DIY Mirror Grinding and Telescope Making

Bill's Homemade Telescope Making Project

This web page provides an overview of my large homemade telescope making project. I read several telescope and mirror making books and visited many amateur telescope making or "ATM" websites to learn how to build a 14.5 inch homemade telescope of this size. These sources of information provided many of the techniques I used to make the telescope. At the bottom of this page there are photos showing the telescope under construction, plus links to ATM sites and weather webpages to better help you determine the seeing conditions. I've also added a short description of a homemade refracting telescope lens I made years ago, making an optical flat, and a section on my astrophotos.

Project Description

Previous Telescopes

In 1978, I finished my first homemade telescope mirror. It was an 8 inch, F/10, spherical mirror and was awful looking! It had about a dozen scratches on it, two bad chips on its edge (I didn't bevel the edge enough) and a hazy unpolished zone around the mirror, starting about one inch from the edge. The telescope itself was not any better looking. Yet, it showed me things in the sky I had never seen before with my own eyes. In 1982, I completed another 8 inch telescope mirror. I ground and polished the F/8 mirror, and it came out better, but I left the mirror surface spherical. I did not have the time or equipment to figure/test the mirror to a parabola. The telescope was completed in 1983 and it worked okay for general viewing, but a spherical mirror of this size and focal length has a ~1/3 wave rating at best. With such a poor wave rating, it could not resolve fine lunar or planetary details. The highest power I could use before the images got really "soft" was about 130X. So, in 1998 I decided to make a new "planetary" telescope that would be larger in size and with better quality optics.

The Mirror Blank

A 14.5 inch diameter pyrex mirror blank (2.3 inches thick) was purchased as part of a kit that included a plate glass tool, numerous grits, burgundy pitch, and cerium oxide (CEO) polishing compound. By making a mirror of this size I would save hundreds of dollars compared to buying one already made. I could have gone with a thinner blank or one made of plate glass to save even more money, but I read that working with such blanks can be a challenge (a thin mirror can end up being astigmatic if you are not careful during grinding, while parabolizing and testing a plate glass mirror can be difficult) and I wanted to avoid such risks even if they were minimal.

To eliminate the need for rough grinding and save time, I had the mirror kit supplier rough grind the mirror to focal ratio of about F/8 (they also ground the back of the mirror nice and flat). Why such a long focal length? Well, I mainly enjoy looking at the planets and so a long focal length and small secondary mirror are desirable. More importantly, figuring and testing the mirror's surface to a good parabola becomes easier with longer focal ratios.

Getting Started - Beveling the Mirror and Tool

To ensure that the mirror or tool edges won't chip during grinding, the edges of the mirror and tool must be beveled. I regret not requesting the factory do this job. Hours were spent with a grinding stone trying to get all the edges to about 1/8" wide. I found this method to be too slow and switched to wet/dry sandpaper (silicon carbide) affixed to a rubber sanding block. The mirror's edge was sprayed with a little water before the beveling was started. 80 grit paper was used first and I finished with sandpaper with the same grit size as that used to fine grind the mirror. It worked much faster and created a nice rounded edge. Moreover, when using the grinding stone I had to be careful not to drop it on the glass blank and damaging it. Dropping a rubber sanding block onto the blanks won't cause any damage. As fine grinding proceeded, finer and finer sandpaper was used. During the final stages of fine grinding I was using 1500 grit paper that left the edges so smooth they almost looked like polished glass. Having such a smooth edge is desirable, because tiny glass fragments are less likely to break away from a smooth edge and scratch the mirror during grinding.

Grinding the Mirror

I then proceeded to grind the mirror starting with 120 grit and ending with 5 micron grit. A table saw covered with layers of newspaper about 1/2 inch thick (to support the mirror and tool) was used as the grinding stand. A "wet" began by spraying the disks with water and smearing a small amount of grit over the tool (or mirror) with my fingers. The mirror (or tool) was then carefully placed on top of the tool (or mirror) and grinding started (i.e., pushing the glass disk on top back and forth). The procedure was quite similar to grinding a smaller mirror, except that the disks are heavier. With the coarser grits, pressure was applied to speed grinding. At the start of grinding, each wet lasted a few minutes before the disks needed a new charge of grit. At first, I tended to put too much grit or water on the disk and much of the grit slid off while grinding. Yet, after some practice I figured out just the right amount of water and grit needed to minimize any waste. To rinse the disks after each wet, I dunked them in a large plastic bucket filled with water.

As fine grinding proceeded I did more and more of the grinding strokes (1/3 "W" and center over center or COC) with tool on top (TOT) and applied less and less pressure. I also slowed down the stroke speed. By the time I reached 20 micron grit, all the of the work was done TOT and only the pressure applied was the weight of the tool. Why only TOT strokes? Well, the mirror weighs about 30 lbs and the tool weighed much less. Grinding TOT rather than mirror on top (MOT), gave me more control over the grinding strokes. A good indicator that the mirror and tool had good contact (and spherical surfaces) was my ability to push the tool back and forth without it skipping or sticking.

After a "walk" around the grinding stand, the mirror was slightly rotated in a direction opposite to the direction of the "walk" (i.e., if the walk was clockwise, around the stand, then the mirror was rotated counter-clockwise). This helped ensure even grinding across the mirror. For each grit, I did about twice as much grinding as called for to ensure that I was ready to move onto the next grit size (the kit came with plenty of grit, but in retrospect, this was too much unnecessary grinding). As each grit was completed, I carefully examined the the mirror (using the reflection from a filament bulb) to make sure fine grinding was complete right up to the edge. Before starting the next grit size, I cleaned the entire work area and dunking bucket, as well as the mirror and tool as best I could. I removed the old newspaper and placed down a new layer. When disposing the old paper I was careful in keeping the dried, used grit and ground glass dust on it from becoming airborne, since it is not good to inhale. I also showered and changed my clothes.

Finishing Up Fine Grinding

As the grit sizes got smaller and smaller, the possibility of scratches from dust and stray grit particles increases. I was doing all my work in my dusty garage workshop and to help avoid scratches I attached a large sheet of plastic drop cloth on the ceiling above and around my grinding stand. To further reduce the likelihood of scratches, the mirror and tool were scrubbed with a tooth brush (a new one) and laundry detergent before moving onto the next grit. To determine the focal length of the mirror, I took it outside, sprayed water on it, and focussed the Sun's image on the back of an old lawn chair (this method works even with the roughest of grits). The distance between the mirror and the image of the Sun was measured at about 115 inches.

When the mirror was ready for 25 micron grit, I added grit and water in a clean jar until I had a thick slurry (like heavy cream). This mixture was then spooned or poured onto the disk. I used more grit than needed, but I believe it helped avoid scratches and seizing of the mirror and tool. To further reduce the likelihood of these problems. I mixed a little liquid dish soap with the grit and water when I started the 9 micron grit. Wets by now were lasting up to 10 minutes or more.

The last grit on the list was 5 micron. I did not use the grit that came with the mirror kit. Instead, I purchased some high quality, 5 micron "Microgrit". I wanted to avoid seizing and scratches and learned that Microgrit would help. As with the 9 micron grit I mixed the grit and water (and a little liquid soap) until I had thick slurry. As work with 5 micron progressed, no scratches occurred, but even with all my precautions the mirror and tool did seize tightly together once. To free them apart, I placed the two disks in a warm water bath, followed by a soaking in cold water, and after a few minutes they came apart (This is because plate and pyrex glass have differing rates of expansion/contraction).

One of the ways I determined that fine grinding was complete was when I could read newspaper print through the dry glass tool when it was placed several inches from the disk. I couldn't use the mirror since the back of it was rough ground. The back of the tool, on the other hand, was polished. I assumed that if the tool was adequately ground, so should the mirror. Another way I tested the mirror for completeness was by examining the reflection of a light bulb (clear, not frosted) filament off the mirror. Any dimming or brightning of the light indicated that the grinding was not uniform. Total time spent beveling the edge of the mirror, grinding the mirror, and cleaning up between grits was about 90 hours over a two and half month period (about 1 to 2 hours of work a day). Again, I did about twice as many wets as called for to grind the mirror.

Some Practice Figuring a Mirror

With fine grinding completed, I was ready to polish the mirror. However, as mentioned earlier, the last time I polished a mirror was in 1982. More importantly, I had no skill parabolizing a mirror. I wanted to learn how to parabolize a mirror before taking on the 14.5 inch. Luckily, a friend gave me a polished 6 inch, spherical, F/10 mirror that he made years ago. I made a lap for the mirror and spent several weeks practicing my figuring strokes.

To determine the accuracy of the mirror, a Foucault knife edge tester was constructed with scrap lumber and easy to find hardware. To improve the accuracy of the knife edge measurements, I used a micrometer to adjust the forward and back movement of the knife edge. I built the tester based on designs appearing in ATM books and webpages. Here's a webpage offering details on how to build a mirror tester:

http://www.jlc.net/~force5/Astro/ATM/Foucault/FoucaultTester.html

Making the Polishing Lap for the 14.5 Inch

Feeling a little more confident about my mirror figuring abilities, I set out to make the polishing lap for the 14.5 inch mirror. The burgundy pitch provided with the mirror kit was very very soft. It had to be gently heated (not boiled) for over 5 hours in an old (but clean) pot before it became hard enough to use. I determined this by pressing my thumbnail into the pitch as hard as I could. When it took about 10 seconds to leave a mark, the pitch was at the right hardness.

I found that using wax paper folded over many times (until it's 2 inches wide or so) was very effective for making the pitch "dam" around the tool. It worked much better than aluminum foil or cardboard. As the pitch was poured onto the tool (~1/4 inch thick) it did not stick to the wax paper and I did not have to worry about little fragments of aluminum getting into the pitch and possibly scratching the mirror during polishing.

After the pitch on the tool cooled, a blow torch was used to remelt the pitch and pop a number of bubbles that formed as it cooled. I then used a "sharpie" ink pen to draw squares about 1 3/4 inches wide on the lap. I made certain that the squares were drawn such that the center square was off-set a bit from the center of the lap to avoid polishing zones into the mirror.

Next, a soldering gun with a ~1/4" wide tip was used to cut the square channels into the lap. At first I tried a soldering gun, but it overheated and broke. A less expensive soldering iron worked much better. The tool was rested against the back of an old chair and cutting was begun from the bottom upwards to the center of the lap. The tool was then rotated 180 degrees and the channels cut again the same way.

After the channels were cut, the lap had to be hot-pressed against the mirror. There are a number of ways to do this, but the best method I found was to create a duct tape "dam" around the lap and filling it with boiling water. I let the hot water sit for a minute or two before quickly removing the dam. The pitch would then be soft enough for hot pressing to go smoothly. The lap and mirror were coated with the CEO/water mixture (~1:4 ratio) and a little dish soap and then pressed together with lots of pressure applied. After the first hot press, many of the lap channels closed. They were reopened with a single edged razor blade or the soldering iron.. Hot pressing was repeated several times until there was good contact between the mirror and the lap.

Polishing

A polishing session started with the lap channels and edge being trimmed with a razor blade if needed. The lap and mirror were then rinsed with water. Next, the mirror and lap were cold pressed (using lots of CEO and water mixed together in a squirt bottle) with a 15 pound weight. After a hour or two, the weight was removed, more CEO and water (about 1 part CEO to 4 or 5 parts water) were applied, and polishing began. Polishing typically lasted for at least one hour or more so that the lap would warm up and improve the polishing action. After the session was over, the lap was covered with plastic wrap (to protect it from dust) and the mirror was cleaned and covered and placed on another table.

All polishing was done TOT in an attempt to avoid the possibility of severe turned down edge or "TDE". I wore gloves to keep my hands from unevenly heating the mirror edge when I handled it. I read that if the edge gets too warm, it expands and an edge defect may occur during polishing. The gloves also helped keep any dirt/grit on my hands from getting onto the mirror and scratching it. To ensure an even polish, each "walk" around the stand ended with the mirror being slightly rotated in a direction opposite to the direction of the walk. I also tried to make each stroke length slightly different from the previous one.

To speed polishing, I applied lots of pressure on the lap and polished until the lap was almost dry before adding more CEO and water. 1/3 W and center over center strokes were used to polish the mirror. As polishing came to an end, I carefully examined the mirror surface for leftover pits and paid special attention to the appearance (checked for any haze) of the edge.

Figuring the Mirror

After ~20 hours of TOT polishing, I did a Foucault test. I read that all TOT work would likely create an oblate spheroid (central hill with a turned-up edge). I placed the mirror in a stand made from old lumber and an old clothing belt that acted as a sling to support the mirror. I then took a look at the mirror with the Foucault tester. Sure enough, the tester revealed a very nice oblate spheroid, but there was also a small central hole. No turned down edge or astigmatism was observed. The mirror's focal length was measured at 113 inches.

Making a New Figuring Lap

After about 20 hours of polishing, the pitch lap had become thin (<1/8 inch thick) and so I decided it would be best to make another lap. To remove the old pitch, I placed the lap in the freezer for a hour or so. This made the pitch very hard and it scraped off easily with a single edged razor blade. Since this is a messy job, I scraped the lap with it placed inside a garbage bag and did the work outside.

For the second lap, I purchased Gugolz #64 pitch. Unlike burgundy pitch, the stuff has an unpleasant odor (smells like tar) when melted I cut the channels the same way as before, but each square was about 2 inches wide. While removing the lap after cold pressing, I unfortunately dropped the glass tool onto the floor and it smashed to pieces.

Making a Plaster of Paris Tool

To make up for the broken tool, I made a new tool with plaster of paris (POP). To do this, I placed the mirror face up on the leveled stand and covered it completely with plastic wrap. Next, I wrapped a ~4.5" wide strip of sheet metal around the edge of the mirror. POP was poured into this "mold" in ~1/2 inch thick layers. I let each layer dry before pouring in the next layer. I poured enough POP until the tool was about 2 inches thick. I removed the POP from the mold and set it on edge to dry. To speed the drying, I placed the tool in my garden shed where the temperatures were climbing well over a 100F during the day with low relative humidity.

It took about a week for the tool to completely dry out. I used 100 grit sandpaper and sanded the back of the tool to get it as flat as possible. I also used a little POP to fill in any crevases in the tool. I sealed the tool with a few coats of polyurethane sealant mixed with a little turpentine. I placed a sheet of self-adhesive plastic sheeting on the back of the tool and wrapped the edge with duct tape. This was done to help keep the POP from getting wet and flaking off the tool during polishing.

Figuring Begins Again

I heated up another batch of Gugolz pitch and poured it onto the POP tool. When the new lap was complete, I started MOT polishing. I tried 1/3 "W" and 1/3 center-over-center (COC) strokes in an effort to turn the oblate spheroid into a sphere. Didn't work. I then tried long, wide strokes (3/4 "W") and this slowly reduced the oblate spheroid.

From the start, I found pushing the mirror across the lap to be difficult. At times it was nearly impossible to push the mirror. I did not have this trouble with the burgundy pitch lap. I tried scratching the lap and pressing onion bag netting into the pitch to ease the friction. This only helped a little. Moreover, I noticed that sticky blobs of pitch were oozing from the pitch where it was in contact with the tool. I found this puzzling since this was occuring at room temperature! When melting the pitch I believe I added a little turpentine that might have been too much and perhaps this caused the lap to be sticky.

Starting Over Again with a New Lap

I was making very slow progress in reducing the oblate spheroid to a sphere with the lap. Moreover, zones started appearing on the mirror that were probably caused either by poorly shaped pitch squares or poor mirror to lap contact.. Lastly, I was getting sleeks on the mirror surface that were possibly caused by the pitch. With these additional troubles I decided it would be best to make another lap. I took a break from polishing and made a new POP tool and this time used burgundy pitch for the lap. When figuring resumed, I noticed an immediate improvement in my ability to push the mirror across the lap.

Parabolizing the Mirror

After a number of hours of polishing MOT, the oblate spheroid was gone and a shallow hole in the center began to appear. The edge showed a narrow, but mild turned down edge zone. The surface of the mirror was very smooth and so I decided to try to parabolize the mirror with the full-sized lap. Parabolization called for long, wide (3/4 W) MOT "W" strokes. Since a shallow hole was already present, I minimized the polishing action in the center of the mirror by reducing the side overhang of the mirror in the parabolizing strokes just a bit. To help gauge the length of the strokes and the amount the mirror was rotated, I marked the back of the mirror in the center and placed a dot near its edge. During this time, polishing sessions were kept very short and I pushed the mirror back and forth very very slowly. I also reduced the ratio of water to CEO from about a 5 to 1 to a 10 to 1 mixture and did not let the lap dry out. This helped ensure a smooth surface. I Foucault tested the mirror after doing only ~15 minutes of polishing (1 "walk" around the stand) and letting the mirror cool down.

Total time spent polishing the mirror to a paraboloid was nearly 40 hours (not including set-up and testing). Add the first 20 hours spent polishing out all the pits and the total was 60 hours of work done during a ~2 1/2 month period..

Testing the Mirror

Foucault knife edge measurements with 4 and 5 zone Couder masks indicated that the mirror had about an 1/10 wavefront error and a Strehl ratio better than 0.96. To help verify these readings, I took a series of Foucault measurements. As an additional measure, I took down and set back up the mirror, Couder mask, and Foucault tester to ensure my measurements were repeatable. Mirror testing software (available on the web for free) was used to do all the number crunching and plotting of the data. Here is a website offering mirror free testing s/w:

http://www.berfield.com/atmsoftware.html

Analysis of the data indicated that overall the mirror was under corrected. To be specific, the center and outer zones were a bit under corrected, while the ~60 to ~70% zones were a bit over corrected. To examine the overall figure of the mirror and determine the width of the turned down edge, I did Ronchi grating tests with 85 and 133 line/inch gratings. Diffraction effects made it difficult for me to measure the exact width of the "TDE", but I estimated that it was less than 1/4" wide. More information on Ronchi testing can be found here:

http://www.atm-workshop.com/ronchi-test.html

Verifying the Foucault Test

Since I used a homemade Foucault tester and was by no means an expert on using it, I was not convinced that my mirror was as good as 1/10 wave. So, I decided to "star test" the mirror. Doing this, of course, would require the mirror be mounted inside a telescope tube.

Building the Telescope Tube

Since the mirror has a focal length of 113 inches (actually it's 113.13"), I decided that a truss telescope tube made from 8 aluminum poles and wood would be the most practical design. Because I had limited skills building a tube of this size, I decided that the tube would be a prototype.

The secondary cage and mirror box were made out of scrap plywood and 6 foot aluminum poles were used to build the truss. Simple steel clamps were used to fix the poles to the mirror box and cage. The mirror mount was made of oak with 9 floatation points to support the mirror. I decided to purchase and not build the diagonal holder (including a 1.83 inch diagonal) and focuser.

I decided to hold off building the telescope mount and do the star test with just the telescope tube. I simply propped the truss tube on a sturdy pole and aimed it at the North Star (it doesn't move much in the sky). The outer 1/4 inch of the mirror was masked with electrical tape to cover up the turned down edge. The actual amount of "TDE" was estimated to be less than 1/4 inch, but masking was done to make sure that all of it was covered. With the TDE out of the way, interpreting the star test would be a little easier. To learn how to do the star test, I read Suiter's **"Star Testing Astronomical Telescopes"**, which can be found, among other ATM books, at this site:

http://www.willbell.com/tm/tm5.htm

The March, 1995, issue of Sky and Telescope magazine has an article on this book and provides an overview on how to do the test. Here's a site that shows star test images and offers test software: http://aberrator.astronomy.net/

Star Testing

Well, as luck would have it, turbulence in the upper-atmosphere made reliable star testing just about impossible. Polaris was simply a boiling mass, inside and outside of focus. I was unable to clearly see diffraction rings. From mid December to early January I tried doing the star test, but bad seeing persisted. Another problem I had to contend with was getting the mirror to cool down to the outside temperature. A large difference in temperature results in poor star images. This is one of the drawbacks of a full-thickness mirror. To help cool the mirror I placed a house fan in the back of the telescope to blow air over the mirror. I also tried leaving the telescope out all night and star testing in the early morning hours. This allowed the mirror temperature to get closer to that of the outside air.

Ronchi and Foucault Tests using Starlight

In addition to the star test, I also tried doing a Ronchi and Foucault test on the unfocused star image. The Ronchi test was done by taking an old 35mm film canister, cutting out the bottom and carefully taping a ronchi grating to one end so that it was flat against the bottom of the can. This "eyepiece" was inserted into the focuser. Next, the focuser was adjusted so that 2-3 Ronchi lines appeared on the unfocused star image (the lines should appear straight across the mirror and **any** bowing of the lines indicates an ~1/4 wave or worse mirror). The Foucault test was done by simply holding a blade at the eyepiece and "cutting" it into the unfocused star image (the image should black out evenly and any uneven shadowing is an indication that the mirror is not a good parabola).

Like the star test, the Ronchi and Foucault tests were difficult to interpret because of atmospheric turbulence. Yet, even with the bad seeing, the view of the moon at 410X was very nice (much better than my old 8 incher ever was) and I could make out details on Jupiter and Saturn (aiming the telescope at them with my crude mount was a little difficult!). I was amazed at how much could be seen with an unaluminized mirror. I estimated that I could see stars as dim as 9th magnitude or so. With bad seeing persisting, I decided to wait until Spring to try the star test again. In the meantime, I would rebuild the mirror box and secondary cage with better materials.

Rebuilding the Truss Tube

I decided to keep the truss tube design simple. The tube would be 9 1/2 feet long, with the aluminum poles making up about 6 feet of the length. I would have used longer poles (and a smaller mirror box), but the widest diameter I could find was 1 1/4 inches. Longer poles would have required a wider diameter to maintain a stiff truss. The steel clamps were replaced with wooden sockets to hold the truss poles to the mirror box and secondary cage. To help improve the balance of the telescope, the secondary cage was rebuilt with thin (3/16") plywood so that it would be as light as possible. Instead of using a brush to paint the inside of the cage black, I used ultra flat black spray paint. It put down a much better coating than using a paint brush.

Star Testing Again

While rebuilding the truss tube, I decided to take a break and try another star test. I reassembled the truss tube with the new pole clamps and secondary cage. (I used the old mirror box). Further Foucault and Ronchi testing in the basement indicated that the TDE was not 1/4" wide, but closer to 1/8" or less wide. To mask the TDE I obtained a long strip (~1.5 X 48 inches) of thin, flexible cardboard and on one edge glued a length of 1/8" thick plastic tubing. After the glue dried the tubing and cardboard strip were painted black. I then taped the strip around the mirror and the plastic tubing masked the TDE.

I tried star testing again one evening in April. Seeing conditions were better than they were in January, but still far from ideal. Nevertheless, the star test appeared to indicate that the mirror was better than than 1/4 wave. The seeing conditions were not good enough to get a definitive answer. I would have to try the test again on night with better seeing. In the meantime, I would continue working on the telescope tube.

Back to Work on the Truss Tube

The mirror box was made of 1/2" thick plywood held together in the corners with steel shelfing brackets. The brackets are strong, lightweight, and bent to a 90 degree angle. As with the secondary cage, the box was spray painted with flat black paint.

Since the truss tube is 9 1/2 feet long, it was designed to be disassembled for easier transport. However, unlike other truss tubes where all the poles are removed, this tube keeps the poles intact by having the upper part of the mirror box (where the poles are attached) come off. This makes setting up and taking down the telescope easier and faster, but transporting this telescope design in my car will not be easy.

Building the Telescope Mount

While designing the mount, I decided to deviate from the traditional Dobsonian mount design and try something different. I had some unused planking (~1 3/8" thick, ~5" wide) used for building decks and I decided to use this wood, 3/4" thick plywood, and other lumber to build the mount. When completed, the mount would look similar to a sawhorse.

1/4 inch thick scrap teflon was obtained for use in the azimuth bearings. The thicker teflon would allow screws (counter-sinked into the teflon) to hold it in place rather than epoxy glue. The deck planking held the elevation bearings and a plywood sheet (~2 X 2 feet) acted as the mount base. To help keep the mount rigid, I used shelfing brackets. On the bottom side of the mount base I glued on a ~1/8 inch thick sheet of plastic using contact cement. Three teflon squares (~3 X 3 inches) sandwiched between the plywood base and another plywood sheet comprised the azimuth bearing.

For the elevation bearings, two 5" diameter PVC plastic plumbing fittings were used. I could have used cast iron fittings, but the PVC parts were cheaper, lighter, and had a smoother surface. I realized that using such small bearings would result in a less stable mount, but I thought I'd give them a try anyway since they were readily available and easy to work with. I planned to use teflon pads to support the elevation bearings, but to my surprise the mount worked fine without them. The motion was nice and smooth.

Using the Telescope Mount

One late afternoon, I set up the telescope to see how well the new mount functioned. The truss tube section attached to the mirror box without any problems. The telescope did require a ~6 lb weight in the back to get it properly balanced. When the first stars appeared I aimed the telescope at one of them and took a look. As expected, the star images bounced around a bit when positioning the telescope and it occurred mostly along the elevation axis (owing to the small bearings). Image motion stabilized after about 5 seconds. Unfortunately, seeing conditions were not good for star testing.

Even though the mount was not very stable, all in all, it worked to my satisfaction. However, I decided to further work on the mount to make it more sturdy. I later added pads between the mirror box and mount and star images stabilized within 3 seconds or less at high magnification. I also pared down the weight of the secondary cage, eliminating the need for the 6 lb weight in the back.

Another Star Test

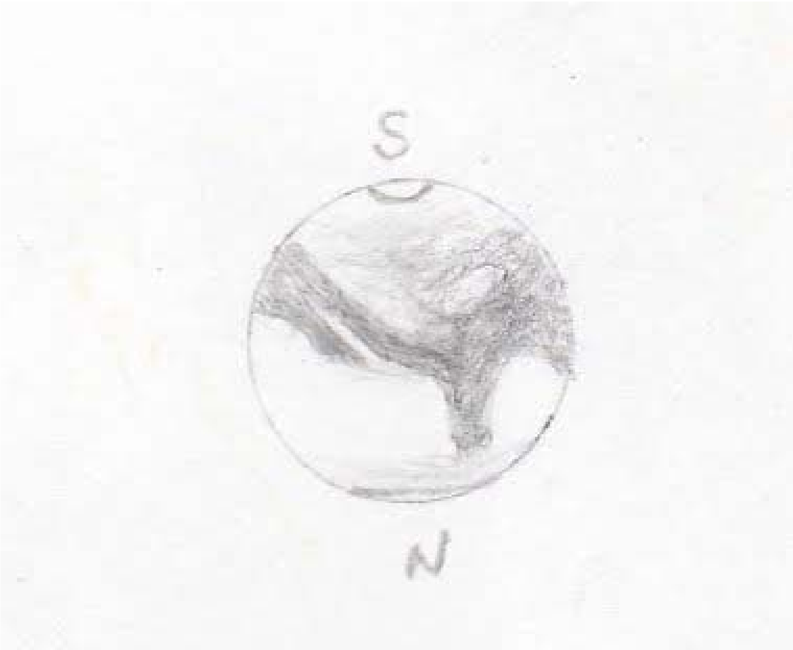
One evening in September, I set the telescope up and did a star test at 575X using a 5.0 mm eyepiece. The image of Polaris was not great, owing to some atmospheric turbulence. However, when I aimed the telescope at Vega, nearly overhead, the image looked better. Inside and outside of focus, the diffraction patterns did not look exactly the same, but were very similar in appearance. The mirror was a bit under-corrected, which was in agreement with my Foucault test measurements. The Ronchi test on a star (as described earlier) showed straight lines. I also took a look at the moon at 575X and the view was very good. Later that night I observed Jupiter and Saturn at 230X. I could make out 4 cloud belts on Jupiter and the Cassini division in Saturn's ring was easily seen. Based on these observations and the star test results, I decided that the mirror worked to my satisfaction. The mirror was now finished and ready for a coating of aluminum.

Conclusions

I have used the telescope for many nights now and it meets my expectations as a planetary telescope. Now I'm not sure if the mirror is as good as 1/10 wave (as indicated by my Foucault measurements), but I believe it's certainly better than 1/4 wave based on what I have seen through the eyepiece. During a night of excellent seeing conditions, I saw the Encke division in the rings of Saturn at 575X. And I will never forget the views I saw of Mars at high power during the opposition of 2003. They were amazing. Some nights, the image of Jupiter at powers exceeding 230X has shown so much detail during brief moments that I could not sketch it all on paper. It was simply beautiful. One evening, I saw bright and dark areas on the surface of Ganymede, a moon of Jupiter. As for our moon, features such as Rupes Recta (Straight Wall) and Vallis Alpes are incredible to see at 575X to 756X on those rare nights when the atmosphere is steady enough for such a magnification to be used. The details that can be seen at this magnification makes viewing the moon a very enjoyable experience. Interestingly, the image of the moon is still rather nice at 1,512X when the seeing is excellent. Check my astrophotos below of the moon taken through this telescope and my old 8 inch. I have also seen Uranus and Neptune with the telescope. So far, I have not had any luck seeing their moons.

Some say a homemade telescope is always being worked on and this certainly applies to me. I have since rebuildt the truss tube and mount to make them lighter and more sturdy. **See Part II of this webpage below**.

And remember the 8 inch telescope with the spherical mirror I built in the early 1980s and described at the top of this page? Well, in 2008 I made a 8 inch pitch lap, polished off the aluminum coating, and then turned that spherical mirror into a paraboloid. The telescope performs much better and I can now use the telescope at magnifications up to 400X.



Here is a sketch I did of Mars on September 7, 2003, with the 14.5 inch, F/8 telescope described on this webpage. It was at 235X and I used filters to better see details. I could not sketch all the details I saw during brief moments when the seeing was excellent. It was an evening that I will never forget.

Mirror and Telescope Making Tips

If you have never made a telescope mirror before or built a telescope and want to give it a try, here are a few things I learned from my own experiences, as well as those from other ATM's, that may help you:

(1) Before buying the mirror blank and other materials, make sure you want to take on a project where you are pushing a piece of glass back and forth for up to an hour or more at at a time. Making an extremely accurate mirror with simple tools and materials can be very rewarding and educational (and to some even "addictive"), but some beginners find such a task to be very boring or laborious and never finish their optic. Read a few books on mirror making and visit ATM websites (there are many good ones). There are also excellent video tutorials on YouTube. A book with a very good section on mirror making is Sam Brown's, "**All About Telescopes**". Unfortunately, it is out of print, but search around and you may find a copy.

(2) With the internet, it's now easy to find sources (Ebay.com as an example) of mirror blanks and kits. But don't buy a mirror blank until you have reviewed the pros and cons of plate glass vs. pyrex vs. fused quartz and thick mirrors vs. thin. For beginners, consider going with a mirror blank with a diameter to thickness ratio of at least 10 to 1.

(3) A homemade telescope mirror can be made with more accuracy and smoothness than the mass-produced, commercial mirrors available today. Unfortunately, the cost of mirror grinding kits and pyrex blanks has increased significantly in recent years to the point where any savings from making a mirror versus buying one are minimal at best. Yet, the larger the mirror you

make the more money you can save when compared to buying a mirror already made. And before buying a kit, surf the internet (e.g., Ebay -- and search for "mirror blank") and you may find all the materials you need for a very low price. Also, I suggest making your grinding and polishing tools out of plaster (dental plaster is quite good), cement, or some other cheap material to save the cost of buying a glass one.

(4) Most people start their mirror making hobby with a mirror 8 inches or less in diameter, gain some experience, and perhaps then go for a larger mirror. While some beginners have made larger mirrors on their first try, I recommend starting small. Larger mirrors take longer to complete and require more of your patience. And if it has a fast focal ratio (<F/6), more complex polishing strokes requiring extra skill will be needed to figure the mirror. How long it takes to complete a mirror depends on numerous factors. I have read of an experienced ATM finishing a 6 inch mirror by hand in several days of hard work. Yet, most beginners take weeks to months getting their mirror completed.

(5) If possible, get the mirror and tool (if glass) edges beveled and consider having a rough curve in the mirror (ground to your desired focal length) generated for you by the mirror blank supplier. This can save you considerable time and effort, especially if the disks are large. Maintain the bevel (between 1/16" and 1/8") as grinding progresses. Some beginners (like me with my first mirror) forget to do this and end up with a bad chip on the edge of the mirror. And if you do chip the edge, don't worry. Just bevel off the sharp edges and keep going. Unless the chip is huge (more than about 1 square inch off the mirror face), the loss of light gathering power of your mirror will be very small.

(6) For beginners, make the focal length as long as you are willing to tolerate. A short, F/4 telescope is nice and compact and offers wide-field, fantastic views, but the mirror is more challenging to parabolize and test compared to a mirror that is F/6 or F/8. If you decide to go with a F/5 or faster mirror, you may very well need to make special polishing laps (and apply special polishing strokes) to parabolize the mirror and use additional testing methods to determine its accuracy (i.e., the Foucault test becomes increasingly hard to do accurately as the focal length becomes shorter and shorter).

(7) Before moving onto the next grit size, carefully examine the surface of the mirror with a magnifying glass and the low angle reflection seen from a filament (clear, not frosted) light bulb, especially near the edge. Any uneven dulling or brightening of the reflection or uneven distribution of pits is an indication that the mirror needs more grinding. As for polishing, don't start testing/figuring the mirror until **all** the pits or haze on the mirror are polished away. A common mistake that beginners make is sending their mirror off to get aluminized when it's not fully polished.

(8) It is **essential** that you keep a detailed log (strokes used, TOT, MOT, etc) of all your grinding and polishing work. Sketch (or photograph with a digital camera) the Foucault and Ronchi images you are seeing while figuring the mirror. This was very helpful for me, especially during the polishing/figuring process. From the log, I was able to determine which polishing strokes worked best to finish the mirror.

(9) If your mirror gets a few scratches or sleeks (very fine scratches) on it while being polished, don't worry about them. I tried very hard to avoid them, but my mirror got a number of sleeks on it anyway. Sure they don't look nice, but unless they are very numerous, scratches will not affect the quality of star images. You won't notice them. Just do your best to avoid them (i.e., keep

yourself and your work area very clean) and continue polishing if they occur. Besides, if the scratches are very shallow they may polish out anyway, especially if you can't feel the scratch when you pass the tip of your fingernail over it.

(10) Take your time figuring the mirror to a parabola. Don't rush your work. Make sure there is good contact between the mirror and the lap. The lap must not be hard or too soft and the mirror should glide across the lap with even drag (no sticking or skipping). Keep your polishing/figuring sessions short and Foucault/Ronchi test the mirror often. Watch for turned-down-edge because once it forms it can be difficult to remove (Try short TOT strokes with a full-sized and hard pitch lap to get rid of it). Polishing stroke speed should be kept very very slow and keep the lap well covered in the CEO/water mixture --don't let it dry out. Give the mirror plenty of time (several hours or more if necessary) to cool down before testing it, especially if it is plate glass. One way to speed up the cool down time, is to simply soak the mirror in room temperature water for 15 minutes. Lastly, the mirror does not have to be 100% perfect to produce a decent image.

(11) Before calling your mirror done, test it in your telescope. If your telescope is not ready yet build a crude telescope with junk parts without a mount like I did. A bare glass mirror reflects about 4% of the light hitting it. This is plenty of light to view the moon, bright stars, and the planets Jupiter and Saturn. Do the test when the atmosphere is calm (see my weather links below) and if you like what you see at high magnification (at least 30X/inch -- or 240X for an 8 inch mirror as an example), then the mirror is ready for a coating of aluminum.

(12) Making a mirror is not hard to do, but it can really try ones patience, especially during the figuring process. Sometimes it just doesn't go right and this is where some beginners become discouraged, call it quits, and never finish the mirror or settle with one that's poorly figured. If you find yourself getting frustrated getting rid of a badly turned edge or figuring the mirror to a parabola, take a break (weeks if necessary!), study the problem for a solution, and try again. **Don't give up!** If necessary make a new polishing lap. Often times a very hard (or soft), very thin (<1/8 inch thick), poorly pressed, or incorrectly channeled lap is the cause of the problem.

(13) As for building the telescope itself, design and build it so that it will get used. Read a few books on telescope making and visit the many webpages out there for useful tips. And YouTube also has excellent tutorials. Keep in mind that a telescope that is difficult and time consuming to set up and use will likely get less use than a scope that sets up quickly and is easy to use to observe the sky.

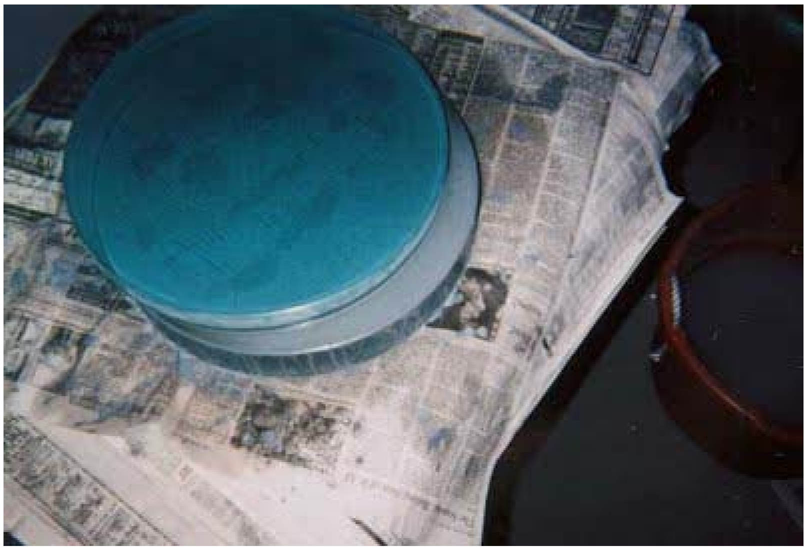
(14) Take your time and plan out your telescope design and construction carefully before starting. If you don't, you could end up with a homemade telescope that costs far more than buying a new one from a manufacturer. To save money, try to make the telescope with scrap parts and other junk items that you can find. Many ATM's have built truly beautiful and functional telescopes this way. Clyde Tombaugh, the discoverer of Pluto, made his first telescope when he was a boy from discarded farm machinery and car parts.

(15) The telescope does not have to be perfectly built (my telescopes certainly are not!) to work well. As long as you can correctly align the optics in the tube and the mount is reasonably stable, the telescope will work just fine. The basic tools you need to build a telescope include a hammer, some screwdrivers, a carpenter's square, a hand drill, and a wood saw. Of course, more fancy tools (e.g., table saw, router, drill press, etc) will make the job go faster and create more precise cuts/holes, but don't buy them if you don't plan to use them again after finishing

the telescope.

(16) Lastly, after making your first telescope you might want to make another. If so, try experimenting with new designs of the telescope components that you have thought up on your own. If possible, use scrap parts to save money with your experimenting. In the end, they might work or they might not. My first telescope design described in this page was not ideal, but I learned a lot and my second telescope design (see below) has worked out very well. And for me, the entire journey along the way was a very enjoyable and educational experience.

Photos



Here's the plate glass tool (top) and mirror (bottom) during grinding. The blanks rest on a ~1/2 inch thick layer of newspaper to provide even support. . I had the mirror rough ground to an F/8 curve at the factory to save time. With a curve already generated, I did not have to start with 60 or 80 grit. I started with 120 grit and finished with 5 micron. Mostly tool on top strokes were used during the final stages of grinding. As grinding proceeded I maintained the bevel on the edges of the mirror and tool. On the right you can see the large bucket used to rinse the blanks between wets. I used a plastic bucket so that if the mirror or tool banged into the side of it, no damage would occur.

Before moving onto the next grit size, I cleaned the blanks, cleaned the entire work area, showered, put on new clothes, and placed down fresh newspaper on the grinding stand. This helped ensure that the mirror would not get scratched by a stray grit particle. No scratches occured during grinding, but in the end I picked up a number of fine scratches during polishing.

Lastly, once while grinding the mirror with 5 micron grit, the mirror and tool seized tightly together. They came apart after they were soaked in warm water followed by a soaking in cold water.

As grinding progressed, the bevel on the edges of the mirror and tool had to be maintained. I used a rubber sanding block (you can see it leaning on the mirror) with silicon carbide sandpaper to do the job. I started with 80 grit and finished with 1500 grit.

Here's the glass tool ready for liquid pitch to be poured onto it. The lap was leveled as best as possible to ensure an even thickness of pitch. Wax paper folded over many times was wrapped around the tool to trap the pitch. Before the pitch was poured, turpentine was rubbed on the tool with a paper towel so that the pitch would adhere better to the glass.

In the background, you can see the pitch being melted on a hot plate. Because pitch has a rather strong odor and is not good to inhale, I later melted all my pitch outdoors. I poured the pitch until the lap was ~1/4 inch thick. As the lap cooled bubbles appeared and I carefully used a blow torch to remelt the pitch a little and pop the bubbles.

There are many ways to create the channels in the lap. I used a soldering gun and soldering iron to do the job.

Here are the pitch (natural burgundy pitch) squares being cut with a soldering gun. When the channels were cut halfway up the lap, the lap was rotated 180 degrees and the cutting repeated. Aluminum foil was placed under the lap to capture the liquid pitch.

At first a soldering gun (as shown) was used, but it broke. A cheaper soldering iron with a 1/4 inch tip was used and it worked better. It took about 30-45 minutes to cut the channels in this 14.5 inch lap.

As careful as I was with the mirror and lap, I still made a big mistake during polishing. One day when I removed the lap (glass tool covered with pitch) during cold pressing, it slipped through my hands and smashed into pieces on the floor.

So that I could continue polishing the mirror, I made a new tool out of plaster of paris (POP). Here's the mold for POP tool. The mirror was placed face up on the stand and plastic wrap placed over it. Next, steel sheeting was wrapped around the mirror and POP was poured in ~1/2 inch layers and allowed to dry before the next layer was poured. The steel sheeting made the sides of the tool nice and smooth. When the last layer was poured, I used a wide blade to smooth the top flat. When completed, the tool was about 2 inches thick.   It took about a week for the the tool to dry out completely (it appeared bone white) before I could sandpaper the bumps and rough spots on it without the 100 grit paper gumming up.

Here is the POP tool completed. A level (seen on the tool) was used to get it as level as possible. This was done so that the hot pitch would spread evenly on the tool when it was poured later.

The POP was sealed with polyurethane mixed with a little turpentine. To further protect the POP from water, the back of the tool was covered with a sheet of self-adhesive plastic and the sides were wrapped with gray colored duct tape.

Note the small patch of Gugolz pitch on top of the tool. This was done to see how well pitch stuck to the POP. It adhered quite well.

After the pitch was poured and the channels cut, the lap had to be hot pressed.

To hot press the lap, the best method I found was by placing a small bucket upside down in a larger bucket (colored blue and shown at the bottom of this photo) The lap was then rested on top of the inverted bucket.

If you look closely, you can see gray duct tape wrapped around the black pitch (Gugolz) lap. This was done to create a dam so that boiling water could poured onto the lap to soften the pitch. After a minute or so the tape was quickly removed to drain the hot water into the blue bucket. With the pitch well softened, hot pressing proceeded smoothly. Now I know plenty of ATM's say that Gugolz pitch is superior to natural burgundy pitch, but I had troubles with it. It was very hard for me to push the mirror across the lap and at one point sticky blobs of the stuff oozed from the lap at room temperature. Perhaps I did not prepare the pitch correctly. Nevetheless, I later made a new lap with burgeundy pitch and I did have any problems at all.

The large red bucket seen at the top was lined with a clean plastic bag (to keep grit out) and filled with hot water. The mirror was warmed in this bath prior to hot pressing.

Here is the lap (foreground) and mirror (background). Small crevases and indentations in the sides of the mirror harbored grit particles that no amount of scrubbing could remove. Duct tape was wrapped around the mirror to trap the particles.   A "clean room" was created in the garage workshop by lining the ceiling with plastic drop cloth and drapping it from the ceiling and around the work area.

Before each polishing session, a single edged razor blade was used to trim the edges of the lap and open up any closed channels. The lap and mirror were then cold pressed with a 15 pound weight for one to two hours or more before polishing started.   Polishing the mirror was done tool-on-top. Gloves were worn to help keep heat from the hands from warming and possibly disfiguring the mirror edge when it was rotated during polishing. They also helped keep any grit on the hands from landing on the mirror and scratching it. To speed polishing, lots of pressure was applied to the lap and polishing was done until the lap was almost dry. CEO and water were initially mixed as 1 part CEO to 4 parts water. Stroke speed was kept to one stroke every 2 seconds or so. I frequently cleaned the work area (replaced the newspaper) to reduce the possibily of stray grit scratching the mirror and also reduce my chances of inhaling used CEO dust.

During the final stages of polishing and figuring, work was done mirror-on-top and the CEO to water ratio was changed to 1 part CEO to 10 parts water. Stroke speed was slowed to 1 stroke every 4 seconds or so and the lap was not allowed to dry out. Lastly, pressure on the lap was reduced to just the weight of the mirror. All these measures helped produce a smooth surface. After a polishing session ended, the lap was left on the stand and plastic wrap was placed over it to protect it from dust. The mirror was also covered and placed on a separate table.

Here's the homemade Foucault tester (fixed light source). It's nothing special and was not hard to make. It was made from scrap lumber and easy to find hardware. I based the design on what I read in ATM books (Mostly from Sam Brown's, **All About Telescopes**) and webpages. The light source was a 7 watt white bulb encased in a sheet of scrap aluminum siding and a strip of wood with a small hole in it to let light through. Two razor blades, taped very close together over the hole created the slit needed for testing.

These photos shows the other parts of the tester exposed. The knife edge board slides on a piece of copper pipe as shown. If you look to the right side of the tester you can see the steel micrometer sticking out. I used a micrometer, rather than a simple bolt as suggested by some ATM books, to allow precise forward and back movement of the knife edge. It was simply inserted into a notch in the wood base and then clamped (tightly) with a small bracket to allow for easy removal. I did not have to modify the micrometer in any way to make it work with my tester. This way I could use it for future projects.

I later made some slight modifications to make the tester into a simple Ronchi tester. I used a 2X2 inch Ronchi gratings available at Willmann-Bell (See my ATM links below).

Above is the mirror on the homemade mirror stand with the Couder Mask taped over the surface. I used 4 and 5 zone masks to test the mirror. The sheet of paper taped below the mask was put there to help reduce glare.

I used "TEX"software available on the web for free to generate and print out the mask. on two sheets of paper. The sheets were taped together and the holes carefully cut out using a razor blade.

More information on making the masks can be found here:

[Couder Masks]

Here's the assembled truss tube telescope. It was a prototype and built to help identify any flaws in the design or construction techniques. It also allowed me to do a "star test " of the mirror The secondary cage and mirror box were made with old scrap plywood and simple clamps to hold the aluminum poles in place. The lessons I learned from its construction would be used to construct an improved tube made with better materials.

Initial star testing was done without a mount. In the photo, the tube is leaning against a ladder, but a pole was used to prop up the tube and aim it at Polaris. The North Star was chosen because it moves little and so readjustment of the crude telescope "mount" would be minimal. Two chairs were positioned on either side of the mirror box to help keep the tube from falling over.

Inexpensive steel pipe clamps were used to fix the aluminum poles to the mirror box and secondary cage. They worked okay, but not as well as wooden pole sockets, which were used later. The mirror and mirror mount with 4 ventilation holes can been seen at the bottom of the box.

If you look closely, you can see black tape along the edge of the unaluminized mirror. This was done to cover a narrow turned-down-edge zone. A better method to mask the "TDE" would be used as shown below.

Here's the completed telescope and mount at a local park. With a tube length of 9 1/2 feet, a ladder is required for using this telescope. To help balance the telescope, the view finder was placed on the mirror box, just above the elevation bearing.

The secondary cage was made from thin (3/16") plywood with 3/4 inch thick wood strips secured on each end. The mirror box was made from 1/2 inch thick plywood held together in the corners with lightweight shelfing brackets. The mount was made from leftover deck planking, 3/4 inch thick plywood, and other lumber. Plastic plumbing fittings were used for the elevation bearings.

Now is this best telescope design out there? No. The mount is heavier and less stable compared to other Dobsonian designs and the secondary cage could be made lighter. But, it was rather easy to build (did not have to do any complex wood cutting) and all in all, works to my satisfaction. Yet, over the years I'll continue to tinker with it to make it lighter and more stable. **Check out Part II of this webpage below to see some of my recent improvements.**

This is a close-up of the elevation bearing. The PVC plastic bearing (Toilet bowl flange - 5 inches wide) rests directly on wood. No teflon pads were necessary. To my surprise the motion turned out to be nice and smooth. However, such a small bearing results in a rather unstable mount, especially in the elevation axis. Experiments with pads (cardboard glued to a sheet of plywood) placed between the mount and the mirror box improved the stability significantly and were installed as shown.

Note the wooden assembly bolted to the top of the mirror box (just to the left of the bearing). It is at this location where the truss tube can be broken down into two pieces. At the bottom of the cage, you can see the pole sockets used to hold the truss poles to the cage (and the mirror box on the other end) They were made with 3/4" thick planks of pine glued together and then cut to blocks. A 1.25" hole was drilled in the block almost all the way through (~1/4 inch from the bottom). Next, a slit was cut into one side of the the block by passing it through a table saw. This allowed a bolt, passing through near the side of the block (not through the pole), to clamp the pole tightly into the socket.

Here's the completed mirror mount (resting on a sheet of plywood) with the TDE mask around the unaluminized mirror. The mask was made by taking a long strip of thin cardboard and gluing a 1/8 inch wide length of plastic tubing along one end. The strip was then spray painted with flat-black paint. Next, the strip was taped around the mirror and the tubing effectively masked the TDE. If you look closely, you can see the black tubing around the edge of the mirror. Star tests done later with and without the mask showed that the TDE was not a problem and so I no longer use it.

The next photo shows the mount under construction. Duct tape wrapped around the mirror was later removed. The mirror rests in on a 9 point floatation mount. The mount design is very similar to that described in Kriege and Berry's book, **"The Dobsonian Telescope - A practical manual for building large aperture telescopes"**. However, instead of using steel, I used wood. The mount was made from 1/4" thick oak boards (triangles) and 3/4" thick oak plywood (16"X16"). Four 2.5 inch wide holes were later drilled into the plywood and its corners trimmed off. All the bolts, nuts, etc, were obtained from a local hardware store. To support the mirror, self-adhesive pads (used for the bottom of furniture legs) were placed at each corner of the wooden triangles, which can be clearly seen. The mount was spray painted with flat black paint to reduce light scattering.

At first a copper band was used for the mirror sling, but it was too brittle. Strapping used for holding bicycles on a car mount was then tried and it worked very well. The strapping is strong and flexible and looks similar to a car seat belt, but not as wide.

Here's a close-up of the secondary cage. It's simply a wooden box made of 3/16" plywood held togther with 3/4" thick strips of pine. To improve the balance of the telescope, I later drilled large holes in the pine strips, as shown, to lessen the weight of the cage.

Here's the back of the scope, showing the mirror mount inside the mirror box. The three mirror adjustment knobs shown were made from steel washers affixed to the end of the bolts that support the wooden triangles on the other side of the mount. These 3 bolts passed through the plywood sheet through the use of "T-nuts" (they were tapped into the plywood sheet and the 3 bolts screwed into them).

Later, a small electric fan (to cool the mirror) was placed over the central hole and suspended by rubber bands to reduce vibration. Also, by paring down the weight of the secondary cage, I later eliminated the need for the weights clamped to the back of the mirror box. Lastly, note the white shelfing brackets used to strengthen the mount. Smaller ones were used to hold the mirror box together. They are inexpensive and quite strong.

A few words about dew forming on the optics. On nights when it is cold outside telescope optics can quickly becomes covered with dew if the scope is brought inside the warm house where the dew point temperature is higher. Dew in polluted air can slowly ruin the coating on a mirror, so it's best that it not form in the first place. When I am ready to bring my telescope and equipment inside for the night, I keep dew from forming on my mirror, diagonal, and eyepieces by using a hair dryer and blowing warm air over the back (so as to not blow any dirt directly onto the coating) of the mirror and diagonal and over the capped eyepieces. I do this outside and the thick 14.5 inch mirror can take up to 10 minutes to warm up, but the diagonal and eyepieces take only a minute or so. Using this method, I never have trouble with dew build-up on my optics when they are brought inside for storage.

Part II: Rebuilding the Telescope

Well, I was enjoying the old telescope design, but I felt I could do a better job with the secondary cage and especially the mount. The mount was bulky, weighed about 55 lbs, and was rather hard getting it through the doorway. And by making the secondary cage even lighter, I could make the mount smaller by shifting the balance point closer to the rear of the telescope. So I decided to rebuild the telescope to make it even easier to set-up and use.

As part of my effort to rebuild the telescope, I needed to cut wood circles for the secondary cage and bearings. Since I didn't want to buy a router to cut a few circles for my telescope, I used a Zip saw and built out of scrap lumber a "circle cutter tool".

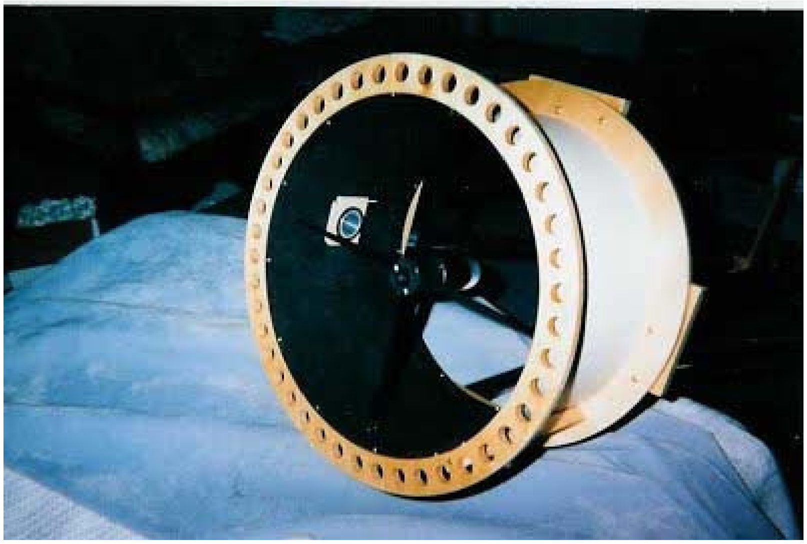


Above are photos of the "Zip saw circle cutter tool" just after a circle had been cut into a sheet of 1/2 inch baltic birch plywood. It's simply a board with holes on both ends (one for the central pivot bolt, the other (~1 inch wide) for the Zip saw bit). Three boards (sides and top) and steel clamps were used to hold the saw securely. This design completely hides the cutting bit from view, reducing the risk of injury. To keep the work bench from being cut, I nailed a sheet of plywood down and then placed the baltic birch plywood on top. Once the cutter and saw were hooked up, cutting the circle proceeded slowly by pulling the cutter around the central pivot. After the circle was cut it was sanded down to remove a rough edge.

If you plan to try this method, please use extreme caution. The Zip saw bit is very sharp and spins at high speed. If you don't have skill using high speed tools, find someone else who is and will do the job for you. Pull the cutter around the pivot slowly or you will likely break the bit. To make sure your cutter works, try it first on a sheet of scrap wood.

The above photo shows the new secondary cage under construction. I had a hard time finding the hardware (i.e., "threaded inserts") needed to make the secondary cage as shown in Kriege and Berry's book on making large Dobs. Also, the smallest sheet of Kydex available at the local plastics supplier was 4X8 feet! Moreover, I thought it might be rather hard for me to build their design correctly. So, I decided to try something a little less complex. The cage is made with two 1/2 inch thick baltic birch plywood rings (inside diameter is 15 1/2 inches) supported by a sheet of formica (10 X 48 inches cut out with a table saw). Formica when wrapped this way is very rigid. Prior to installing the formica, I drilled the holes for the focuser, secondary mirror holder, and the screws to hold the formica to the rings. I also spray painted the inside of the sheet black. If you look to the right you can see a strip of pine placed vertically between the rings. This was done to secure the ends of the formica sheet. Small screws hold the formica to the rings. To save weight, I drilled 3/4" holes into the top ring.

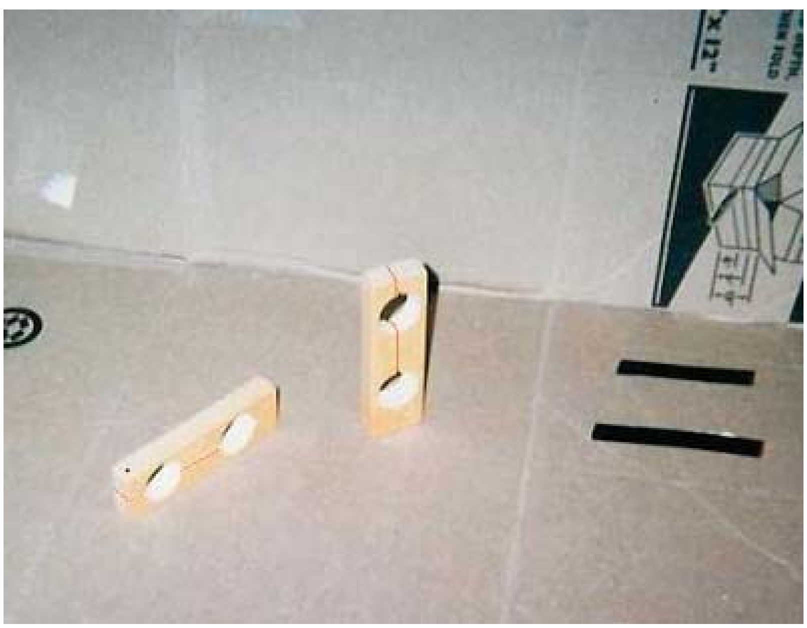
Without the focuser and secondary cage, it weighs only about 3 lbs. Compared to the first cage I made, it weighs over 2 lbs less. It's also about the same weight (1 square inch of formica weighs ~1 gram) as a similar cage made using 4 aluminum tubes and kydex to support the wood rings (ie the Kriege and Berry design) . Behind the new cage, note the large wooden ring (21 inches in diameter). This was a practice cut to see how well the circle cutter worked.



Here's the completed cage attached to the upper part of the truss. I used a rather simple helical focuser from Odyssey, because I wanted something light and this focuser weighs a little more than 100 grams.

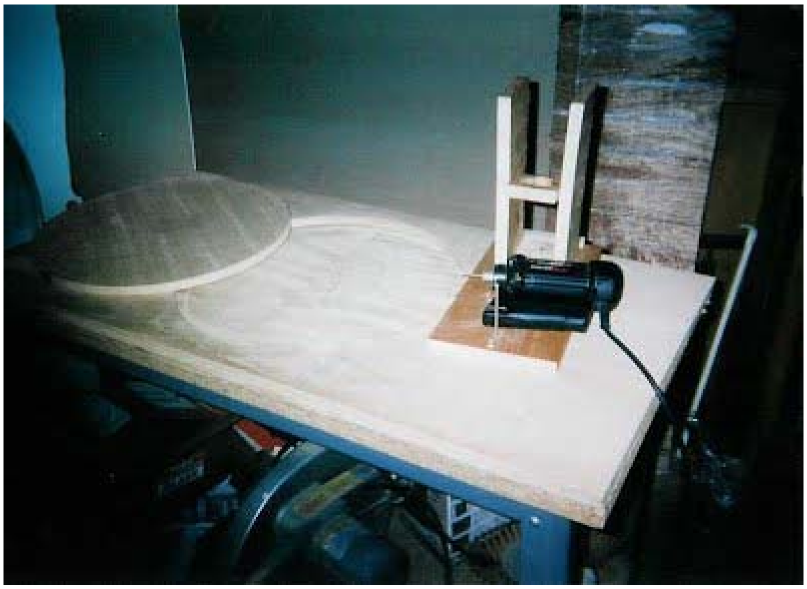
As it turned out, the hole I drilled (1 7/8 inch wide) in the formica for the focuser was very close to the right size. After some light sanding of the edge of the hole, the focuser fit in rather snugly. I made a simple wooden clamp, shown inside the cage and unpainted, to hold the focuser in place. It was painted flat black later. This arrangement worked okay, but the clamp needed tightening from time to time. Moreover, some of my friends could not focus images easily with this focuser design. So, I eventually replaced the focuser with a light weight (about 8 oz and a bit heavier than the Odyssey) Crayford type focuser from Jim's Mobile Inc..

I also added self-adhesive black flocking paper, available at Edmund Scientific, to the inside of the cage opposite the focuser opening. Unfortunately, the adhesive did not hold well, so I applied a very thin coat of Titebond II glue to the back of the paper and it adheres quite well now. All in all, this cage design has worked out very well.



Here are the truss clamps to hold the poles to the cage. They are made of 1 3/4" wide by 3/4" thick pine and each hole was drilled at an angle of 83 degrees to properly accomodate the pole, Next, I cut a slit lengthwise and almost through to the end. A bolt was passed through on the other end to clamp the poles down tightly. Another bolt was passed through the center between the holes to clamp the poles even tighter.

The clamps are placed over the poles and then bolted to the bottom of the secondary cage.



To make the mount and elevation bearings, I used a 2X4 foot sheet of plywood, 3/4 inch thick, and cut a hole 20 inches in diameter in the center with my homemade circle cutter. This disk and a duplicate were cut in half and glued together to make the elevation bearings for the scope.

The remainder of the sheet was cut in half and used to make the sides of the mount that would support the elevation bearings. I had little waste leftover with this sheet of wood..

Again, if you plan to try this method of cutting circles, please be very careful and don't do it if you have no skill using such high speed tools.

Here is the completed mount. I used the old mirror box and painted it white. If you look closely, you can see the holes for the old bearings. They were filled in later. I also used the same mirror mount as described above.

The mount was made from 3/4 inch plywood. The elevation bearings were made from two 3/4 inch thick disks glued together (I used Titebond II wood glue and lots of wood clamps!) that were cut in half. To give better support of the bearings, I added a strip of plywood to each side of the mount near the top as shown.

The base of the mount measures 18 3/4 X 18 3/4 inches. A strip of formica was used on the side bearings and small teflon pads were screwed (countersinked) into the top of the mount. It works much better than the old mount and weighs much less.

With the new, heavier focuser, the telescope is more top heavy and requires about 6 pounds in the back for balance. I think I can eliminate most of this this dead weight after I add a better cooling fans behind and in front of the mirror mount and attach a small telescope to the mirror box.

Here is the base of the mount, unpainted. The white plastic sheet base was salvaged from the old mount and trimmed down a bit. The plastic sheet pivots on top of the 3 teflon pads (~3X3 inches) that were screwed (countersinked) onto a board. I wanted to use "Ebony Star" laminate instead of a simple plastic sheet because I read it provides smoother motion, but I could not find it. The plastic sheet works okay, but I do have to apply a lubricant once in awhile to make the motion smoother ("Armor All" used to clean and protect car interiors works quite well).

Update: In 2011, I bought a 4'X8' sheet of FRP Laminate (or glassboard as some call it) at a local hardware store. This material is very similar to Ebony star. I simply glued a sheet of the laminate directly over the old plastic sheet. The results are amazing. The scope now moves with ease with very little stiction or excessive drag. I sold the remainder of the large sheet to another telescope builder.

The board holding the pads was painted underneath with exterior grade paint to keep out moisture. The rest of the mount was given several coats of varnish.

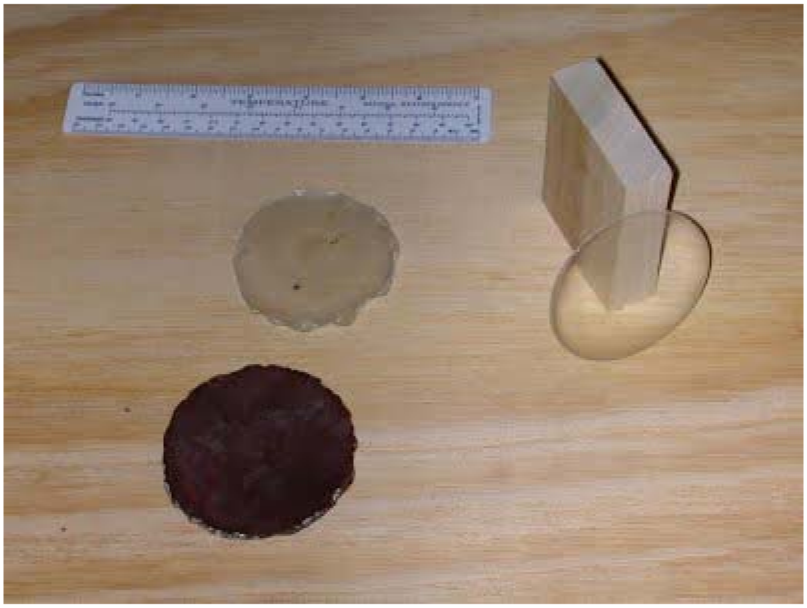
As with my earllier telescope design this one also breaks down into three parts: truss, mirror box and mount. The truss is held to the box with 4 bolts. Set-up and take down is rather easy. It typically takes less than 15 minutes to carry out the parts to the yard and assemble them. Collamination of the optics is usually a minor adjustment. Yet, there is one drawback; I can't easily transport this telescope in a car.

Pasted to one of the elevation bearings is a sheet of paper with elevation marks (0 to 90 degrees). I pasted a similar sheet on the azimuth bearing (0 to 359 degrees) in the mirror box. These crude setting circles helped me find the planet Uranus.

After use, the telescope is often stored in the garage of my next door neighbor.

I am very pleased with my remodeled telescope and it works much better than my first design. It has held up surprisingly well since 2002 and no failures in the components have occurred as of 2016.

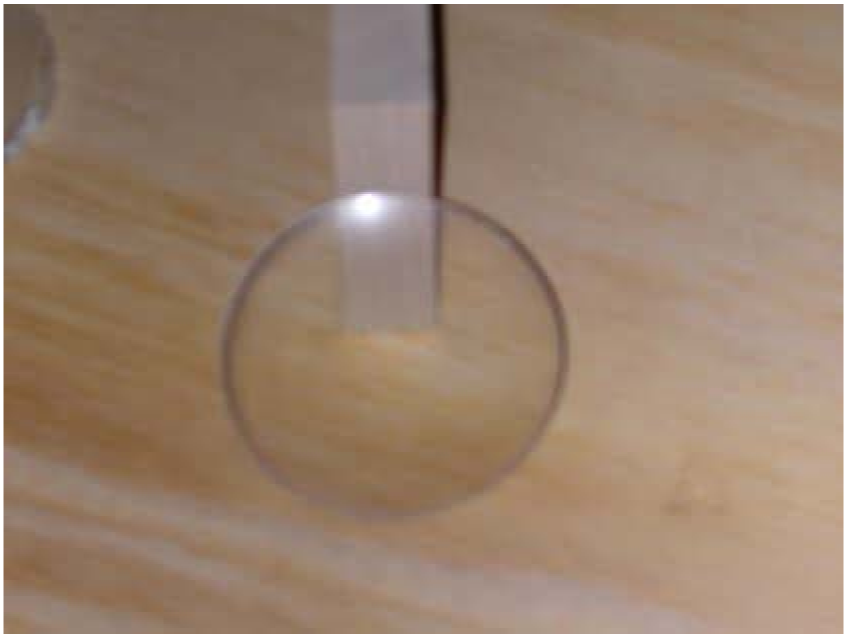
Homemade Refractor Telescope Lens...from a bottle bottom



In the late 1970s, I read that the optics maker Bernard Schmidt (inventor of the Schmidt camera/telescope) made a telescope lens using the glass from the bottom of a bottle when he was a boy. Since I had plenty of grit and pitch leftover from making an 8 inch mirror, I thought I would try my hand at making a lens in a such a way.

I had no instructions on how Mr. Schmidt made the lens and so I had to think things through as I progressed. I found a old cranberry juice jar (yes, they were once made of glass and not plastic) and carefully (lots of sharp edges) cut out the bottom of the jar. Next, I ground down the rough edge using a grinding stone and water and created a reasonably round disk 2 3/4 inches in diameter. This lens blank had a positive meniscus shape.

For the lens grinding tools I used the bottoms from two other jars. I did not bother grinding the edges of these tools so that they were nice and smooth. I just ground out all the sharp edges. I then proceeded to grind and polish both sides of the lens as if they were a small mirror. For a polishing tool I used the base and stem from an old wine glass. I flipped the base upside down, poured pitch onto the glass base, and stuck the stem into a block of wood. For pitch channels, I simply pressed onion bag netting into the pitch.



Once the lens was all polished out, it had a focal length of about 20 inches. There was also a noticable strain mark runnning across the glass. I next made a simple tube to hold the lens and put a 25 mm eyepiece in the other end. Later, I aimed this little refracting telescope at the moon and saw craters. I also looked at Jupiter at saw its 4 moons. Now the lens has it's share of wedge (uneven thickness around the edge) and spherical and chromatic abberation (the images were not sharp), but it does magnify objects. Aside from my time, it cost nothing to make.

If you want to try to grind your own refractor lens, you don't have to use a bottle bottom. Surplus Shed sells small, inexpensive lens blanks and you can buy the grit and polishing materials from Got Grit.

Making an Optical Flat

In 2003, I ground and polished a small 3 inch, F/9 telescope mirror and made a small telescope with it. The leftover glass grinding tool is 3 inches in diameter and one inch thick. It is clear glass and not likely plate glass. This tool sat on a shelf for years. In 2015 I decided to try my hand at making an optical flat with this 3 inch tool. Doing so requires two grinding tools and I obtained them from a fellow ATMer. I used information from this website to get started:

http://www.astrosurf.com/jwisn/diagonal.htm

The leftover glass tool, now called an "optical flat blank" was labeled "C" and the tools were labeled "A" and "B".

Grinding

As noted on the website above, the grinding cycle for each glass surface was as follows:

Blank A ground on top of Blank B,

Blank B on top of A,
Blank C on top of B,
Blank B on top of C,
Blank C on top of A and
Blank A on top of C.

A second cycle was started, but it was reversed, with it starting B on A, A on B, B on C, etc, and then I moved onto the next grit. This needs to be done for each grade of grit and so a lot of work is required. One can modify this grinding cycle as they see fit, but the key is to make it consistent for each surface and keep a detailed log of the work done. Too much or too little grinding on one or more surfaces will result in a convex or concave surface. And the amount of time grinding each side >must< be the same. Grinding one surface for a total of 80 minutes and another surface for say, 60 minutes with the same grit size will likely cause a non-flat surface. I used a timer to keep the grinding times equal for each cycle. I used short COC and W strokes to grind each surface for 10 or 15 minutes (plenty of time to grind a small 3 " blank for each grit) before moving to the next cycle.

Since my optical flat blank was once a grinding tool, it had a convex surface on one side. It took a little work to grind this surface to a flat one. I used the same range of grit sizes (120 grit to 5 micron) as used for mirror grinding to grind each surface. Note that I did not start with 80 grit. I did not need to. And for blanks that are already reasonably flat one could start with grits near 320 in size.

To check the flatness for all three surfaces a spherometer is a must and must be accurate to 0.001 inch. I made one using a Machinists Dial from Harbor Freight,

http://www.harborfreight.com/1-inch-travel-machinists-dial-indicator-623.html

some scrap wood, and other hardware. I checked the surfaces often and if one surface was either slightly convex or concave I did a little more grinding to correct it. Blanks on top tend to gain a concave surface, while blanks on the bottom gain convex surfaces. Knowing this, corrections could be made to keep all surfaces flat.

Polishing and Testing

Once fine grinding was completed, I made only one polishing lap. To help keep the surface flat, I needed to use a hard pitch lap. I used very old (1968!), hard burgundy pitch that I obtained from another ATMer. It worked okay, but the pitch was very brittle. I finished up polishing using a lap made with hard, artificial "Accu-Lap" material. I pressed the lap before polishing and did mostly short blank on top or blank on bottom W and COC strokes at 10 or 15 minute intervals. I used a timer to make sure the amount of polishing done either way was consistent.

Once I obtained a somewhat polished surface, I checked the flatness of the polished surface by placing it under a homemade mono-chromatic light source and then placed a highly accurate (1/20 wave) 2 inch diameter optical flat (borrowed from an ATM friend) placed on top of it. I used these websites to learn how to do the test and understand the fringe lines:

http://commons.wikimedia.org/wiki/File:Optical_flat_interference.svg

http://www.edmundoptics.com/technical-resources-center/marketing-literature/files/eo-optical-flat-manual.pdf

http://www.grahamoptical.com/interpnew.html

I also read some books on optical flats to understand how to read the fringe lines. Corrective polishing actions were mostly more polishing with the lap or flat on the bottom or top and then testing again. And good pressing the flat into the lap often helped. To polish out this small flat only took a few hours. In the end, I achieved an accuracy somewhere between 1/4 and 1/8 wave on the surface I made. If you want to make your own optical flat and perhaps use it as a secondary mirror in your telescope, you can buy small glass blanks at Surplusshed.com. Here are some key things to remember when making your flat:

(1) Use the right type of glass blank and with adequate thickness. I am not sure what type of glass makes up the flat I made. It could be pyrex or some other optical glass that is suitable for making flats. For beginners, avoid plate glass as it expands/contracts considerably with temperature changes. Don't use a overly thin blank as it can flex during grinding, causing problems with the surface.

(2) Be very consistent with the grinding of each surface. Do not skip steps in the grinding cycle. Keep a grinding and polishing log and use a timer to keep the grinding cycle time for each surface >exactly< the same.

(3) Use a spherometer to often check the flatness of each surface as you grind from one grit to the next. You can make one easily and at low cost.

(4) You are grinding three surfaces with each grit size and many steps are involved. This is a lot of work. And you will need special testing equipment to finish the flat.   Make sure you want to take on project like this before proceeding.

(5) Have fun learning something new. I may never use the flat I made for any project, but I really enjoyed making it.

Photos



H

On the left are the two optical flat tools ("A" and "B") covered in pitch. Polishing a flat and keeping it flat calls for hard pitch. The lap on the left is pitch from 1968 (very hard) and the lap on the right is made from hard "Accu-Lap", a man-made material. The photo on the right shows my 3 inch optical flat under a yellow monochromatic light source, which was built by a fellow ATMer. Note the coat-hanger device. The wire stretched across it was placed over the flat being tested. It determined the amount of curve in the fringe lines and the wave rating of my flat.

Here is my flat under test. A two inch wide, 1/20 wave flat, was placed on top and you can see the resulting fringe lines. My optical flat is, at best, about 1/8 wave accuracy and there is some slight irregularity in the surface as the fringe line curves are not smooth and uniform. Also the photo on the far right shows some slight edge defect.

My Astrophotos

Here are my first attempts at photographing the moon in 2002 with a digital camera. The first shot of Clavius at top, the best of several, was taken at 1st Quarter with my old homemade 8 inch F/8 telescope (spherical mirror), shown above, and stopped down to a 6 inch F/10.6 to improve the image sharpness. The camera lens was placed right over a 40 mm eyepiece with a 2X barlow and the camera was held in place with a homemade wooden bracket as shown in the photo above. The camera is a Nikon Coolpix 2500 digital camera set in manual mode and I used the zoom feature almost to the max along with the built in 10 second timer. No clock drive used.

The 8 inch telescope was completed in 1983, when pipe-mounts were still somewhat popular. Such mounts work okay, but they can take some time to settle down when the scope is aimed in a new direction. After these moon pics were taken, I made a pitch lap, polished off the 25 year old aluminum coating, and refigured the mirror to a parabola in 2008. The telescope performs much better and magnifications of the moon to 400X or more are now possible. I guess one could say that it took me 25 years to finish the mirror!

The pics above are thru the stopped down 8 inch telescope. The last one shows Rupes Recta (thin black line). Several years ago I tried photographing this feature with a 35mm camera and film, but had little luck.

This photo of Clavius was made using my homemade 14.5 inch scope (no clock drive) with the 2X barlow and 40 mm eyepiece with the Coolpix camera. Again I used the zoom feature and no bracket was used to hold the camera. I just held it over the eyepiece as steady as I could. Seeing conditions were not good.

I later made a bracket for the 14.5 incher to hold the camera steady and took the photo of the 1st Quarter moon shown in next photo using the 10 second timer.   This photo was made using a 25mm eyepiece and I did not "zoom" in as much. Seeing conditons were better, but the image is still not as sharp as seen by my own eyes through the eyepiece.

This last photo was taken using another camera, the Canon PowerShot A560 and the 14.5 inch telescope. Seeing conditions were excellent that night. I did not use the zoom feature in the camera. Finer details can be seen. Again, no clock drive was used. I just placed the camera over the eyepiece. Actual lunar details seen with my eye were better than shown in the pic.

Now these shots are certainly not perfect, but I am amazed at what a digital camera can accomplish in the hands of a novice like me. I will keep trying different settings in the cameras to see if I can further improve future pics of the moon.

ATM Links:

Victor's Telescope Making Webpage An excellent site for beginners. Lots of information on mirror and telescope making. I found it very useful.

Large thin mirror making by Mel Bartels A number of the techniques I used to make the 14.5 inch mirror came from this website. It was very helpful.

Here are some other large mirror making sites you might find helpful:

Making a Large Mirror - Part I

Making a Large Mirror - Part II

14 inch telescope mirror making log

Worried about all those bubbles in your mirror blank? Then take a look at the Mt. Wilson 100 inch telescope mirror! This plate glass mirror was last polished and figured in 1916, but still provides excellent images. It also proves that glass does not "flow" over time as some believe. Take a look: 100 inch Telescope Mirror

Mirror Testing:

If you are concerned that you can't make a good Foucault Tester or use it correctly, then try the "Matching Ronchi Test". The equipment is much easier to make and interpreting test resutls is more simple. After completing the 14.5 inch mirror I refigured my old 8 inch f/8 mirror using this test method.

Sources of telescope and mirror making supplies:

Surplus Shed All kinds of inexpensive eyepieces, lenses, small telescope mirrors, small glass blanks, and other optics.

Willman-Bell This company offers mirror kits up to 12.5 inches, but they are recently sold out (as of late 2011). They also offer inexpensive Ronchi gratings and a wide range of ATM books.

Thin Plate Glass Blanks Here you can buy thin plate glass blanks for a reasonable price. With care you can make an excellent mirror using plate glass.

Got Grit Supplies inexpensive grinding and polishing materials, as well as thin mirror blanks.

Salem Distributing Co. Supplier of mirror grinding and polishing materials, including Microgrit and Gugolz pitch.

Newport Glass This site provides kits and materials for making small and large mirrors. Kit prices are expensive.

Ebay I have not purchased any optics there, but search the site for "mirror blanks" Sometimes there are blanks listed at low prices. Also check other websites that sell used items

Need a mirror cooling fan, power supplies, or other electonics for your telescope? Try, All-Electronics

Well after I finished the telescope, I found this site offering those hard to find threaded inserts or tube connectors: McMaster-Carr

Weather Links:

The following webpage provides upper-air data that I use to help determine if the seeing conditions will be good or bad for viewing the moon and planets: Upper-air Soundings

The data is collected from rawinsondes or "weather balloons" released twice per day (00:00 and 12:00 UTC) by the NOAA National Weather Service and from hundreds of other stations around the world. You can see wind profiles from the surface to over 30 km up. If you don't understand upper-air "Skew-T Log P" charts, you can display a table showing the data (heights are in meters and wind speeds in knots).

Generally speaking, the lighter the winds aloft, the better the seeing (ie less turbulence) conditions tend to be. I have found that when winds at the surface are light and less than about 25 knots aloft, excellent seeing conditions are possible. On nights when the winds are changing direction with height and exceed about 75 knots in the profile, it's a good bet the views of the planets will not be sharp at high power. Of course there are other factors such as local low level turbulence near the ground that may effect the seeing conditions.

Here's another website that observers might find useful: NOAA Turbulence Forecasts   This NOAA website shows up to 12 hour computer forecasts of atmospheric turbulence from 11,000 to 45,000 feet. When the turbulence forecast maps show yellow area (lots of turbulence) over my observing site I have found that it's a good bet that the seeing won't be good for viewing the planets. When there is no color shading over my location, views of the planets and moon at high power are likely.

NOAA CAT Forecasts Another NOAA website that provides Clear Air Turbulence forecasts from 30,000 to 34,000 feet:

Bill's Homemade Weather Instruments. A description of my inexpensive homebuilt windvane that displays the wind direction on a LED display inside your home or office. I also provide instructions on making simple thermometers and humidity sensors.

Other Links

My recipe for hot sauce Making your own hot sauce is easy and tastes great.

Web content created 2000 - 2014

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Disclaimer Statement: The information on this website is provided for informational purposes only. The telescope making techniques described by the author worked for him, but your results may vary. The author disclaims any liability for any damages, injuries, or any other losses of any kind you may incur.

About the Author: "H. William James" is the pen name for a professional scientist with over 30 years of experience. For over 40 years he has enjoyed spending his spare time designing and building, telescopes, low cost scientific instrumentation and other mechanical or electrical devices. He is also interested in botany and organic gardening.