How to...

MAKE A TELESCOPE – PART 3

In detail Complete instructions for part 3

Use these instructions in conjunction with the diagrams, photos and video. Any small parts you have not been able to get hold of can be bought from The Camden Amateur Telescope-Making Society at retail price plus postage. For a list of parts and their prices, send a stamped self-addressed envelope to:

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Introduction

The cradle has to take the weight of the telescope as well as allowing the tube assembly to move freely in its vertical axis. With the tube assembly weighing in at 12kg the cradle can be made of 12mm plywood, but if the tube was any larger you'd need to use 19mm plywood.

The plywood must not become too warped, as can often happen after it has been cut off the board. If the cradle base is warped it can affect the angles of the fillets and sides and whether the cradle ends up square or not. So it's a good idea to construct the cradle without gluing it together, just using screws, and then put the tube assembly in place to see that its bearings line up. If there is a warp, you can adjust the components by trimming here or packing there to straighten things out. It shouldn't be a problem you'll have to face, but by not using glue you can take the cradle apart if necessary.

Step 1

Start by marking out the hexagons (see the 12mm board plan). Draw a line 225mm up from the long side of the board and another at 500mm. Using the 30°/60° set-square placed at the bottom corner, draw a line at 30° up to the board's narrower edge so that it meets the line at 225mm. Flip the set-square over and draw another line at 30° to meet the 500mm line. Measure how long this latest line is and use this figure to measure and mark along the 500mm line so you end up with four sides of the hexagon.

Next, use the set-square to draw a line 60° from the 500mm line back to the centre 225mm line. Then draw the sixth side of the hexagon by flipping the set-square over. If there appears to be any discrepancy, recheck your measurements and try again.

Cut out the hexagons and smooth the edges with the file or sandpaper, if you want to make them match exactly, clamp the two boards together and plane/rasp all the sides until they are equal. Leave drilling the large central hole through the middles of the hexagons until the last minute, before they are bolted together.

Next mark up and cut out the other components, except for the front and rear panels – see later. Draw the 115mm-radius semi-circular cut-outs on the cradle sides before you cut them out. Once you've cut out the cradle sides, use a coping saw to remove the semi-circles. If you discover that your coping saw cannot reach all the way in, you will have to cut a 'V' into the semi-circle to give the saw more room.

All the diagonal cuts are 30° or 60° depending on their orientations. Think twice about each piece before marking and cutting it, depending on which side of the plywood you want to see. For example, take the two bearing reinforcing fillets. One of keepers on the cutting plan will be facing you as seen, but the other is positioned so that the other side of the board will face you after it is cut out and flipped over.

If the back of your board looks significantly different, then the fillets will look different on the sides facing you later. If this is important to you, mark the second fillet out the other way around, so the two are a mirror image of each other. This is only a potential problem if your board differs on each side and you plan to varnish the scope later

Step 2

Having cut off all the diagonal sides, you need to remove the small rectangular slots in the two bearing keeper pieces and their reinforcers so that they join together at 90°. Use the coping saw to get neat, straight lines in each piece. Cut both straight lines first, then start half way along one cut and gently tease the blade sideways to develop a curve towards the opposite corner, so that at the end of the cut you are just starting to go along the short line at the back of the slot. Then turn the blade in the opposite direction to cut back to the opposite corner to finish off. Check the two keepers and reinforcing pieces slip together nicely without force and that the two pieces are square with each other.

Place the bearing keepers centrally against the side panels and mark them at the bottom of the semi-circular cut-out. Draw a line from that point to the top of each keeper, 3mm in, and cut out. These will house the felt between the keepers and the tube bearings. If necessary finish all these delicate cuts with a file or sandpaper so that they are flat and straight.

Wrapping 120 grit sandpaper around a piece of 9mm strip (about 250mm x 50mm) will help to keep the sandpaper flat so it will remove high points without cutting down into low points. Use the 80grit paper to remove thicker waste ply and 120grit for finer finishing. You might wish to get an even finer grade of paper to smooth the surface before a final coat of paint or varnish.

The tube's side bearings are made using the centre cut-outs from the baffles made in part two. Because the bearings need to be slightly smaller than the semi-circular cut-outs on the cradle sides, you need to cut 3mm from them so that they will fit after the laminate and PTFE are glued on.

Use the compass to draw a circle of 227mm diameter on to the bearing discs and cut them out using the coping saw. With the original baffles you cut on the pencil line and in towards the centre; this time cut out towards the edge or you will remove too much. Once they're trimmed, mark each disc carefully, with a thick 1.5mm line down the exact centre.

Cut them in half with the 1.5mm thick handsaw, with the saw centred on that line, removing it as it cuts. You should get four reasonable semi-circles. Align all four as closely as possible by putting them straight-face down on the worktop. Clamp all the semi-circles together to round them off as one. Use the square to get a right angle to the work surface and if two of the semi-circles are larger, place these on the outsides.

For this next procedure, support the bearings in your lap. With your gloves keep a firm grip on the assembly and as you smooth the semi-circles, keep the rasp or plane pushing away from your legs or supporting hand. Use the rasp or plane to remove any large lips from the circular surfaces, remember to work diagonally in towards the centre of the piece to avoid splintering the edges. Slowly reduce the high points using a rocking motion to follow their curve.

Work steadily around the piece from one side towards the centre. Turn the piece, and then work on the other side. As the bearings slowly even up, check that the

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curved surfaces are square on the sides. By constantly moving over the curve removing small quantities, evenly across its surface, your aim is to keep it circular.

When all of them are square and even, use the fine file to smooth the surface further. Finish them off with a piece of 120 grit sandpaper. Use a circular rocking motion, as before, following the curves, until they look and feel relatively smooth. A small amount of surface roughness will always be evident on plywood, except after painting or varnishing it. The roughness actually helps with the bonding process when you glue the laminate on later.

Step 3

With a printout of the 'Making a Cradle 2' diagram, note the screw holes for the front panel, rear fillet, bearing keeper and reinforcing piece on the cradle side pieces. Starting with 2.5mm pilot holes, drill all the holes in the side panels.

Put the first keeper up to the first side panel, holding both of them square on the worktop; place your set-square vertically to check the fillet is perpendicular to the side. The top centre hole in the side panel should correspond with the centre of the bearing keeper's. Holding the two together firmly, drill a pilot hole into the keeper, using the pilot hole through the side panel to guide it.

Then drill a 4mm hole in just the side panel and countersink it. Drive a 4mm x 40mm screw into the keeper. Turn the cradle side so its inside face is pointing up and align the keeper's base to the side panel's bottom hole. As above, drill and screw but use a 4mm x 30mm screw. Do the same for the end holes of the two reinforcers, using 4mm x 30mm screws. Now the side panel is secured to the keeper and reinforcing fillet by four support screws. Pilot drill all the remaining holes.

Take the cradle apart and drill and countersink the remaining cradle side panel holes to 4mm. Don't forget, the front panel and rear fillet holes are to be drilled later but will be countersunk on the outer side.

Clamp the side panels together so that the side panels are aligned as closely as possible. Get a piece of 80 grit sandpaper and fold it in three. Using your gloved fingertips to grip the paper in a curve matching the recess, work it along the semi-circular curves to smooth them both, removing all cut marks until they are even and equal. As with the bearings, keep moving the sandpaper along the curve to keep its circular profile. Stop when the cut-out is smooth and double check that it's square, which is trickier with an internal curve.

You have to follow around its edge with your eye level to the edge. As long as they are almost equal that should do, as they are only holding the PTFE bearing pads. The rest of the recess only needs to look good and not foul the bearings above, and that is unlikely unless you are way off. Screw the keepers and reinforcers onto the cradle sides, remembering which sides face which way. All screws on the outside corners should be 4mm x 30mm to prevent splitting, while in the centres of the panels use 4mm x 40mm to provide additional strength.

Put the tube in front of you and place the focuser towards you, on the right. The width of your cradle will be the tube's mirror box plus a bearing spacer on each side, with the bearings resting on the cradle. But before you measure across the tube, make sure you have shaved off any overlapping plywood that might affect your measurements. Then measure the width of the tube.

Your cradle – inside face to inside face – will be the tube's width plus 24mm exactly, and this is the measurement for the width of your front panel and rear reinforcing fillet. Now you can cut them both out and smooth off, but don't round off the joining faces as they need to be as square as possible to help keep the cradle box square. Next repeat the steps as above to drill through the side panel for the front panel and rear fillet. With the side panels held together by the front panel, it is easier to pilot drill the four rear fillet holes.

The screws for the cradle are a mix: use 4mm x 30mm for the holes next to corners and for the middles of the panels use 4mm x 40mm screws. Screw all the upper cradle components into place keeping them square, so that the screws help hold the box square. This is critical on the cradle. If it's even slightly out of square the tube may be very difficult to line up accurately and will possibly not even move properly or worse, pop out of its bearings.

If the cradle is not square, slacken the screws very slightly and pull the cradle square. Make four small, right angled fillets fromm offcuts of 12mm plywood, and check them against the set square. Drill two holes horizontally through each fillet and screw them into the bottom of the cradle at each corner of the box to pull it square. With their countersinks, the holes should be deep enough to take 4mm x 30mm screws without the screws going through the sides of the front panel, side panels or rear fillet. Finish off by tightening all the other corner screws and double-check the box for square.

Step 4

Now the cradle box needs to be attached to the cradle base. Check both hexagonal plates to make sure they have not become warped. If they are slightly warped then sit the cradle 'inside the dish'. The ground board's warp should go the opposite way, so the feet are 'inside the dish'. Because the two boards have their corners bending away from each other they are unlikely to touch each. If one hexagon is straighter than the other, use this for the cradle base as it is less likely to distort the cradle box.

Put the cradle down on the selected base, best looking side up if possible, then centralise it so that the sides of the cradle are parallel with the sides of the hexagon and the four corners are equally spaced from their respective sides. Draw all around the cradle, inside and out, with the sharp tip of the pencil, going as close into the corners as possible. When you take the cradle off its outline will be marked out.

Draw a line along all of the centres of the cradle outline and every 3 inches or so mark up points for screw holes. Keep these holes at least 30mm in from any corners to avoid splits near the edges of the cradle's panels and use plenty of holes to keep the cradle-base joint well consolidated.

Drill all of the pilot holes with a 2.5mm bit. Put the cradle upside down on the worktop and place the outlined face onto it and carefully line up the outline with the cradle. Starting with one corner, drill through the first pilot hole into the cradle. Open up the hole in the base with a 4mm bit, countersink the hole and screw in a 4mm x 30mm screw. Go along to the next corner to do the same but before drilling check that the outline is still true to the cradle. If not check your first hole is correctly placed. When all is well drill each corner like the first and secure with 4mm x 30mm screws. Pilot drill the remaining holes.

Take the base off again and re-drill all the holes in it to 4mm and countersink them, making sure that they are deep enough for all the screws to be below the surface so that they don't interfere with the laminate that will be glued over them. Screw home the base. Use 4mm x 40mm for all the second screws in from the outer screws, followed by 4mm x 30mm for all the remaining screws. Should any 30mm screws be loose, replace them with 4mm x 45mm.

If that still doesn't work shove a 50mm-long matchstick into the hole and hammer flush. Trim any excess with the tip of the craft knife, re-countersink if necessary and apply the 45mm screw again.

Step 5

Cut out four 1- to 2-inch 12mm plywood squares for the ground board's feet. Now draw a circle of 195mm radius onto the top of the ground board. Divide the circle into equal thirds, one corner to the centre, miss the next corner then mark the one after, and

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miss the next and mark the last one. Drill two 4mm holes centred on the circle you've drawn, 7mm each side of the marks, for the holes. Countersink them to allow the screw heads to go past the surface as before. Put wood glue on to the first foot and two 3.5mm x 20mm screws in the first fixing holes, then offer the foot up to the screws so that they go into the foot near its centre.

Make sure the screws are still central on the foot as you press it up against the board. Clamp the foot into place with your hand and screw it into place. Wipe away any excess glue and then do the other two feet.

While the glue dries on the feet, cut out the felt strips for the bearing keepers, so that they are slightly wider than the keepers and project above the tips, but not right down to the circular recess (leave last 4mm or so). Make sure you're in a well-ventilated room as the adhesive is noxious. Put contact adhesive onto the bearing keepers and press the first felt strip on, pressing it well into the surface with the glue still wet. Repeat for the opposite keeper, then go back to the first and put more glue onto the felt. Press the second felt strip on. Put the second felt on the other side.

Next, mark the side panel semi-circular cut outs 60mm either side of the centre bearing keeper. This mark corresponds with the lower edges of each small PTFE strip. Put a dab of glue onto the circular recesses from the 60mm line up to 85mm and while it's still wet, place the brown side of each of the small PTFE strips down onto the glue and press them into place. If they don't seat properly because of the curve, manipulate them into shape gently, until they match the curve and then reapply them.

Then go back to the ground board, cut three rubber shoes to size and apply glue to them and the three feet and leave to dry. Now stick them on the feet. After a couple of hours you can trim them with the craft knife, bevel them so that they go in from the edges of the feet towards the centre. This makes them less prone to being scraped off if you drag the cradle along the ground.

Step 6

The cradle is done, the tube is done, now comes the simple act of marrying them together.

As this should really be done after you have acquired your 3.3kg main mirror and secondary optical flat, do not glue the bearings on. Because the telescope works by balance alone, there is a fair chance you'll have to alter their position after the mirrors are actually fitted. In the meanwhile, you can use anything to hand to add 3.3kg to the bottom of the tube, and a medium spanner to stand in for the weight of the secondary optical flat.

Now we come to balancing the tube in order to locate the position where the bearings will be attached. First put a broom handle across the worktop and clamp it down a right angles to the bench front.

Place the tube on top of the handle. The 3.3kg mirror sits on the mirror cell and is 40mm thick, so you have to create stand-in load for the tube, placed centrally where the mirror will go. Measure from the back of the mirror box to where the front of the mirror will be when fixed in the tube. Then collect 3.3kg of assorted weights and place them on the tube, above where the mirror would be. Put a 2-inch eyepiece into the focuser to create a likely setup at that end and also place about 100g on the centre over the spider to stand in for the secondary mirror.

Move the tube back and forth until you reach the balancing point where it will almost hang in mid air over the broom. Then check that the tube is positioned square on the broom handle by measuring from the broom to the back of the tube; these should be equidistant. Mark the positions of the very top of the broom handle, where it meets the tube. Using the square or handsaw blade, draw a line joining these points across the three accessible sides of the tube.

Measure the distance from the centre of balance to the back end of the tube; we'll call this figure *a*. Next, measure the distance from the top of the bearing recesses (the widest part of the semi-circle cut-outs) to the back end of the tube; this is figure *b*. Then subtract *a* from *b* to find the height of the tube in the cradle when stowed upright; this is figure *c*.

Now take thicknesses of scrap plywood and fill the base of the cradle to the depth of figure *c*, making sure that all four corners are at figure *c*, so that the tube remains stable. If the tube is not square on its base or the cradle floor is not true, use a spirit level to accurately check which bits are higher or lower so that you can make up the difference. With the tube square in the cradle and at the right height, the balance line should be level with the tops of the semi-circular bearing recesses. Now put two substantial 12mm off-cuts down each side of the bearing sides of the tube to centralise the tube in the cradle. Check that the tube is the correct distance from the front panel, and screw the bearings onto the tube sides with 4mm x 40mm screws, so you do not push the tube out of alignment.

Now with the tube running smoothly in its cradle, you can now disassemble the cradle and reassemble it using wood glue on every joint. Have a bowl of water and a lint-free rag handy to wipe off all excess glue; be thorough as even small quantities of glue left on the surface can seal the surface causing pale patches that will show up if you varnish.

Next, we'll glue on the laminate disc. Turn the cradle upside down and put it onto a folded dust sheet on the floor. With the compass or a screw in the middle with a piece of wire or string attached, measure out to 225mm from the centre and draw the circle for the laminate disc.

Brush plenty of contact adheisve onto the cradle base, overlapping the line by about 5mm to ensure the disc is stuck to the very edges. Then put the adhesive onto the back of the laminate disc. Again brush it to the edges but be careful not to get the glue on the laminated side (if you do, it will come off with white spirit). When it is fully covered, leave to dry for at least one hour because the laminate is so wide and completely impermeable, you want as much of the solvent to dry off, so it doesn't leech out from the edges.

Now drill a 10mm hole through the dead centre of the cradle base, using a 5mm pilot hole as a starter. Put the 2-inch, 10mm bolt through the hole in the laminate from the good side, pointing in towards the cradle. Slowly lower the laminate towards the base, not letting it touch before the bolt has gone into the base's hole. Slowly lower the laminate to the base so that the two are perfectly aligned. Once the laminate has touched the base, the two will instantly bind; simply press the laminate onto the base in a spiral pattern. Use a moist rag to press the laminate onto the base, working out from the centre to the edge, applying firm pressure throughout. Do this for about five minutes to ensure good adhesion.

Finally, retighten the nylon lock nut on the 10mm bolt. Your telescope is finished, and you have good reason to feel proud of yourself.

Shortly you will be able to open your window to the Universe, when we show how to make make a telescope mirror in next month's magazine. ✪