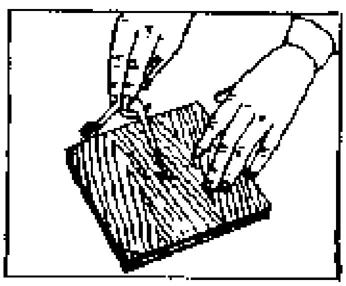
Cutting out the tailgate.



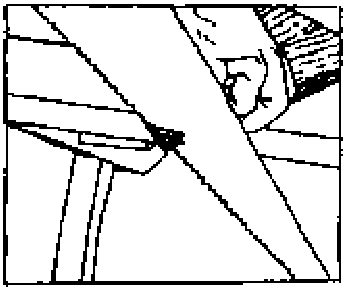
Finding the center of the tailgate.



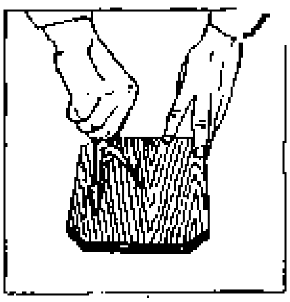
Set the compass for the radius OF THE INSIDE OF THE TUBE. (Not the radius of the mirror.)



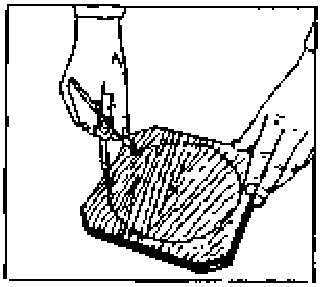
Drawing a circle with the compass point at the center of the tailgate. Only the very corners of the wood will be touched by the pencil.



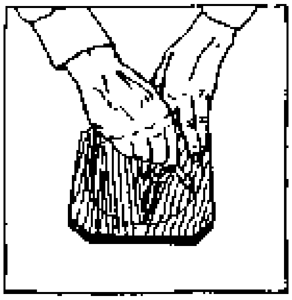
Sawing off the corners of the tailgate at the pencil marks. Now the tailgate should fit inside the telescope tube. (Plane or sand to fit if necessary.)



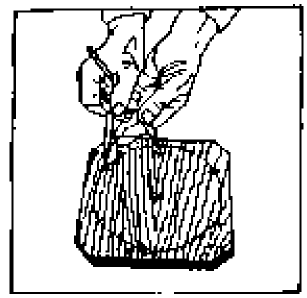
Drawing a second circle for the placement of the tailgate bolts.



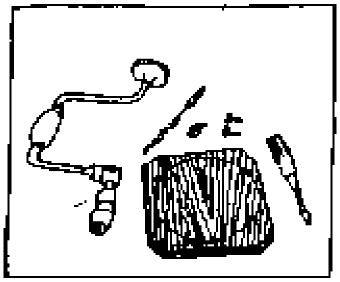
This circle should be 2" smaller than the diameter of the objective mirror. (e. g. for a 10" mirror, we need an 8" diameter circle.)



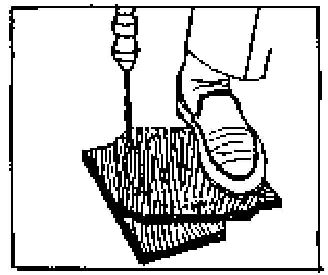
Dividing the circle into six equal segments (the radius of the circle you just drew).



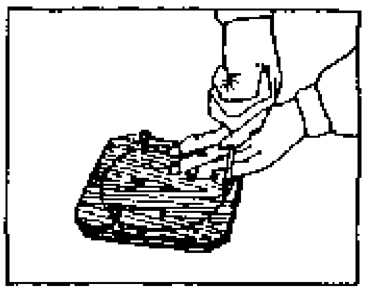
Marking the circle at each of the six points.



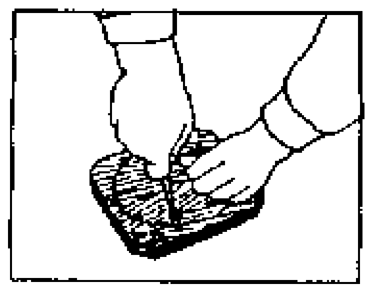
Of the six marks on the circle, we choose three (every other one) for our equilateral triangle. *We want two of our three marks to be towards two of our "cut-off" corners.* One bolt is placed at each of the three angles.



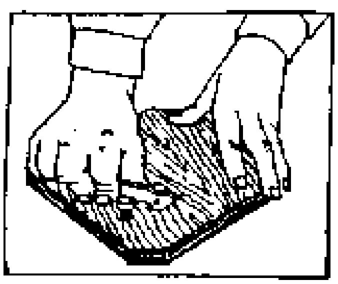
Drilling bolt holes. (A power drill also works well, if available).



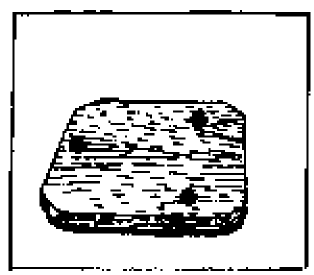
The bolt holes should be one sixteenth of an inch smaller than the bolts (5/16"), so that the bolts will fit snugly.



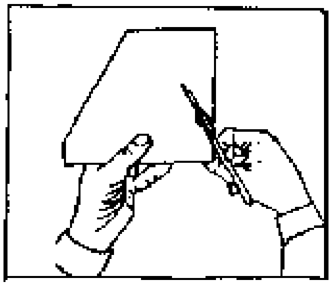
Screwing in the tailgate bolts. The bolts should be threaded right through the wood.



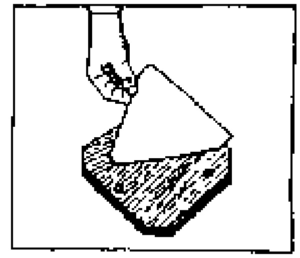
The bolts should be quite snug and difficult to turn.



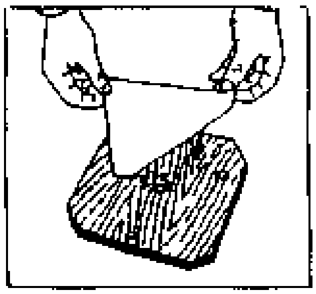
The view from the other side: tailgate bolts poking through the wood.



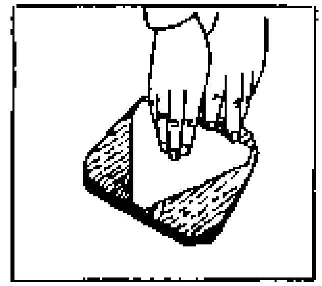
Now we cut a piece of thin (e. g. cereal box) cardboard into a triangle which will cover the protruding bolts.



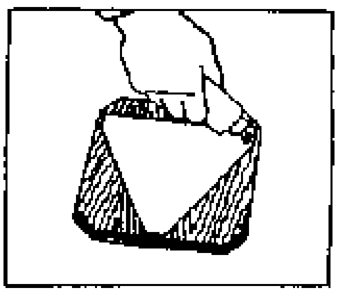
The cardboard should cover all three of the bolts where they come through the wood.



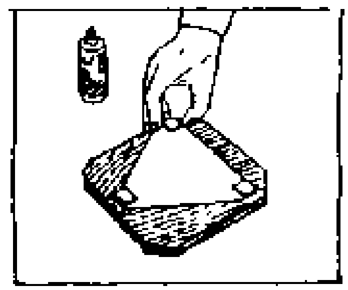
Gluing the cardboard in place. (Apply glue at the center of the cardboard only!!!)



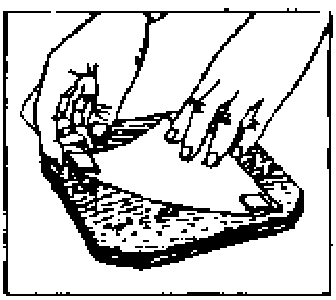
Letting the glue set.



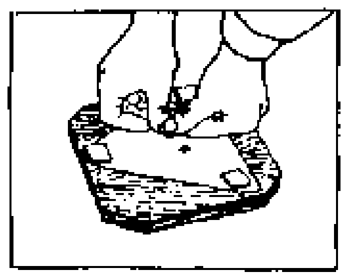
Now we apply glue to the cardboard at the three places where the bolts poke through the wood...



...and glue the squares of Masonite (about 1" square) onto the cardboard directly over the protruding bolts.

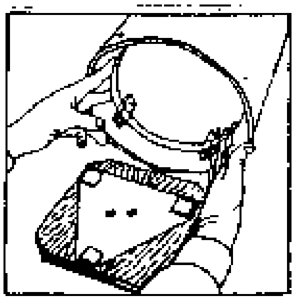


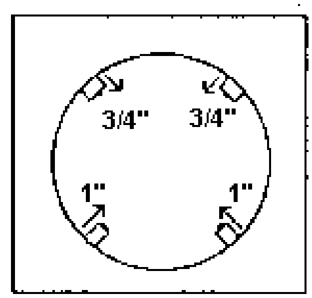
This cardboard protects the mirror from the tailgate bolts if the telescope is dropped on its end. This cardboard must be floppy so as to allow alignment of the objective.



Fixing the position of the cardboard with two thumbtacks. (Double-check first to make sure each Masonite square covers its protruding bolt!)

MOUNTING THE MIRROR IN THE TUBE



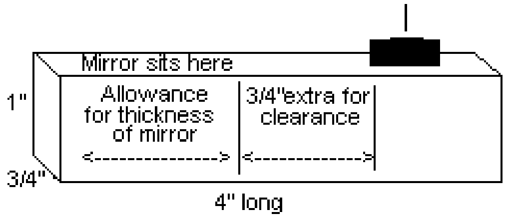


We use four mounting blocks to mount the mirror in the telescope tube. When the mirror is installed, it should rest on the two bottom blocks, but clear the two top blocks. Furring nails, or rubber furniture glides, are placed at the ends of each of the mounting blocks to prevent the mirror from rolling out of the front end of the tube. After you have installed the mounting blocks and the mirror, check to make sure that the mirror cannot get past the furring nails, or furniture glides. If it does, you will have to increase the height of the mounting blocks as necessary.

The mirror mounting blocks are designated PART F in the plywood cutting plans.

The mounting blocks are screwed in place inside the telescope tube. The mirror sits on the two bottom blocks and should just clear the top blocks under no circumstances should the mirror be pinched or squeezed between the blocks.

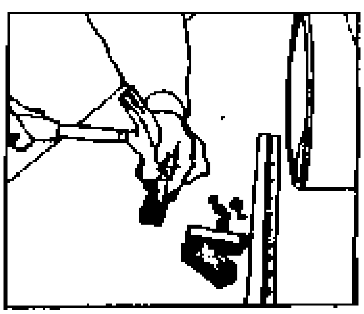
If the blocks are cut from 3/4" plywood and are 1" wide (they should be about 4" long), we will probably have to place two blocks with the 3/4" side "up" and two blocks with the 1" side "up" in order for the mirror to fit nicely (see diagram above).



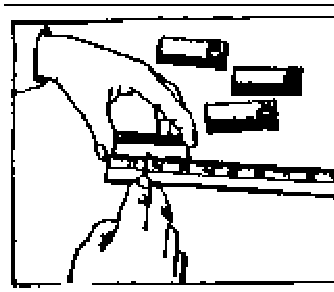
Wood Mounting Block

A furring nail (or rubber furniture glide), is hammered into each block before the blocks are screwed into the telescope tube. The furring nails prevent the mirror from rolling out the front end of the telescope tube. To determine the placement of the furring nail, allow room on the block for the width of the mirror, plus an extra 3/4" for clearance. Please note: the drawing at left is for bottom blocks (1" high); for top blocks, they should be turned 90-degrees and only be 3/4" high before nailing furring nails or rubber furniture glides on.

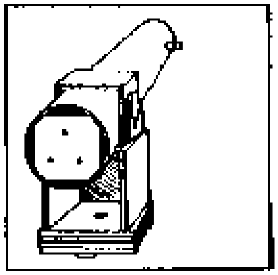
INSTALLING THE MOUNTING BLOCKS



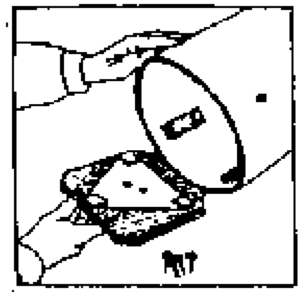
A furring nail should be hammered into one end of each of the mounting blocks (allow necessary clearance see previous figure above) before the blocks are screwed into the tube.



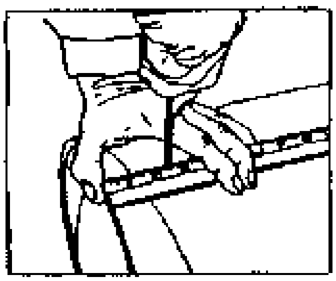
Preparing the blocks for installation in the telescope tube. A pilot hole for the screw may be made in each block (on the side of the block without the furring nail). 2" from the end (i. e. the end without the furring nail).



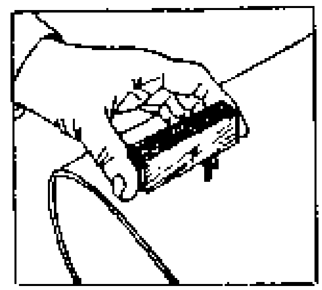
It is convenient to have the eyepiece hole on either the right side (shown), or the left side, depending on which of your eyes is "dominant." To determine which eye is dominant, simply hold your fist up to your eye and imagine this to be an eyepiece--which eye do you instinctively use? If it is your left eye, mount your tailgate so the eyepiece hole is on the right; vice-versa if it is the right eye. This will be more comfortable if, in the future, you decide to mount a Telrad, Quikfinder (1X finding aids), or a finder scope. The eyepiece may be positioned horizontal (as depicted), or canted down about 30-45-degrees; the latter helps insure your eyepiece doesn't fall out accidentally, and usually lends itself to more comfortable viewing.



Mounting blocks are screwed into the tube so that the four corners of the tailgate (when installed) will butt up against all four blocks. Please see previous note to determine where you want your eyepiece to be positioned. You also want two collimating bolts to be at the bottom; one on top--as illustrated above and previous.

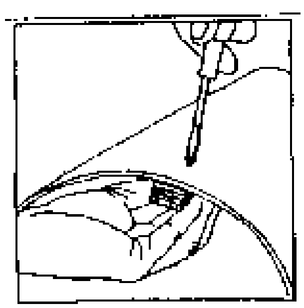


Preparing to screw the mounting blocks into the tube. Pilot holes for each of the screws may be made in the main tube 3" from the rear end.

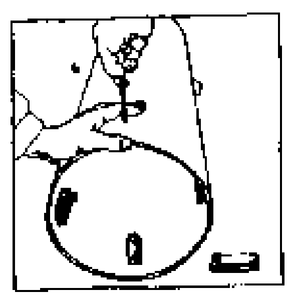


This gives the ends of the blocks 1" clearance from the rear end of the telescope tube, and leaves adequate space for installing the tailgate.

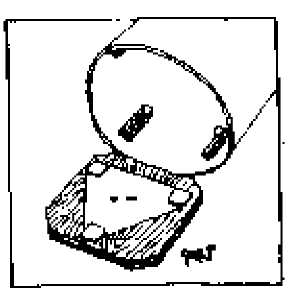
INSTALLING THE TAILGATE



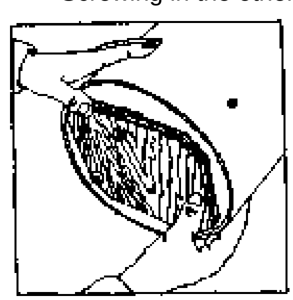
Screwing one of the mounting blocks securely in place.



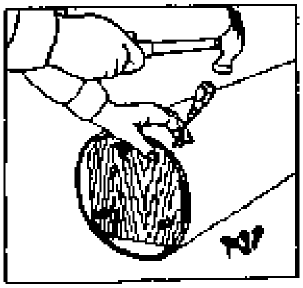
Screwing in the other three blocks.



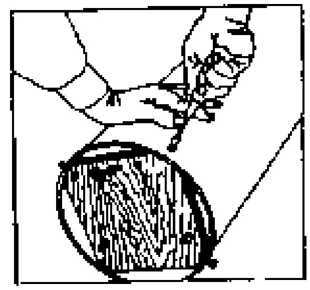
All four blocks are installed. Time to put in the tailgate.



The tailgate should butt snugly against <u>all four blocks</u> so that it won   t rock when pushed alternately on opposite corners. If it <u>does</u> rock; try gluing cardboard to the end of the offending block.

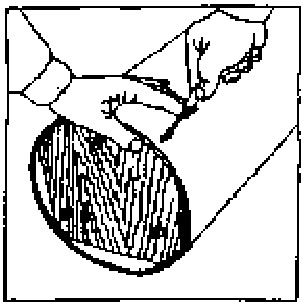


Making pilot holes for the four tailgate screws. The screws go through the cardboard tube and into the wood.



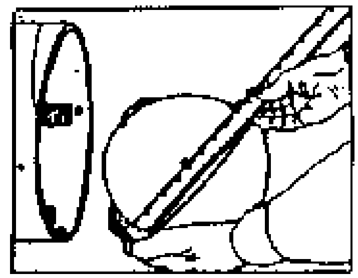
Screwing in the tailgate at all four corners. (Check the fit of the tailgate before installing the mirror).

INSTALLING THE MIRROR

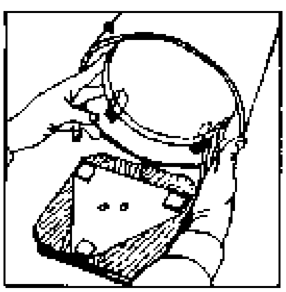


When the tailgate is snug, we are ready to install the mirror. (Of course, you will have to remove the tailgate again).

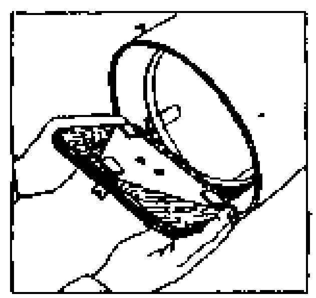
CAUTION: HANDLE YOUR MIRROR INDOORS OR IN THE SHADE!!!



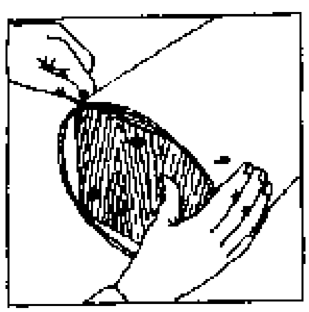
Carefully place a sticker or decal at the exact center of the mirror. This sticker will be used later to align both the diagonal mirror and the objective mirror.



Installing the mirror--very carefully!



After installing the mirror, close up the tailgate...

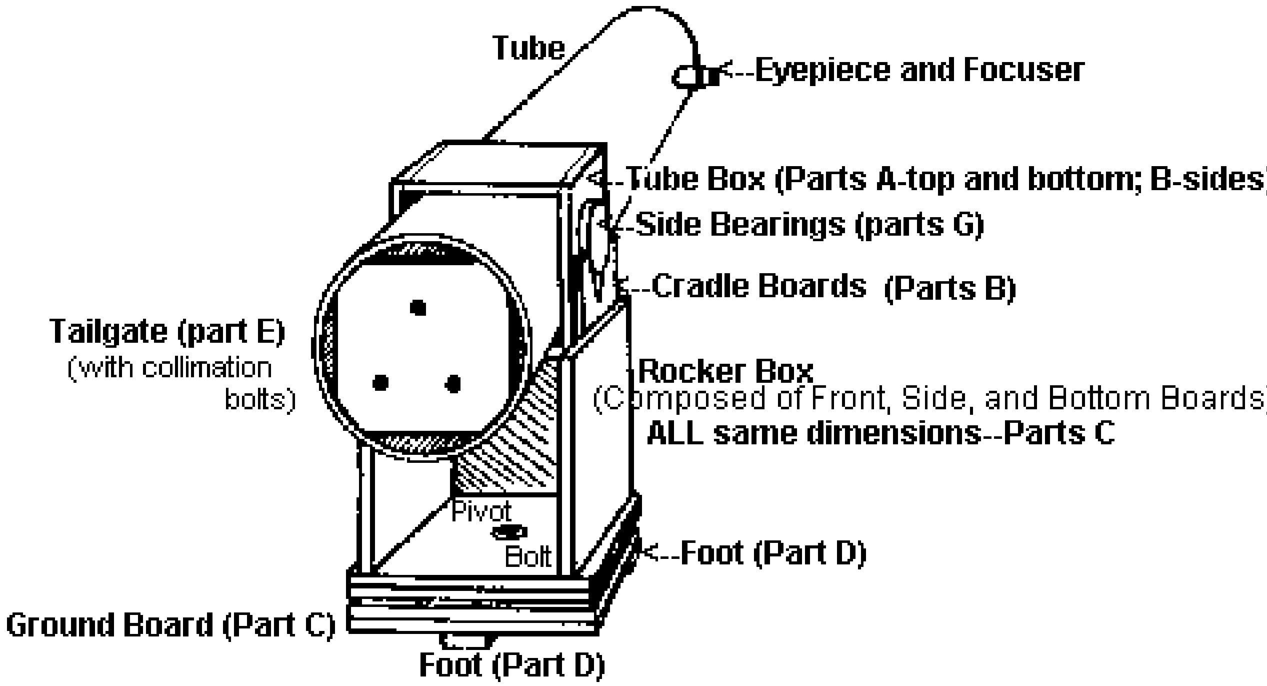


...and screw the tailgate in.

Now we are ready to build the tube box and rocker.

Section "C" of: Making a Dobsonian Telescope

MAKING THE MOUNT

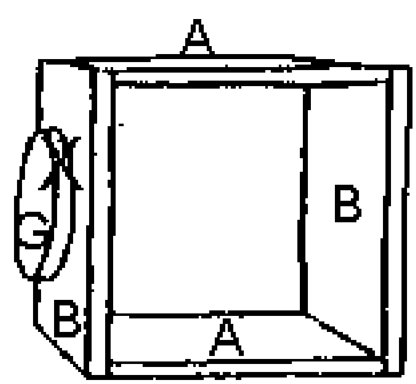


The completed telescope

Assembling the Tube Box

1) Glue and nail the **Tube Box** together as shown.

2) Nail the two **Side Bearings** (circles) onto the sides of the **Tube Box** as shown. **Side Bearings** should be centered. Side bearings do not have to be 6" in diameter, by the way. Many folks use circular plumbing parts, which are much smaller. You may also want to put side bearings on ALL four surfaces--this way, you can rotate your scope 90-degrees for a more comfortable viewing position when desired--especially useful if you have a short (fast focal ratio) tube scope.You might opt to have your circles cut out with a router, by your local, friendly cabinetmaker. While, he/she is at it, ask him to band the edge with plastic laminate ("Formica"); use a screw and a finish washer at the plastic joint. When mounting your side bearings, make sure this screw and washer is mounted at the top when your telescope is pointed at 45 degrees above the horizon ("X"--in the illustration at right)--this insures that they will not interfere with your Teflon bearing surfaces.



3) Slide the telescope tube into the **Tube Box**. If the tube is too loose in the **Tube Box**, the fit can be tightened by placing a board or boards (Masonite works well) of the necessary thickness between the tube and the **Tube Box**. After the telescope is fully assembled and balanced, a screw can be screwed through the tube into the **Tube Box** from inside the tube to make sure the tube "stays put."

VERY IMPORTANT NOTE!

Read This Before Assembling The Rocker Box On The Next Page!

u u u

POSITIONING THE SIDE BOARDS

One of the TRICKIEST parts of assembling the **Rocker Box** is getting the right amount of clearance between the **Side Boards**. This is how to determine the clearance:

1) Measure the width of the **Tube Box** but do NOT include the width of the **Side Bearings** (circles) in this measurement!

2) The **Tube Box** needs to fit inside the **Rocker Box**, with clearance for two **Cradle Boards**, i.e., Part B (in which the **Side Bearings** sit): PLUS an extra 1/8" clearance on each side.

FORMULA FOR DETERMINING THE SPACE BETWEEN THE SIDE BOARDS:

Width of Tube Box PLUS width of (2) 3/4" Cradle Boards PLUS 1/4" clearance.

Example # 1 (for 6" Dob)
Tube Box..10"
Plus 3/4" each for 2 Cradle boards ....1-1/2"
Plus 1/4" clearance (1/8" on each side)...........1/4"
Distance between Side Boards =................11-3/4"

Example #2 (for 8" Dob)	**Example #3**(for 10" Dob)
Tube Box 12" wide .... 12"	Tube Box 14" wide................................... 14"
Plus 3/4" each for 2 Cradle Boards........... 1-1/2"	Plus 3/4" each for 2 Cradle Boards........ 1-1/2"
Plus 1/4" clearance (1/8" each side).............1/4"	Plus 1/4" clearance (1/8" each side)..........1/4"
Distance Between Side Boards =............ 13-3/4"	Distance Between Side Boards =......... 15-3/4"

NOTE: All of the plywood sizes for the Tube Box and Rocker Box of a Dobsonian telescope are determined by the width of the tube. By using the above formula, you can calculate the sizes of the plywood for any size Dobsonian telescope.

ASSEMBLING THE ROCKER BOX

1) Glue and nail two PART C pieces together for the **Bottom Board,** this will be the base of your soon-to-be **Rocker Box.** (i. e. make it DOUBLE THICKNESS for added stability and extra "meat" for the lag screw--your pivot bolt--to rotate around).

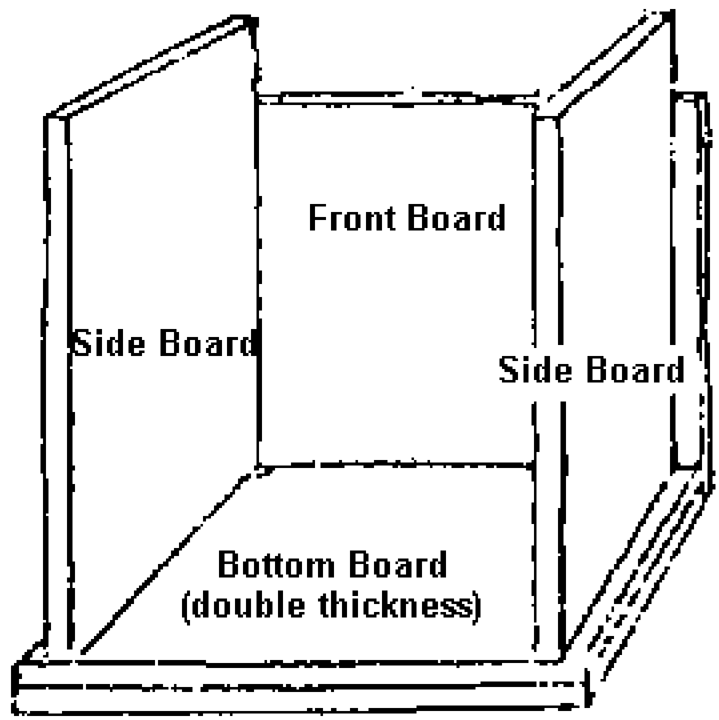
2) Glue and nail the bottom ends of the **Side Boards** (Part C) to the top surface of the **Bottom Board** the correct distance apart (use formula above for correct spacing between **Side Boards**).Be sure that the front edges of the **Side Boards** are even with the front edge of the **Bottom Board**, because we will need an even surface on which to glue and nail the **Front Board**.

(**Note**: The **Side Boards** are attached to the top surface of the **Bottom Board** "long side" up. The **Front Board** is attached to the front edge of the **Bottom Board** "short side" up and should cover the front edge of the **Bottom Board**.)

3) After the **Side Boards** are glued and nailed, set the **Front Board** in place to see how far up the front edges the glue needs to go. Then glue and nail the **Front Board** to the front edge of the **Bottom Board**. Check to make sure that the spacing between the **Side Boards** is correct (see above) before nailing the **Front Board** to them.

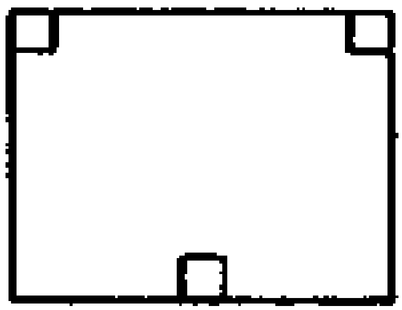
4) Glue and nail together the two remaining Part C pieces to make the **Ground Board**. (As with the **Bottom Board**, the wood is doubled for added stability and extra "meat" to which our very important lag screw will be affixed to).

5) Find and mark the center of the **Ground Board**. Then turn the **Ground Board** upside down and glue and nail the three **Feet** (part D three pieces) in place as shown (the TWO feet go in FRONT--on one of the longer edges, that is):

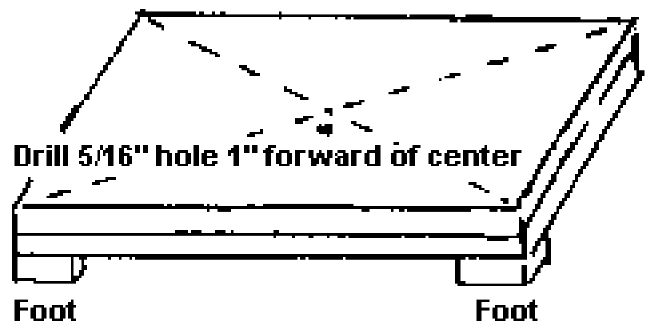


The Rocker Box

Front edge of **Ground Board** (upside down, "plan view")--one foot at each corner:



Back edge of **Ground Board** with foot centered



The Ground Board

(double thickness)

6) Now turn the **Ground Board** right-side-up. Make a mark one inch forward (toward the TWO front feet) of the center. *(Do NOT let this **1" forward** confuse you; this is just an approximation of <u>the center of the triangle</u> the three feet make. The three sides of this triangle are <u>not</u> equal--the front side of the triangle--the one with a foot in each corner is longer than the other two sides pointing back to the other foot. A more accurate way to determine this center is to find the midpoint of each side of the triangle and draw a line at a right angle to each side toward the center; the intersection of the three lines is the true center of the triangle formed by the feet.)* Drill a hole on this mark for the lag screw. <u>This hole should be three sixteenths of an inch smaller in diameter than the lag screw</u> (5/16") to insure a tight, threaded fit. Be careful to drill this hole as square as possible (have a friend "sight" for you as you drill).

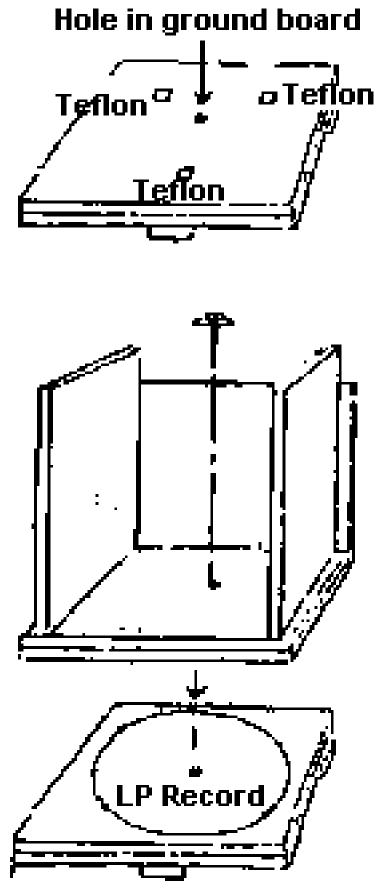
7) Turn the **Rocker Box** upside down. Place the **Ground Board** (which you just drilled a 5/16" hole near the center of) on top of the upside down **Rocker Box**. Orient so all sides are flush (even) with each other.(Actually, the **Front Board** will "hang over" the **Ground Board** 3/4"--"split the difference," if you like). Using your 5/16" drill bit and the **Ground Board** as a *template*, drill through the bottom of the **Rocker Box** (the **Bottom Board**). Now use a 1/2" drill bit to make this hole (the one in the **Rocker Box** <u>ONLY</u>) larger--1/2" is the diameter of your lag screw/pivot bolt. Always drill as square as possible--you might have a friend "sight" for you as you drill. <u>Leave the **Ground Board's** hole at 5/16"</u>!

Note: The hole in the LP record will not be big enough for the lag screw to fit through, so you will have to enlarge it with the drill--might as well do it now while you have the 1/2" drill bit in the drill!. Use the same bit you used to drill the hole in the

Rocker Box, i. e., the same size as the diameter of the lag screw (1/2"). (CAUTION: Have someone hold down the record for you while you drill it or it will madly ride up on the bit).

8) On the **Ground Board** (which should be right side up, i. e. with the feet on the ground), nail or screw three squares of Teflon in a circle at three angles of an equilateral triangle about half way between the "center" hole and the feet. (The phonograph record will ride on these Teflon squares, so check to make sure the squares don t extend past the edge of the record).

> **Note:** Plastic Laminate ("Formica" is a brand of Plastic Laminate) can be used instead of an LP record, and may be easier to find nowadays--try your local cabinetmaker--they usually have tons of scrap they will let you have for free, or try http://www.crazyedoptical.com/ for inexpensive Teflon and Plastic Laminate "kits." Do not use the "gloss" kind of PL, the rougher the surface, the less the friction--Wilson Art's *Ebony Star* is generally considered the best. Some **Home Depots** sells *Ebony Star* in less-than-full-sheet amounts. Plastic Laminate can be cut with tin snips and then filed flush if you do not have access to a router. Glue your Plastic Laminate down with contact cement like 3M's *Spray 90.* Of course, if your plastic laminate is cut circular (like an LP record) there is no need to glue it to the **Bottom Board** (the base of the **Rocker Box**).



Teflon squares are underneath the record or *Plastic Laminate* (see note at left)

Use finish nails (small heads) to nail the Teflon onto the **Ground Board**, and use a nail set to inset the nail heads. If you opt to attach the Teflon with screws, use only flat-headed wood screws and countersink the screws so the screw head is "buried" beneath the top surface of the Teflon.(The record must ride smoothly on the Teflon and not be scraped by the nail or screw heads).

9) Now we are ready to assemble the **Rocker Box**, LP (or Plastic Laminate), and **Ground Board** in a sandwich like manner: Place the record (or Plastic Laminate) over the **Ground Board** and the **Rocker Box** over the record on the **Ground Board**, so that all the holes are lined up. Insert the lag screw (with its washer) and screw it in. (Be vigilant as you do this to make sure that the lag screw goes in straight, not at an angle). Tighten the screw until it is snug and then back off a bit--an 1/8 of a turn, let's say. The **Rocker Box** should swivel smoothly on the **Ground Board**. Voila: Our azimuth motion!

10) Now we are ready to balance the telescope and attach the **Cradle Boards** (Part B).

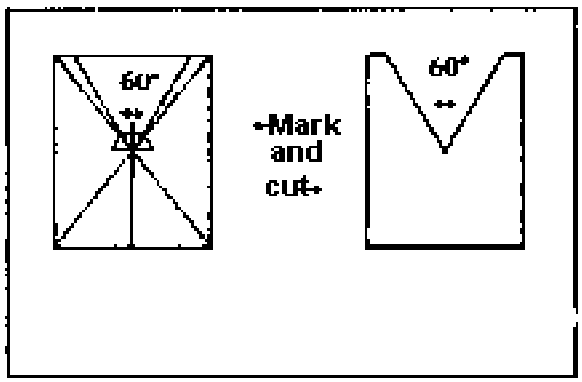
Cutting the Cradle Boards And Balancing The Tube

CUTTING THE CRADLE BOARDS

1) Use the two remaining pieces of Part B for the **Cradle Boards**.

2) The **Cradle Boards** need to be cut to hold the **Side Bearings** (circles). (Note: Cutting a V-shape is the simplest way to cut the **Cradle Boards** and is very satisfactory, but some people prefer to cut a semicircle for aesthetic reasons. (The V-shape can be easily cut with a handsaw.)

3) To cut the V-shape, find and mark the center of one of the boards (Part B). The angle of the "V" should be about 60 degrees. **Note:** *Lay your Side Bearings and Teflon onto the surface of your Cradle Boards to insure you cut away enough material so that your Side Bearings nestle nicely into the Cradle Boards.* Use a protractor to mark the "V" and cut it out with a hand saw (see below). Do both **Cradle Boards** the same way.



Cradle Boards (Part B)

BALANCING THE TUBE

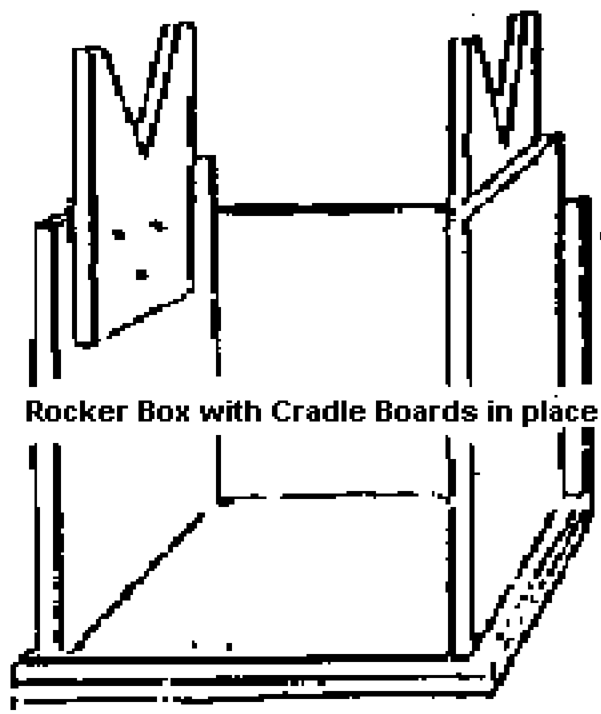
1) To balance the tube we will need to install the primary mirror, the spider with the diagonal mirror in the telescope tube, an eyepiece, as well as any 1X finder or normal finder that you plan on using with your telescope. Remember: **HANDLE MIRRORS WITH CAUTION!!!**

2) Slide the telescope tube into the **Tube Box**. The fit of the tube should be snug in the **Tube Box**. If the fit is much too loose, a piece of masonite or thin plywood, or shim shingles (the kind you used for the spider) may be glued inside the **Tube Box** to tighten the fit as needed.

3) Slide the **Tube Box** along the tube to the spot where the weight of the telescope is *balanced* at the middle of the **Tube Box**. Use a broom stick handle to aid you in finding this balance point. Knowing this "balance point" will aid you in determining where (how high) to attach your **Cradle Boards**.

ATTACHING THE CRADLE BOARDS

1) The telescope s **Side Bearings** (the circles on the **Tube Box**) sit in the V-shaped notches in the **Cradle Boards**, allowing the telescope to be moved up and down easily. Position the **Cradle Boards** so that there will be at least 1" clearance between the lower end of the telescope tube (i. e. the tailgate end) and the Bottom Board of the **Rocker Box** when the telescope is sitting vertically in the Cradle Boards. The telescope must also be able to move forward into a nearly horizontal position without interference by the **Front Board**.



Rocker Box with Cradle Boards in place

2) The **Cradle Boards**, when properly positioned, may be nailed or screwed to the **Side Boards** as shown, slightly forward of center (in line with the bottom pivot bolt below). The **Cradle Boards** must be far enough back from the **Front Board** to allow the telescope to stand straight up in the rocker.

Note: Since the **Cradle Boards** may have to be moved around a few times to get the placement just right, it is a good idea to "tack" them in place with just a couple of nails while you are making adjustments. Glue and nail--or screw--them firmly in place later.

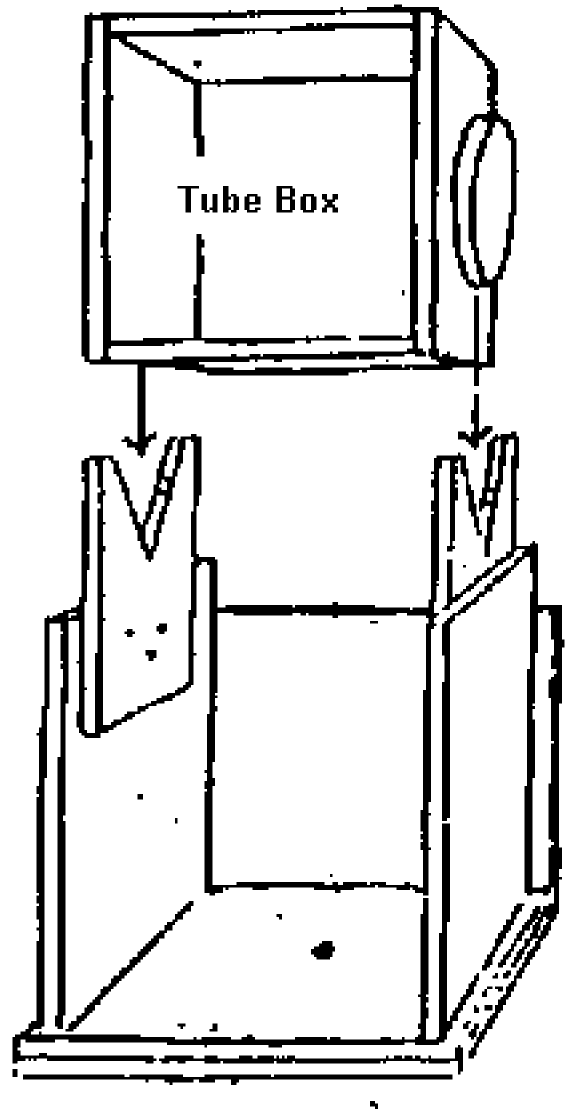
Another note: Cradle Boards *are not found on any commercial "Dobs," and few homemade ones, anymore. Most just incorporate these "altitude bearing holders" into the Side Boards. The advantage of Cradle Boards (other than being simple to design and manufacture) is that they stiffen up the side boards a bit, as well as widen the "footprint" of our base ("Ground Board"); thereby adding stability and rigidity: This is a good thing.*

[We will henceforth refer to the ***Tube Box****-and-tube assembly (with mirrors installed) as the* ***"telescope."*** *The mount in which the telescope sits will be referred to as the*

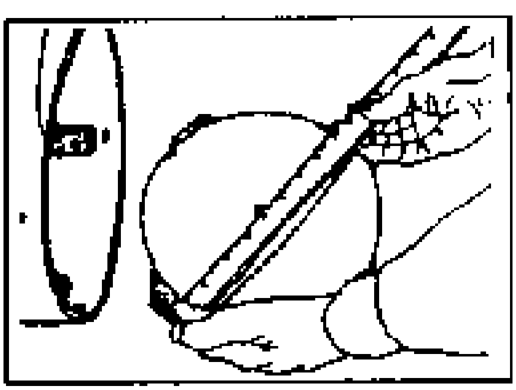
***"rocker"*]*.*

3) To enable the telescope to move smoothly in the up-and-down direction, we nail small pieces of Teflon at the points where the **Side Bearings** contact the **Cradle Boards**. Place the telescope in the rocker. Make a mark on the wood of each of the V-shaped notches at the two points where the **Side Bearings** make contact.

4) Nail a small piece of Teflon at each of the four marked contact spots (two on each side). Let the Teflon protrude a little over the inside edge of the **Cradle Boards** to keep the **Tube box** away from the **Cradle Boards**. Use finish nails and set the nails with a nail set. Place the telescope back in the rocker. The **Side Bearings** should glide smoothly on the Teflon.



ALIGNING THE DIAGONAL



As mentioned earlier, a small sticker or decal should be placed at the exact center of your primary mirror. Visit your local stationary store--I like to use a "hole reinforcement" or a "gold star." This sticker is used to help in the alignment of both the objective and the diagonal. Don't worry: this does not harm your telescope in any way--this sticker is well inside the shadow your diagonal mirror casts.

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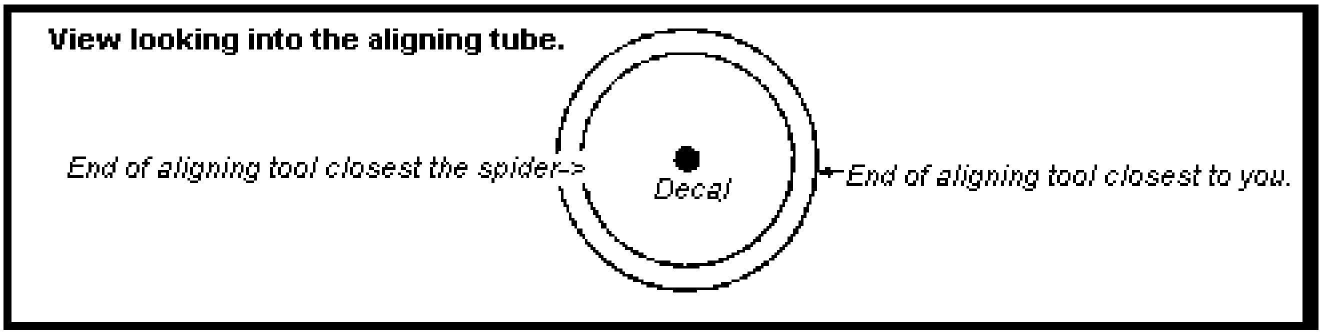
1) Set up the telescope (i. e. place the telescope with the spider and objective installed, in the rocker).

2) Adjust the spider in the tube in such a way that you can see the entire objective mirror reflected in the diagonal mirror. You should be able to see the ENTIRE OBJECTIVE MIRROR, not just a part of it. Be sure your eye is centered over your eyepiece tube.

3) Place a piece of metal tubing (about 6" long the same width as the piece in which your eyepiece is nestled) inside the cardboard eyepiece tube, so that it protrudes out several inches. Now think of the two ends of this metal tube as CIRCLES.

4) When you look down the metal tube, the CIRCLES (i. e. the two ends of the tube) SHOULD APPEAR CONCENTRIC, AND THE DECAL ON THE MIRROR SHOULD BE EXACTLY IN THE CENTER OF THESE CONCENTRIC CIRCLES. You will see the three legs (shingles) of the spider reflected in the objective, <u>but for now, ignore them.</u>



The way to get the alignment perfect is by fiddling with the position of the spider in the tube. When you have it just right, you can glue the spider in place. Apply a line of glue on either side of each shingle where it contacts the tube--100% black silicone glue works well here.

(Note: <u>Before</u> installing the spider you may wish to screw a small eye-hook dead-center into the 90 degree cut end of the wood block that supports the diagonal. After the spider is installed, another eye-hook may be screwed into the telescope tube, and a string may be tied between the two eye-hooks. This will protect the objective mirror if the spider is accidentally knocked out).

ALIGNING THE OBJECTIVE

Remember: Do this indoors or in the shade!

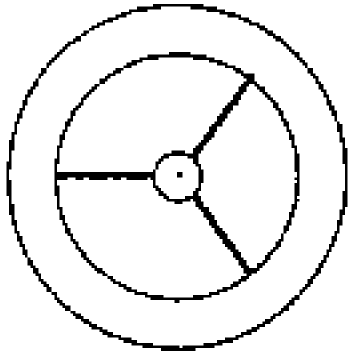
We have come now to the final step: aligning the objective mirror.

(We won t need the aligning tube anymore).

To align the objective mirror, we turn the tailgate bolts till the reflection of the eye moves under the decal.

NOTE: If the alignment must be done in the dark, you may have to shine a light on your mirror face in order to see the reflection of your eye in the objective.

Through the eyepiece hole, it should look something like this:



Keep the mirror pulled back against the tailgate during alignment.

Note: If you have a friend turn the bolts, you can watch which way the mirror moves--it is more difficult if you are doing it by yourself. Call the bolts "yours," "mine," and "ours": representing the furthest bolt from you; the nearest bolt; and the middle bolt (top) one, respectively. ;-)

Go use your scope! ...After you *know* everything works well, you can paint and finish to your desire!

A Few Finishing Tips:

Eighty-percent of a good finish is preparation. Fill any glaring holes or gaps in your plywood mount with putty or spackle (the latter only if you plan to paint it an opaque color). Take the extra time to sand your mount, especially "breaking the edges"--rounding them, if you will; so that no loose splinters come to harm anyone. If you plan to stain your mount, first experiment on a piece of scrap plywood--not all woods (birch and fir, come to mind), take stain well. Use a weatherproof paint; or varnish, or polyurethane as a final coat over stain. Be sure to seal any raw edges, including the cardboard tube, which is particularly sensitive to moisture.

Some folks use sticky-backed shelf paper to wrap their telescope tubes in. I use *Monocoat* or *Ultracoat,* found at your local hobby store: it is used to wrap model wooden airplane wings and fuselages. It is a little pricey; but it "shrink wraps" with the aid of an iron into a beautiful, glossy, weatherproof finish for your tube. Comes in lots of colors, too!

Again, you might peruse what http://www.crazyedoptical.com/ offers to gussy up your scope. He sells things like "tube rings" and one-power sights, which most people find useful: Otherwise sight down an edge of your Tube Box; that's how you aim the thing!

Care Instructions:

Do not store your scope outside. If you don't have a large closet or garage, put a lampshade on your scope and store it in your living room!

Remember: Door jambs destroy homemade focusers!

Cover your scope when not in use--dust and moisture--are the enemies! Plastic garbage bags, at both ends, work fine.

Despite your best efforts; your mirror will accumulate dust, and will require cleaning from time to time... Remember: this is a "first surface" mirror--a very fine deposit of aluminum is deposited on the surface--you do NOT want to introduce any "micro scratches" here! You can remove most of the dust with a rubber air blower (found at your local pharmacy store). Once or twice (at most) a year you should wash your primary. Here's how I do it:

First, you will need:

1) A suitable, clean tub.
2) A drop or two of mild (ivory) dishwashing soap.
3) A box of sterile cotton balls.
4) A gallon (or less) of distilled water.

1) Wash your sink, *Rubbermaid* tub, whatever, thoroughly.

2) Fill sink, whatever, with *room temperature* tap water (to avoid thermal shock between the layer of aluminum and the glass--this could help loosen the adhesion between the two surfaces--use only room temperature water throughout these steps); add one or two drops (ONLY) of dishwashing soap.

3) Submerse mirror in water. Swish around. Let soak.

4) Replace soapy water with fresh soapy water. Do not hold mirror under a running tap--some people do; I don't recommend it (localizing the "thermal shock" possibility, plus the danger of overdoing it with too much pressure).

5) With STERILE cotton balls wipe your mirror--from the center out--while mirror is still submersed. Be liberal in your use of the cotton balls (change frequently). *Roll* the cotton while swiping. Do not apply much pressure.

6) Replace soapy water with room temperature tap water to rinse away any soap.

7) With bottled, *distilled* water, rinse your mirror for a final time. (This removes any harmful salts that might be in your tap water). This is an important step--do not forget it!

8) Set mirror on edge to dry. Check on it in twenty minutes, or so. Any residual water droplets (usually just one or two) can be soaked up with any cotton balls you have left.

Frequently Asked Questions (FAQ's)

Q: How much is this going to cost?

You can research this as well as I can. The primary mirror will be your greatest expense, followed by eyepiece(s), accessories (like a 1-power finder), and your diagonal mirror. Some prices (as of 1/26/99) are as follows (prices do not include shipping):

Mirrors (Primary + Diagonal--from Coulter, as an example):

- 6" $134.95+$29.95
- 8" $189.95+$39.95
- 10" $329.95+$52.95

Eyepieces (from Orion):

- 26mm Plossl= $49.95
- 10mm Plossl= $49.95

One-Power Finder (from Rigel Systems):

- QuikFinder= $39.95

Sonotube and other miscellaneous parts from these plans are incredibly inexpensive. A sheet of plywood will cost about $30 (but you will use less than 1/2 a sheet if you make a six-incher... maybe you can scrounge scrap material from a local cabinetmaker?

Remember: ***The San Francisco Sidewalk Astronomers*** have a long, proud tradition of helping folks make the least expensive/scrounged materials quality telescopes in the world!

There is nothing preventing you from spending more on your scope, however. A good commercial focuser can cost upwards of $100; a diagonal mirror holder and spider can cost $50, a commercial mirror cell can cost $30...

Q: What eyepiece(s) should I get, and what power will I get from them?

I recommend Plossl eyepieces like the Orion ones above--good eyepieces, not too expensive. Power is determined by dividing eyepiece focal length into the telescopes' focal length--in millimeters. Let's take a six inch f/8 telescope, for example: 6 X 25.4 (the number of millimeters per inch)=152.4mm. Multiply this by your focal ratio (f/8, for example)=1,219.2 mm. Divide a 26mm eyepiece into this and you get 46.89 power. Divide the same 1,219.2 mm by an eyepiece with a 10mm focal length and you get 121.9 power, right? These are good focal length eyepieces to start out with; one low power, and one medium power... You may want to add to your collection later.

Q: What will I be able to see?

Jupiter and Saturn will probably be smaller than you like (at the 121x example given above), but you will be surprised at how much detail you can see: Many cloud bands on Jupiter, not to mention the four

Galilean moons, as well as the great Red Spot (which is more pale yellow nowadays); cloud bands on Saturn as well as its glorious rings and (most likely) Cassini's division--the most notable gap in the rings. The Moon will be extremely detailed. Star clusters, nebulae, and galaxies (invisible to the naked eye) will vary considerably in their glory and appearance. Do not forget to allow your scope to come to ambient temperature ("cool-down")--this is extremely important! Otherwise, excess turbulence within your scope will produce nothing but "blobs" at the eyepiece! Allow at least an hour for cool-down time. Sometimes, the "seeing" (upper atmosphere turbulence) never settles down, and you will be frustrated with the views all night... nothing to do but try another night!

Q: Is a ten-inch scope that much better than a six or eight?

Size does matter, but as is often said: the best telescope is one that is used the most often... A smaller telescope is easier to handle, to transport, and will (generally) be used more often. I very much like six-inch f/8 or f/10 scopes for use in light polluted cities: images of the planets and the Moon are stunning through quality scopes of this aperture. Eight-inchers of faster focal ratios (say f/5.6) are also very manageable with ordinary vehicles, and often visually outperform similar aperture commercial Schmidt-Cassegrains costing upwards of $2000! For ten-inchers, their aperture really comes into play at dark sites and with "deep-sky" objects. For this reason, especially if this is your first telescope, I recommend the smaller sizes unless you have ready access to dark skies, or know yourself to be a fanatic about this hobby already!

Q: How far away can I see with this size telescope?

The Sun is eight light minutes away; Jupiter a few hours; Saturn twice that distance; star clusters within our Milky Way are typically hundreds to thousands of light years away; galaxies are millions of light years distant, some billions... However, "How far away can I see?" is not really the question: The naked eye, for example, can see the Andromeda Galaxy which is 2.9 million light years away! Sure, any telescope will make the Andromeda clearer, and that is more to the point: The larger the diameter of the telescope, the more ***resolving power*** one has available to your eye/brain. Just as expensive computer monitors have more lines of ***resolution***, and therefore display a more detailed image, a larger telescope mirror will collect more light and is therefore capable of higher magnification and higher resolution; enabling us to detect more detail in celestial objects.

Q: Will I be able to see color... anything like the beautiful space photographs I have seen?

No. We have all been spoiled by the Hubble Space Telescope, NASA, *Star Trek* and other beautiful space images--real or imagined. However, there is no substitute for seing the Universe as it really is through a telescope that you have made! I strongly suggest you attend a public "star party" in your locale and look through as many telescopes as you can. Go to http://www.skypub.com/ for an extensive listing of astronomy clubs--to find one in your area.

Q: Can I take photographs through this telescope?

No. Dobsonians can be made to track with computers or equatorial platforms, (see my Dobsonian Evolution links page) but at quite an expense... Even so, these set-ups are generally for visual use, not photographic. For photographing the sky through a telescope, I suggest a different kind of telescope, with a different kind of mount. Be prepared to spend at least $2000 on the telescope and another $2000 on photographic accessories. In short, you are on the wrong Webpage<g>.

Q: How long will it take me to make this telescope?

Oh, about two weekends, I would guess. I think you will find most of your time spent at the beginning and end if your project: the gathering of the materials; and the final sanding, painting and finishing--everything else goes pretty fast--and is quite satisfying.

Q: Can I use a PVC (plastic) tube instead of a Sonutube (cardboard concrete forming tube)?

It *has* been done; but it is not recommended, for several reasons: PVC warps with heat (like in the back seat of a car on a hot day); PVC also warps with weight, adding to collimation problems. PVC is also quite heavy.

Q: Even the six-inch scope in your plans is a bit ambitious for me and my young child--is there someone that makes a kit in a smaller size?

Yes! I recommend *Stargazer Steve*. Steve sells very affordable kits in various sizes.

Q: Where can I get a printed copy of these plans?

If you can't print--for whatever reason--from these pages, I suggest you contact the Los Angeles Sidewalk Astronomers; last I heard, they are still sending out hard copies for $2.00 from this address:

The Sidewalk Astronomers
1946 Vedanta Place
Hollywood, CA. 90068

If you are requesting these plans be mailed to another country, the price may be higher.

I do not send any plans through the mail, nor do I have any infuence over those that do.

A Final Note:

If you are new to the world of astronomy, the Internet is a great resource! (But don't forget your local Library, either)!

Here are a few WebPages devoted to helping the beginner:

- Absolute Beginner's Astronomy Page
- Kevin Daly's Astro-Nuts Page
- Bill Ferris' Cosmic Voyage
- Don't forget Yahoo!'s Astronomy Links

Top

Welcome to

Victor's Home Page

Member of the Fraser Valley Astronomers Society

A page for Telescope making, Mirror making and testing, and all kinds of stuff!

My email address victorp@uniserve.com

Information especially for beginners who want to make their own telescope

Page updated February 27th 2002

Awards for this web-page

Choose from the **MENU** below

Telescope making	Mirror making
How to make a telescope	How to grind & polish your own mirror

A knife edge tester
>

Testing your mirror

Making a knife-edge tester

How to test your mirror

Parabolising

Some Supply Sources

How to parabolise your mirror

Some supply sources

A binocular box

F.V.A.S. Home Page
>

The easy way to stargaze with binoc's

Club page lots of astronomy info

NEW

Pictures of typical Club telescopes

Sign My Guest-book Guestbook FROM htmlGEAR View My Guest-book

If you sign my guest-book and/or if you have any questions about mirrors, telescopes or the sections above - please email me at victorp@uniserve.com

Hosted by the Fraser Valley Astronomers Society

Space news from around the internet - updated every weekday - Click here
Courtesy of **Universe today**

For more information on Telescope Making Click Here
Courtesy of San Francisco Sidewalk Astronomers, (Ray Cash's page)

Here is a link to lots more Astronomy and space information
From BILL McCOY

Telescope Making
Web Ring

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If you choose "Mirror making"

Before you start: Whilst you are learning to set up and grind your mirror - and waiting for the necessary supplies to be obtained- You can start by learning something about the sky, if you are not already familiar with the constellations and nebulae etc. A good pair of binoculars (which most people already have on hand) can show you lots of star groups and other items in the sky. A good star atlas can guide you in learning what is out there, to be seen at higher magnification when you finally have your telescope completed.

7 x 35, or better yet 7 x 50mm binoculars will giveyou a wider view of things than the rather narrow section of sky (Usually only 1/2 or 3/4 of a degree) that you will see with a telescope. Higher magnification Binocs., say 10 x 50mm are hard to hold steady so if you have such a pair - click on

the design for a "Binocular Box" which is easy to make from odds and ends, and can make your viewing much easier.

In the U.S. and Canada there are magazines : "Sky and Telescope," "Astronomy," and (in Canada) "Sky News" which contain advertisements for supplies and accessories, such as eyepieces, focus-mounts, mirror-kits etc. Willman-Bell, publishers, also supply books, mirror-kits and other materials of interest for amateur astronomers.

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Mirror making:

The following information is based on my own, and other Club -members' experience in making, or helping make, test and finish about 50 or so mirrors over the last fiteen years. No guarantee is given that this information will enable you to make a perfect mirror, but is intended simply to share our knowledge of the subject in order to help those who have no experience - and are making a mirror for the first time:

This file will print out on about 12 pages (letter size)

This information updated October 12th 2001

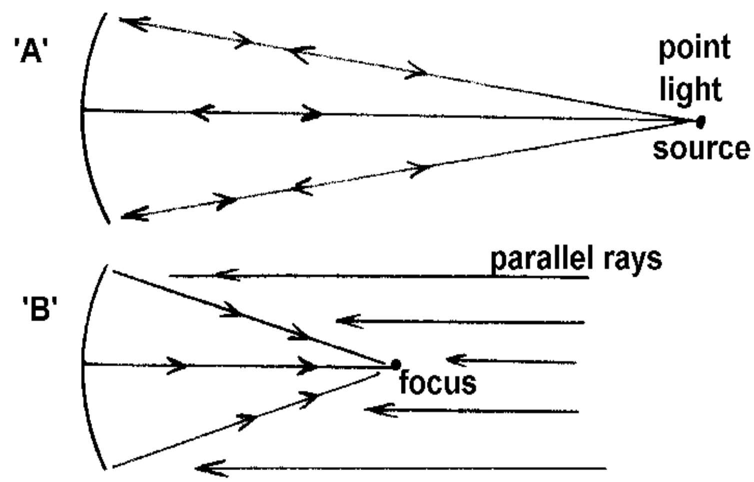
If you have never made a mirror or a telescope before - one of the best things you can do is search for a local Astronomy Club. In many clubs you will find members who have already made telescopes - either from 'kits' which contain all the necessary parts - or 'from scratch' using the least expensive materials and methods. Most telescope makers are quite proud of their efforts and very willing to pass on their experience and knowledge to others. Another (most essential, in my opinion) is the acquisition of a good BOOK on telescope making. Both the above can make life much easier - even for the experienced mirror and telescope builder.

Before we start - a bit about the shape of a reflector-type telescope mirror The primary mirror in a Newtonian type reflecting telescope is a 'concave mirror.' It is of course usually a round mirror and thus is shaped as though it were a 'slice' cut out from a sphere, or a round ball. So that across any diameter of the mirror the curve in its surface is a section of a circle. This is normally the shape that is automatically formed by the process which is described in the following text. (In practice though, this does not give perfect images when parallel light rays coming from very distant objects are reflected to its focus point. So, in practice, we have to shape it so that its cross-section across any diameter becomes a cross-section of a parabola, rather than a cross-section of a circle. This is what is referred to as 'parabolising' the mirror. The reasons for this are explained further in the following text, and **the process of 'parabolising' is done after the mirror is ground, polished and tested.)**

TO START OFF - a bit about optics

Figure 1 (A) shows light coming from a point source located at the center of curvature of a concave spherical mirror. This would form an image of the source superimposed on the source - as all the rays are reflected back to the source, as they all meet the mirror's surface at a 90 degree angle.

Figure 1.
Reflection from a curved mirror



If we moved the point source slightly to one side the image would move slightly to the opposite side and could be seen by placing a screen at that point. Below is shown the same mirror (B) but with **parallel light rays** coming to the mirror surface from distant objects - stars, planets etc. In this case the light rays meet the mirror surface at differing angles from edge to edge of the mirror. They are bent further inward and form an image at what is termed the FOCUS of the mirror. Once the source of incoming rays is a few miles away - the rays are effectively parallel, and they will meet at the 'focus' of the mirror. This point will be a point halfway between the mirror and the center of curvature of the mirror's surface.

Note:the numbers given in the following are in inches...if you are used to metric numbers 1 inch = 25.4 millimeters, So an 8" mirror would have a 203 mm diameter in metric measurement.

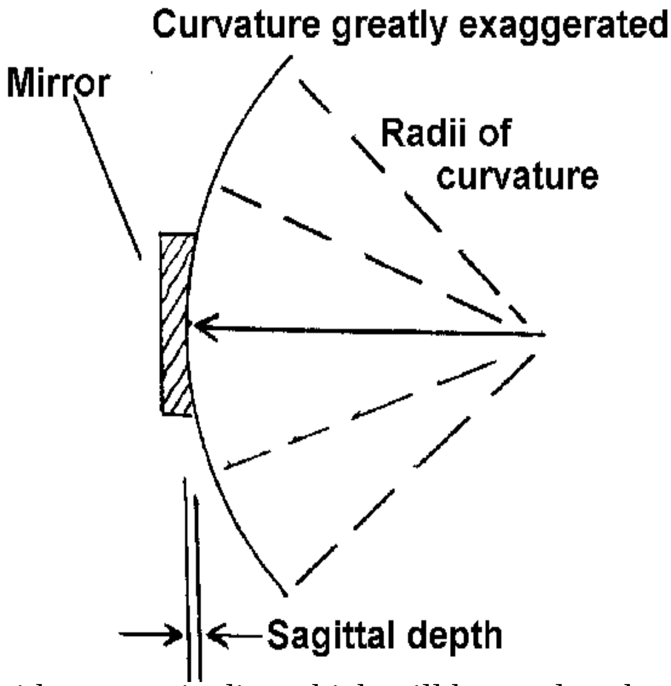
From the foregoing you will see that if a mirror is to have a 'focal-length' of let's say 40 inches - the radius of the curve in the mirror's surface will be 80 inches. Therefore if we want to make a 6 inch mirror and have a 36 inch focus - the "radius of curvature" will be 72 inches. We would refer to this mirror 6" diameter, 36" focal-length as an "F-6" mirror.

This is simply the ratio between the mirror's diameter and the focal-length. So an "F-8 " mirror of 8" diameter would focus at 64 inches (and would have a radius of curve in the mirror surface of 128 inches.)

O.K . NOW HOW DO WE GRIND THE MIRROR - and how do we figure out how to get the depth of curve that we want?

The details that follow apply equally to any size and any f-ratio mirror --(within the ranges up to 20" and F5 to F10 - if you're planning to make a 30" F-3, you're either nuts! or you've had a ton of previous experience)

We will start with the decision that we are going to make an **F-8, 8 inch mirror:** This means that our radius of 'c' will be 128 inches. The sectional curve in the mirror is really part of a complete circle, and we can visualise that our cross-section is a small slice from this circle which has a radius of 128"



The depth of this 'sagitta' as it is called is calculated by multiplying the radius of the mirror by itself and dividing the result by twice the radius of 'c'.. that is, in this case 4 x 4/256 = .0625" a mere 62 thousandths of an inch! (It just happens that this is 1/16th of an inch, which is much easier to remember!)

Now we have decided how deep the curve in our mirror will be - we can move on to the really messy stuff - **rough grinding:**

I assume that you are starting with a mirror-kit, from one of the suppliers of kits and materials:

Some suppliers will send you a 'pyrex' mirror disc along with a ceramic disc which will be used as the tool, some still supply two 'pyrex' discs and you should pick the better one to become the mirror.

An important note here: The disc - from whatever source it comes should be of even thickness all the way around. There should not be any significant difference in thickness (less than perhaps 1/2 millimeter - (10 thousandths of an inch)) Also the back surface should be **quite flat** and even - some discs are cut from sheets of glass and may have either noticable corrugations or other unevenness. These discs should be **ground flat** before starting to grind the mirror.

Note the two discs are both flat discs to start with. It is the type of offset stroke which produces the curvature in both the mirror disc and the tool disc. The mirror disc is used on top of the tool disc. This produces a concave curvature in the mirror, and the tool disc becomes convex. If the correct strokes are used then they both develop an almost perfect 'spherical' curvature.

Note also that you should bevel **both edges** of the mirror and the tool at a 45 degree angle - or sharp edges will develop during grinding - and a sharp edge will 'splinter' very easily if it happens to hit the edge of the tool or any other hard surface. Use a sharpening stone or a fine sanding wheel and be sure to do this by grinding the edge in a direction away from the surface of the disc.

We have cut expense a couple of times - by buying a kit containing two pyrex 'blanks' (along with the necessary grit etc.,) and using **both** pyrex blanks to make **two mirrors**. To do this we have bought 1/4" or 3/8" thick glass discs from a local glass shop - cut the same size as the mirror - glued these to 3/4" plywood discs (with epoxy glue - be sure to **spread the glue evenly** right to the edges of the surface of the ply-disc) Bevel the edge of the glass and then paint the plywood base to seal it - so that grit cannot hide in any cracks. **If necessary repaint the edge between grit sizes.** Make absolutely sure that the disc is evenly glued to the glass, and that it **cannot flex** due to spaces between the glass and the plywood backing disc.

As the depth of curve in the average 6 or 8 inch mirror is usually less than 1/10", these tools work fine. (the plate-glass wears down a little more than the pyrex but not enough to cause a problem) The kit also usually contains enough grit etc., to make at least two mirrors. The **other** expense-cutter has been to buy a few port-hole glass discs. 9" or 10" diameter from marine suppliers. About five or six of our members have successfully made mirrors with these. Again using a thinner glass disc on plywood as the tool for grinding them

You now need to find a place to work - where the temperature is as even as possible - and also the area should be dust-free. You also need a **sturdy and stable** small bench - preferably one which you can walk around. You also need a bucket of water or a nearby sink in which to wash the discs, and a few small sponges 3 or 4 inches square for wiping things off. We have frequently bought a packet of cellulose sponges - about 4 x 8" and cut them in half.

During the grinding and polishing process - if you have any concern about 'dust' or breathing problems - I would recommend wearing a mask, or tying a large handkerchief around your mouth and nose. In the finer stages of grinding and polishing microscopic bits of the powders, or polish and glass particles could be inhaled as they are present in the air around your bench, especially as the 'wets' start to dry out.

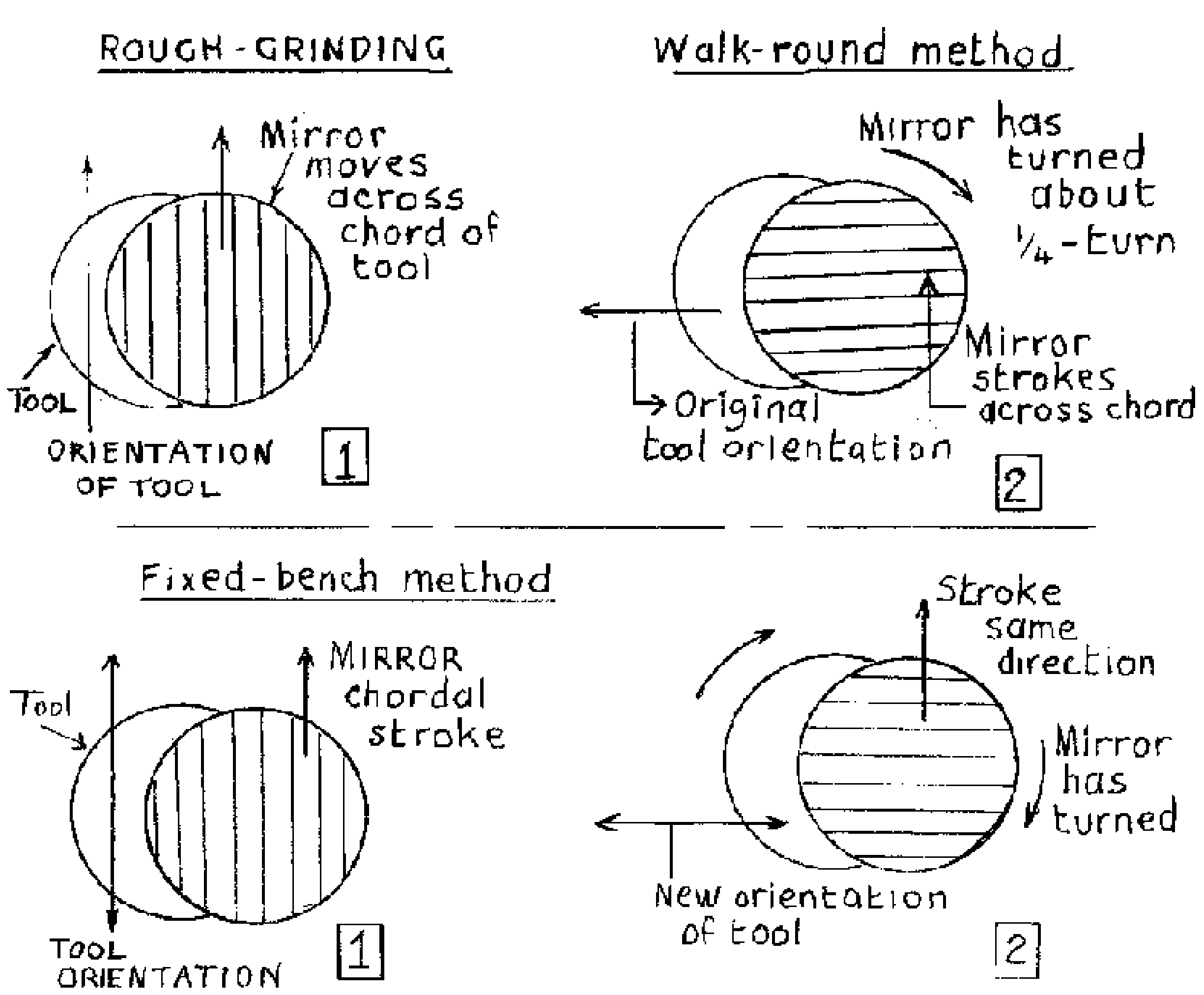
In the **rough grinding** process - we place the tool disc on the bench - and then apply a small amount of the abrasive grit (number 80 grit) with enough water to form a creamy paste spread around the surface - we place the **mirror disc on top;** then swirl the discs around gently to evenly spread the mixture. See below for details on applying the grit.

Click here for a summary of the procedure:

Then we off-set the mirror about half its diameter - but not enough that it will tip over the edge of the tool as we move it backwards and forwards across a 'chord' of the tool. We use pressure as we stroke the mirror disc across a chord of the tool - making about 10 or 12 double strokes. -- but not counting exactly the same number of strokes each time. Then we turn the mirror disc about a quarter turn (on average - but not exactly a quarter turn - we are relying on the law of averages to even out the grinding process) We also step around the bench a little in one direction (left or right - but once you decide which - you must always go the same way) and we stroke across a different chord of the mirror - and, as we have stepped around a little way we are also stroking across a different chord of the tool. You should try to make about eight or ten small steps around as you do this - so that you gradually work your way around the lower disc. This ensures that the discs are ground out evenly and ensure that the surface becomes spherical. In this way as we **keep grinding and turning around the mirror** we will gradually cover the complete surfaces of both so that they will become ground **evenly.** (See diagram below)**Don't forget to turn after every 10 or 12 strokes !**

During the initial grinding we are going to be applying **fairly heavy pressure between these discs.** (The grit works best at cutting the glass under strong pressure) So we need 3 small wooden 'cleats' less than the height of the disc - fastened to the bench with screws. This will prevent the lower disc from moving around. The cleats should be positioned close to the disc, at 3 points close to but not quite touching it, so that we can turn it as necessary.

For an 8" disc we would apply about a half to one teaspoonful of #80 grit and sprinkle it around the surface. (NOTE: for 4" 5" or 6" discs we would recommend using #120 grit for the rough grinding -this of course works less quickly, but you need a certain **minimum** number of strokes in the rough-grinding process to ensure that the 'spherical figure' is obtained) Then apply a small amount of water and spread the mix with our finger to make a reasonably good mix of water and grit. If the mix is too dry, then the discs will tend to bind and be hard to move - if so - we add a little more water and try again. If it is too wet the grit will wash out over the edges of the tool . With a little practice you will soon get to know the right amount to use. When grinding - if the mixture is good you will be able to tell by the loud grating noise as you rub the discs together.



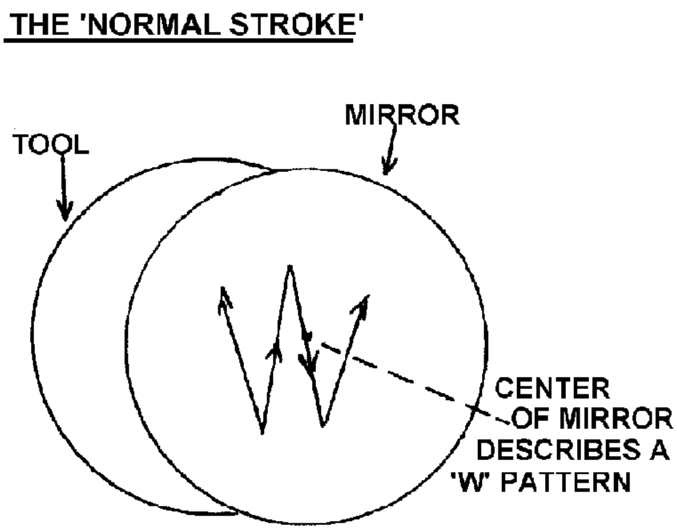
If you have to work on a bench which does not allow you to walk around - then to work around the mirror evenly you need to turn **both** the mirror disc and the tool disc about a quarter turn (but not exactly a quarter turn each time) so that you will grind across a different chord of each. You will in effect "walk around the tool" by turning it - but you will make your strokes across the bench in the same direction all the time. When you turn the discs - try to do this methodically. Center them first, then turn **both** discs together, now turn the top disc only. This way you will have turned each of them about a quarter turn. Then you off-set the top one and continue with the next set of strokes. (Remember to vary this 'quarter turn' - as we want this turning to average out so that both discs become ground out evenly across their whole surfaces.)

We continue with the off-set stroke constantly working our way around the mirror . The mix dries out after just a few minutes of work - (2 to 4 minutes) and the loud grinding sound dies away. The discs get harder to move and tend to bind together. As the grit mixture dries out, we stop - clean off both discs and add a fresh mix of grit and water. This few minutes of work, after which we clean and recharge the mix, is referred to as a **"Wet".**

Depending on the size of the mirror and the depth which we need in the mirror's curvature, after an hour or two we need to check the depth. The easiest way to do this is with a good straight-edge, a steel rule or other such item laid across the mirror from edge to edge and across the centre. Using a feeler gauge or small drill bits of known size we can measure the clearence between the rule and surface at the center of the mirror. If we are not yet close, we continue with the grinding until our measurement is **reasonably close** to the depth we require. Once we reach this point we can stop the rough-grinding and begin to consider the next steps.

FINISHING ROUGH GRINDING - Now that our depth is about right we need to change to a different type of stroke. We also now **reduce the pressure used previously** using only the weight of the mirror disc.

The stroke which we will use now - and for **all** of the smoothing and polishing of the mirror, is going to be a stroke in which the discs will be approximately **centered** and the pressure used is just enough to keep good contact between the tool and mirror.



As you can see from the drawing - the stroke is more over the center of the mirror and moves only about 1and 1/4 inches to each side (for an 8" disc) and the vertical stroke is about 2 and 3/4 inches. The center of the mirror therefore, describes a letter "W" shape.

When pushing the disc back and forth across the mirror - be sure that you don't 'rock' or turn the disc during or at the end of a stroke. This can be a common mistake, the disc between your hands should remain oriented in the direction in which you are moving it.

You must not allow it to twist between your hands as it goes back and forth - whatever direction you may be pushing it. **Remember to turn both discs frequently as before.**

You still keep turning the mirror (between each series of back and forth 'W' strokes) when using this new W - stroke ..its just that you should avoid twisting the disc when doing the back and forth stroke.

After a number of strokes you then turn the mirror a little as you walk around the bench so that you keep stroking across different diameters as you apply the strokes (about 10 or twelve double strokes at a time.)

If you can't walk around the bench you need to turn **both the tool and mirror** (in opposite directions) approximately 30 to 40 degrees of turn. This ensures that your smoothing action smooths the whole surface of the mirror evenly as you work.

For any size of mirror the sideways motion should be **no more than a quarter of the mirror's diameter** (this is the total sideways motion - about an eighth of the mirror's diameter on each side, about 1 inch overhang on each side for an 8 inch mirror) - and the back and forth motion should be **about a quarter to a third of its diameter in total.** This can and should **vary a little bit,** but not by much. Again the law of averages works in our favour. (When lenses and mirrors are made by machine, this variation has to be deliberately introduced or 'cyclic' effects will cause errors in the final surface figure.)

For the final part of our rough grinding we will grind the mirror for perhaps a couple of dozen or more 'wets' using this 'normal stroke'. Also we **no longer** apply weight to the mirror - we let the weight of the mirror apply the **only pressure needed.** Now we simply guide the mirror during our strokes. **If the depth in the center starts to get too deep** - we simply **reverse the tool and mirror** - and continue with the tool grinding on top of the mirror. This reduces the depth of curve in the mirror. It is also one of the reasons that we don't have to be too precise in attaining our depth exactly to a thousandth of an inch during rough grinding. As we start to use the finer grit sizes to smooth out the surface we can adjust the depth more exactly.

After perhaps another hour or so using the centered stroke we can check that our depth is close to what we want, and, if so we can call a end to the rough grinding process.

*Note - If the depth is more than the depth required, you can reduce the depth by doing a number of 'wets' with the tool on top. If it is not yet deep enough, you continue with the mirror on top.

At this point - if you have done everything right - you now have a rough-ground mirror of very nearly the correct depth of curvature. The surface figure should be almost perfectly spherical and you can look forward to smoothing it out and polishing it.

Now you have reached the most IMPORTANT part of the whole process:

The bench, mirror, tool and bucket (if used) and anything else that has come into contact with the #80 grit must be thoroughly cleaned. You need to wash your hands - including scrubbing your fingernails, to be sure that not even a single grain of the #80 grit remains. The cleats which held the tool on the bench should preferably be discarded - along with the sponge , and new cleats and a new sponge used for the next grit size (which will probably be # 120.)

This 'thorough clean-up' must be done when each session with any grit size is completed. If for example, you were to smooth out the mirror and get down to using a #400 grit size, and one single grain of 120 or 80 grit 'got into the works' you would wind up with a very obvious 'scratch' - which you will either have to live with, or go back two or three grit sizes and start over, to remove it.! In any case you would have to stop - and clean everything up again before you could continue. So you might as well do it the first time and avoid such disasters.

SMOOTHING the MIRROR:

The grit sizes supplied with most kits are #80, #120, #220, #320, #500, then 12, or 15-micron, 5, or 8-micron. The last of these are often Aluminum Oxide rather than the Carborundun or Emery grits. The numbered grits are finer as the numbers **increase** and the micron sizes are finer as the micron-size **decreases.**

These should be kept in separate containers and , if stored together - should **always** be kept with the finer grits above the coarser ones if they are ever stacked one above the other.

SMOOTH GRINDING - or smoothing as we will call it from here on, is quite similar to the final stage of the rough-grind. Here again we do not use any more pressure **other than the weight of the mirror disc or tool.**The tool is again set on the desk with the mirror disc on top - a mix of water and the next size grit (usually the #120, is applied and using the 'Normal' W-stroke we do a series of 'wets' (for perhaps about an hour and a half.)
During this time do **about 15 minutes with the mirror on top** of the tool. Then, **for the next 15 minutes - change positions of the discs** - putting the mirror on the bench, and the tool on top. Continue to use the same stroke and keep **interchanging the position of the mirror and tool at 15 minute intervals.** This will ensure that the curvature remains the same. Then we clean off the mirror, dry it off and examine the surface carefully under a good light - with a hand magnifier if available, to see if the surface looks evenly pitted.

If there are a number of larger pits scattered around the surface, continue with more wets with the 120 grit, (or the next finer grit if making a smaller mirror - such as a 4 to 6 inch size, where you may start the grinding with 120 grit.) until the surface appears to be smooth and even, and the pits in the surface are all the same size. Pay special attention to the outer edge of the mirror - it seems always to be the last part to smooth out. Check that the pits are the same size all over and that the pits in the glass are all of the same, finer size than those of the previous grit that was used. (You need to check this smoothness after each size of grit used.)

Once the surface is properly smoothed, take 'time-out' to check the center of curvature and the resulting focal length. This can be done a few different ways: Firstly if you have a sunny day (always the optimist) you can take it outside, and dip it into a bucket of water to wet the surface. Then you reflect the image of the Sun's disc onto a white card or similar 'screen' and adjust the distance to get the best focussed image of the sun. This will directly give you a measurement of the Focal-length! You simply have to measure the distance between the mirror and Sun's image on the screen. You probably need someone to hold the screen and do the measuring for you.

A word of caution If you are doing this **in the sun** - be sure not to aim the mirror towards anyone's eyes, **even the uncoated mirror gives a very bright reflection which can damage one's eyes.**

Another method is to take a good flashlight, and some type of white card to make a vertical screen. Set the flashlight and card next to each other on a table. Then, again using a bucket of water or a spray-bottle wet the mirror surface and from about the distance you expect the radius of curvature to be, try to reflect an image of the flashlight back on to the screen. Move back and forth to get the best focussed image on the screen, if necessary wetting the mirror again

Try to keep the flashlight at the edge of the card and focus the image as close to that edge as possible, so that the distance between the reflected image at the edge of the card is within a couple of inches only to the side of the flashlight.You are looking for an image of the front end of the flashlight., which should be placed with its face level with the card. The distance between the card and the mirror will be the measure of the Radius of Curvature, and half that distance will be the Focal-length.

If you are not close enough to the required radius, you can then continue using the 120 grit and either reduce the curve (using the tool on top) or you can deepen the curve (using the mirror on top) depending on whether your focus measured too long, or too short.

This 'optical' way of measuring should allow you to attain the desired focus to within an inch or so. In any case it is more accurate than any mechanical means of measuring the depth of curve of the mirror disc. The focus can still be 'trimmed ' even during the finer stages of fine-grinding if you want to be within a fraction of an inch of the true 64 inch focus which this particular mirror is supposed to have.

If you are happy with the measured radius. You can now repeat the 'cleanup' process again. Remove the mirror and tool, the cleats and throw away the new sponge which you used for the 120 grit. This will be a **standard procedure** every time you finish with one size of grit and start on the next finer size.

Now you are ready to start again - but this time with the next finer grit size (220) You will continue this way, until you finally reach the finest grit size. When you finish with the 220 size grit, **re-check your focus** and use it with either the tool on top (to increase the focal-length) or with the mirror on top (to reduce the focal length) After this step - you continue with the finer grits - changing the position of the tool and mirror every fifteen minutes or so, during all the next finer grit sizes to preserve the curvature of the mirror's surface.

The time required to remove the pits left by the previous grit will vary, usually becoming less time needed as the grit sizes decrease. For the 220 grit you may need less than a couple of hours work, and as the grit size reduces the time spent will become even less. The best guide though - is to examine the surface very carefully - to be sure that all the deeper pits from the previous grit are ground out. It is better to do a little too much than not enough. Above all else - be sure to really clean up perfectly after each grit session is completed, before starting the next one.

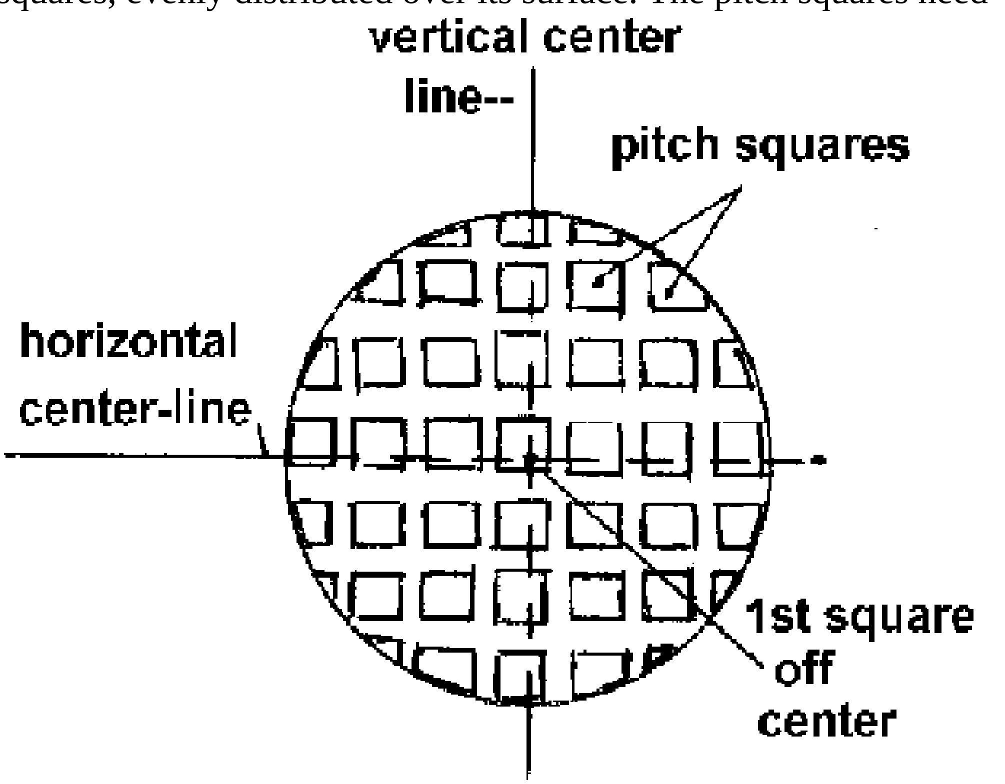
When you start to use the finer grit sizes - such as the 500, and especially the 12 micron or 5 micron, you must mix the grit and water carefully and make sure that the mix is evenly spread and does not contain 'clumps' of powder which can act as a much larger size grit and produce 'scratches' After applying and spreading the mix, place the tool or mirror in position and move it around carefully, this should 'spread' the mix evenly before you continue with the normal stroke.You should not hear any 'scratchy' sound nor should you feel the discs trying to bind together.

Once you have finished with the finest grit size, and are sure that the surface is evenly smooth over the mirror - you have reached the point at which the next step is POLISHING - "Oh Boy !! "

And - by the way - CONGRATULATIONS !

POLISHING the Mirror:

To polish the mirror - we must build a new type of tool - using the existing tool-disc. But now the tool has to be covered with a number of pitch squares, evenly distributed over its surface. The pitch squares need to be placed **slightly off-center,** across both diameters of the tool. If they are precisely centered they can lead to 'periodic' patterns on the final polished surface. Between Each row of pitch squares is a channel - about 3/16" wide to allow water and polish to circulate, and to allow for spreading when pressed on the mirror.



There are many ways of making the lap - One way is to use a specially designed 'mat' obtainable from kit makers, this is placed on the tool and the pitch poured over the surface. When it has set, the mat is peeled off leaving a series of channels between the squares. In some designs the 'squares' are either circular or perhaps hexagonal. In other cases a layer of pitch is poured, allowed to set, and then channels are cut very carefully (with an old saw)

The consistency of the pitch is important. Pitch normally supplied is quite hard and extremely brittle - I usually mix in a little linseed oil (a small bottle from artists supplies can last for a long time) I use perhaps about 5 milliliters for each pound of pitch, then also I add about half a cubic inch of beeswax (about 1/2 ounce.) These two together soften the pitch and also make it less brittle. Before making up a batch of strips - I pour a small amount into a mold - about 1" by 2" and about 1/4" deep. Allow it to set and cool to room temperature. It snaps in two when bent quickly, but will bend if gentle pressure is slowly applied with both hands. The pitch should not be too soft, but must be soft enough to 'flow' when polishing. **See additional notes below**

Our preference has always been to apply the squares individually. We cast a number of pitch strips - about 3/4" wide and perhaps 8 or 10 inches long. This is done by making a wooden mold, with thin wood strips, about 3/8" thick, to form a mold with 6 or 8 long channels into which the molten pitch is poured. The wood strips and the base of the mold are first given a good coat of varnish, and on the top of the base a layer of aluminum foil is placed. The varnish prevents the pitch from 'glueing' itself to the base and the varnished strips are lightly nailed on top with the nails sticking up so they can easily be removed. When set and completely cooled the wood strips are removed, and then the strips of pitch are cut into squares. This will provide about 70 or more squares of pitch 3/4" square and about 1/4" thick. This is done starting with the outer strips, by twisting them sharply after the nails are removed, and the pitch is quite cold.

If need be we put the mold in the fridge to really cool it. The strips of pitch can be peeled off the foil-covered base plate quite easily. The finished strips are cut using a hot knife. With the right amount of heating the knife will cut 5 or 6 squares, before having to re-heat it. The resulting squares are stuck to the tool's surface. Before doing this a very light thin layer of pure turpentine is applied to its surface. This ensures good adhesion of the squares. The squares are heated with a match or small torch until the bottom side is just beginning to melt - and then quickly applied to the tool's surface.

As shown in the diagram above the columns of squares should be applied so they are off-set slightly from the center of the tool disc. A pattern can be drawn on the tool first with a pencil to act as a guide.

The pitch usually supplied is quite hard, and may need softening by adding a little bit of turpentine, and possibly a small amount of beeswax, the wax is usually supplied as part of the kit. Some suppliers will provide an already softened pitch. You do not want the pitch to be too soft, it should appear hard - but strong pressure for 20 or 30 seconds with your finger should make a definite impression on a square. You can pour a bit of your melted pitch - before you fill the mold, and after it is completely cooled - a few hours later, test it and adjust your mix if you think it is too hard - or too soft.

Once the pitch squares are cut and applied to the tool's surface - **the outer squares must be trimmed off.** (You can do this with a chisel or an old knife) A sharp tap with a light hammer or even your hand will shear off the pitch squares efficiently. Trim them to just inside the edge of the disc.

A few additional notes:

The pitch should be heated slowly and not made too hot or it will lose some of the natural solvents it contains. A fairly thick creamy consistency is best - fluid enough to pour easily but not too 'runny' Be sure to have the mold ready before the pitch is melted and ready to pour. The sooner it is poured and cooled the less solvents will be lost.

The last time I made a pitch lap - I cast a 'block' of pitch, This was made a little softer than the formula above (I had a deeper mirror to polish) I added about 1 ounce of beeswax and about 8 to 9 milliliters of linseed oil to 1 lb. of pitch. The 'block' I cast was about 10" long by 4-1/2" wide and 5/16" thick. This was heated in a tub of water at 95 degrees F. for about 5 minutes. It was then possible to cut 3 or 4 strips 3/4" wide x 4-1/2" across before re-warming the block again to cut more strips.

Afterwards the strips were cut into squares (3/4" x 3/4") in both cases I did this with a cold knife, without the pitch breaking. This seemed to me to save a lot of time. The squares were then fixed to the tool in the normal way: before applying the squares the tool was coated with a **very thin** layer of turpentine, then the squares were heated, one by one, with a candle flame untill the bottom of the square was 'wet' and then they were applied to the tool and gently pressed to ensure good adhesion.

Following this the whole tool complete with the new pitch squares in place was heated in the 95 deg. water for a few minutes. Then with a layer of Aluminum foil placed on top of the mirror, the warmed tool (or lap) was pressed firmly on top until the squares were all evenly pressed to the shape of the mirror - this needs to be done carefully - so that the squares don't get compressed too much and run together. It is better to do it two or three times - applying more gentle pressure each time until they appear properly pressed. Wetting the back of the tool also allows one to see the squares underneath, so that the degree of pressing of the squares can be seen.

When you are sure that things are o.k. lift off the tool and gently peel off the Aluminum foil. The pattern on the foil may also give a good indication that the tool is correctly pressed. After this 'cold pressing' can be done. (see below)

Before the next step - **a word about polish.**In most mirror-kits the polish supplied is Cerium Oxide. This is a very fine pinkish colored powder which polishes faster than the Optical Rouge which was used in the past.

Rouge although the best of all polishes is extremely messy and stains everything it contacts. Very few people use it today. An alternative, which is somewhere between the polishing speed of rouge and Cerium Oxide is a product called **Zirconium Oxide**. It is available from many suppliers of kits and is a clean white powder - and is the polish we recommend.

When the lap is finished it needs to be 'pressed' against the mirror. To do this - take a quantity of polish and water and apply it to the mirror's surface. Then the lap is placed and on top, and swished around to ensure that the polish and water is covering both surfaces of the mirror and tool. Now center the two discs and apply a weight - about 10 to 15 lbs for an 8" mirror.

Allow them to press for maybe 20 minutes to perhaps an hour or more, depending on the hardness of the pitch. During this time you **must** check that the polish does not dry out - **this is very important** - or they may stick together as if you had glued them. Every ten or fifteen minutes you must remove the weight and move the mirror around to ensure that it has not stuck. If necessary - add more water and polish. Then continue the pressing. Sometimes the mirror disc or the lap may need warming if the pitch is too hard. This can be done by immersing one or the other first into tepid water and carefully stirring in hotter water until the temperature is about 90 to 95 degrees F.

Once the pressing is complete, check that the squares have not closed together too much and that the channels between them are clear and at least an1/8th inch wide. If the edge squares have pressed out and overlap the edge of the tool, cut them back again **so that they do not overhang the edge.** Press the mirror again for ten minutes after this - and then you can start to polish.

Note : During the polishing - if you are not able to do at least an hour of polishing continuously, don't start! You will do better to lay the tool aside, and come back to it when you do have the time.

NOW FOR THE BAD NEWS: To completely polish an 8" mirror requires some 12 to 15 hours of polishing time! If possible you need to be able to do 2 or 3 hours work at a time. During polishing, as the tool and mirror reach a 'working temperature' and bed down into complete contact with each other, the polishing becomes much more effective and the whole surface of the mirror polishes most evenly. So never do less than at least an hour at a time. Here we are talking of the actual polishing-time on the mirror, not counting the initial 20 minutes to half hour needed to again press the discs together before starting, nor the time spent cleaning up afterwards.

When you finish a session of polishing - simply clean off the mirror and put it aside. Wipe the tool (lap) gently and set it aside separately also. **Never** leave them together on the bench, one on top of the other - or again they may stick together as if you'd glued them. This is also the reason that you must press them again before starting another session. The pitch, seemingly solid, is really an extremely viscous fluid! and will gradually settle when left face-up on the bench between sessions. If you are a few days between each session of polishing, you may have to press them for at least a half-hour. You will be able to tell, when you start polishing - if they slip or tend to stick - you may need to press some more

At the start of polishing - after the discs have been pressed - you apply a mix of water and polish, **not much polish is needed,** and enough water to make a thin 'milky' mix spread across the surface of the tool or mirror. Polishing - like all the previous 'wets' is done with the NORMAL "W" stroke, but, unlike the 'wets' used in smoothing, this is a **continuous** process. As the polish starts to dry out - (after perhaps 3 to

5 minutes) you simply add a little more water and polish, swish the discs around and then continue polishing. You still need to rotate the discs about a quarter-turn every 15 or 20 minutes to ensure that the mirror is evenly polished. Apart from that the work is a continuous polishing, stopping now and then to add more polish and water, and to turn the discs.

About every hour of polishing - you can interchange the mirror and tool positions - this helps them polish evenly from the center to the edge. This is similar to the effect of deepening or lessening the depth during the grinding process. It has little or no effect on the curvature - but does allow a more even polish.

At the start of polishing, you may feel that the mirror (assuming that you start with the mirror on top) feels 'sticky' and not very smooth. If this happens, try pressing again for another 15 minutes and try again. If it still feels 'sticky' then persist for a few minutes, stroking fairly slowly, and applying a bit of pressure on the center of the mirror until they begin to feel smoother. Then continue **without pressure** letting the mirror's weight and the weight of your hands be the only force applied between tool and mirror. Also try to move the mirror in its w-stroke without letting your fingers hang over the edge of the mirror. Believe it or not! this can cause local areas of the mirror disc to become heated and 'expand' enough to cause local wear around the outer edge of the mirror during polishing. (Remember that when finished the surface of the mirror should be accurately ground and polished to within a few millionths of an inch - or better!)

Don't skimp on the polishing - even after a few hour's work the mirror will start to look polished - but don't go by first appearances. It takes a lot of hours to properly polish the mirror, and you cannot really polish it too much.

After about an hour of polishing, take a look at the pitch squares on the tool. If they are beginning to flatten out and spread a little, this is a good indication that the pitch is about the right hardness. If they are flattening out too much then you must trim them to ensure that the channels between them do not disappear. If they have not deformed at all, your pitch may be too hard. They should also appear evenly impregnated with the polish - a sign that they are making the proper contact with the mirror's surface. If some squares are shiny and don't have any sign of polish, then you should press the tool again.

If things get too messy during polishing, you can rinse off the 'muddy' mix of polish and water, from both the tool and the mirror. Just rinse - don't wipe them with anything - let them dry out a bit. Re-press for a few minutes and then continue.

When completely polished you won't be able to see any surface characteristics even under a strong magnifier (It is possible that you may see a number of 'scattered' pits around the surface, probably left over from the fine-grinding stages. However, if there are not too many of them, they will make very little difference to the performance, and they cannot be removed by polishing.

A final word about accuracy - The median wavelength of visible light is about 22 millionths of an inch. Thus a quarter-wavelength, which is given as the required accuracy for the images reflected from a good mirror - is a mere 5.5 millionths of an inch. However, the surface of the mirror has to be better than that by a factor of two.

This is because a ray of light reflected from a mirror is reflected at the same 'angle-of-incidence' but in the opposite direction to its approach angle. Therfore any errors on the mirror's surface will double upon reflection. So now the required accuracy for a 'good' mirror means that it must be accurate to a little under 3 millionths of an inch ! or - to an eighth wavelength.

Don't let this scare you ! If you have done everything right , the grinding and smoothing and polishing stroke tends to form a mirror with this kind of surface accuracy naturally. Surprising that a hand-process can produce such a result !!! But the most accurately made mirrors are **all hand-finished !** See my comment below about testing.

Once you are sure that you have done enough hours of polishing (or done so many that you used up all the polish supplied with the kit- which is probably enough to do more than one, and maybe two!) **then you can give yourself a good pat on the back, sit back awhile and savour the feeling of accomplishment!!**

Now that you've celebrated a while - and are getting the urge to have it coated and put it into a Telescope - !! A bit of testing is necessary to ensure that it really did come out right!! Recall that at the start of this text I mentioned that a 'pefect mirror' should have a 'parabolic' cross-section. So some testing is needed to ensure that you have ground and polished your mirror accurately and to something very close to the right shape.

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MAKING A TELESCOPE

Updated March 31st 2001

Simple plywood construction: The following designs are typical of the types of telescopes made by some of our Club members.

Prints 9 pages letter size.

First of all - some words on overall design

The main (or Primary) mirror can be either made - or you can buy a ready-made mirror of the size and focal length you would like. The following is based on a 6" or 8" diameter mirror although the Construction and other details may apply equally to larger mirrors.

The size of the diagonal (secondary) mirror is important. (These are usually purchased, as they are relatively inexpensive - perhaps $15 or so.) You must decide on how much fully-illuminated sky you are going to see at the lowest magnification of your Telescope. This is usually only about 1/2 to 3/4 of a degree. If you choose more than that it will lead to a large and 'obstructive' size of the 2nd mirror, which should not be more than about 20% of the diameter of the primary mirror. If you make it larger then it causes a major change in the 'diffraction pattern' of the stars you see.

We have a formula to calculate the size needed :

Size of diagonal = $\{ (D - d) L / F \} + d$

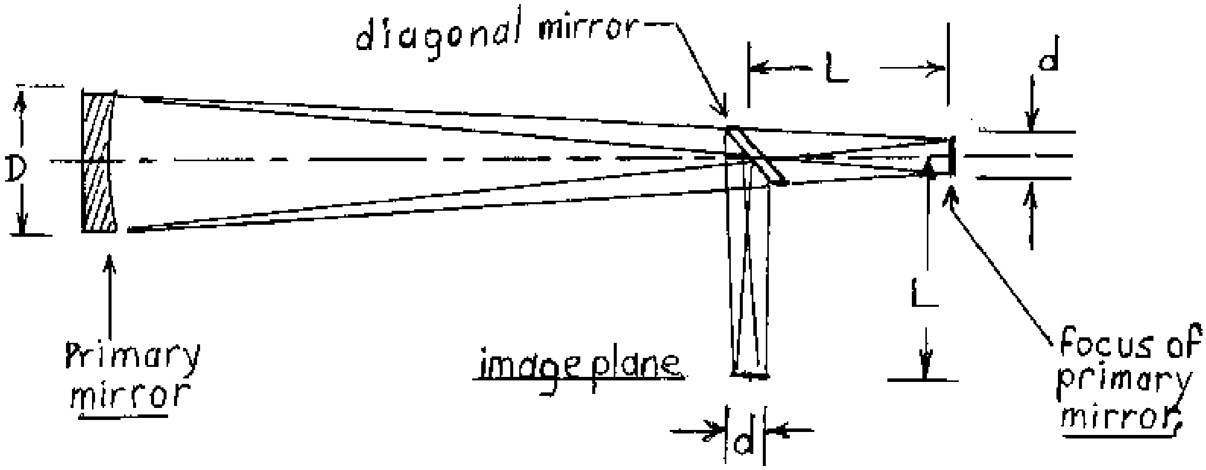
where D = diameter of primary mirror,

L = distance **inside** of the focal distance of primary mirror.

F = focus (of the primary mirror)

and d = the size of the image-field reaching the eyepiece.(That is the inside of the focus-mount on the side of the tube.)

These measurements are illustrated below:



As you will see this is exaggerated a bit to show the diagonal placed inside of the main mirror focus. We could simply place a screen at the focus of the mirror and look at the image. But if we stick our head in front of the 'scope we will block all the light reaching it! So we place a diagonal mirror some distance inside to project the image out of the side of our telescope tube. There we put a 'focus-mount' which can hold various eyepieces of differing strengths. This determines the magnification of our image.

The size of our diagonal, which is an elliptical shape because it will be mounted at a 45 degree angle, is always specified as the narrower dimension. Now the whole thing is going to depend on the 'field of view' which we decide to have. It is usually about 1 to 1-1/2 times the diameter of the full moon. That is about 1/2 to 3/4 of a degree.

The size of the moon's image at the focus of the mirror, depends only on the **focal length** of whatever size mirror we use. (Only the focal length - the diameter of the mirror makes no difference.) It is calculated by multiplying the focal-length by .009 ! So with an 8" mirror at 64" focus the image will be .576" Now if you compare that with the image of the moon formed at the back of your eye - which has an average focus of about 1" the image in your eye will be a mere .009" . Wow !! So the 'magnification' inherent in the telescope is .576" / .009" = 64 times ! We must use an eyepiece of 1" focus to match the focus of our eye-lens, then we will see an image of the moon 64 times larger than when we look at it directly.

I'm digressing here - so lets get back to the **image size** that we figured our mirror is going to give us. **(.576")** This will be the factor **'d'** in our calculation above. Let's say too that our tube will have an outside diameter of 10" To project our image outside of the tube we must 'shoot' it at least half of that diameter. Also we are going to have a focus mount and we want our image to form up inside that where our shortest focus(Highest magnification) eyepieces can view it. So we add say another 1-1/2" to 2" for that - depending on the height of the fully collapsed focusser. So we arrive at a distance of 5" + 2" = **7"** from the center of our diagonal mirror. This will be the factor **"L"** in our calculation. The focal length is 64" so our mirror must be mounted 64' - 7" **(57")** from the face of the main mirror.

So in the case of our 8" mirror, and designing for a field of 3/4 degree (almost 1-1/2 Moon diameters, i.e. 1.4 x .576 = .81) we would have: Diagonal = { (8 - .81) x 7 / 64) } + .81 = 1.6" (approximately) The preferred size would be 1.6" across the 'minor axis'. However these items usually come in a series of 'standard sizes' and we might have to settle for a 1.5" mirror. This would decrease our field of view slightly, but not enough to worry about. It is only 0.1" smaller than our calculated size. We could also use a 1.8" size which would increase the design field a little.

One important note here -- the diameter (minor axis) of the diagonal mirror is normally held to be about 16 to 20 per-cent of the diameter of the main mirror, for visual use. (20% is the maximum we recommend) If the diagonal is much larger than 20% of the main mirror diameter - then the "diffraction disc" is adversely affected. This reduces detail and causes a more objectionable 'flare' on brighter images. It may also cause some reduction in contrast and an increase in 'coma' at the edge of the field of view. Even though this may (at 16% especially,) reduce the 'fully illuminated field' to perhaps less than half the field seen by the lower magnification eyepieces you use, for visual use this is hardly noticable by most people. Remember that the 'magnitude level' assigned to the stars we see is based on a change of some two and a half times in brightness before the eye notices that one star is definitely brighter than another. (In 5 'magnitudes' a given star is 100 times brighter than another)

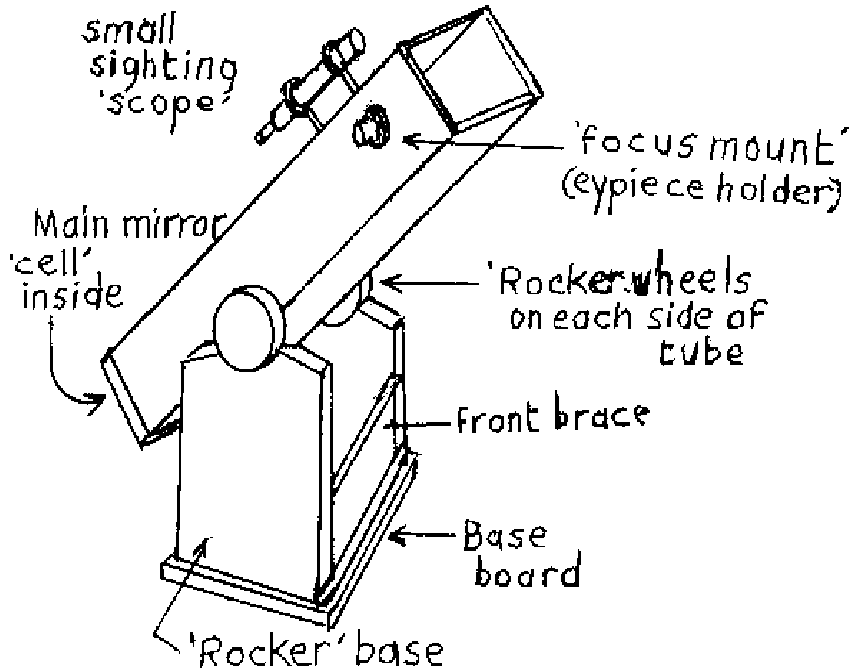
Also note that with a smaller diagonal (16%) you may need to move the diagonal and focus-mount closer to the main mirror to get enough 'sideways throw' to put the image in the right place outside the tube, in order to reach focus with your eyepieces - this means a reduced field of view, although this can still be quite enough for visual work. Or you may find you can do ir by using a very 'low profile' focus-mount.

We usually make the inside diameter of the telescope tube a bit larger than the mirror, firstly to accomodate the mirror's mechanical support, and also to allow space at the front end for the 'spider' which holds the diagonal mirror. There are a other reasons for making the tube's inside diameter larger : One is that air currents (due to temperature changes) tend to run along the outer walls of the tube and can interfere with 'seeing.' The other reason is that the edges of the mirror must be able to 'see' at least a half to three quarters of a degree, otherwise the outer areas of the mirror will not see past the front edges of the tube. For our 8" mirror I would suggest about 9-1/2" to 10."

So now you've got all the numbers you can start building the tube, along with the mirror support, and the diagonal mount, as well as the focus mount.

If you want to be really 'basic' the tube can be made of plywood, square in section - or you can make or buy a round metal or fibreglass tube of the size and length you need. As to the length - it is usually about the same as your mirror's focal length or a few inches longer. Allowing perhaps a couple of inches for the mirror and its mount at the back of the tube, and taking into account that the diagonal is going to be 7" inside the focus - then its best to add a couple of inches to the tube length. Otherwise the diagonal will be quite close to the front end. This can allow 'dewing' of the diagonal on colder, damp nights. So its best to add a little to the tube length so the diagonal is further inside the end.

The inside of the tube should be painted a very **flat black** to prevent other external light from 'bouncing around' inside.



On the left is a drawing of a simple plywood design, based on the "Dobsonian" mount. There are probably as many variations in the Dobson-mount as there are home-built versions of it. It is a simple ALT-AZIMUTH type of mount. That means that to follow the motions of stars etc., you must track in two directions - up and-down, and left and right along the horizon. For general 'stargazing' this is no real inconvenience. The 'rocker box' swivels on a pivot at the center of the base-plate which has three small Teflon pads (about an inch square or less) These are placed at 120 degree intervals on a circle of about 10" or 12" diameter, and the upper face of the bottom of the box is covered with a layer of Formica (best) or Arborite, which allows enough friction against the teflon pads to give a very smooth, but not jerky movement. The front-board is made low enough that the tube can be placed horizontal, and another brace can be put across the back, if the tube does not strike it when completely vertical.

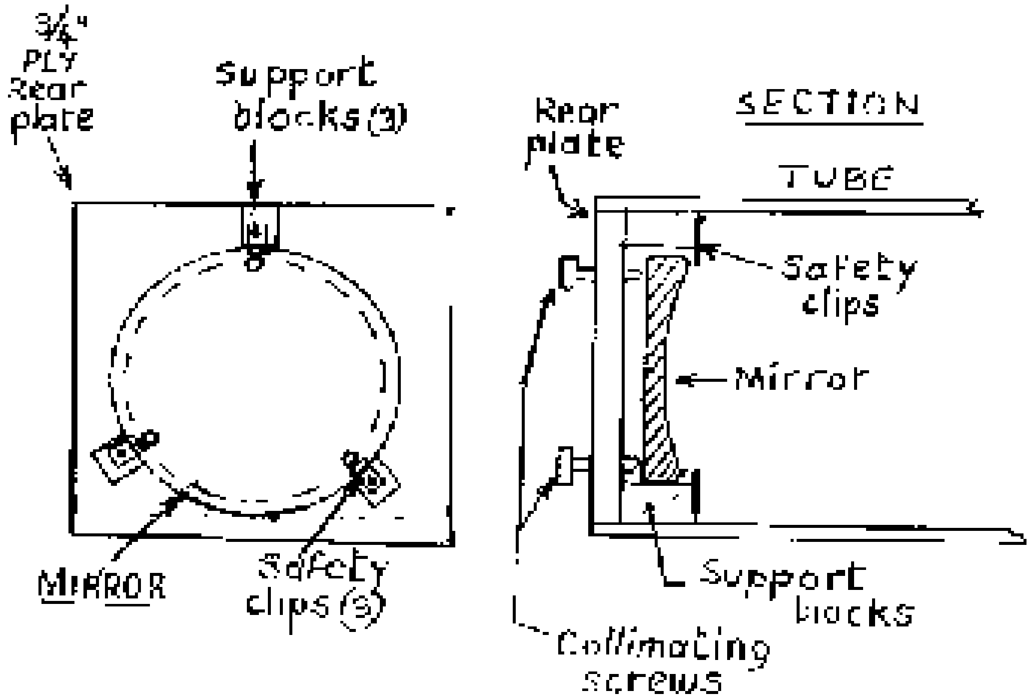
If this type of unit is made with a round tube - then you need to make a small frame around the tube where the 'rocker wheels' are fastened. Under the base plate you need three small blocks arranged like the bottom of a tripod so that it stands evenly on any kind of surface. (We have used 3 hockey-pucks in some cases, they are ideal - they don't rot and it doesn't matter if you are standing it on wet or dewey grass in your backyard.)

On top of the tube I have shown a small 'sighting scope' This can be as simple as a hollow tube or can be a couple of small rings (like a gun-sight) which allows you to aim the scope at the various objects in the sky. When you are ready to attach the rocker-wheels, have everything mounted on the tube - including whatever eyepiece you have (the heaviest one) and balance it across a small round dowel to find the point of balance. The centers of your wheels should coincide with this point. Perhaps make it slightly ahead of this - so that the tube is if anything, a little back-heavy. You only need to add a small weight at the front to balance it afterwards, but if you add anything in the future such as a heavier focusser or sight scope, it will need a lot more weight at the back to re-balance it.

On each of the sides of the rocker-box section where the wheels on the tube rest, put two small teflon pads about 3/4" x 1" towards the outside of the 'arc' these will act the same way as the pads underneath to allow slight friction when the tube is tilted, but again will be quite smooth and not jerky. The wheels are made from 3/4" plywood - as are the rocker-box and the base-plate at the bottom. The tube can be 1/4" ply and will be rigid enough to hold the optics without sagging.

MOUNTING THE MIRRORS

The mirror should be mounted in such a way that there are no **stresses placed on it**. A very simple way to do this is to put three blocks or supports in a circle just slightly larger than the mirror, spaced at 120 degrees, with two of these positioned at the lower part of the tube section. (see diagram) Behind the mirror and screwed through the back plate of the tube are three 1/4 x 20 machine screws - about 1/2" inside the edge of the circle, on which the back of the mirror rests.



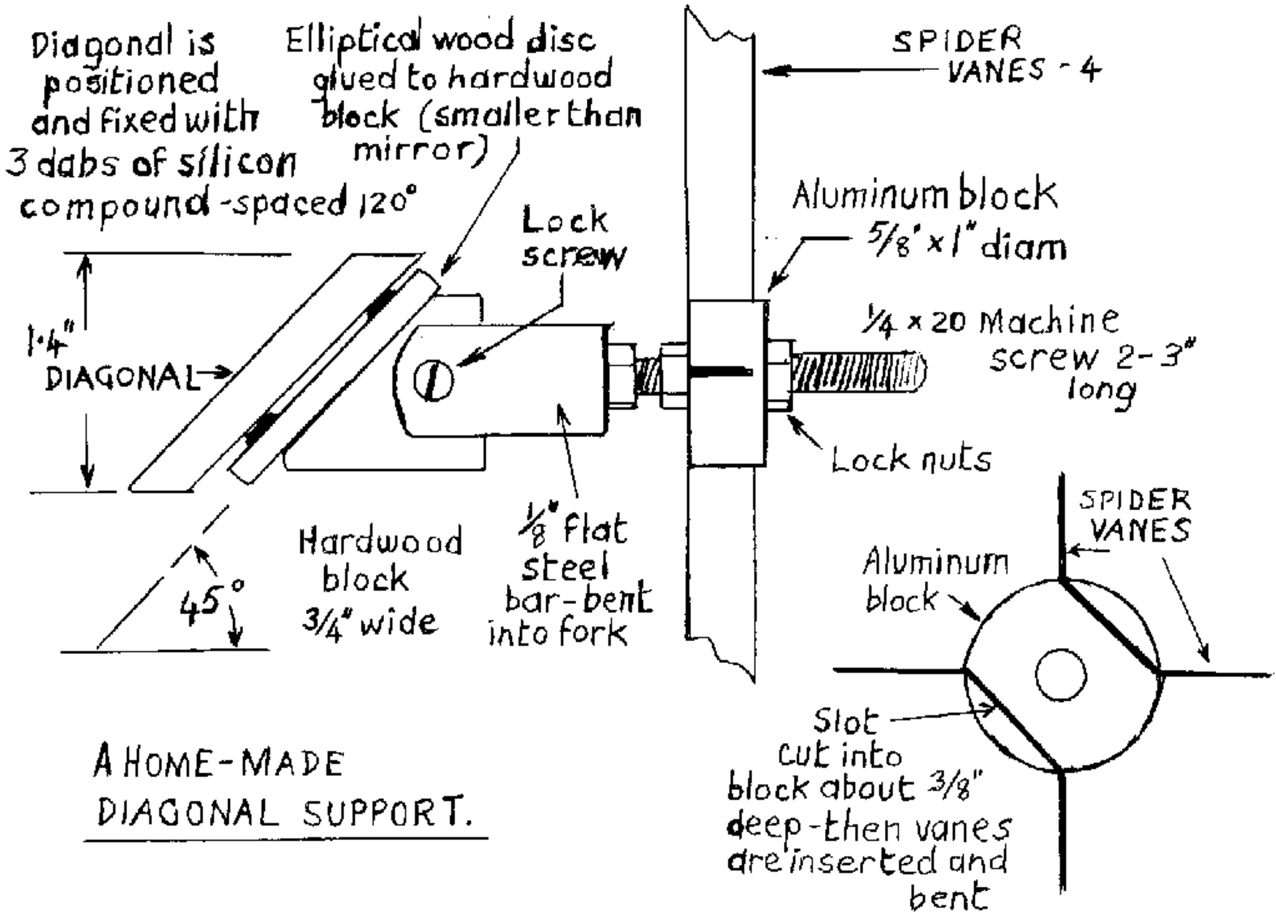
As you can see from the diagram - the mirror rests on the two lower blocks. In normal use this is enough to prevent it from moving sideways, but puts no stress on the mirror. The support blocks should be slightly tapered downward toward the rear - this makes the mirror lean back and rest against the three screws coming through the back-plate. The screws should be tipped with a tiny piece of thin plastic or leather to prevent metal to glass contact. In the front of each block is fastened a safety clip - to prevent the mirror from tilting forward. The end of these clips should overlap the edge of the mirror by perhaps 1/8" or 3/16"

This way of mounting the mirror is easy to do, and is the way we recommend - unless you have bought a metal (usually aluminum) mount specially made for the purpose. There are also some designs for wood versions of mirror-mounts - but we'll leave you to investigate those on your own !

Mounting the diagonal mirror

This mirror must be supported as carefully as the main mirror. A poorly mounted diagonal can easily ruin the quality of image which the primary mirror can produce. Like the first mirror, it must be supported without stress - and it must also be made adjustable so as to align the reflected image exactly with the center of the focus mount. There are diagonal mounts available commercially from various astronomy suppliers which satisfy these conditions.

You can however save some expense by making your own, so I'll describe a method which we have used which is not difficult to make. See diagram : The main support is an Aluminum disc about 1 to 1-1/4" diameter and some 5/8" thick. Through the center is a 1/4" hole for the screw which holds a small metal fork. In the fork is a hardwood block with the front cut at a 45 degree angle on which is glued a piece of 1/4" plywood cut to an elliptical shape but a little smaller than the diagonal itself. The diagonal is fastened to this flat plate by using three small 'blobs' of silicon caulking compound. These are arranged in a 120 degree pattern so that they hold the diagonal, which is carefully centered to the axis of the 1/4" screw which holds the fork. The diagonal is placed gently onto the 'blobs' with the mounting plate held horizontally - until the silicon dries.The silicon holds the mirror quite firmly but puts no stress on it



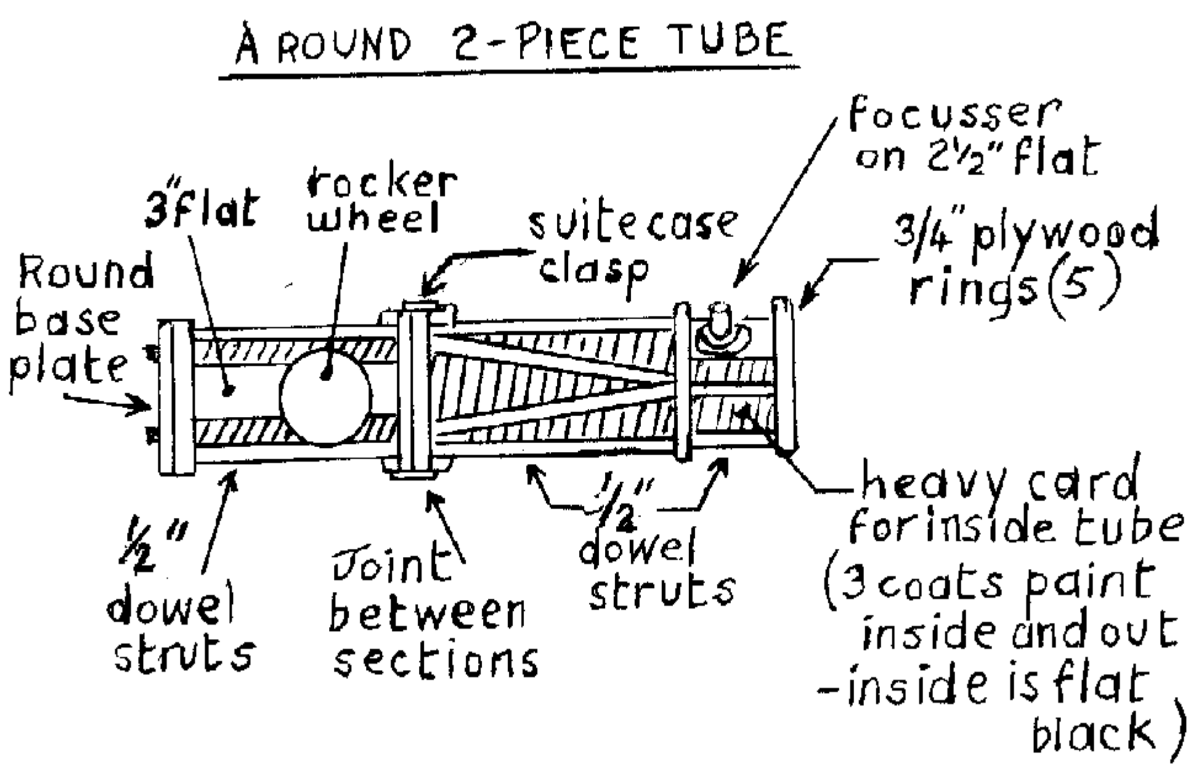
Most diagonals are made with the top and bottom areas cut at a 45 deg. angle so that when mounted they produce a circular shadow onto the main mirror, so some care is needed to center them correctly. The 'spider' vanes which hold the complete assembly to the tube can be brass or steel - about 1/2" wide and long enough to reach across the tube and have some left to bend over at the ends, and also to allow for the part which fits across the groove in the aluminum block. When fitting them into the grooves, you can use a center-punch to tighten up the grooves by punching a few spots alongside the blade. If necessary, if they are a bit loose in the groove you may have to 'shim' them with some very thin metal foil.

If the block is some 5/8" thick you can cut grooves perhaps a little more than 3/8" deep - using a hacksaw with a blade that cuts about a 1/16" groove to match the thickness of the vanes. The vanes can be marked where they should bend and be bent at least partially before inserting them. The grooves are cut so that the two blades, when fitted can be bent so as to reach across to each side of the tube - and also cut so that the vanes are 'in-line' at opposite sides of the block., When fitted to the tube - the mirror can be moved forwards or back to align it exactly to the center of the focus-mount, By adjusting screw passing through the aluminum block. It can be rotated to align the mirror exactly perpendicular to the focus-tube. The diagonal can also be tilted in the fork to make it exactly 45 deg. with the optical axis of the primary mirror.

Choosing your eyepieces (Some guidelines for selecting eyepieces.)

A few words about other types of tubes. (Typical amateur telescopes section)

The earlier diagram shows a square-section tube. The tube is not fastened to the rocker-base section but simply 'sits there' under its own weight. So it is easy to pack into your car - and head off to a nearby 'dark site' well away from the city lights for better viewing ! Below is another design using the same plywood construction, This has a 2-piece tube section. It is also a round tube which is split into two sections joined together about 1/3rd the way from the back.



This would produce a three-piece telescope which can fit easily in a small car for good portability. It can be assembled in a matter of less than a minute. If you find cutting 5 separate rings from your supply of plywood is wasteful (which it is !) you can do the same thing with a square tube arrangement - except that the 'rings' will now be squares which can be made up of four straight pieces of wood. Also you could use the same 'strut' connections between the sections and make a round paper or card tube inside. We don't recommend an 'open' tube design.The closed tube serves a few purposes : It keeps other light off the optics and also prevents disturbance of the image caused by air currents (or wind) moving through the optical train. It also protects the primary mirror from 'dewing' and helps keep it clean.

THE BASE

the base unit is made from 5/8" or 3/4" plywood. It is basically a 'box' open at the rear and top, with 2 half-circles cut at the top of each side-piece about 1/8" larger than the diameter of the wheels on the tube section. This allows for the addition of the two teflon pads on each side upon which the wheels rest.

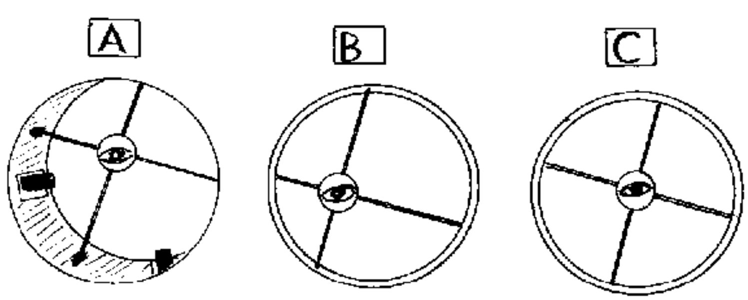
The bottom of the box has a 3/8" or 1/2" bolt through the center to join it to the baseboard underneath. When fitted to the base the bolt should be long enough to allow for the teflon pads. When tightened up it should have no play - but should be loose enough to prevent binding against the teflon pads, and a lock nut should be added.

The side supports should be high enough to let the tube be tilted to the vertical position and clear the bolt holding the base-section. It can be made higher if you find that the eyepiece is at too low a level when looking at stars etc., high above. If you extend the height too much for this purpose - you might need to add some extra bracing to keep the sides from spreading.

So far this is about the simplest type of reflector telescope, but there are some disadvantages to making an 'alt-azimuth' type of mount. Firstly to follow the stars as they move across the sky you need to move both up or down (as they rise and set - just like the Sun and Moon) and along the horizon. Secondly if you ever hope to try your hand at taking photographs of stars or nebulae it is virtually impossible to track them this way for more than a second or two (perhaps for a picture of the Moon - which can be done in a fraction of a second with the right film.)

There are methods of 'computerising' the motions with electronic control of small drive motors for each motion, but this still limits the time avalable for photography as the image at the eyepiece will rotate. For simple visual work though this can make viewing much easier. Another possible answer to this is to make a "Poncet" type of mount which allows perhaps a half-hour or so of 'equatorial' drive. If you are likely to want to try astro- photography - then it is better to **start** with an equatorial-mount. This will be described further down in this page.

Before that - I should tell you **how to align the optics** once your telescope is completed : You must be sure to put the center of the focus-mount **directly over the center** of the diagonal mirror. It should also be exactly perpendicular to the length of the tube. (If need be, you may have to 'shim' it to make it so.)



Then extend the focus mount close to its maximum height and with no eyepiece in place, look down at the circle of the bottom of the eyepiece tube. You should see a reflection of the main mirror in the diagonal . You may also see part of the inside of the tube, an off center image of the diagonal and your own eye in the center of that, as shown in "A" The **diagonal is adjusted** to bring the **image of the main mirror's outline** (ignore the reflections in that mirror for now.) until the **outline** of the main mirror **is concentric with the outline of the eyepiece tube-** as shown in 'B'

It can help to keep your eye located in the center of the eyepiece tube - if you find a plastic 'cap' or insert which fits the tube, and drill a small hole (about 1/8" or less) in it so as to locate your eye centrally.

Once you have it set-up so that it looks like the drawing 'B' you move to the rear of the telescope. At this point it helps to have someone to assist. Then the **3 screws at the back** against which the main mirror is resting are adjusted, **one at a time** to bring the **reflected image of the diagonal** and its 'spider' or support, into the center of the field of view.

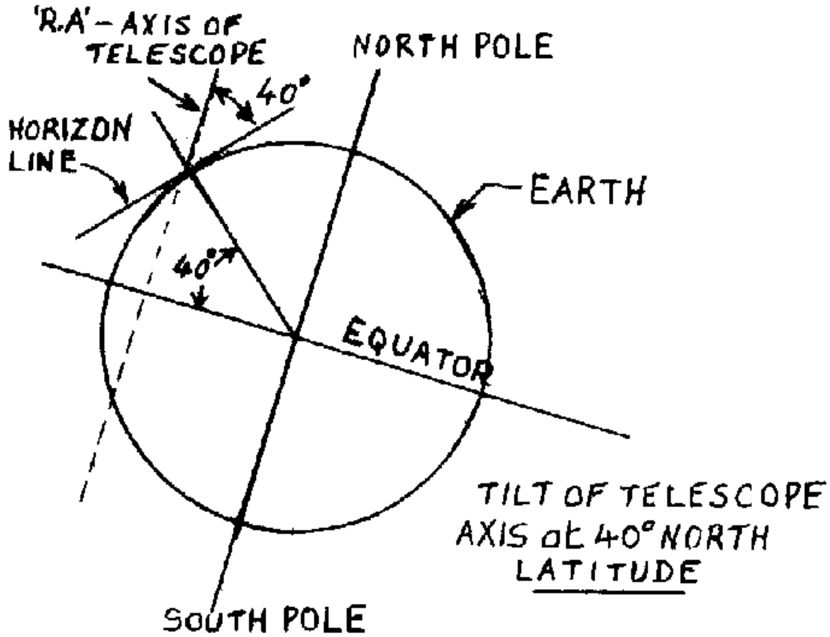
Finally you should arrive at an adjustment where the image will appear as in 'C' You will also see the reflection of your eye, in the center of the diagonal. When you arrive at this point - your optics will be mechanically aligned as accurately as you can do. Any further refinement of these adjustments can only be done by using special 'alignment-eyepieces' or by adjusting on the slightly out of focus image of a bright star. For normal viewing - the adjustments given above should provide good images when viewing through the telescope.

AN EQUATORIAL MOUNT

If we placed our alt-azimuth telescope at the North or South poles of the Earth we could follow the motions of the stars with a single motion of the telescope. This is because our base pivot would be an extension of the Earth's axis. At any location in between - we can get the same effect if we make **the axis around which our telescope turns parallel to the axis of the Earth !**

To do this we must tilt the main axis towards the N. or S. pole (depending whether we are North or South of the Equator) See diagram:

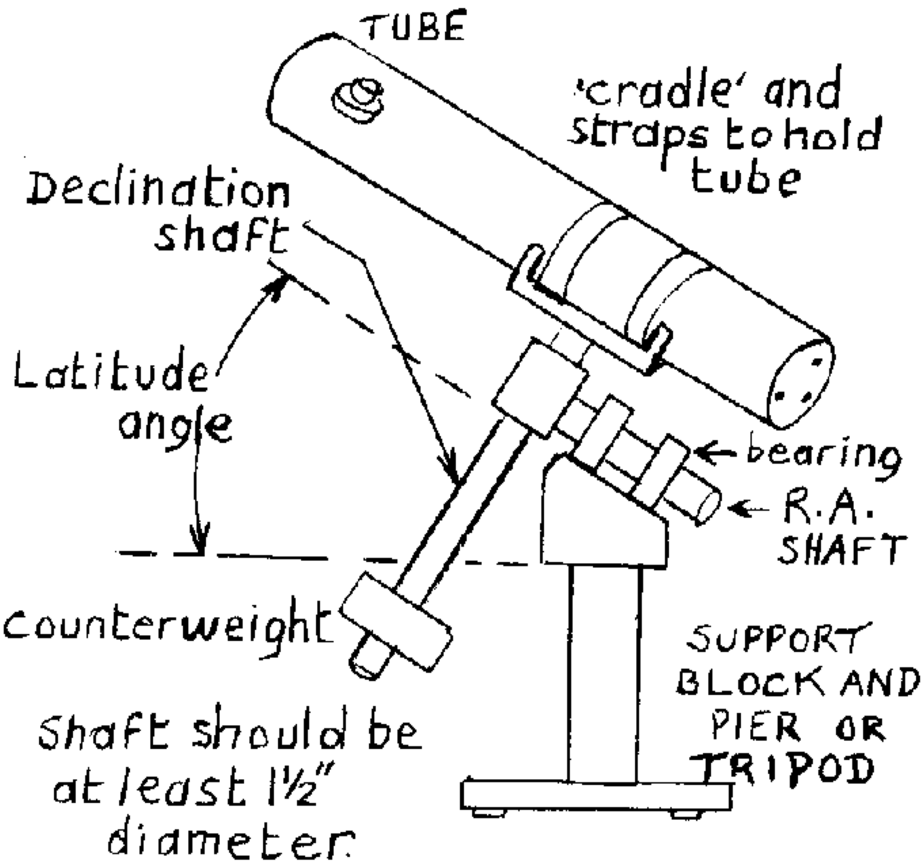
As shown if you are located at 40 degrees North latitude, you would tilt the axis towards the North pole at a 40 degree angle. (If you were South of the equator at 40 degrees South latitude you would tilt it at 40 degrees towards the South pole.) Then if you are following a star you need only to turn your 'scope around this axis to keep the star in view continuously. The addition of a 'clock-drive' can make this even easier. Once you have sighted on a star you need only 'start the drive' and concentrate on the view !



The axis which is tilted - around which the telescope now turns is called the **"POLAR AXIS"** and is also referred to as the R.A.(Right ascension axis) and the new axis around which the tube turns (which must still be at right-angles to the other) will be called the **Declination axis** These terms describe the positions of the stars and planets etc., on the Celestial-Sphere. The sky is imagined to be a huge sphere which forms the background for the stars. It is extended from the Earth's equator and the ' celestial equator' will appear to be located 40 degrees above your horizon if you are located at 40 degrees latitude. The axis around which the 'celestial sphere' revolves extends from the Earth's poles. The locations of the stars - their Declination for example is their position above and below this imaginary equator in the sky. Their position along the 'celestial equator' is referred to as their Right Ascension. All sky atlases and maps will show these postions as R.A. and DEC.

There are many different types of equatorial mounts but they all follow the principles outlined above.
The easiest to make is described next :

The first shaft is the 'polar axis' and the second, which carries the tube is the declination axis. The tube



shaft has to have a counterweight to balance it as it is rotated. This can be made of any heavy material, lead, Steel and sometimes concrete which can be cast into a tin - with a wooden centerpiece to make a hole through which the shaft fits. Some plastic, sandfilled weights used for weightlifting may be adapted also to this purpose. The shafts (for an 8" tube") which may weigh some 15 to 20 pounds with the diagonal, focusser and sight-scope etc., should be of fairly large diameter - about 1-1/4" to 1-1/2"it is very easy to underestimate the rigidity of these shafts - which will lead to vibration of the image, especially at higher magnification.

The shafts can be made from plumbing piping (cast iron) and pillow blocks or brass bushings for the bearings. The pipes can be smoothed with emery cloth - and tee-fittings used to join the declination shaft to the polar shaft. Mount the tube support fairly close to the upper end of the other one, as long as it will easily clear the tilted block at the top of the main support. A 'saddle' is fastened to the top of the polar-shaft and the tube can be fixed to it with a pair of flexible metal straps. If possible you should provide for loosening these in order to rotate the tube. In some positions of this type of mount - the eyepiece can assume some awkward positions for viewing. Turning the tube can bring the eyepiece back into a more comfortable position. nother thing - sometimes the bottom of the tube may 'conflict' with the main support, whether it is a tripod type or a pier - in this case you simply rotate the tube around the declination axis by 180 degrees and line it up again.

There are lots of books available from Publishers or your Library on the subject of telescope-making, with plenty of designs for all types of telescopes. This web-page is really written for the beginner - and I would recommend that to start out - make the easily constructed Alt-azimuth type of unit. You can always build an equatorial mount for your tube when you have learned more about this subject.

If you would like plans for a "Dobsonian" telescope, courtesy of the San Francisco Sidewalk Astronomers member "Ray Cash" Click on this link

Good luck with your projects - and HAPPY STARGAZING !

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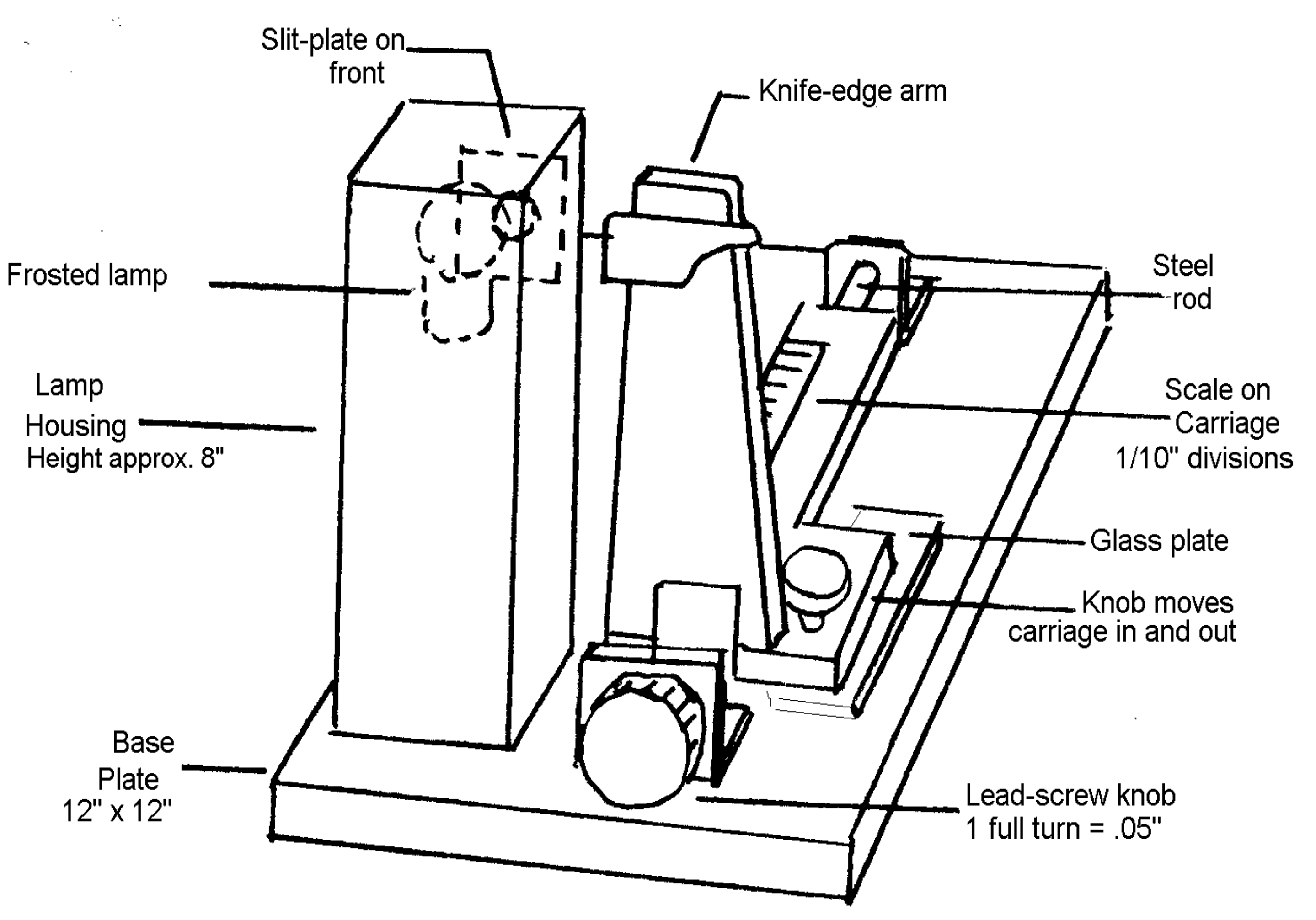
A Knife-edge Tester An overall view and diagram of details

This is based on a design suggested in "How To Make a Telescope" By Jean Texereau, published by Willman-Bell,Inc. - **Prints out on 2 pages, Portrait orientation,legal size paper 8.5" x 14"**

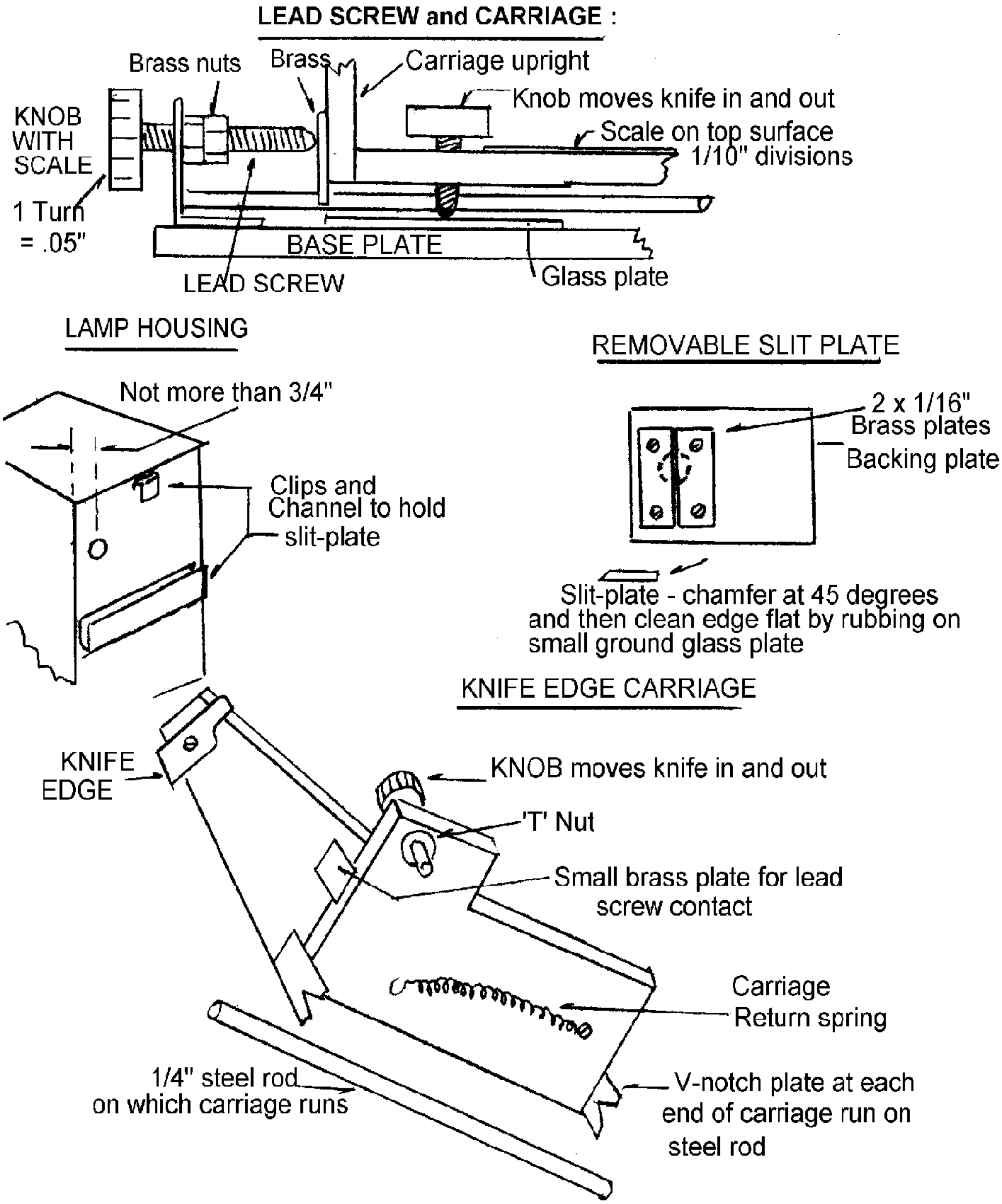
Page updated July 6th - 2001

Parts required:

1. A 6v.or 12v. auto lamp bulb - frosted by rubbing with emery cloth.
2. Transformer for the lamp. Use a 1 amp. fuse in the primary.
3. A slit-plate - brass, see details for making it in the second drawing.
4. Plywood base and knife edge carriage (can be made of metal or plastic if desired)
5. A round steel rod about 1/4" diameter 10" long.
6. Small thin glass plate on base for the carriage adjusting screw to run on -about 1" wide x 2" long.
7. A 1/4 x 20 screw about 2 1/2" long, for the lead-screw to drive the carriage along the steel runner.
8. 2 or three 1/4 x 20 brass nuts for the lead screw to run through. These are tightened enough to allow the lead screw to turn without back-lash. They are soldered to a brass support plate and provide very smooth running of the knife-edge carriage.
9. Lead-screw knob about 1 1/4" diameter.
10. Knob about 1" diameter, to drive the knife edge carriage sideways to move the knife in and out of the reflected beam from the mirror.
11. Assorted hardware and screws to complete construction.



The next page shows the details of the way I made the tester that I use.



Important notes below

The hole in the slit-plate (behind the slit) should be about 1/4 inch diameter. Also the hole in the lamp housing which coincides with the one behind the slit when it is set in place can be made slightly larger (perhaps 3/8 inch to make it easier to find and position the reflected image (slit-plate removed) when setting up, prior to making measurements.

The knife-edge attached to the top of the carriage upright, is made in the same way as the two pieces on the slit-plate. It is a piece of brass fastened to the carriage by a single screw and nut, so that it can be tilted to align the knife-edge parallel to the reflected image of the slit. The edge is chamfered with a small file and then the edge is made flat and even by rubbing against a flat piece of ground-glass. This can produce an edge which is almost optically flat...and is much preferred to using a razor-blade or other piece of metal - the edge of which may not be quite as accurately flat.

Afew extra notes - The slit width used should be set as close as possible to about **3 to 5 thousandths of an inch,** although the unit will work with a wider slit the narrower the slit the better! The two plates forming the slit should also be parallel as closely as you can make them. A couple of strips of typewriter paper can be used to help in this respect. When setting up for a test the slit-plate is taken off temporarily so that you can find the reflected image more easily, and then after aligning the reflected image between the knife-edge and the lamp housing, the slit-plate is replaced for making the tests.

Usually the scale on the tester is marked off in **10th's of an inch** and the knob (if you are using a 1/4 x 20 thread screw) is marked in intervals to represent **thousandths of an inch.** A pointer of some kind should be made to read the scale on the knob's circumferernce. Generally you can divide the circumference of the knob into divisions each equalling 5/1000th's of an inch and then guestimate the distances in between to the nearest thou.(One full turn of a 1/4 x 20 screw = 50 thousandths of an inch) so the marks on the knob scale would go from **'0' to '50'.** Two full turns of the knob should move your longitudinal scale by **1/10th inch.** So your pointer for the knob should be set so that when the other scale is at a 1/10th position, the scale reading on the knob is set at zero.

So you would (for example) start at a position where the longitudinal scale read 0.1 inch and then add (say) 12 thou read off the side of the knob...which would give 0.112 as your reading. The next window in the Couder screeen after moving the knife-edge further away from the mirror might be 0.1 plus 75 thou read off the knob scale...giving you 0.175. etc. **It is best** if the longitudinal scale is marked with the numbers (.1 .2 .3 etc.) going away from the mirror...so that your total readings increase as you move the knife-edge away from the mirror. The absolute value of the numbers does not matter - what you are after is the relative spacing between each reading as the knife-edge is moved towards or away from the mirror for the darking position at each window of the Couder screen.

If you are using metric measurements, then make your scales accordingly. The 'coarse' scale on the carriage can be marked in millimeters. The lead screw for the in and out movement of the knife-edge carriage can be a metric screw with threads of 1mm. Then the scale on your drive-knob for the carriage can be marked with 10ths of a millimeter on its circumference, as one complete turn will give you one millimeter of movement. You could also 'estimate' the third decimal (100th's mm) by estimating between the 10 marks on the edge of the drive-knob.

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PARABOLISING the polished mirror :

Updated September 3rd 2001

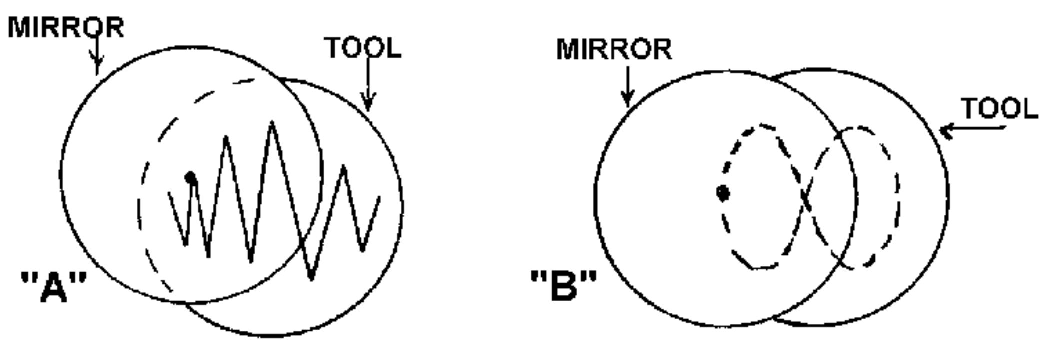
If you are amongst the lucky people who find that the finished mirror is almost spherical to start with, and has no major 'zonal' ridges or depressions - well, what can I say !? "Good for you! "

If that is not the case - then see later in this section for info on correcting zonal defects, and other nasty problems!

The difference in cross-section, for the average amateur mirror of 6 or 8 inch diameter is only a few millionths of an inch when the sphere and parabola are compared at the edge. In the case of the 8" F8 mirror discussed in this page's 'mirror' section the difference at the edge of the mirror is about 15 millionths of an inch. (15 x 10^-6) If they are compared by making the centers tangent and the edges intersect, the difference can be even less (about 4 x 10^-6 .)

The difference between the two curves is that the parabola is a little 'flatter' at the edges and a little deeper in the center. So we can **selectively polish these two areas to 'parabolise' the sphere by using a different polishing stroke.**

It should be obvious that to determine what action is necessary, you must be able to **measure** the existing profile of the mirror. Then if it is close to a sphere you can apply the modified stroke **("A" in the diagram) which is normally used to make it into a parabola.**



This stroke is like two or three letter W's together - WW(W) - and is wider and longer than the normal stroke, and is done **with the mirror on top.** Starting at one side with the mirror on top of the tool and offset perhaps 3" or more, you push the mirror about 3" or so up and down at the edge - gradually increasing the length of the stroke as you cross the center - up to perhaps a little over 6" and then reducing it again as you move to the other side. The long stroke across the center tends to deepen the center and the wide sideways motion works more on the edge of the mirror to reduce the edge.

The time for doing this should be short - only about 10 to 15 minutes for the first session, and the mirror must make **an even number of turns.** Then let the mirror settle for at least 8 hours (for pyrex) - (possibly 5 or 6 for plate glass) and check the result. The mirror surface is heated during even 10 or 15 minutes of polishing and will take a long time to settle properly. If you check it too soon - it may seem that nothing has changed and you will perhaps work it some more. Then when it has finally settled you will find that it was overdone. So be sure to give it lots of time to settle - after each 'figuring' session.

Before starting, the mirror and tool should be **properly pressed** to ensure good contact, and the polish should be **mixed a little thicker** than for normal polishing. **Any correction**, either parabolising, or fixing some zonal defect, should be done by degrees - the action of the tool is **sometimes not** what you expect it to be ! So do only a few minutes at first, then if all is going the right way, you can simply do some more until a good parabola is obtained.

When doing this you should mark a point on the edge of the mirror, so that you know where you start. After about a minute - turn only about a 5th or 6th of the circumference of the mirror, so that you do five or six steps to make one complete turn. Usually it is best to make only two or three turns and take about ten or 15 minutes total time polishing, for the first attempt at parabolising. At the end of the last turn stop a little way short of where you started so that you do not overlap a section which you have already done.

Another method - which some people may find harder to do **(if so, stick with the 'w' stroke)** - is to use a wide "lazy-eight' stroke, which is a figure 8 stroke but lying on its side, as in "B" in the diagram. **The normal 'w' type stroke shown in "A" is generally easier to use.** In each case the jagged line shows the track made **by the center of the mirror.**

Another method is to modify the pitch lap, by cutting the outer squares to form a 'star' pattern. We have never tried this method - so I do not know how well it works. Modifying the tool is not always a good thing - the full lap is not something to be lightly altered. It can be very necessary for blending defects in the mirror - and smoothing it out again if previous actions have caused a problem. The other possible method is to make a smaller lap (using a plywood disc as the base) - making it about half the normal diameter of the mirror. This can be used selectively to deepen the center first, using a long stroke with some two or three inch sideways motion, and then again to reduce the edge with a shorter chordal stroke across the edge, again using some 'spreading motion' so as not to 'dig a channel', until a good parabola is obtained. In this case - the mirror may be on the bench - and the small lap used on top - but an even number of turns around the mirror should be made.

The use of a small lap has some dangers - it can very easily produce grooves in the mirror - especially if used too long, and without adequate sideways motion to blend into the other areas of the mirror. If you are determined to make a mirror accurate to a 1/5th wave, or better, you may have to take the risk. Frequently - after using the small lap you may need to smooth things out again overall with the full-size lap. Too much use of the small lap can produce a rough appearance to the surface, and re-polishing for an hour or more may be required afterwards.

The choice of which method to use is up to the mirror-maker. There are probably yet more ways to do the job - but the above should provide a couple of ways that you can try. The small tool is often the method of choice with larger and much shorter focus mirrors, where it can depart from a sphere by a large amount (such as the 20" F5 mirror we made for our Club, edge difference= about 150 millionths")

The process of accurately 'figuring' the mirror can be time-consuming and requires lots of patience. The final guide to accuracy will be the time spent testing and graphing the results of each step you make in getting the correct shape If all goes well, with patience and perseverence you'll wind up with a smoothly parabolised mirror of a quality which would cost you dearly, if ordered from a company who will guarantee an 'observatory' or 'research grade' mirror, which would require hand-finishing and careful measuring to ensure the best of quality.

This is probably the main reason, apart from the challenge of learning a new 'craft,' for making your own mirror. There is always also the feeling of satisfaction - especially when looking through the finished telescope, of having accomplished something (which although a 'simple' process can present quite a challenge to complete successfully) There are many finished mirrors available at reasonable cost from various suppliers today. Careful attention to the various aspects of making, testing and finishing your own mirror though is still likely to cost less - and you have first-hand assurance of its quality if you are successful.

If you are reading this because you are making your own mirror - or intend to do so - I wish you lots of success.

CORRECTING the polished mirror:

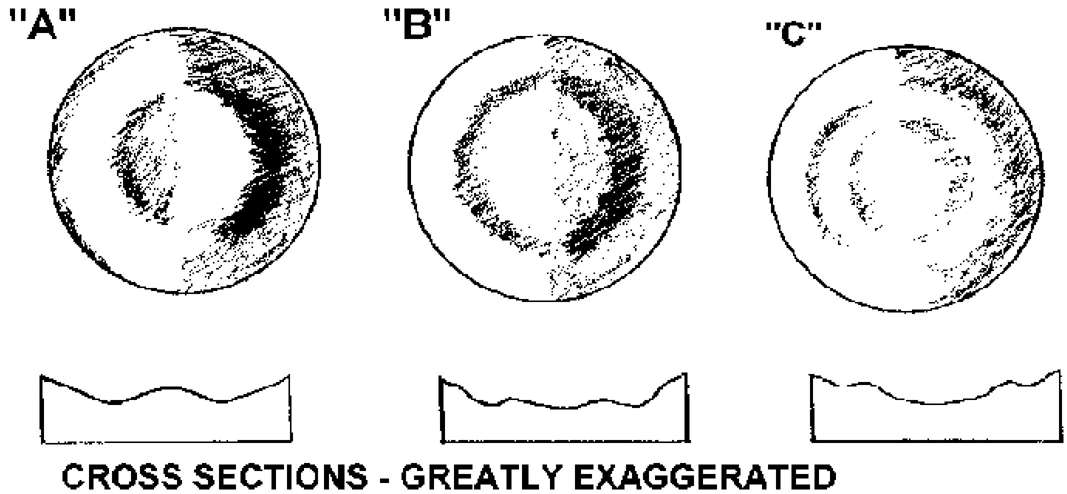
Oh -Oh - it didn't come out right ! So this is real life ??

Well, these things happen - but unless your mirror is so far away from being a reasonable curve, whether it is too deep, has a raised hump in the center, or a deep 'hole' in the center, a couple of concentric 'ridges' or a turned down edge, you may be able to correct it by selective polishing !

These things are of course only visible if you are looking at the mirror with some kind of tester. If the knife edge position is set at the **center of curvature,** a perfect sphere will darken across its whole face as the knife edge enters the reflected rays of light. If it is elliptical it will show some form of an 'upside down dish shape," and if it has zonal ridges or depressions they will show as lighter or darker 'rings' which are concentric to the circumference of the mirror disc.

Making a complete measurement, using a Couder screen and plotting the result will show you where your mirror departs from a perfect sphere. You may even get very lucky and find that it is already close to being a parabola. (If you need a 'refresher' on this - see the section on Testing, back at "home-page")

In the diagram - **'A'** represents the kind of shadow you would see with the knife-edge cutting the rays from the edge of the mirror.**(Assuming that the light is coming from the left side across the mirror)** Underneath is a 'profile' of the defect - greatly exaggerated. In **'A'** the defect is a **raised central bump.** In **'B'** the drawing shows a mirror with a **depressed channel** a little over half-way out from center. This is one of the worst defects you could find ! If it is fairly shallow it is probably best to check your polishing lap first - it could have oversize squares in some area, or perhaps was not properly pressed.



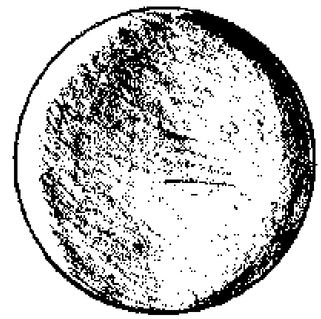
Another possible cause is applying (unconsciously) pressure on one side of the lap or mirror during the polishing stroke. Whatever the cause - firstly try about an hour of polishing again - check the squares of pitch on the lap for evenness and that no squares are contacting any other, that the channels between them are clear, make sure the tool is really well-pressed, and check your polishing stroke carefully. If this doesn't fix it - then your only possibility is to make a small lap (about 4") diameter and try to polish the areas inside and around the channel. Not a very nice problem to solve. Perhaps the best answer is to build a new lap (full size) make sure it's pressed and polish for two or three hours.

Well - after that - the next problem, a raised ridge as shown at **'C'** is a 'piece of cake' !! Any **raised ridge** can be reduced by centering the tool (lap) over the point on the radius where the ridge is, and using a short chordal stroke, work around the mirror for an **even number of turns.** Once again - do this only for a few minutes, and then check the effect. Make sure that you are blending the action into the rest of the mirror surface by moving the stroke a little to each side.

If you find more than one defect - for example a central hump and a raised zone further out : The best way to approach this kind of fault is to attack the center hump first. Then you can deal with the raised ridge after the central area is corrected. If you try to do both at the same time you can make things more complicated. The action of the lap when used for just a few minutes can give varied results and you could wind up with three areas to correct afterwards. It is better to correct one part of the mirror first, then move on to the next. You may also, after making a correction of a raised ridge - find that you need to use the normal polishing stroke for a maybe a half-hour to 'blend' things together and smooth the surface.

Depressed zones, provided that they are not deep (that is they are not grooves) and are fairly wide can be corrected by reducing the zones on either side of the depressed one. Then the whole surface can be 'blended' again by the use of the normal polishing stroke. This most likely calls for the use of a small lap - perhaps only 2 1/2" to 3" in diameter. Some defects just have to be dealt with this way. Although the action of a small lap is fairly predictable - and certainly only affects a small area of the mirror on which it is used - over-use can cause more problems than just going back to 'square one' and using the full lap to polish for a couple of hours. (making sure that it is pressed and in good shape, and that your stroke is carefully done)

Almost all the people I have talked to about mirror-making mention the **'dreaded turned-down edge'** Why this is so I really don't know. I don't think it happens to everyone - I've certainly seen lots of mirrors **without** turned edges.



A turned- down edge

With the knife cutting the edge rays of the mirror - this shows as a dark ridge on the right side of the mirror, with the rest of the disc having the appearance of a 'satellite dish' or a hollow 'salad dish.' The best indicator is the graph of your readings from the tester. To correct this you can try polishing with the lap centered about an inch to inch and a quarter inside the edge, using the chordal stroke. This, if the turn down is not too serious, will have the effect of 'blending' the edge into the rest of the 'figure' and will change the focus very slightly. Causes of a t.d. edge can be either too soft a pitch or maybe too wide a polishing stroke, or again possibly unconscious pressure over the edge of the mirror during polishing, or even too high a temperature in the work area.

In the end - **experience** is the main requirement, along with lots of patience if your mirror turns out to have any serious zonal defects. The only way to get experience is to persist - and spend the time necessary to find out what works for you ! If you have defects other than zonal ridges or depressions - such as astigmatism, where defects appear at different cross-sections of the mirror, your only choice is to go back to polishing for a few hours. Check the condition of the lap and the arrangement of the pitch squares. If all else fails - build a new lap and try again.

I hope the above helps you make a really fine mirror and GOOD LUCK

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Fraser Valley Astronomers Society

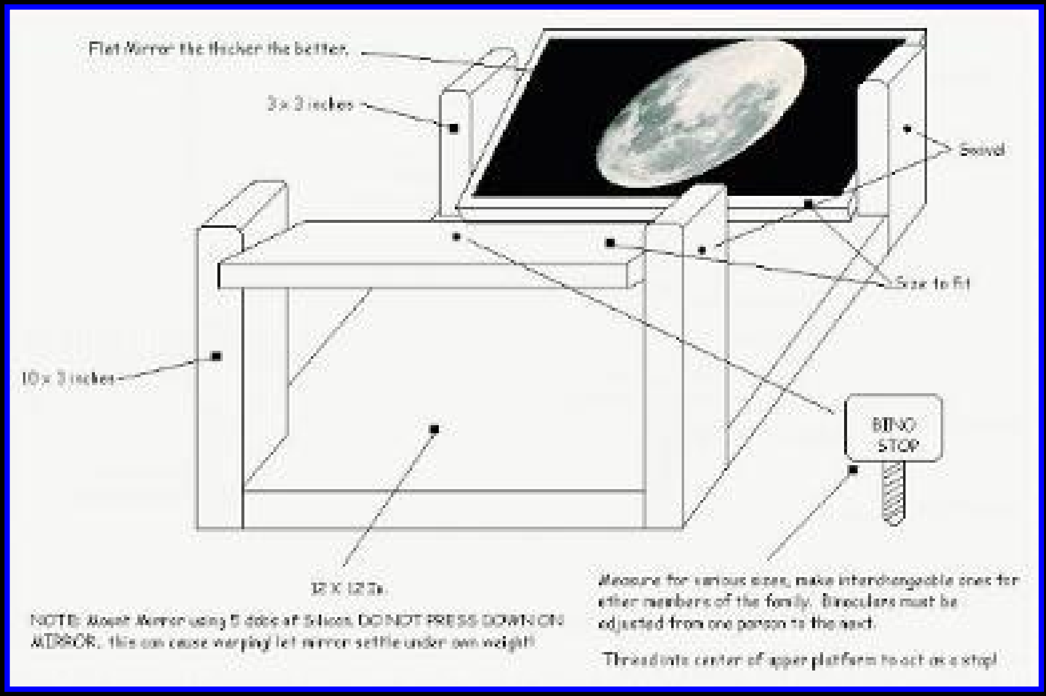
THE BINOCULAR BOX!

Warning!
DO NOT LOOK
AT THE SUN WITH THIS UNIT!
Severe Eye Damage can and will occur Instantaneously!

This unit is meant to be used under Dark Night Skys!
The above warning is true for Telescopes as well that are not equipped with safe and proper Solar Viewing accessories.

"Keep out of the hands of small children!" Adult! supervision advised!

"CLICK HERE FOR PLANS"



Click on the Plans for a Larger Picture! If you wish to print these plans, PRINT USING "LANDSCAPE" in your printer setup.

" RECOMMENDATION: "

Use a "THIN" FLAT FIRST SURFACE MIRROR if you can find one for the best results! First surface mirrors from optical companies can be very expensive! A Great Source for First Surface Mirrors believe it not can be found at your Auto Supply Store. At a very reasonable price!

These stores carry a large selection of Truck or Van replacement Rear View Mirrors, these mirrors are thin and flat, and have a first surface coating to them. These Mirrors can appear to be silvered on both sides! To check for the correct surface that you will be needing, you will need to do the credit card test. With the edge of the card placed edge down onto the mirror, see if you can see a gap between the image in the mirror and the card itself, if you can!? That is the WRONG SIDE! Flip the mirror over, and do the same test, if the image in the mirror meets the edge of the card and there is NO GAP between them, then THATS the side you Want! To have facing up on the bino box mount.

Also when you mount your first surface mirror, this is a tip from STEVE "Saratoga Smitty" place long nails under the mirror prior to setting it down on the silicon dobs. This way the mirror never really touches the surface below and it allows the mirror to expand or contract, if it needs too. DO NOT PUSH DOWN ON THE GLASS, just set it in place and let GRAVITY do the work.
Once the Silicon has dried, slip the nails out and your done! Enjoy and Have fun!

The **"ULTIMATE"** First Surface Mirror's

Available From The Good Folks at

" The Surplus Shed!"

"Click Eye Piece
to Purchase Products!"

Willie Schaf's Photo's!






Troubles? Questions?
Email me @ pgreenhalgh@fvas.net

ANSWERS FOR YOUR QUESTIONS:

1.Yes the image will be upside down if you are looking at the sky in front of you - but right way up if you are looking at the sky behind you.

2. Dowels could be ok, but you need something to 'lock' in position so you don't have to balance the Binoculars. The "Original" used wing nuts and short bolts for the pivots.

3. a) Base is 12" x 12" usually

b) The Mirror can be mounted onto either a piece of wood or one could use a rearview mirror that has a central swivel point as depicted in the pictures above. This would eliminate the need for the 3"x 3" supports for the mirror board as depicted in the plans. Note of Caution here, you can purchase an entire rearview mirror unit with the mirror included, but I find that most of the time the mirror is of poor quality, so personally I will purchase both the entire rear view assembly and purchase a mirror replacement at the same time.

Mount the entire unit, fill in the depression of the unit until it is level with silicone or some other filler, let it dry over night in a level position and then mount the replacement mirror on top of that again using 5 dobs of silicone, Place several LONG NAILS between the dobs so that the mirror will not settle right down onto the surface, mount the mirror but DO NOT PRESS DOWN. Let the mirror settle on its own. LET GRAVITY WORK FOR YOU!

c) Side supports for bino box is 10" high where as the mirror supports are 3" high and about 2 to 3" wide, 1/2" or 3/4" thick. Support board for binoculars is 10 1/2" wide (just like the mirror support) enough to rest binocs - rest at front can be a 1 1/2" square block, for the front swivel of the binocs to rest on (mounted close to the inside of the binoc support board) Only needs adjustment if other family members have different-size binocs or different widths between their eyes. Usually not necessary. Hope all this helps.

READ THIS!

The Fraser Valley Astronomers Society are dedicated to the education of Astronomy! It has been my experience that people from all over, are very interested with respect to what is out there in our universe. The young and the old, from all walks of life, have this unquenchable thirst to know whats out there in the great beyond. People all over the world from time to time, stop and look up, ponder and wonder. And usually a remote thought will enter their minds.. I wish I had a telescope right now!

Trouble here is, "MOST" people already DO! Maybe not in the real sense of the word.. but a telescope none the less.. BINOCULARS...YES thats right Binoculars! Now how on earth, you may ask, can binoculars be deemed as a telescope?

Here's how! Anything that can aid the human eye in magnifying an image in space can be considered a telescope! I don't care if all you have are a pair of opera glasses.. they too can be used as a telescope.. and the great thing about the binocular box is that you don't end up with a sore neck..nor sore shaky arms.. remember!?! GRAVITY REALLY WORKS, 17 p.s.i! Or as my young son would say...DAD! GRAVITY SUCKS! Hence the shaky arms after holding those bino's up for a long period of time...

HERES THE TRICK!

Take a flat mirror..the thinner the better (first surface mirror are better still, they can be found in old xerox machines.)..and place it on a picnic table. Now using your arms, like a tripod..position yourself over the mirror..and look into it with your binoculars.. WELL whaddaya know STARS! TONS OF EM, THOUSANDS of em...Billions and Billions and Billions of em.. *Ahem sorry got carried away there!*

Now get a bit more inventive..and put a 1 inch dowel under the mirror or a piece of wood to change the angle of the mirror..now your looking behind your head or down towards the horizon, depending on which way the mirror is tipped! (You remain in the same position the only thing that moves is the mirror!) You will succumb to the realization, that "HEY!?! This is like reading a book!!

The Bino Box..allows the user to mount his binoculars on a secure platform, granting him/her a hands free, steady, sturdy image of the night sky. Check it out..make one for the kids this spring,summer,fall,winter!...They'll sit there for hours!!

DON'T HAVE TELESCOPE OR BINOCULARS??? Well don't run down to your favorite mega store and pay 300 bucks for a dust collector telescope, I'd hate to see you waste your money! Get yourself a nice pair of 10x50 binoculars to start your odyssey..they range in price from 49.95 to 500.00 dollars and at those prices you should find it easy to fit a pair into your budget. If you compare the Binoculars against the (what I affectionately call the) curiosity telescope "50mm" at the store..you'll realize they are almost the same things in nature..

The objective lense at the front of the telescope is 50mm the Binocular's are the same 50mm! The only real difference between the two are the eyepieces.. the telescope may come with a 20mm, 12.5 mm and a 4 mm, where as the binoculars come with a 27mm set of eyepieces..or there abouts!

Now some food for thought..at night your eyes dilate to somewhere, near 7 millimeters, so in order for you to see an image in a 4 mm .965 eyepiece.. what do you need to do? To see an image in that 4 mm eyepiece?? Yep you guessed it, the all important and necessary FACE PLANT! And what do most kids see at those kinds of magnification?? EYE-LASHES! *Blink Blink!*

For the most part the 12.5 is difficult as well. Hence the reason why I call the 50mm telescope, the..in the closet, upright, dust collecting, paper weight! So what will Johnny or Sarah use most if they are using the 50mm telescope? Why the 20mm eyepiece of course! So why bother?? With the 10x50 binoculars (10 meaning 10 times magnification) and a Binocular Box.. Johnny and Sarah will see the very same image as if they were using the 50mm telescope and 20mm eyepiece.. and HERE they gets to use BOTH EYES!

NOW! When they have the bug for Astronomy!!! And have done some considerable learning of the night sky, with respect to constellations, and the where abouts of some deep sky objects or for that matter the positions of the planets.. would I consider buying them a telescope! Not just any ole telescope.. A REAL TELESCOPE! A telescope that has a respectable aperture, 4", 6", 8" or for that matter maybe a 10" Dobsonian (fondly known as a LIGHT BUCKET)or even a greater size (depends on the appetite *huge grin*).. These types {Cassegrain, Dobsonian, Newtonian's, just to name a few) are telescopes that require a 1.25 inch eyepieces.. (1 1/4 inches in diameter much larger than the standard .965 eyepiece) these are comfortable eyepieces..and work very very well.. But lets not get into that at this point of the game... the thing here is we want you to enjoy looking at the moon, the milky way, the moons orbiting Jupiter or just clusters of Stars.. So I offer up these plans for the Simple Binocular Box.. Print it off and enjoy your vacation amongst the stars!! I recommend that you print these plans out using the "LandScape Mode in your printer setup!"

Clear Skys all!

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