BUILDING A JOHNSONIAN-DOBSONIAN-NEWTONIAN REFLECTOR TELESCOPE

under the tutelage of

Phil Johnson, RASC Calgary

by

Nic David

1. Introduction

In the fall of 2009 I enrolled in Phil Johnson's annual telescope building class which meets most Saturday afternoons from 1 to 5 pm at Phil's house. In the past Phil has had up to seven pupils but this year I and Victor Barbu were the only ones building a telescope from scratch, or rather from optics, since we each either had or in my case acquired mirrors recuperated from other telescopes. This meant that, instead of there being some sharing out of tasks among the builders as has happened in the past, I was responsible for making the all non-optical parts myself. As an ethnoarchaeologist, one of my tasks has been to observe and describe African technologies – iron smelting and pottery manufacture amongst them – and it seemed to me that to do the same here could be useful: for myself to understand better what I was learning, for Phil (and the RASC) as a documentary record and as a students' guide when he is instructing at a distance, and for others unable to benefit as I have done from Phil's perfectly collimated teaching and guidance. It has been in every way a great experience, increasing my technical skills and allowing me to soak up astronomical lore and know-how from Phil and the many others who worked along with us for parts of the winter or who dropped in to have a problem solved or for uranian gossip.

After a few weeks note-taking with an occasional sketch I began to document the process in photographs, and to write up my notes as a coherent account intended to enable others to build a scope from scratch given access to the right tools, none of which are out of the ordinary, though few will have all of them in their home shop. Besides a carpenter's bench and a range of hand tools, minimal power tools needed include a plunging router, a drill press, a table saw and a jig saw. It helps to have or have access to a small lathe, a router, an air tool for nailing, a Dremel tool, a band saw, a disc and belt sander and a random orbital sander for use in the painting stage.

When, as often, you need to make multiple examples of the same part, it saves time in the long run to make a jig in order to achieve precise standardization – and best make a couple of parts extra just in case.

In the description below I have noted what was done in each session, making minor adjustments so as keep phases of construction together. Some sessions were longer than others, though we very rarely stayed after 5 pm, while others were shorter, as when we were off to volunteer at the Rothney Astrophysical Observatory. If you take parts home with you, you can gain some time, but reckon that a 12" telescope will take you from late September until April at least, with final sanding and painting, staining and/or varnishing still to be done. Instructions are given mostly in the form of imperatives, those relating more to my particular telescope as first person narrative.

Building a telescope with Phil is a demystifying experience that puts you in control of your own equipment. It's worth every minute.

Session 1. Sat 26 Sept. 2009

What kind of scope?

Phil Johnson began by discussing telescopes of various sizes and builds. I decided to build a 12” f5 reflector as such a scope has an aperture large enough for hunting faint galaxies but is not too difficult for a beginner to build. Also Chinese-made 12” f5 mirrors are significantly cheaper and not significantly worse than mirrors 3 times their price. “You might notice a difference two or three nights a year!”

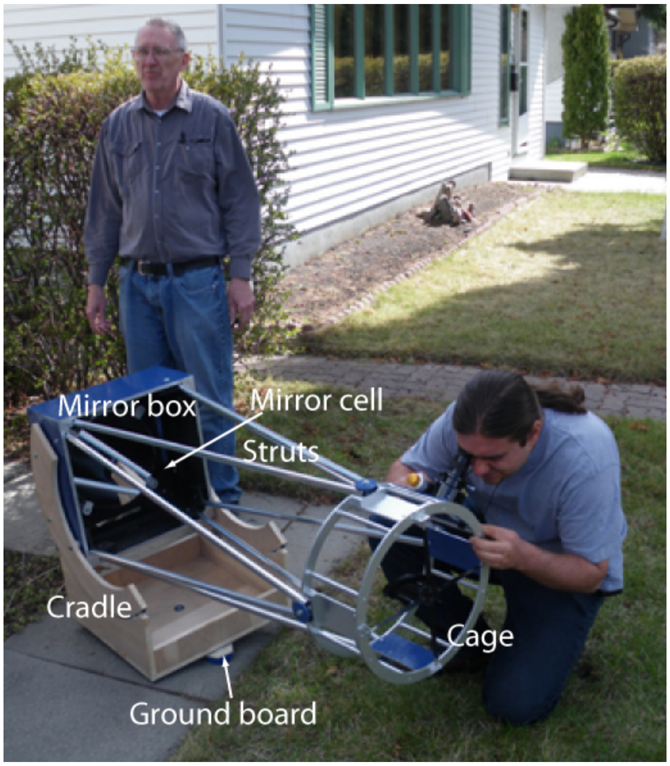

Figure 1. The completed and partially painted telescope. Victor Barbu checks the focus; “Uncle” Phil Johnson presides.

Such a telescope has a number of main components (Fig. 1). These are, from top to bottom:

1. The cage – containing the secondary mirror and the focuser
2. The struts – connecting the cage to the mirror box and supporting a plate (not shown) on which a red dot finder and a finder scope are mounted.
3. The mirror box – surrounding the mirror and also serving to store the cage when the telescope is not set up. The base of the box is open except for triangular pieces of ply in the corners. Side bearings attached to the mirror box allow the telescope to tilt up and down to the desired altitude.
4. The mirror cell – a board, with equipment attached for supporting the mirror and holding it in place, and which is itself attached by bolts to the triangles in the

corners at the base of the mirror box. Thus the mirror projects upwards from the mirror cell into the mirror box.

5. The cradle – a topless box with two concave sides that support the side bearings of the mirror box. When the telescope is not in use the cradle serves as a lid over the mirror box and cage.
6. And finally a ground board attached by a bolt to the center of the bottom of the cradle in such a way that the cradle and telescope can be rotated to the desired azimuth.

Session 2. Sat 3 Oct.

Design basics

In order to start building a telescope only a few basic measurements are necessary. Focal length and the sizes of the primary and secondary mirrors are the constraining factors (Fig. 2).

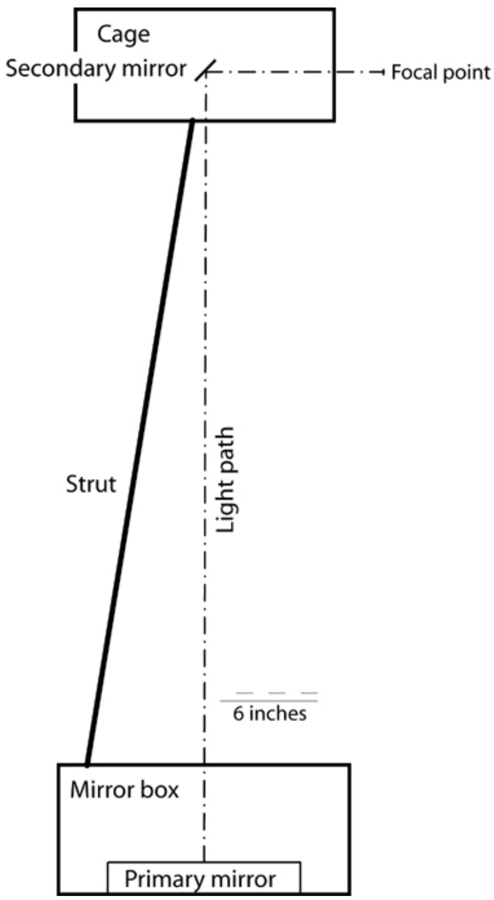

Figure 2. Basic design, showing the relationship between mirrors, mirror box, struts and cage. The centers of the eight struts enter the mirror box 1 ¾" from the corners and the cage ¾" off the center line of each quadrant. A sketch such as this enables the angles of the struts to be measured and the strut clamps that will be built to receive them to be designed.

Light from the primary mirror is reflected onto the secondary and deflected at 90° towards the focuser to form an image at the focal point, where it is observed through an eyepiece. The secondary mirror has to be large enough and far enough from the primary to be able to intercept all the light reflected. Eyepieces are designed to observe an image just beyond their distal lens component, and focusers are built to accept eyepieces outside the cage. These various factors are taken into consideration in determining the distance of the cage from the primary mirror, and the position of the focal point relative to the cage. In the absence of an actual secondary mirror or a focuser, I relied on Phil's experience to position the focal point about 3" outside the cage.

2. The cage

Although there is much freedom for variation, cage size is here based upon secondary and primary (here 12") mirror size. Primary mirror size and available space around it in the mirror box limits the exterior diameter of the cage. The relationship between the secondary mirror and the focuser, in my case a relatively heavy, 2", 2-speed model, largely determines its height. We decided on a 16" exterior diameter, formed of 1" wide rings of ¼" birch plywood spaced apart by ½" dowels 6 ½" long. Overall height is therefore 7".

Cage rings and dowels

1. Tape two pieces of ¼" birch ply together, mark the center and draw out 15", 15 ½" and 16" circles. Then draw lines across at 0, 45, 90 and 135° and mark screw holes at intersections of these lines and the 15 ½" circle, which will be at the centre of the cage rings.
2. Attach taped pieces with 2 screws to another square of ply used as backing. This has a strip of board attached to its back that is placed in Workmate jaws to hold it firm. A ¼" hole is bored in the center and a dowel inserted.
3. Use a plunging router, rotating round the dowel, to cut progressively deeper circles into the birch ply along the outer side of the 16" and the inner side of the 15" circle to produce 1" wide rings.
4. Mark and label one screw hole in the top of the top ring and a corresponding screw hole in the bottom of the bottom ring. Bore $^{3}/_{32}$" holes in the rings to accept #4 screws and countersink them in the top of the top ring and bottom of the bottom ring
5. Cut a set of eight (with spares) 6 ½" long dowels in ½" diameter dowelling.

Session 3. Sat 17 Oct.

We started off by calculating the relationship of the cage to the mirror box and worked out that struts will enter the cage at a 10° angle. When I later used QuickCad to draw up figure 2, I found that the angle should actually have been 9.2°, but the difference is not significant.

Cage assembly

1. Sand (fine grit) the birch ply cage rings and the dowels. Take or make a simple jig consisting of a hole drilled in a small block to accept the end of the dowel and a screw drilled from the other direction projecting into its exact centre. This allows the centre of each dowel to be marked and makes it easier to drill holes in the ends. Drill screw holes ($^{3}/_{32}$") in tops and bottoms of the 6 ½ " dowels.
2. Then, using white glue, glue and screw (#4 ¾" screws) through the top and bottom cage rings into the dowels, producing the skeleton of the cage (Fig. 3).

Figure 3. The cage with strut blocks and their vertical backing plates in position.

Strut blocks

(A set of struts is often referred to as a truss. I will avoid this word.)

1. Take two pairs of wood blocks, each 3” long, ¾” thick and 1” high (pine – good to have a little play here) and tape each pair together (forming a block 3” * 1 ½” * 1”). The thickness of the taped blocks is with the wood grain because it is best to drill across the grain.
2. Drill a ¼” hole through the middle (1 ½” combined thickness) of each block with its center ⅜” above the base.
3. Mark center points of strut entrance holes ¾” from the ends on the bases of the taped blocks. Tip drill press to 10° and bore ¾” holes through the taped blocks from bottom to top.
4. Separate the pairs of strut blocks by removing the tape. They are now ready to receive struts to be held in place by discs attached by bolts through the ¼” holes bored in step 2.

Session 4. Sat 24 Oct.

Building the cage.

1. In preparation for fixing the strut blocks, fit a stiff paper jig between the dowels. Measure a mid point on it and transfer this point to the upper surface of the bottom cage ring.
2. Use a thin straight edge to draw guide lines between dowels. Place each strut block so that the center of the block with the drilled recesses for the struts is flush with the exterior of the ring. Take care to set each strut block parallel to its guide line. At this stage the ends of the strut block project outside the line of the cage ring. They will be sanded away. Glue the strut blocks (white glue) and clamp in place. As always remove any excess glue (a plastic drinking straw is very effective).

3. Cut four 3” * 6 ½” plates in ¼” birch ply as backing for the strut blocks, and also eight smaller plates (3” * ¾”) in the same material.
4. Fit but do not glue the larger plates behind the blocks, taking care that they are tight against the block and vertical. It is advisable to sand the lower outer edge of each large plate a little in case glue prevents it sitting tight against its strut block.
5. Glue a small plate (and as always clamp for 15 minutes or more) in place under the top edge of the ring on the outside of each large plate. Once this is in place temporarily remove the large plate and any excess glue.
6. After 15 minutes for drying, glue the large plates top and bottom and clamp them in place.
7. After another pause, glue and clamp the remaining four small plates in place on top of the strut blocks. They thus become strut stops.

At the end of the session the cage is much stronger and still very light.

By this time I had bought a SGO focuser and the 12” mirror together with its secondary and (damaged) spider from an Antares Dobsonian that had been blown over and damaged beyond repair.

Session 5. Sat 31 Oct.

Building the cage, continued

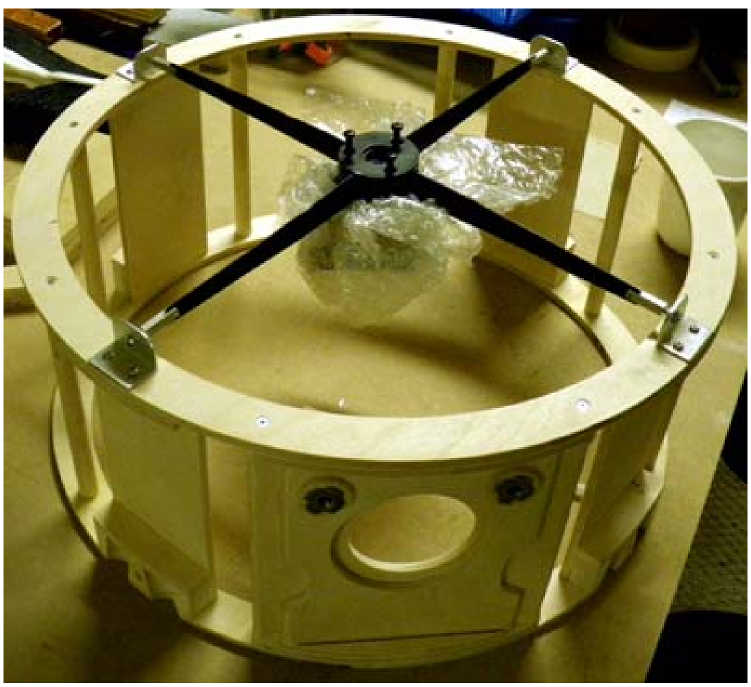

Figure 4. The cage with strut blocks and plates in place and sanded, both focuser plates installed and the spider in place held by aluminum mounts.

1. Sand down those parts of the plates and the strut blocks that project outside the diameter of the cage rings (Fig. 4). This is most easily, quickly and precisely done using a belt and disc sander, second best with a sanding drum on a drill press, and if necessary by hand.

2. Cut and dry fit a 6 ½ by 6 ¼" plate of ¼" birch ply outside and across two of the dowels. This plate will be fixed in position to support the focuser.
3. At this time recheck the fit of the spider, secondary mirror and focuser. In my case we found that the mirror could not be removed from its long necked support and that a screw on the base of the focuser would require that the cage be rebuilt one half inch taller! Rejecting this idea we decided to mount the spider on top of the cage.

To do this I cut four 1 ⅛" lengths of ¾" aluminum angle iron as spider mounts. These will be attached to the upper ring by screws that go through the upper ring and into the small plates described in step 4 of the previous process. I then used a suitable washer and a metal scribe to mark rounded ends on the upper corners of the aluminum pieces. After cutting off excess metal with tin snips, I formed rounded ends with sanding equipment and a fine file, and finally gave a smooth finish to the spider mounts with fine sandpaper and steel wool.

Session 6. Sat 7 Nov.

Attaching the spider

Before going to this session I visited a friend with a machine shop and he made (from two old computer parts 2 ⅞" inches long and ¼" wide with screw holes in their ends and a solid middle) four pieces with the screw holes at the outer end and the inner end grooved to accept the ends of the spider arms. These were attached to the spider arms by steel pegs inserted into holes drilled through the metal.

We drilled two ⅛" holes through the bottoms of the spider mounts for attachment to the cage top and one in the rounded upright portion through which a screw passes, entering the pieces previously machined to tension the spider arms.

Then,

1. I attached the spider mounts to the top of the cage with #4 ½" screws. The upright portion of the mount is on the inside and the corners of their outer edges flush with the outer rim of the cage. This makes for strength as the screws penetrate the small upper plates.
2. The spider was attached. About $^{5}/_{32}$" separates the end of the spider arms from the inner side of their aluminum mounts – room for adjustment if needed.

Fitting the focuser

The focuser plate (to which the focuser will at a later stage be glued) is attached by bolts and tee nuts to the fixed plate located between two of the cage dowels (Fig. 5). The focuser plate is positioned between ¼" strips of ¼" plywood glued (**a**) to the bottom of the upper cage ring and (**b**) to the top of the lower. A narrow third strip of ply (**c**) glued on top of **b** helps hold the base of the focuser plate in the observing position. When not in use the focuser on its plate is removed and reattached inside the cage by the same bolts.

Figure 5. The fixed and the movable focuser plates in position, held in place by small plates **a**, **b** and **c**. Note the tee nuts, here attached to discs glued onto the movable focuser plate. Bolts passing through both plates screw into the tee nuts, holding all together.

1. Carefully measure the distance – 4 ⅜” here – from the centre of the secondary mirror to the base of the cage. This determines the centre point of the holes in the plates through which the focuser will project.
2. The fixed plate rests against the outer sides of two of the dowels.
3. The movable plate, 6” by 5” in this instance, is half an inch shorter and its width is such that it does not extend outside the outer rim of the cage:.
4. The **a** and **b** strips of ply 6 ¼” long and 5/8” wide hold the fixed plate in position and **c**, 4 ½” long by 5/16”, holds in the bottom of the movable plate.
5. Make these parts of ¼” birch ply and sand the fixed plate so that it fits and holds by pressure alone.
6. Tape the two plates squarely together in the relationship demanded by the measurements and mark the center of the holes for the focuser. The diameter of the hole on the fixed plate is determined by the size of the focuser tube that will move back and forth through it – 2 ½” in this instance – and the size of the hole in the movable plate by the size of the flange on the focuser to which it will be glued. There is going to be a lot of variation in this. My dual speed focuser required a hole in the movable plate 3.142” in diameter.
7. If you don’t have a hole saw of the required size and have to produce this diameter by sanding, draw a fractionally larger circle on the movable plate.
8. Drill a ¼” hole through both plates to serve as the centre of the hole saw.
9. Saw a hole 2 ½” diameter in the fixed plate and 3” in diameter in the movable plate.
10. Place the fixed plate in position (there is no preferred position among the four possible ones so long as it abuts the two dowels and fits equally against them). It can be glued in place but because I had an excellent pressure fit I decided not to.
11. Glue and clamp strips **a** and **b** described in step 4 above to hold the plate in place.
12. After time for drying of the glue, glue and clamp the remaining small strip **c** on top of the larger one, leaving a gap of ¼” between it and the fixed plate. This will

prevent the bottom edge of the movable plate from moving when it is in the observing position.

13. Sand away the parts of the newly glued plates that project beyond the circumference of the cage rings.
14. Increase in increasingly smaller stages the diameter of the hole in the movable plate by sanding with a sanding drum until it exactly fits the flange on the focuser.
15. Use a Dremel tool with a small sander drum to carve out the parts of the lower cage ring that need to be removed so that the struts can enter the strut blocks.
16. All should now have been ready except that I discovered my focuser now fit so flat against the movable plate that it was difficult to turn the focusing knobs. So I notched each side of the movable plate as seen in figure 5.

Session 7. Sat 14 Nov.

Fitting the focuser (cont.)

tee nuts in the movable plate are used to attach the focuser when in use to the outside of the fixed plate and for storage on the inside of the cage.

1. Mark out two symmetrically placed points near the top corners of the movable plate and bore ¼" holes through them. Because the movable plate will be attached on different sides of the fixed plate in its observing and storage configurations, take great care to establish the symmetry of the bored holes
2. Glue and clamp a 5 ¼" by 1 ⅜" strip of ¼" ply on the inside of the fixed plate over the area to be bored through. This is needed for the movable plate to clear the dowels when stored inside the cage.
3. Clamp the movable plate in position on the fixed plate and bore ¼" holes through the holes in the movable plate to pierce the fixed plate and the backing strip..
4. Use a hole saw to make two 1 ⅛" diameter discs of ⅛" birch ply and glue them symmetrically over the holes on the outside of the movable plate. These are needed to accept tee nuts.
5. Back to the drill press to drill $^3/_8$" holes through the discs to accommodate the barrels of the tee nuts.
6. Place the tee nuts over the newly bored holes and draw them into the discs using, from the inside, a ¼" slot-headed bolt that goes through a protective washer, the plate and then the tee nut, entering a nut on the exterior of the disc. Tighten the head of the bolt to draw the tee nut into the disc.
7. Check that the movable plate hangs symmetrically both on the outside and inside of the fixed plate. In my case it didn't as I had slightly misaligned the holes. However Phil was quickly able to adjust the holes by filling them with dowels and then re-boring them to save the day!
8. Now or later, glue the focuser to its plate. Make sure that the focuser is attached to the side of the focuser plate that has the tee nuts. After cleaning the focuser edge to be glued with acetone in order to remove any grease or dirt, use JB Weld epoxy to bond the focuser to the movable focuser plate.

The cage is now complete except for clamps to hold the struts in position.

Session 8. Sat 21 Nov.

3. The mirror cell

At this point it became necessary to decide how to how to mount the 12” mirror. It had come with its original mirror cell. In order to investigate the cell and the mounting of the mirror:

1. The mirror cell’s outer heavy frame was removed.
2. The inner frame was built as a circle divided into six portions by radial bars, each of which was accessed by a screw passing through the outer frame. Three of these screws in a triangular pattern were used to collimate the mirror by adjusting the tilt of the inner frame and the remaining three to lock down the adjustment once collimated. Thus the lock down screws were not next to the collimating screws but half way between them, a bad design as their use would tend to de-collimate the mirror.
3. The mirror itself rested on three triangles made of metal covered with plastic that were attached to three of the arms of the inner frame. The attachment was by a short screw supporting a plastic ball which is pressure fit into a corresponding cup on the underside of the triangle. The triangle cups are free to move on the balls within a limited range. Pads at the corners of the triangles where contact is made with the mirror back needed replacement.
4. We decided to redesign the cell but retain the triangular mirror supports.

Session 9. Sat 28 Nov.

Designing the box and the mirror cell

The mirror box (less lid) will be 18” by 18” by 8” tall in order to hold the cage in storage configuration and protect the mirror, the bottom of which will be approximately at the level of the bottom of the box. Thus the mirror box will not have a base but only four triangular corner pieces. The mirror will poke up through the gap between these corner pieces supported by a mirror cell base board made of a 16” by 16” square of ¾” ply. Bolts through the corners of this square attach to the corner pieces at the base of the box. Besides linking mirror cell and mirror box, these bolts are also used for collimation.

Construction of the mirror cell

The mirror cell consists of a base board, three triangular supports for the mirror that tilt within a limited range (each contacting the mirror at three points) and mirror posts (Figs. 6 and 7). Aluminum tabs on top of the mirror posts extend over the edge of the mirror to prevent it from falling out of the cell when it is tipped in use. Collimation and attachment to the mirror box are achieved through bolts at the corners. A fan is inserted in a cutout at the center. Rails on the underside support the mirror cell in storage configuration.

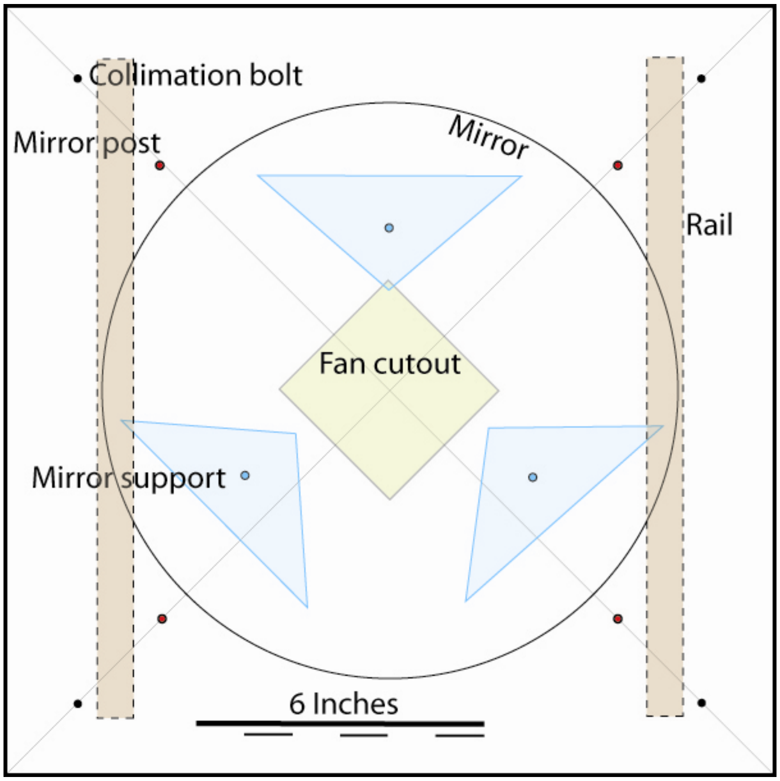

Figure 6. Mirror cell baseboard layout. The rails are on the underside of the mirror cell.

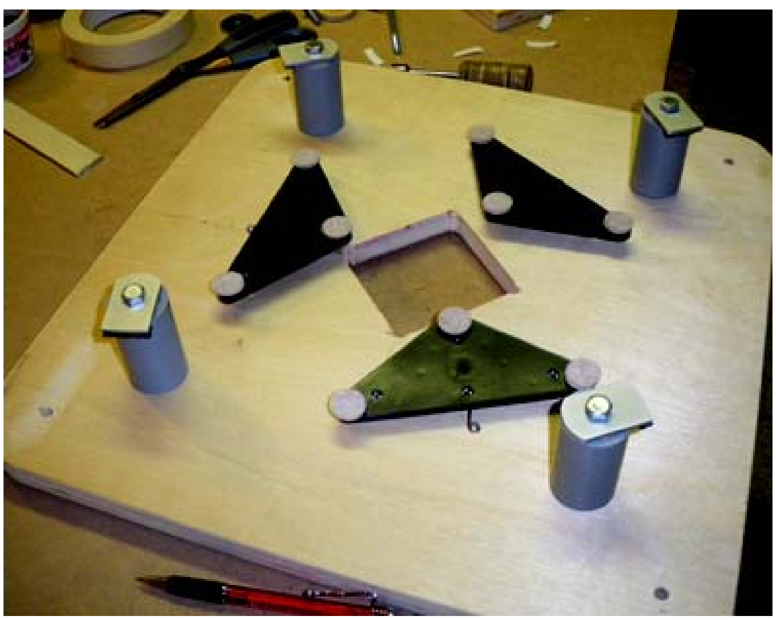

Figure 7. The mirror cell showing a central cut out for a fan, three triangular mirror supports, four mirror posts with tabs on top to prevent the mirror from tipping out of place, and a hole near each corner of the base through which bolts used in collimation will pass and attach the cell to the corner pieces in the base of the mirror box. The upper side of the cell (see 2 below) is on the left.

1. Cut a 16" square of ¾" ply for the base and find and mark its center.
2. Place the three triangles in such a way that when the telescope is tilted during observation, two of the triangles support the lower part of the mirror and one the upper. As shown in figure 6, drill ⅜" holes in the base board to accommodate aluminum bushings that hold the triangle supports. The bushings are pieces of aluminum tubing tapped on the inside to fit a ¼" bolt.

3. To accommodate the fan, cut a square out of the center of the base board using a drill and a jigsaw.
4. Attaching the triangles to the base plate required making bushings $^{5}/_{8}$" long out of aluminum tubing and tapping them with the right threads so that the triangle supports would screw into them (a thin washer intervening) from the top while ¼" bolts would hold them in place from beneath the plate. Tapping the bushings was achieved partly on a lathe worked by hand until the threads were well established. The bushing was then removed and tapped by hand.[1]
5. The bushings were then glued in place in the base plate, the rounded plastic tops that press fit into the base of the triangles were screwed into the top of the bushings and small bolts screwed into the bushing bases.

Session 10. Sat 5 Dec. 2009

Construction of mirror posts

The mirror is prevented from falling off its supports by four posts attached to the base board. These have aluminum tabs at the top held by the ¼" bolt that holds the posts onto the base board. The tabs should not press on the mirror (which might deform it) but are set just above, with intervening felt tabs put on their under sides, to retain the mirror when tilted, jolted or (God forfend!) turned upside down.

1. Cut and trim the ends of four lengths of PVC piping 1 $^{5}/_{16}$" in external diameter and of the same height as the top of the mirror above the base board. The internal diameter of the piping is 1 $^{1}/_{16}$". For strength it is necessary to fill this space, rendering the post solid.
2. Use a hole saw of the next size up from 1 $^{1}/_{16}$" to cut four sets of (mostly $^{3}/_{5}$") plywood discs that when placed on top of each other make a column the height of the posts. Glue each set together with Elmer's white glue and thread them on a ¼" carriage bolt holding them tight with a nut.
3. Fix the bolt in a lathe and reduce the discs in diameter until the set fits fairly tightly in its piece of piping.
4. Fill the posts with the plywood columns. Use Elmer's Ultimate glue which sets up, foaming, in contact with water. Smear the glue thinly on the inside of each post pipe with a cotton tipped stick; moisten the plywood column on the outside and push it into the pipe. Wipe away any foam appearing at either end.

This took me longer than it should as I was learning to use a lathe and wasted one of the plywood post interiors by reducing it too much in diameter.

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[1] To hold the bushing firmly but without crushing it during this process a hole of a size to fit the bushing was drilled in a piece of wood about 1" square. A narrow cut was then made down from the drilled end of the piece of wood to and a little beyond the base of the hole. When placed in a vice this held the bushing firmly, allowing it to be tapped right though.

Session 11. Sat 16 Jan. 2010

Setting and retaining the mirror in position

1. Attach the plastic-covered steel triangle mirror supports to their bases and add felt pads to the corners. It is important that the blunt apex of each triangle point to the center of the mirror and that the triangle moves only very little when the mirror is placed on top of it. This was achieved for each support by means of small pieces of stiff copper wire bent to a right angle with a small loop formed at one end, perpendicular to the plane of the wire. One was inserted into a hole near the base of each triangle and screwed down onto the base board using a #4 ⅜" screw (Fig. 7).
2. Position the mirror retainer posts using the layout lines (Fig. 6). Set the two posts on the lower part of the mirror against the line of the mirror and the two at the top $^{1}/_{16}$" away from it. Use a punch passed through the central hole in the post to mark the center and a small drill to make a guide hole. Drill a ¼" hole and set the posts provisionally in position.
3. Set the mirror in place. A good moment!
4. It remains to make the aluminum tabs to retain the mirror. Cut four 1 ⅝" pieces of 1" by ⅛" aluminum strip and drill a ⅛" followed by a ¼" hole through each on the center line in such a way that the mid-point of one end of the strip lines up with the exterior of the post. Use a metal scribe to indicate what part of this end of the strip needs to be removed to conform to the outline of the post. Remove this with a disc and belt sander, first using the disc part and then the belt. In the same manner regularize and smooth off the end of the tab that will project over the mirror. Finish with a fine sanding sponge or steel wool.

Session 12. Sat 23 Jan.

Completing the mirror cell

1. Mark and drill ¼" holes for collimation bolts 1 ½" from each corner of the base board, then round the corners.
2. Insert tee nuts into the bottom of the base board to receive bolts passing down through the retainer posts. If necessary re-drill the posts to remove any glue infiltrated into the hole. Check the post assembly – post and aluminum retaining tab with intervening washer (so that bolt pressure falls on the washer and not on the PVC post exterior) – for height, making sure there is about $^{3}/_{16}$" between tab and mirror surface, and then saw and file the ¼" post bolt so that it does not project beyond the tee nut into which it will screw. Finally, after adding strips of stick-on felt to the projecting parts of the lower side of the tabs to prevent metal to glass contact with the mirror, screw down the post assemblies into the tee nuts.
3. Either now or later, add rails of a hard wood (Phil supplied strips of a hockey stick ¾" wide) to the underside of the base board (see Fig. 6). These raise the mirror cell a little above the ground in its storage and transport configuration and protect it and especially the fan.

4. The mirror box

Session 13. Sat 30 Jan.

A mirror box made of ⅜” ply surrounds the mirror and has attached to it the side bearings that allow the mirror to tilt to different altitudes. On the inside there are, from bottom to top (Fig. 8):

- triangular corner pieces through which the collimation bolts in the mirror cell base board are attached,
- reinforcement strips of wood run horizontally along the sides to above the level of the mirror, allowing for a semi-stiff protective cover to be placed over the mirror, and,
- in the upper corners, clamp assemblies angled at 10° to receive the aluminum struts.

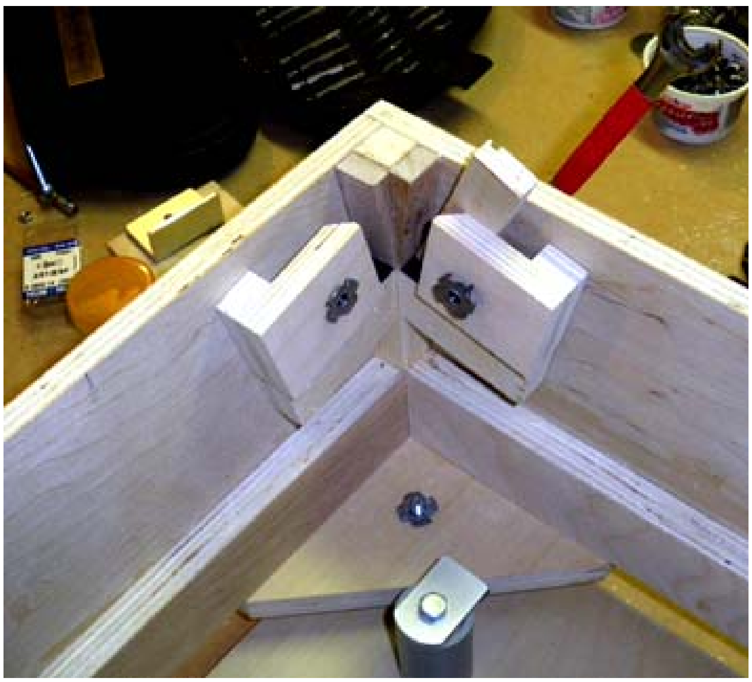

Figure 8. A corner of the mirror box showing fittings and mirror cell attached. The tee nut in the right hand strut clamp is being drawn into the wood. A piece of ply in the approximate position of a strut prevents the strut clamp being deformed in the process.

1. Cut and assemble the 8” deep sides of the box – two 18” long and two 18” minus two thicknesses of the ply. First, glue and clamp one long side and one short side, and then air nail them together from the long side into the end of the short. Then add the remaining short and finally the long side in the same manner. Because it is very difficult to get perfect positioning for more than one joint at a time, it is best when adding the second long side to apply glue to the ends of both short sides but temporarily prevent one end of the long side from gluing by placing a thin metal rod between it and the short side. When gluing and nailing are completed check that box is square and clamp it in that position.
2. Cut four 6” isosceles triangles of ¾” ply to fit in the corners of base of box to strengthen it and to attach the mirror cell. Cut off the two apices of the triangle away from the box corner perpendicular to the sides of the box so that the length of the cut off edges is the same as the thickness of ¾” ply. This allows inlay of short lengths of ply along the sides of the box between the triangles, giving the box a flat

base and preventing penetration of stray light. Attach triangles with glue and air nails.

3. Cut four side strips of the same ply 2” wide to fit the inside the box and glue them on top of the triangles, reversing the longer/shorter pattern of the sides.
4. Decide which side of the box will be the top – that is to say higher when the telescope is tilted during use. Best to make it one of the sides with 18” long ply as the side bearings will then largely hide the apparent ply edges on the sides with shorter lengths of ply. Label the box exterior and the underside of the mirror cell appropriately with tape or pencil.

Session 14. Sat 6 Feb.

Fitting mirror cell to mirror box

1. Place the mirror cell (less mirror!) on the upturned mirror box base, aligning the previously labeled top sides of cell and box. After making sure that cell and box are set quite square to each other, drill ¼” holes through the triangles using the holes previously drilled in the mirror cell base board as a guide. Then countersink ⅜” holes in the tops of the triangles to receive tee nuts. Insert the tee nuts and draw them into the wood as previously described.
2. Take two *ca* 4.5 cm diameter plastic balls (Dollar Store); cut them in half with a box cutter then bore through the center of the halves with a ¼” (Brad) drill.
3. Attach the mirror box to the mirror cell by passing 2 ½” bolts up through a small exterior washer, the mirror cell base board and the plastic ball hemispheres (flat base down) into the tee nuts set in the box triangles.

Making strut clamp assemblies

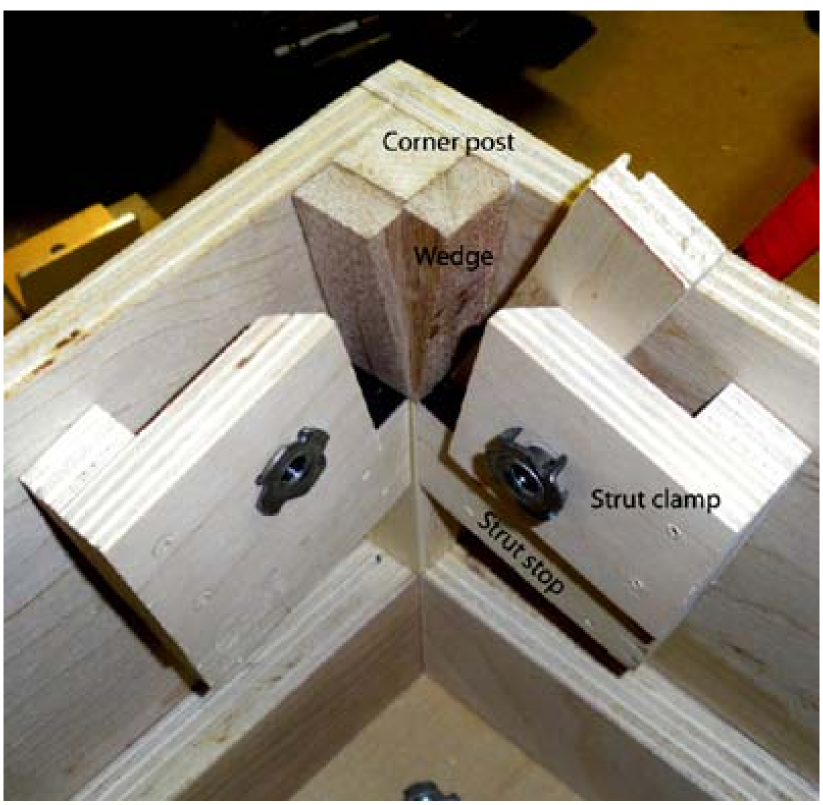

Figure 9. Strut clamp assembly.

The next step is to make clamp assemblies for the struts that will link the box to the cage (Fig. 9). These require:

- Four pine corner posts that extend from the top of the box’s side strips to the top edge of the box (5 1/8” * ¾” * ¾”).
- Eight strut stops on which the ends of the struts will rest. These are of ¾” ply, 2 ⅝” long by 1 ¼” wide and are cut at a 10° angle at one end. An Arborite strip is glued (and temporarily taped in lieu of clamping) to the top to provide a hard surface for the struts to rest on.
- Eight strut clamps. Made of ½” ply, the larger part is 2 ¼” long by 2” wide. The end nearest the post is beveled to hold the strut (leaving a blunt tip to avoid a fragile end). To the inside of the other end is glued and screwed a strip of the same ply ¾” wide. (Rather than making these individually two strips were glued together and cut into pieces of the right size.)
- Eight wedges (2 ¼” * ¾” * 7/16” at top and 1/16” bottom) of a hard wood (mahogany) cut at a 10° angle. These have their narrow tips cut off to make a end with a relatively strong edge. Phil provides a jig for making these pieces. The narrow tip of each wedge is slipped into the jig, scored with a knife and then snapped off. The upper ends of the wedges are later cut off at the level of the top of the corner post and the box edge. No precision measurements necessary!

Session 15. Sat 13 Feb.

1. Glue and clamp the posts to the inside of the box.
2. After trimming excess Arborite, place the strut stops in position using a jig of ½” ply. The top of the jig, 6” long, aligns with the top of the box, the 2 ¼” inch inner end abutting the corner post. The lower side of the jig is cut to run at a 10° angle from the post to the outer end. Opposite sides of the jig are used for right and left hand corners of the box.
3. Clamp the jig into position and glue and air nail the strut stop into place with its 10° end abutting the post and its top edge tight against the bottom of the jig. Repeat for other stops.
4. Glue and clamp the wedges in place against the corner post, their ends resting on the strut stops.
5. Using the drill press, bore pilot holes through the thick part of the clamps half way across the strip and ¾” from the top and bottom. Drill a third pilot hole through the other end of the clamp an inch from the top and 1 ½” from the thick end.

Session 16. Sat 20 Feb.

1. One after another, clamp each strut clamp in position on top of the strut stop with a short piece of ¾” exterior diameter aluminum tubing – a dummy strut – in position against the wedge and a piece of ½” ply inside the clamp to prevent any deformation. Number each strut clamp and its position in the box in order to ensure that drilled holes line up exactly.
2. Extend the pilot holes (see 5 above) in the thicker part of the clamp through the mirror box sides. Then enlarge them in the reverse direction by drilling with a 9/64”

bit through the box exterior and countersink on the outside. Screw two #6 1 ¼” screws through the box exterior into the thicker part of each clamp.

3. Unscrew and remove the numbered clamp assemblies.
4. Drill a ¼” hole through the side of the box back along the line of the third pilot hole. Achieve verticality by drilling through a cylindrical jig, made of plywood circles glued one on top of each other.
5. Use the drill press to enlarge to ¼” the pilot holes through the thin ends of the strut clamps and widen these to ⅜” on the flat (interior of the box) side in order to introduce a tee nut.
6. Screw the strut clamp back into position. After replacing the dummy strut and the ½” piece of scrap ply mentioned in 1 above, use a 1 ¼” bolt with a wide washer to draw the tee nut into the strut clamp.
7. Replace the wide washer with a smaller one and remove the dummy strut and piece of scrap ply. Repeat for the remaining seven clamps.

At this point borrowed struts can be temporarily set in place to link the cage and the mirror box. Another moment to remember! Now is a good time to work out how long your struts should be. (Of course if you have everything precisely planned from the beginning, made no changes as Uncle Phil or yourself have had ideas for improvements, and you have your QuickCad plan with you, you can ignore the next section.)

5. The struts

Calculating strut length

With some borrowed struts temporarily spring clamped into place on the cage, I measured the vertical distance from the top of the mirror (actually the bottom of the retaining tab on a mirror post) to the middle of the focuser hole in the cage. This gave 52” – remember that the mid-point of the focuser was made to be the same height as the middle of the secondary mirror. The focuser was temporarily held in place and the distance measured from the center of the spider to a notional focusing point 2 ½” outside the cage This distance was found to be 10 ½ inches. The total distance from mirror to focusing point was therefore estimated at 62 ½ inches, or 2 ½ inches too long for a 12” f5 mirror.

I therefore had to reduce the distance from the primary mirror to the middle of the secondary. The temporary struts were 45.75” long and the distance of their bases from the center of the side of the mirror box 7.375”. Thus the square of the vertical height of the temporary struts can be calculated using Pythagoras theorem as $y^2 = 45.75^2 - 7.375^2$ giving y = 45.15. This must be reduced to 43.15 to obtain the correct focal distance and by reverse calculation the correct length of the struts can be calculated as 43.77” (or 43 49/64”). This later proved to be too long! And the exercise futile. It can be done more simply in practice.

Session 17. Sat 27 Feb.

Putting it all together

Final touches to the cage (Fig. 10):

1. Drill through the center of the four strut blocks and the plate behind them following the pre-existing ¼" hole, and then drill back part way with a short-stopped ⅜" bit to let tee nuts into the plate.
2. Draw in the tee nuts using a 1 ¾"long bolt and a large ¼" ply washer with a metal one next to the head of the bolt.
3. Saw five 2 ⅛" discs of birch, beech or other hard ply. Stack them on a bolt and insert it in the drill press chuck. Use a sanding block and later fine sandpaper to smooth and slightly bevel their edges.
4. Four of these are then fitted on bolts that pass through the outside of the strut blocks and into the tee nuts. They serve to clamp the struts.
5. The fifth ply disc is retained for making the clamp to hold the finder assembly (described below)

Figure 10. One of the four strut clamps on the cage. The bolt passes through the strut block and into a tee nut embedded in the vertical plate behind.

First tree!

It is a significant moment when the cage and the mirror box with its mirror in place are carried up from the workshop to a room with a window through which the scope can catch its first glimpse of the outside world. Borrowed/test struts are installed and clamped into position un the following sequence:

1. Insert struts into the strut clamps in the mirror box but do not tighten.
2. Insert struts into the cage strut clamps and once they are all properly in position tighten the clamps.
3. Tighten box strut clamps.

Figure 11. Phil Johnson checks focus and focal length on the first occasion that the telescope, with borrowed struts, is put together.

Lift the telescope onto a convenient surface with a view to the outside and lay it on its side (Fig. 11). Then:

1. Check that the secondary is aligned with the primary mirror and the focuser hole.
2. Move a mid-range eyepiece, at this time without the focuser, in and out of the focuser hole till you get a focused image of something at a considerable distance, for example a tree. Note where this focus point is in relation to the cage. (It will be just in front of the inner lens on the eye piece.)
3. Aim by adapting strut length to adjust this focus point to be outside the cage and located at about half way through the in and out focusing movement of your focuser. Thus if the focusing point is presently inside the cage you will need shorter struts to reduce the distance between the primary and secondary mirrors – and vice versa if it is far outside the cage.

We found that the test struts were indeed too long and that I needed a set of 43" or less.

Making struts

1. Cut eight 43"struts with a hacksaw. Use a jig and, starting with the shortest strut, use a table saw with metal cutting blade to trim them all to exactly the same length.
2. File off exterior burrs and sharp edges, cutting out interior burrs with a box cutter. Clean the insides of the struts by pushing paper wads through with a dowel (one doesn't want anything falling on the mirror), and wipe down their outsides
3. Finish the strut ends by twirling them on a sanding sponge, rotating them between the palms in the same motion one would use for a fire drill.
4. Polish (though not necessarily at this stage) the struts using steel wool. (SOS pads or the equivalent work well and best when wetted.) Finish by waxing them with

Turtle wax to reduce oxidation and prevent getting one's hands black. Finally (but not necessarily immediately) cover most of their length with pipe insulation foam tubes. This is partly aesthetic but also practical as aluminum struts get very cold.

The new struts were then fitted and the telescope remounted on its side. The focuser was put in place and an eye piece inserted. Focus was obtained but it was agreed that the struts were still about 1" too long.

Session 18. Sat 06 Mar.

After taking the struts home and cleaning them with soapy steel wool, I forgot to bring them to this session. Therefore I had to do other things.

6. The finder assembly

The finder clamp assembly attaches near the cage between two struts and should be as light as possible while large enough to accommodate both a finder scope and a red dot finder. What follows is a description of the building of my first finder assembly. I soon discovered that this didn't suit me as

a) even when the Orion EZ red dot finder was installed at the top of the plate, it still required painful contortions to sight on anything near the zenith, and

b) when using it my head constantly bumped the 9 by 60 finderscope I eventually fitted.

I explain my eventual solution to these problems at the end of this section which is included as originally written because the principles and techniques remain the same.

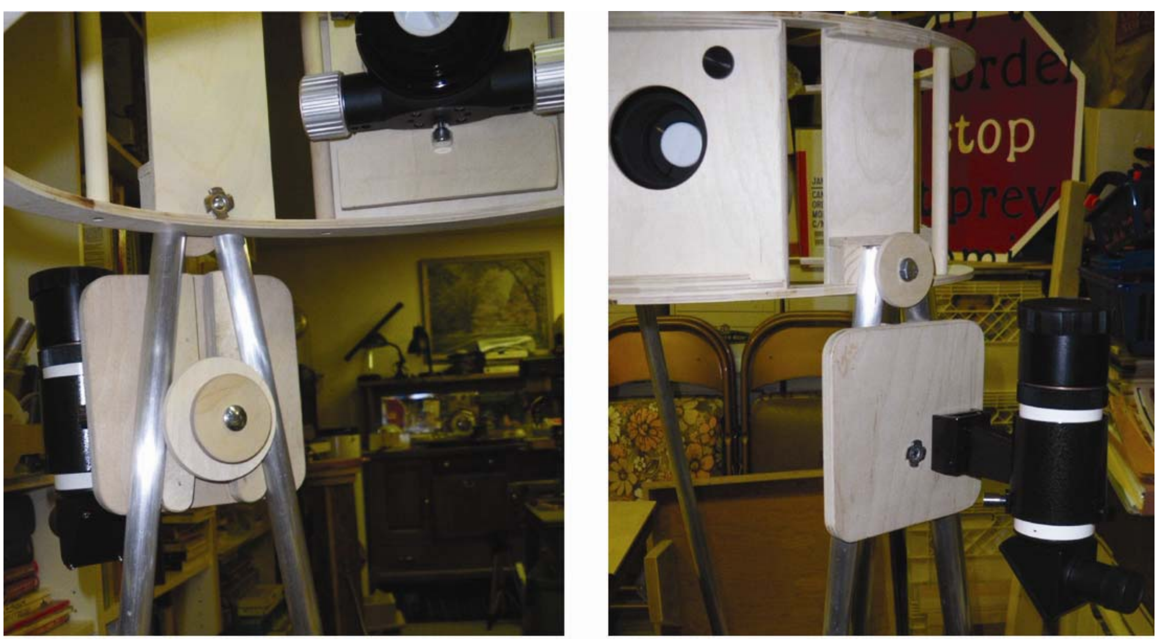

Figure 12. The back (left) and front (right) of the finder assembly showing its attachment to the struts and relationship to the cage and focuser. A red dot finder will be installed next to the finder scope.

Cut parts as follows:

- one 5 ½” square plate of half inch ply
- two 5 ½” * ¾” strips of the same ply, which are then placed in a jig to remove a strip from half of one side at a 10° angle. Each piece is thus ¾” wide at the base and ¼” wide at the tip, the angle between the long sides of the piece near the tip being 10°
- a disc cut out of ¼” birch ply with a 3” hole saw, and
- a disc cut in the same ply with a 2 ⅛” hole saw.

Also required are:

- a 2” long ¼” carriage bolt (screw runs full length) and a nut,
- two small washers.

These are assembled as follows:

1. Designate one surface of the plate as the exterior and the other as the interior of the finder assembly.
2. Insert a tee nut into the exterior surface 2” from the base and half way across.
3. Put together the finder assembly clamp as follows:
   carriage bolt, pulled well down into the wood of the
   smaller disc
   washer
   nut, tightened
   washer
   larger disc
4. Screw the bolt bearing the above pieces through the plate into the tee nut.
5. Set the finder assembly temporarily in place on the assembled telescope between the two struts on the top side of the telescope. It’s easiest to do this in reverse with the clamp on the *outside* of the struts. Positioning should leave a small gap between the top of the assembly and the bottom of the cage. Ensure that the top of the square plate is parallel to the bottom of the cage.
6. Slip the left hand strip into position inside the struts in such a way that its straight side is tight against the left hand strut, its top aligned with the top of the plate. Now mark with a pencil the position of its inside, angled, edge on the plate. Do the same with the right hand strip.
7. Remove the finder assembly from the scope and unscrew the clamp. Attach the left hand strip to the plate using air nails in such a way that its angled side runs along the pencil line.
8. The right hand strip is similarly placed on the other side along its pencil line, and then attached with a #6 ½” countersunk screw or small, doubly countersunk, bolt through its middle and about 3” from the top. By boring a very slightly too large hole through this strip before passing the screw or bolt through it, it will have a little play and both strips will fit snugly between the struts.
9. Before replacing the clamp *either* attach the finder scope and red dot finder *or* an equivalent weight to the plate. Reattach clamp and attach the finder assembly to struts, this time the right way round with the clamp on the inside.

Later modifications to the finder assembly

On a f5 12" scope the struts are relatively short which means that the finder assembly described above is uncomfortably low for many observers. There is also the problem of lack of space between the red dot finder and the finderscope. Avoiding hitting the latter with one's head when using the former requires bending down even lower and contorting one's neck even more.

My solution, seen in figure 13, is to:

a) to move the red dot finder up onto the cage, snug against the underside of the upper cage ring on the plate to the right of the focuser, and

b) to make an asymmetrical finder assembly plate attaching to the struts in the same manner as the old but extending far enough away from the observer for comfortable use of both red dot finder and finderscope. In building this piece I substituted a solid block of ply that fits tightly between the struts. Little or no calibration of red dot finder, finderscope and main scope is now needed after scope assembly.

Obviously the finder assembly has to be adapted to both the telescope and the observer. A petite woman has different requirements from a man over 6' tall. However I suggest that a Rigel or EZ red dot finder will almost always be more convenient on a f5 or faster strut reflector telescope than the much longer Telrad or even the cheaper red dot finders. On an f8 on the other hand ….

Figure 13. The revised finder system with red dot finder attached to the cage and a 9 by 60 finderscope on the finder assembly board.

Session 19. Sat 13 Mar.

7. The side bearings

Design

The bottom of the side bearings attached to the sides of the mirror box form the arc of a circle of a radius that depends upon the center of gravity of the scope in its normal use state. The bearing rotates on glide pads attached to a concave surface in the top of the cradle that is the negative of the side bearing (Fig. 14).

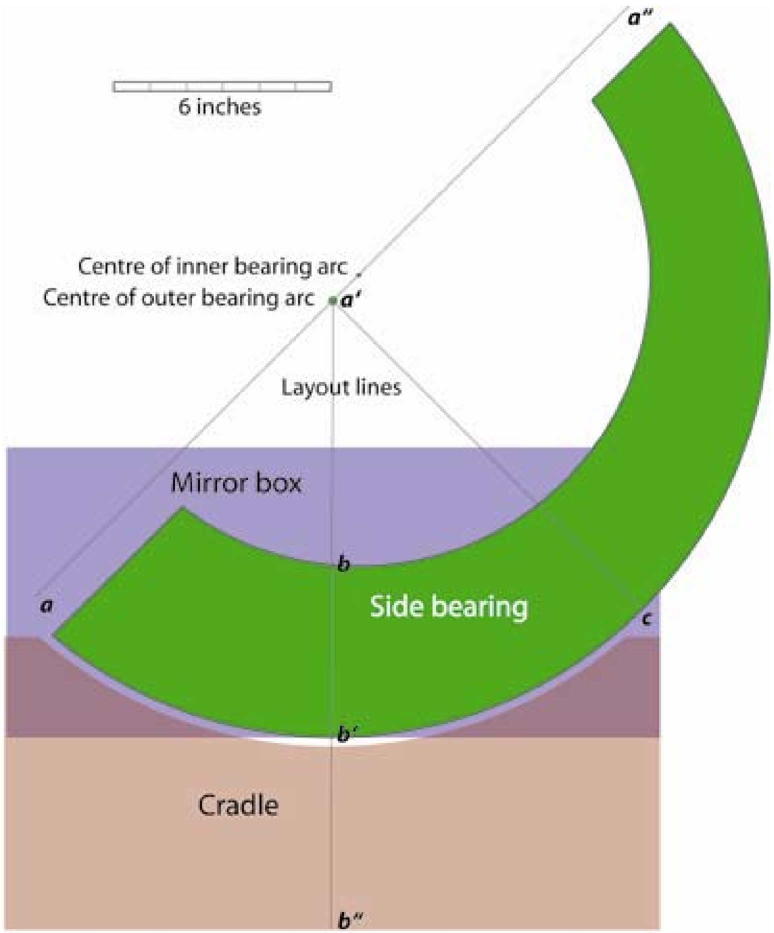

Figure 14. Side bearing with radii of arc 12" and 8", mirror box and cradle. The center of the outer bearing arc is the center of gravity of the telescope equipped for observation. The ¼" gap between side bearing and cradle is exaggerated in the drawing.

1. After attaching the finder assembly with finder scope and red dot finder (or equivalent weight) in position, and the focuser with a relatively heavy eyepiece inserted, lay the assembled scope down on a smooth floor with the two struts on the lower side resting on a piece of 1" metal pipe that lies parallel to the top of the mirror box.
2. Roll the telescope gently back and forth over the pipe to ascertain its point of balance. Once this is found measure the distance from the point of balance to the top of the mirror box. In my case it was 4''. This 4" plus the 8" side of the box gives the 12" radius of the weight-bearing lower surface of the side bearings.

3. The upper surface of the side bearings can be of any shape consistent with retaining strength while minimizing weight. Phil's solution is to cut an offset arc of circle of lesser radius in the side bearing. By offsetting by one inch the centre of this arc on the 45° line ***a – a' – a***", one ends up with a strong side bearing that is wider lower than above and not displeasing to look at.

Session 20. Sat 17 Mar.

Cutting side bearings

1. Cut two boards of ¾" ply each 16 by 26". Draw a centerline perpendicular to the shorter axis. This corresponds to ***a' – c*** on figure 14.
2. Take a piece of scrap ply large enough to support both boards (33 * 30" is fine), and nail a strip of wood 1" wide on its underside across its width. Place this strip in the jaws of a carpenter's bench or Workmate. Above it on the top side attach a strip of wood 2" wide running from side to side, into the central point of which insert a ¼" dowel. The middle of this strip is approximated by the line ***a – a' – a"*** on the figure. The dowel is the centre of the arcs forming the outer surfaces of the side bearings, and the point of rotation for a plunging router.
3. Place the two boards onto the scrap ply with their centerlines (***a' – c – b"***) in line with the dowel. Nail them in place, positioning the nails about 6" from the dowel so that they will not pierce the side bearings you are about to cut. Each piece will produce one side bearing and one side of the cradle on which the side bearing will rest and tilt.
4. Before proceeding any further, draw two lines at 45° angles to the center line from the dowel across one of the two pieces of wood. One of these lines will become the line ***b – b'.*** (It depends on which side of the central point you offset the center for the smaller arc.)
5. With a plunging router cut an arc the diameter of the outer edge of the side bearing through each board (12" in this case). Remove the outer part of each and set aside for making the cradle.
6. Remove the dowel and insert it into a hole in the center of the wood strip 1" away from its previous position. Now repeat the process, cutting an arc corresponding to the inner surface of the side bearing (8" here). This produces two identical bearings, wider at the bottom than at the top. After light sanding, tape them together and transfer the line ***b – b'*** from one bearing to the other.

Session 21. Sat 24 Mar.

Attaching arborite strips

The next step is to attach an arborite strip squarely onto the outer edge of each side bearing. Resting on glide pads attached to the cradle, it will ensure smooth tilting of the telescope to the desired altitude.

1. Cut (with a table saw or a special angled knife) two strips of arborite 1" wide and an inch longer than the length of the long (outer) side of the side bearing. If necessary, refresh mark ***c*** in the middle of the side to be glued.

2. Lay the side bearings on their side raised above a table or other flat surface by pieces of ⅛” ply. Apply contact cement to the arborite strips and the edge of each side bearing.
3. Wait for a considerable period, perhaps 45 minutes, until the glue on the arborite has become transparent and on the side bearings is so tacky that a piece of newspaper will not stick to it. Check that the mid-point marks are still visible, refreshing if necessary.
4. Then, working out from the middle of the side bearing, and with the side bearings resting on their ⅛” supports and lower edge of the arborite on the flat surface, firmly press the arborite onto the side bearing. You only get one chance at this! The excess will be trimmed in the next step. Clamp the ends of the arborite strips to the side bearings for a short period.
5. Using Phil’s jig, trim excess arborite (Fig. 15) and clean off any excess glue using an acetone-dampened rag and sand paper.

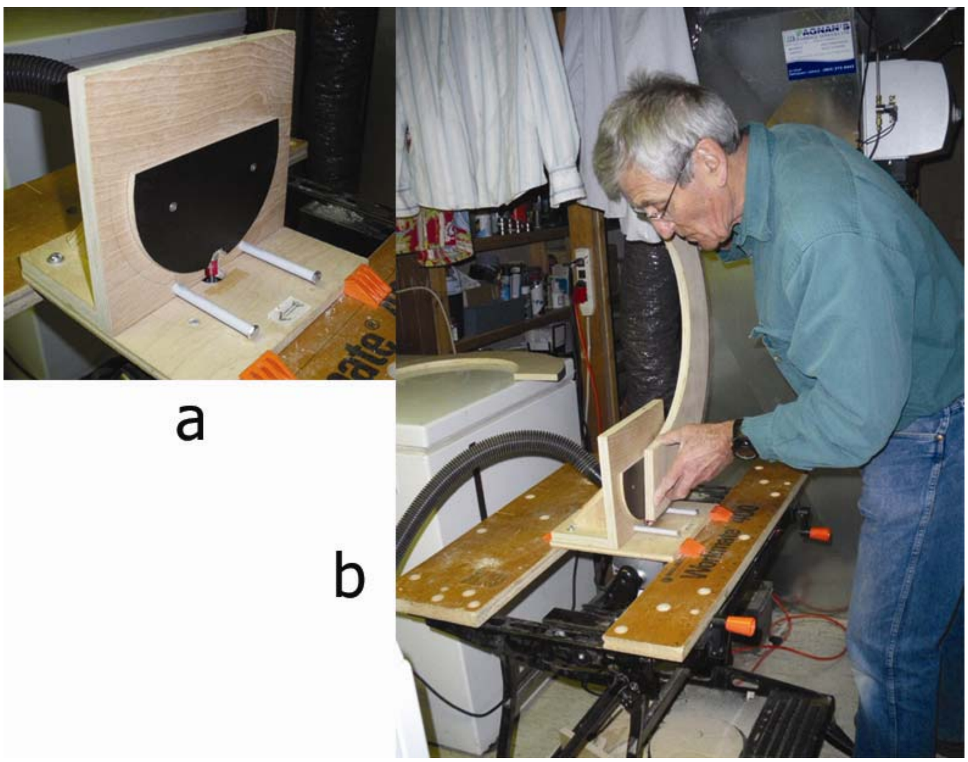

Figure 15. a) The arborite trimming jig developed by Phil Johnson. The black plate is ⅛” thick and aligned with the cutting edge of the router bit coming up from below. This has a rotating disc attached to its tip that is also aligned with the plate and which helps the side bearing to move easily across the jig.
b) The jig in use. The side bearings are pressed flat against the black plate and moved smoothly from right to left resting on the white tubular supports. This trims the arborite to the edge of the side bearing. Excess arborite at the ends of the side bearings is best removed before this process by holding the side bearing perpendicularly (but not vertically) to the black plate and using the router bit to remove the excess a little bit at a time.

I also corrected the positioning of the focuser on its cage plate during this session. This required filling old drill holes with a dowel and trimming off the excess with a small Japanese saw. (Tip: before gluing the dowel in position it is a good idea to crimp its sides with pliers to provide a larger contact area for adhesion of wood glue.) After checking the position of the focuser using a collimating tool – a 35mm film canister with a hole pierced in the centre of its top suffices – new holes were drilled and the focuser replaced.

Over Easter

8. Filling and painting

Take everything that isn't screwed or nailed down to bits! I didn't at first and it was a mistake. By the end I had everything apart except for the triangular mirror supports. When disassembling the mirror box and mirror cell (re-)mark their top sides so that they will fit together at the end without problem. And make sure the marks survive or are replaced through each coat of paint.

Filling

I brought the cage and mirror box and cell home and applied Bondo Sun-Activated Body Filler (Canadian Tire) to seal all ply edges and fill other flaws. The filler is a sticky paste best applied with a palette knife; a thin coat well pressed in suffices. This took about three hours.

Figure 16. Not buttering a Ritz cracker; the author seals the ply edge of a strut clamp before painting.

After two partial days in the open with some sun but lots of cloud, the filler was well hardened – when rubbed with sandpaper the excess comes off as a white powder – and ready for sanding. I found a handheld orbital sander with 150 grit sanding disk extremely useful and used a small sheet of medium coarse grit sandpaper to get rid of lumps of filler. Finish with 300 grit and a wipe with a damp cloth. The mirror box and cell took three hours and the cage little less.

Painting

I used Tremclad oil-based primer on everything before applying Tremclad rust paint: Flat Black on the inside of the mirror box and the mirror cell, Aluminum gloss on most of the cage, and my own mix of dark blue gloss on the outside of the mirror box, the finder platform and parts of the cage. Even with fine bristle brushes, paint had to be applied in very thin coats if it was not to run. In the end I found it best to apply paint wherever possible to horizontal surfaces – e.g., one side of the box, tops of the top and bottom cage rings – leave them for at least three hours and then turn them and paint another horizontal surface. Light sanding and a final wipe with a moist cloth between coats is essential.

Lots of time and patience and brush cleaning are needed! In retrospect I should have learned to apply spray paint. After one coat of primer and two of paint it begins to look good. Someone has already mistaken my cage for an aluminum casting! There is no point in fine finishing until the side bearings are attached and the cradle and ground board manufactured.

Session 22. Sat 10 April

9. Attaching side bearings

Note that the narrow ends of the side bearings rise up from the *lower* end of the mirror box. The bearings attach to the sides of the box by three bolts, the lower two passing through spacing discs of about 1 ½" diameter made of ¼" ply and the reinforcing strips of ¾" ply on the inside of the box. The third bearing normally attaches through a spacer of lesser diameter into a strut clamp.

It is critical that the two bearings are identically attached. The point of departure is the 45° diagonal line (***b – b'*** on figure 14) drawn across the wider part of the side bearing before it was cut. This establishes the *vertical* of the side bearing in position.

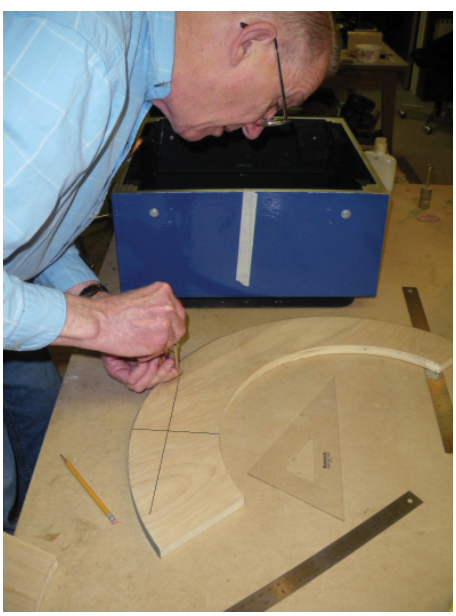

Figure 17. Phil Johnson has laid out a line perpendicular to the side bearing vertical. Two bolts placed on this line will attach the bearing to the box. He has chosen a point of attachment and is using a compass to check that the spacer will not project beyond the line of the side bearing.

1. If you have not already done so, clamp or tape the side bearings together and extend the line of the ***b – b'*** vertical around their tops, outer sides and bottoms.
2. After removing the mirror cell, mark (use masking tape) the verticals of the midpoints on the sides of the mirror box to which the side bearings will be attached. Extend these lines across the bottom edges of the box.
3. Ensure that the bottom of the side bearing as marked by the vertical line is aligned with the vertical on the box and that the bottoms of the side bearings are level with the bottom of the box. Work out how high above the bottom of the box the two lower bolts should be so that they a) pass through the interior reinforcement strips and b) that the spacing discs noted above are hidden behind the bearing. Lay out on a side bearing a line perpendicular to the vertical at the appropriate height (about 2 ½" should do it) and mark two points on it for bolt attachment, allowing for the size of the spacers (see figure 17).
4. Clamp the two side bearings together being very careful that they exactly coincide. Then drill the two bolt holes (¼") through both bearings. As soon as the first hole is bored, stick a bolt in it to doubly ensure coincidence of the next hole across both bearings.
5. Separate the bearings and attach them provisionally with bolts to the sides of the box. At this point you are likely to find that the upper part of the side bearing runs across one of the bolts used in a strut clamp. This is not a problem! For the moment just remove the strut clamp bolt. Clamp the side bearing in position and run a bolt with a point on it from the inside of the box through the tee nut in the strut clamp and the side of the mirror box to mark the center of the bolt on the inside of the side bearing. Needless to say Phil has adapted a (carriage) bolt for precisely this purpose. Do the same with the other side bearing.
6. Drill ¼" holes through the side bearings.
7. With a hole saw, make ¼" thick ply spacers to hold the side bearings away from the box. The lower spacers should be 1 ½ to 2" in diameter, the upper one about 1". Sand them down and glue them in place on the side bearings using bolts as clamps (Fig. 18). Wait 15 minutes or more and remove the bolts.
8. Using ¼" bolts of the appropriate length bolt the side bearings and attached spacers in place.
9. Finally test that all is well by turning the box upside down on a flat surface and resting it on the tips of the side bearings and the upper corners of the box. It should sit absolutely square with all four points touching the surface.

Figure 18. Side bearing spacers glued and temporarily clamped in place by bolts and nuts.

10. Inserting a 12V fan in the mirror cell

It is preferable that the mirror-cooling fan exhausts air from the inside of the mirror box and cell to the exterior as this makes for even cooling and prevents grass and dust from being sucked up into the mirror cell and deposited on the mirror surface. A hole for the fan was cut at an earlier stage (see fig. 6). The fan cable passes through the mirror cell baseboard near the top of the mirror and is connected to a 12V battery.

1. Cut a 4" square of a aluminum sheet (thin enough to cut with scissors) and cut out a circle the size of the fan. Round the sheet corners.
2. Bore inner and outer holes through the sheet and attach the inner ones to the corners of the fan with screws (supplied with the fan) and the outer with #4 ½" screws to the underside of the mirror cell base board.
3. To insert a connector in the base board near its upper side, use a ½" Forstner bit to drill through most of the baseboard from the bottom up, leaving about an ⅛" of the ply in place. Drill a central pilot hole through the remaining thickness of the ply and enlarge it to ¼". This permits the insertion of a connector with its battery terminal recessed into the baseboard (Fig. 19).

To improve on the fan to battery connection, Phil removed the connector supplied and soldered a bridge rectifier to the wires with the positive and negative outputs on the fan side and the AC outlets on the battery side. Short lengths of wire were then attached from the rectifier to a new connector and the wires taped to the upper surface of the baseboard to avoid possible interference with the triangular mirror supports. The benefits of the bridge rectifier are threefold. It prevents misconnection of the battery; it reduces the power flow to the fan (and its noise); and it lengthens the life of the battery.

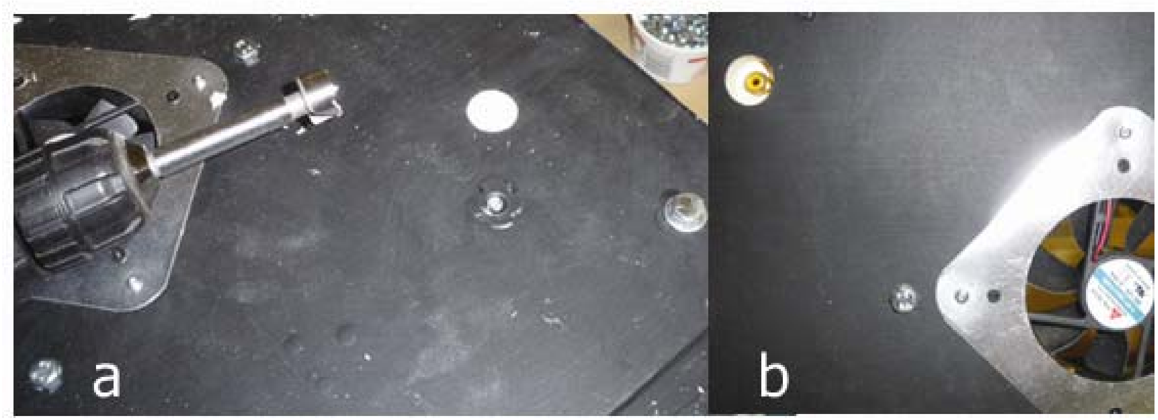

Figure 19. a) Fan in position under drill; Forstner bit and hole drilled part way through the mirror cell base board; b) Fan, with connector recessed into mirror cell base board.

Session 23. Sat 17 April 2010

11. The cradle and ground board

The cradle

The cradle is made of ¾” ply. Its most important elements are the parts of the boards left over from making the side bearings. It is their concave surfaces on which the side bearings will rest and tilt.

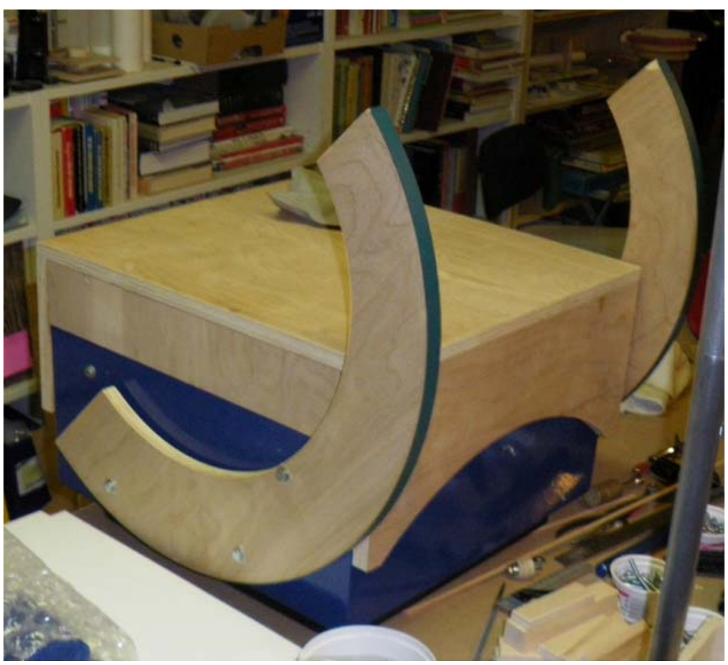

Figure 20. The cradle in its storage configuration as a lid over the mirror box.

When the telescope is not in use the cradle will be turned upside down *and around 90°* to be used as a lid over the mirror box (Fig. 20).

The length of the two straight sides of the cradle is determined by the spacing of the side bearings. The sides must be of a length so that when the cradle is in observing position, the concave sides of the cradle box engage with the side bearings. This also ensures that the concave sides fit over the mirror box and the strut clamp bolt heads projecting from its sides. The height of the straight side pieces, 3” in my case, is designed to combine room for storage of the cage with clearance for the mirror box when the telescope is tilted back and forth.

The concave sides that support the side bearings in use are trimmed in length to ensure that the deepest part of the concavity is at the middle of the cradle and that the straight sides of the cradle clear the strut clamp bolt heads in the mirror box sides.

1. Cut the concave sides of the cradle to length and the trim the tips of the “horns” at either side of the concavity to produce sturdy ends.
2. Cut the other two sides and a bottom (in use position) or lid (in storage position) out of ¾” ply.
3. Assemble the cradle using glue and air nails.

The cradle rotates around its center point on a ground board to which it is attached by a ¼” bolt. Smooth rotation is achieved by covering the bottom of the cradle with a sheet of arborite and attaching glide pads to the upper surface of the ground board.

1. Cut a sheet of arborite slightly larger than the bottom of the cradle and glue it on using contact cement. As in the case of the arborite on the side bearings, apply contact cement to the wood surface and to the underside of the arborite. Leave to dry for about 45 minutes or until a piece of newspaper will not stick to the cement. Then lay four strips of wood or other flat material lightly across the cradle base over the contact cement. Place the arborite in position over these strips (Fig. 21). Glue by removing one inner strip while holding the arborite in position and then pressing the arborite over the space left by the strip down to bond the glued surfaces. Then remove the other inner strip and press the arborite down, then the strips at the ends. Press to ensure contact over the whole area, working from the middle towards the edges. A rubber roller is helpful here.
2. Use a router to trim excess arborite from the sides of the lid. A rotating disc attached to the router bit prevents it cutting into the lid.

Figure 21. Technique for gluing arborite to the base of the cradle with contact cement.

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The ground board

The ground board is a triangle made of ¼" ply with apices removed (Fig. 22). It is raised above the ground by short legs. Two thicknesses of ¾" ply are commonly used to make a short pyramidal leg. I decided to use hockey pucks. On the upper surface of the board "Super Slidex" glide pads (Canadian Tire) ¾" in diameter assist the arborite surface of the cradle to ride smoothly over it.

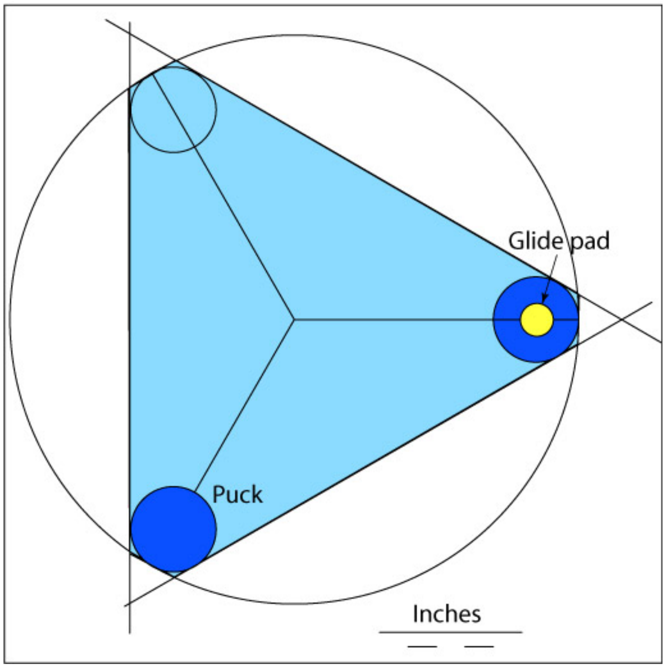

Figure 22. Laying out the ground board. The center points of the "legs", in this case hockey pucks, should be an inch inside the base of the cradle since they are also the center points, on the top side of the ground board, of pads over which the arborite-covered bottom of the cradle glides as it is rotated.

Dimensions are worked out as follows:

1. Turn the cradle upside down and find the middle of its non-concave sides. On a piece of masking tape draw a line across the base between the marks. Find and mark the center of the base.
2. Place a glide pad on the line just drawn with its center about one inch from the edge of the cradle. Measure the distance between the center of the ground board and the center of the glide pad and mark it on the line. This point is also the centre of a leg on the lower side of the ground board.
3. Lay out the ground board as in figure 22. The sides of the triangle are drawn and the apices of the triangle cut off along lines tangential to the outer edges of the legs.
4. Measure the distance between one cut off apex of the triangle and the opposite edge and cut a strip of ply of that width. Use a jig with a 60° angle to cut the other two sides of the triangle and trim the apices as necessary (Fig. 23).
5. Drill a ¼" hole through the center of the triangle.

Figure 23. Phil Johnson uses a jig to cut the 60° sides and apices of the ground board.

To complete and attach the ground board:

1. Use a hole saw to cut a disc 1" or more in diameter and glue it over the center of the upper side of the ground board. This helps maintain the bolt attaching the board to the cradle in an upright position.
2. Drill hoes through the pads and their plastic bases using a fine (about $^5/_{64}$") drill, then use the screws provided to attach them to the upper side of the board. See that the screws go through the board and into the centers of the legs on the underside of the board.
3. Attach each leg firmly with two screws of suitable size and length (#6 1" for hockey pucks) (Fig. 24).
4. Attach the cradle to the ground board with a ¼" bolt passing downwards through a washer, the center of the cradle base, the disc glued to the center of the ground board, the ground board and into a nylon locknut.

Figure 24. Pad and puck leg in position on the upper and lower sides respectively of the ground board. Note that the screw in the pad is tightened so that it is below the level of the pad surface, assuring smooth movement of the pad against the arborite on the cradle.

Attaching glide pads

The telescope should move equally easily on altitude and azimuth axes; the side bearings should sit squarely on the cradle and be prevented from tilting too far up or down. To ensure this:

Figure 25. Part of the cradle showing placement of a glide pad and a guide.

1. Attach a glide pad near each end of each cradle concavity. The further the pads are from the center of the concavity the less easily will the telescope tilt but the easier will it be to control the degree of tilt. About 2” from the end of the side is a good place to start (Fig. 25).
2. To prevent any sideways slippage of the side bearings attach guides to the inside of the cradle concavities. The guide shown is made of a computer hard disk sawn into quarters. Mark each quarter on one surface before taping them together and drilling to allow passage of #4 ½” screws. Lightly countersink the holes before screwing the guides in place with the convex edge standing about ¼” proud. Take care
   a) to place the guides where they will not contact strut bolts on the cradle when the telescope is in its storage configuration, and
   b) to place the guides with the marked sides all either apparent or hidden; this will allow them to be removed without numbering them individually for painting and replacement in the same screw holes.
3. Screw small stops about ¾” from the ends of the arborite covered surfaces of the side bearings. Use #6 ¾” screws and faucet washers thin enough to fit between the side bearing and the cradle concavity until stopped by the glide pad.

Final touches

Mirror cover

When not in use the mirror should be covered to prevent dust falling on to it. A light corrugated plastic sheet (Coroplast, Twinplast or equivalent) 4 mm thick is stiff enough to do the job without touching the mirror surface and without adding significant weight. This is cut to the dimensions of the interior of the mirror box with notches in each corner to take account of the corner posts. It is then cut in half so that, even when the struts are in position, it can easily be placed in position on the reinforcement strips running round the inside of the mirror box (Fig. 8) and as easily removed before observing. To prevent dust entering between the half covers and for ease of removal a strip of Naugahyde 4” wide is attached to one half of the cover by glue in such a way that, when placed in position, half of its width extends beyond the half cover to which it is glued and over the other.

Making a light baffle

A light baffle placed behind the secondary mirror and across from the focuser prevents unwanted light and possibly confusing reflections from reaching the eyepiece. Phil’s solution is typically simple, elegant and cheap, using commercial steel strapping, Creatology Fun Foam or equivalent, and two aspirin-sized magnets.

1. Using steel strapping ¾” wide, make two 1” pieces bent in the middle at right angles. Epoxy these to the top of the bottom cage ring and the underside of the upper cage ring so that they are directly opposite the focuser, each presenting a vertical face that is aligned with the inner edge of its cage ring.
2. Take a piece of black foam – a 12” * 18” piece 2 mm thick does admirably – and cut out the largest disk that will fit between two spider arms on your cage.
3. Cut out two discs in the foam large enough to accept the magnets and the right distance apart for the magnets to adhere to the pieces of strapping on the cage.
4. Insert the magnets in the holes and fix them in place with black duct tape applied to the outside of the baffle and pieces of black felt glued on the inside.

Place the baffle inside the cage with the magnets snapped onto the strapping and you are done. When not in use the baffle can be stored on the mirror cover.

Congratulations! Your Jodo Newt telescope is ready
for assembly, collimation and
….finally….
observing

Acknowledgments

“Every astronomy club should have its Phil Johnson!” as Gary Seronik wrote in *Sky and Telescope* (Aug. 2009), and I thank him and my lucky stars that I came to the right centre to benefit from his instruction, his eagle eye for errors – often not yet committed – and his generous hospitality. Thanks also to Joan Johnson for her warm and friendly tolerance of the Saturday afternoon visitors, and to Victor Barbu for collegial support and advice.