A Low Profile Equatorial Table

By David Shouldice, DAS

Being a planetary observer, and having been accustomed to tracking, the purchase of a Dob left me wanting.

The goals for tracking were:

1. Lowest profile possible - my scope did not need me to climb up to the eyepiece, and I didn't want to start. My goal was a 2" max. increase in eyepiece height.
2. Primarily For visual astronomy, i.e. only a 1 axis drive
3. A component that I could put the scope on if I wished, not a permanent part of the scope.
4. Ability to use my digital setting circles
5. A one person operation, i.e. easy to use.
6. Within my ability to build with available tools and parts.
7. Minimal electronics, hopefully all off the shelf.

What I ended up with:

1. A pure D'Autumn design table
2. All of the above
3. Cost was < $100
4. Weight 8 Lbs.
5. Strong, No visible bending or flexing
6. Small, it barely extends beyond the Dob base.
7. Easy to reset at the end of the tracking (45 minutes)
8. No electronics (except motor) (I use an inverter in the field to convert 12 VDC to 115 VAC)
9. I can view at 1000X and image barely drifts.
10. Although designed for my big scope I can set smaller ones on the base for solar viewing.

References:

In my research I found 3 articles of note:

1. D'Autumn's article in ***Sky and Telescope***, Sept '88 p 303 - This tells of the pro's and cons of table designs and has pictures of his creation.

2. **www.tiac.net/users/platform.html** and **http://www.atmpage.com/platform.html** - An article by Chuck Shaw on the ATM page, gives many construction details that I borrowed from.

3. **http://www.airnet.net/warrencami/Astronomy/ASTRONOMY.HTML** - a good article by Warren Peters with calculations and graphics. I performed all the calculations, and referred to the drawings many times.

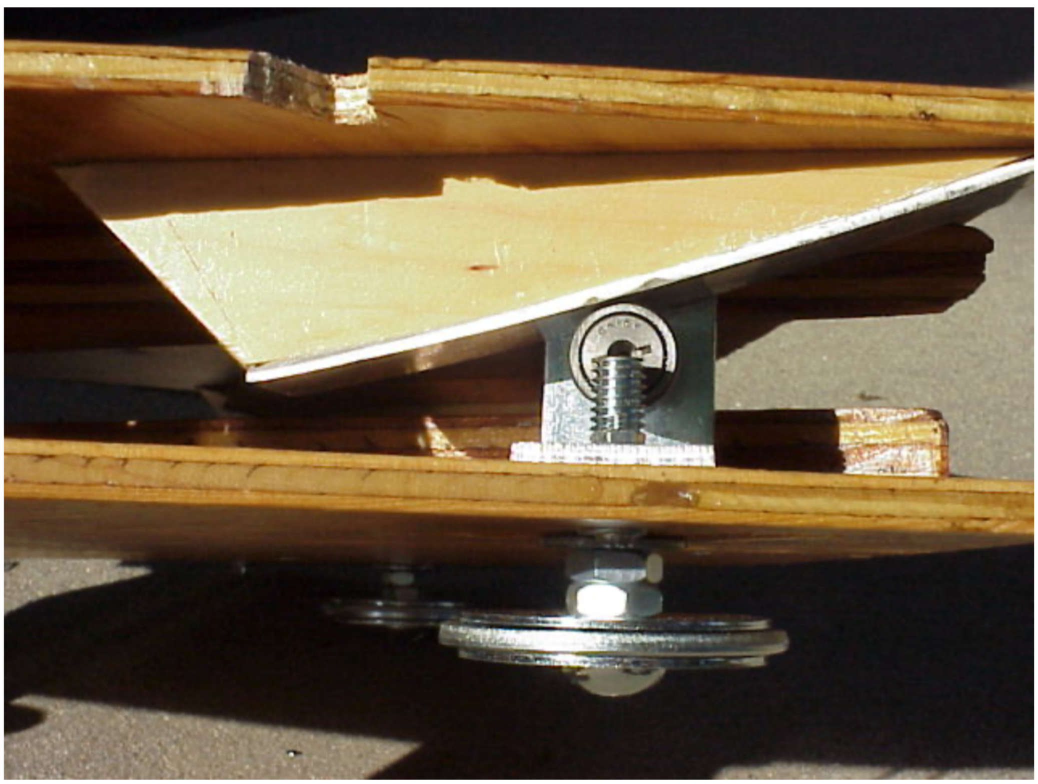
4. **http://astronomy-mall.com/regular/products/eq_platforms** - Also I looked at the best platform on the market made by "Equatorial Platforms"

The key to a low profile table was to put the feet and the bearings directly below the scope's Teflon pads. This minimizes the need for a top or bottom structural baseboard. Most equatorial tables that I reviewed seemed justly concerned with the cantilevered loads, and opted for ¾" or 1" plywood for the top (baseboard) and bottom (ground board). Due to my eyepiece height issue, I tried to use structure only where needed.

The Forces:

The 3 Teflon pads that compose the azimuth bearing on the dob carry all the weight. The desire was to place 2 feet to the North of the table with one to the South.

North Feet:

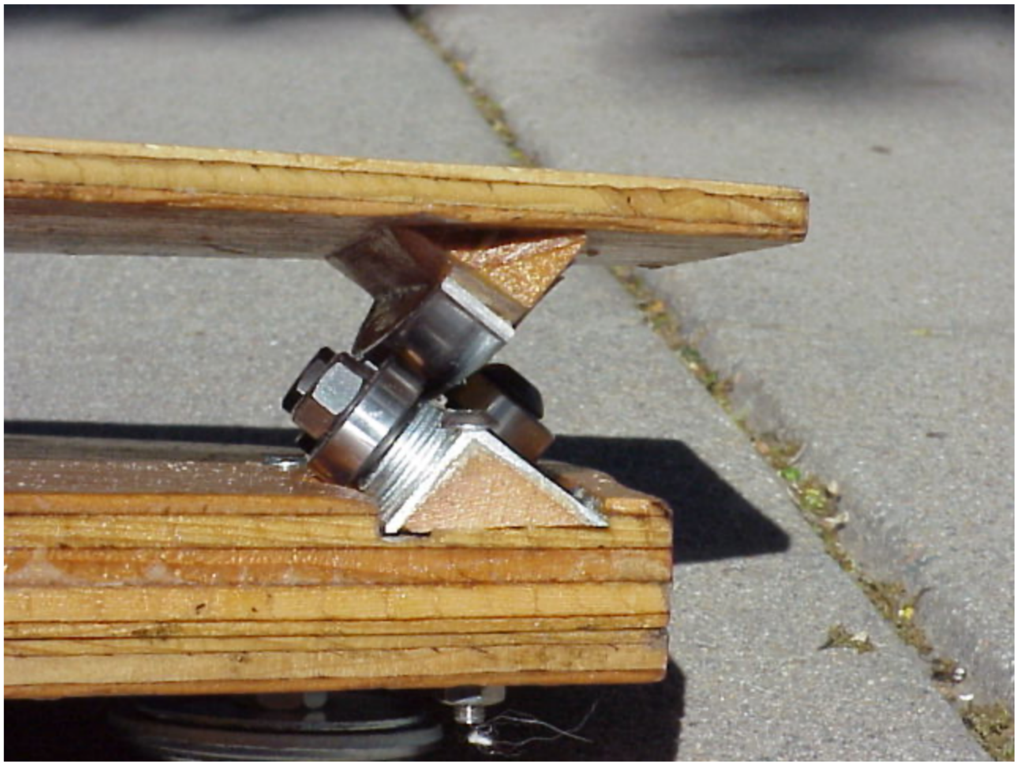


The 2 North support tracks attach to the bottom of the baseboard. Per D'Autumn, this baseboard rotates around a virtual axis that points to the North pole, but passes through the center of Mass of the telescope (centered between the 2 altitude bearing axis). This is important. If you don't rotate the table around both your center of mass and the pole, your motor torque, and price will greatly increase. The added power is needed as the motor will have to lift your scope. Also, the imbalance will make your scope tippy.

The curved tracks attached to the baseboard mark D'Autumn's conic sections. As there is only 15 degrees (1 hour) worth of tracking, you can make the N. bearing track from a vertical board, like the one the "Equatorial Platform" design. The weight is directly supported. My design has a maximum a 2.5" horizontal distance between the Teflon pad and the roller bearing that supports the curved track. I added a brace behind the tracks on the baseboard to minimize the droop of the baseboard when it is at the end of travel. I lined the tracks with a piece of rolled stainless to reduce friction and prevent denting of the track.

A pair of cam rollers is attached to the ground board with an angle bracket that hold the threaded insert for the adjustable feet. As the force at the roller bearing is almost vertical, only minimum support is needed from the ground board for these feet.

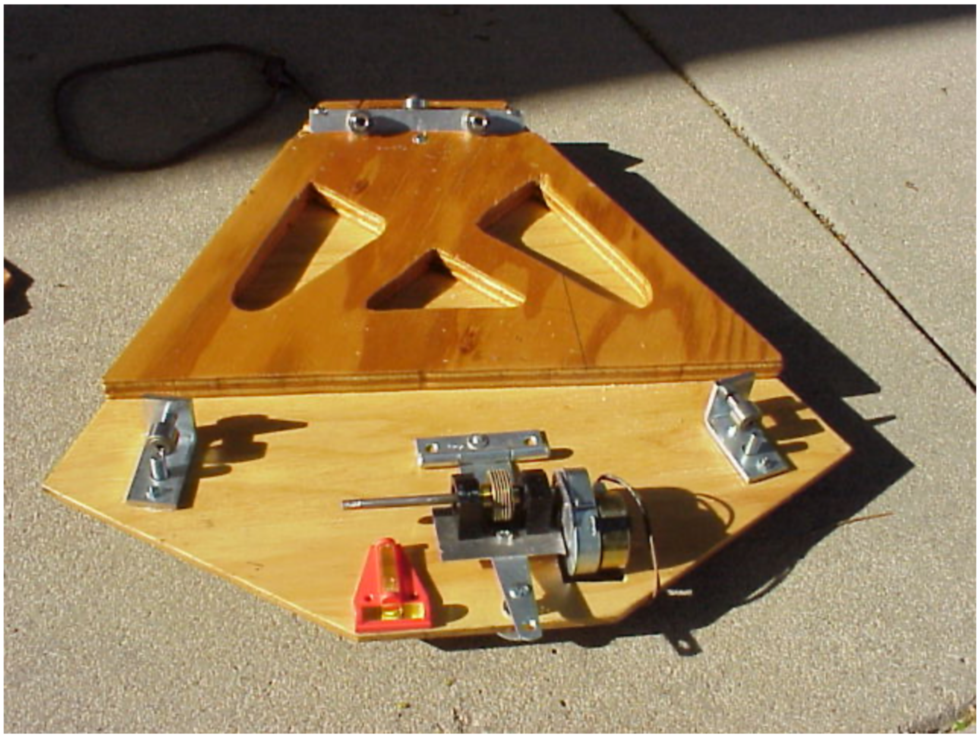
South Foot:



The South pad sits over a conventional cylindrical bearing section bolted to the South end of the baseboard. This is held up by 3 bearings, 2 supporting the radial force, with 1 supporting the axial. The axial keeps the baseboard from moving N. or S. of the resting position. Gravity keeps it from moving E or W.

The South foot of the table is held by a threaded insert near the S. bearing holder (angle bracket). The rotation of the table shifts the weight (from the S. Teflon pad) E. Or W. of the S. foot. To deal with this you either need a ground board that doesn't twist (I added a ¾" brace), or you could add 2 South feet.

Forces from below:



The first time I set up on my lawn, I learned of another force, the grass, that pushed up on the center, between the feet, bowing my base. Most of the weight (hopefully) is supported by the feet, but short of making the feet higher than the grass (and raising my eyepiece) I reinforced the bottom board with a ¾" plywood with holes to decrease weight. This also stopped the twisting of the S. baseboard.

The Drive

This too took a lot of research. I decided that I was only interested in a single axis tracking drive, not a hand controller for fine tuning, or slow motion axes. To add these features would have driven the design to stepper motors with controllers, computers etc. adding complexity, failure modes stress etc.

The result was to make a synchronous worm gear drive like Shaw chose. Designs like those made by D'Autumn and Ken Florentino of CSAS show how to use threaded rod for the worm and rack. The motor and worm are located on a bracket mounted on a spring loaded hinge. When the hinge is moved to disengage the gears, the table can be reset to the beginning of travel.

This project took me 4 months of obsessing to design and build, with most of the time in calculations and drawings. I assume you will only take a fraction of this. On first use I saw the central star in the Cat's eye and have tracked the planets for 45 minutes.

I still use my DSC (digital setting circles), with the DSC aligned when the table is reset (at the beginning of travel). To find an object by the DSC, I first reset the drive. If it is a struggle to locate, or at setup of the DSC, I turn off the drive. Actually I tend to run the drive mainly when I am with the public, when using high power, or for long stares.

Construction:

(download all the pictures, graphs, and perform calculations from Peters' and Shaw's articles)

1. Measure the vertical distance from the bottom of your scope to the center of the altitude bearing pivot. Measure the distance center to center between your Teflon foot pads. Use these in the Peters article to calculate the dimensions of the radius of curvatures of the N and S bearings. I made the south bearing 6" long arbitrarily. Long enough for E / W support, but not so long to cause bowing of the baseboard. This resulted in a kite shaped baseboard. Note that the motor drive bearing rack will mount to the N. end of the baseboard, so leave room. Do the calculations in Peters' article to determine the radius needed dependent on the pitch chosen. Make sure you will have room for the rack and motor between the N. bearings.

2. The base and ground boards are made of 3/8" plywood with 3 coats of urethane. I mark the center point (azimuth pivot point) of the scope on the baseboard, as well as the location of the scope's Teflon pads. The bearing surfaces will be directly below these points.

3. Make a polar axis fixture board. This is used to allow you to rotate the baseboard around the polar axis of the table, and is used to grind your bearing surfaces. I bolted a ¾" plywood triangle of wood to the top center N/S axis of the baseboard with a 4" shelf bracket so that it's top edge would point along the polar axis of the table. I bolted hinges to it (see picture) so that I could rotate the baseboard around this pivot point. The fixture needs to be quite solid, but easily removable from the baseboard. You will have the fixture on and off the baseboard several times before and after you are done. When done, to check it out, attach it to the baseboard. Take them outside at night, level the top surface of the baseboard, point its N/S axis North, look through the center of the hinges, and see if your polar axis points to Polaris. Fix, cut or shim it if it does not. (see afterthoughts)

4. Make the South bearing like Peters' or Shaw's. I used a 6" X 2" X ½" solid wood board, cut roughly to the radius, added a 1X1 brace to the N side, glued them together, then cut the assembly to tilt to my latitude. Bolt the bearing to the top board with countersunk wood screws (Nothing should extend above the top surface, as this would increase the height of the table).

5. Drill holes for countersunk mounting screws through the center of the location of the 2 North Teflon pads. These mark the resting locations of the bearing on the bearing support. To make the N. bearing supports I cut two triangular 1/2" boards. The length of the board should be a bit greater than the length of the 15 degree (1 hour tracking) circumference. (N. Radius *2*PI*15/360). As I made the base a bit longer on the inside, my 2 N. bearing supports (triangular boards) measured 7", 6" and 1". Screw the middle of the long side to the countersunk hole. The roller bearing will almost touch the baseboard at the side. Draw a vertical line on the support block below the screw to mark the future resting location of the roller. This will be used later when attaching the roller bracket to the baseboard.

6. We have the N. bearing supports held by the middle, but now need to rotate them to be tangent to the rotational axis. Rather than lined up E/W, they will be pointed to the location where the polar axis crosses the plane of the baseboard. Now, to figure out the angle, bolt the baseboard to the fixture, and bolt the hinges to a solid wall. (see pic above) I used a planter. Take a pointer or pencil and have it gently touch the location of the bottom of the above line (the resting roller position). I piled up some concrete blocks to support the pencil. The pencil marks the location of the roller as the table moves.

7. As you rotate the table on the hinges, note that the pointer will at some point touch the bottom of the baseboard. Mark this point on the bottom of the table, and rotate the N. bearing support so it touches this point. This has placed the N. bearing supports so that as the table rotates, the roller will be directly below it, and not wander N/S.

8. When it has been located, put another 2 screws (each) to secure the N. Feet to the baseboard.

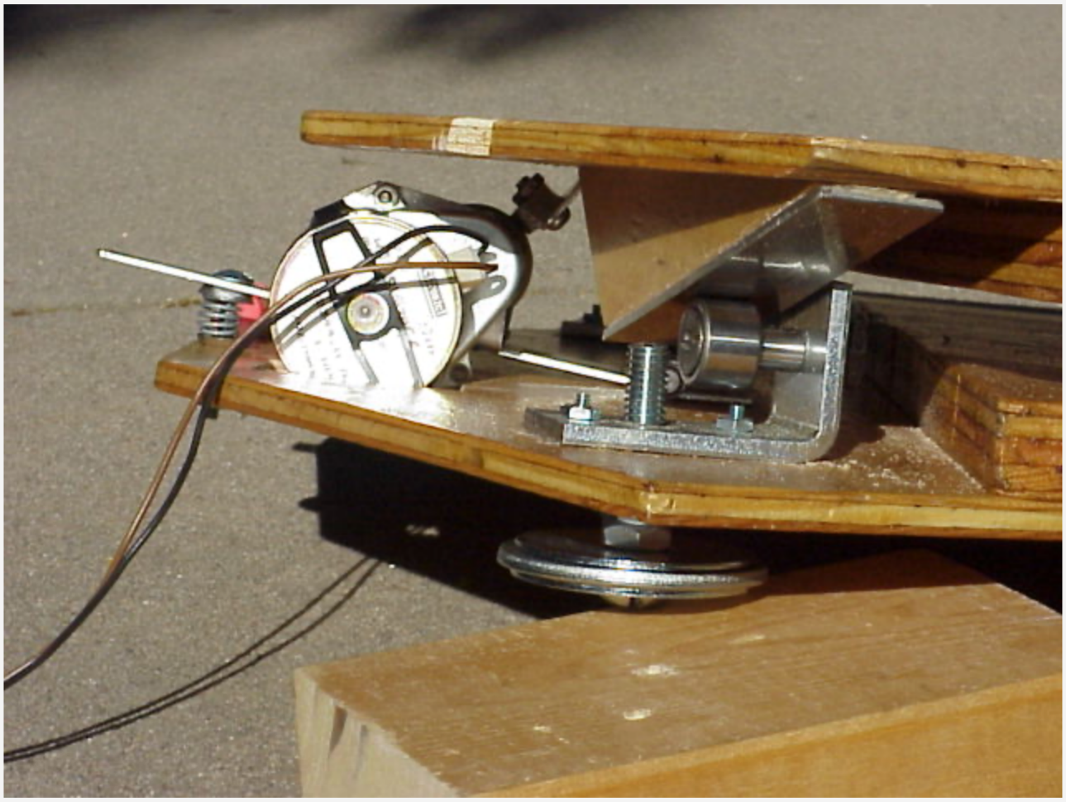
9. Now grind the bearing supports. Bolt the hinges to a wall, support your grinder (I used a power drill with a sanding disk). Slowly grind your N. Bearings with the grinder parallel to the baseboard, grind the S. Bearings with the grinder parallel to the pivot axis.

10. Measure the radius (distance from the polar pivot axis) and length of the completed bearing surfaces. Order 1/8" stainless steel rolled to this radius and width for the S. Bearing, verify that they can also roll a cone with the radius you measured, to your latitude. A sheet metal company did it for me for $35. My N bearing was a 82 degree cone of 1" wide 5" long 1/8" thick with a radius of 19.5". My S. bearing surface was ½" wide, 6" long and 9.4" radius.

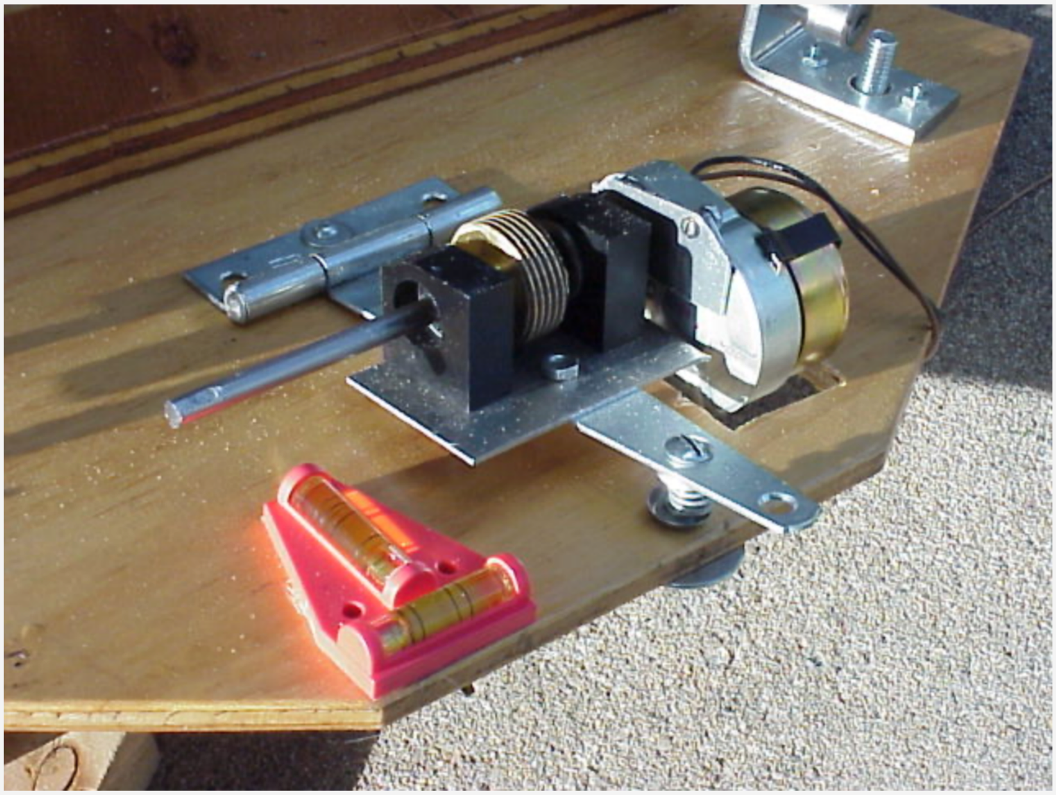
11. Glue these to the ground bearings with a flexible glue. (I used liquid nails). I also glued (thin glue) a piece of brass sheet metal to cover the S. face of the S bearing rolling surface.

12. Cut a ground board much the same size as the top, it needs some extra room on the N. end for the motor drive. So much for the woodworking, now the drive.

13. Measure (using the fixture) and calculate the position and radius range for the motor gear rack. With this radius determine, from Peters' calculations, the pitch needed for the threaded rod. Except, note that the # of teeth for a full revolution at 1 RPM is 60 minutes * 24 hours * 364/365 = 1436. I chose a 1 RPM 115 VAC synchronous motor (MMC $21) with a 12 pitch rack (and rod). The calculation defined the radius of the rack to be 19". Wider pitches give better contact with the threaded rod. If the position is off, you can move it N or S. to compensate. (But the motor will need to move too). For a minimum height table, the big challenge is to make the motor centered between the baseboards. It cannot extend above the baseboard or the scope will hit it, below the ground board you hit the ground and you wont be able to uncouple the gears to allow the table to be reset.
The motor will need a gear to drive a gear on the threaded rod. This keeps the motor from hitting the rack. The distance of the motor from the rack, the centering of the motor between the base and ground board, and the calculated radius of the rack forces the location of the rack. It is advisable to make the hinged motor support and rack before attaching the rack. I cut a hole in my ground board to allow for more space. At end of travel, ensure that the rail does not hit the motor. Mine clears by ¼". Also, to avoid need for an end of travel limit switch, I offset my motor W so that at end of travel it runs off the end of the rack.



14. Make a bracket (1/8' aluminum to hold the motor and threaded rod (held in place by sealed bearings (MMC) (McMaster Carr). The choice of gears should be done early in case it impacts the pitch. There is a small selection at MMC. Note that if you use gears, and a clockwise motor (viewed from the end of the shaft), your motor will be on the E. Side of the rod, not the W. like mine. The rigidity of this plate is important as it will define the stiffness of the drive. Bolt the bracket to a solid hinge. I used a gate hinge that I had taken apart and hammered on the hinge to take out the slop. I also inserted a washer in series with the hinge to take out lateral movement. Don't bolt this to the ground board yet.



15. Make (fabricate and grind) a surface like the S. bearing surface with the calculated radius (- ½ thickness of the threaded rod) to support the motor rack. Note that the height of this surface is critical to the height of the table, and needs to be coordinated with the motor bracket to center the motor between the base and ground boards.

16. Buy threaded rod of calculated pitch. Cut a piece for the rack (>15 degrees). Grind one side flat until it can be smoothly bent, and rigidly attach around it's needed radius. D'Autumn cast his rack with epoxy using his threaded rod as the mold.

17. Now that you can figure the separation of the base and ground boards, you can figure the needed height of the bearing supports. For the N. bearing support on the ground board, I bought a 1 ½" X 1/8" thick large gate handle and cut it into 2 right angle brackets. I drilled and tapped holes for the Cam follower bearing (MMC $4.40) 2 screw holes to bolt it to the baseboard, 1 hole to insert the 3/8" #16 threaded insert (inserts from below). I put double stick tape on these to hold them in place on the ground board before I drilled it. The distance above the threaded hole (cam bearing mount) cannot be too high, as the top board of the table can hit this when it tilts at end of travel. Note that the bearings are on a cone and point to the centerline. I had to shim these to make sure they were in full contact with the bearing surfaces.

18. For the S. Bearing support I followed D'Autumn, Peters and Shaw and used an aluminum angle with screws to hold the bearings. This is bolted to a spacer board to raise the S. end, and make the table level. I had to bend and shim these too to make sure all 3 bearings are in full contact.

19. Attach the hinge to the ground board so that it makes full contact with the rack.

20. Add a spring on a screw between the hinge and the ground board. I used a lock nut to adjust the "stop" of the spring so that it would just engage but not force the rack.

21. Then, without the motor attached, I took a power drill, with a shaft extension on the motor shaft, and ran with fine grinding powder on the rack and shafts. (You might try toothpaste). I ground the assembly until it ran smooth when clean. I lubricated the gears and rack with a bike chain dry lube, then, finally I attached the motor and make sure it works.

22. I added a level bubble to the ground board, and a N/S line to align a compass.

23. I made the ground feet from a round headed bolt with 2 ½" washers and fender washers bolted together. I made them as long as I could without hitting the baseboard when fully retracted. I added a bolt to snug them in place if they were too sloppy after adjustment. Just rotate them to adjust to E/W level, after that the S foot. Check the operation for good bearing and gear contact and motor function.

24. I added a stiffener board to the ground board and end of travel stops to the N. rails to improve function. It does not interfere with the baseboard. I also added a brace to the baseboard behind the N. rails to stiffen from bowing of the baseboard when off center. I added end of travel stops (aluminum bracket) to keep the N rollers on the tracks.

25. Time for a daylight test. Set up on concrete in the daytime, put your scope on the base with the feet on the marks on the baseboard. Make sure nothing flexes as you rotate the scope over it's range of travel. Make sure bearings stay in full contact. If so shim or add support. You can also redo the test of step 3 with the fixture to see if the polar axis points to the pole when the ground board is N/S and level, and stays pointing at the pole as you rotate through the travel.

26. To test the tracking, I leveled the base, used a compass to point it N/S, put a small scope with a solar filter on the table and tracked the sun for as long as I could. I used a large FOV eyepiece and watched how the image drifted. If it drifts E/W it is because the radius of the rack is not exact. Mine is ¼" too far from the polar axis, so mine tracked too slow. I unbolted my rack and moved it ¼" S. This is a little late to find this out, but I couldn't figure out how to know it sooner. I have an old "Digitrack", a product for old scopes that all used 115 V synchronous motors. It generates 115 V 60 Hz from 12 VDC or 115 VAC. It allows trimming the frequency for free, so it gives a single axis control to your scope. I use this in the field. I could use a 115 V inverter that you can get from RV camping stores.

27. When it looked like I had a good base, I remade my scope's ground board. It supported the Teflon pads and was ¾" plywood, with ¾" feet. I made it from ¼" aluminum plate so it would sit on my table without adding height. I drilled a larger hole at the pivot point on the table's baseboard for the pivot bolt, and used the scope's new N. feet to align the 2 baseboards together. All together with the adjustable feet to minimum, it is less than 2.5" additional to the eyepiece height.

28. ***Clear skies***

Afterthoughts

1. By the way, and also, not a casual note I am at 40 degrees latitude, so the polar axis splits the loads between radial and axial forces. Also, my scope weighs 100 +lbs. ,there is 14.5" between my scope's Teflon foot pads, the height from the Teflon pads to the center of the horizontal scope bearings is 18".
2. When I calibrated the table with full weight on top, it was rotating about a point 2.5 degrees above the pole. I believe this to be the result of the remaining torsion noted in the discussion of the S. bearing, but I can not see any deflection.
3. When I went to a star party in a neighboring state, I was forced to realize that the pole shifts 1 degree for about every 350 miles N/S. The table needs to be tilted to accommodate. I have recently added to the ground board a small mirror with a target on it and a small eyebolt to align the table to Polaris. After a normal alignment, I look through the eyebolt at the reflection and move the table till Polaris is on target.
4. The power usage of the table is so slight that I am contemplating getting a 12 VAC synchronous motor instead of the 115 VAC so that I can run off a small battery pack.

I really love the table, and use it all the time. I have to believe, soon, most Dobs will have them built in.

David Shouldice