

Building a 6-Inch Unobstructed Yolo-Newtonian

I have designed an optical system that can be thought of as an unobstructed Newtonian telescope. This system uses a standard paraboloidal primary and a small secondary mirror. In this telescope, however, the secondary is not flat but is concave and cancels the aberrations introduced by the tilted primary; the resulting image quality is good as long as the primary is slow.

The optical system can also be considered an extreme case of a Yolo; therefore the formulas given in "How To Design a Yolo Telescope" (*Telescope Making* #37) can be used to predesign it. Because the tilt of the secondary is quite large, it is necessary to optimize the predesign using ray tracing software.

My design uses a 6-inch $f/12$ paraboloidal primary. The characteristics of the system are given in the table with the same notation used in "How To Design a Yolo Telescope." The field performance was evaluated using spot diagrams for the on-axis image, and five positions around a semifield of view of $1/4$ degree. The field is limited by about $1/2$ wave of linear astigmatism, and the image plane is tilted 8 degrees. The image anamorphism is 1.4 percent.

TMs who do not have access to a computer still can design their own unobstructed Newtonians. This can be done by optimizing their predesigns using my optimized design as a guide. To do this, design my system using the formulas given, estimate the percentage error, and then correct the design.

The correction is first applied to the secondary angle of tilt, then to the secondary long radius of curvature. The correct setting of these parameters make the secondary cancel the on-axis coma and astigmatism produced by the primary. This method will work provided the systems considered are similar to my design, say, for systems using a 6-inch primary with a focal ratio between $f/10$ and $f/14$. Scaling can also be done to specify smaller systems.

It must be remembered that minor adjustments to correct residual on-axis aberrations due to fabrication errors and slight calculation errors can always be done after the optics have been made. These adjustments are done changing the secondary position and tilt.

Making the Secondary

The surface of the secondary mirror is a section of a

concave oblate ellipsoid that has two principal radii of curvature. The first step to make the mirror is to grind a long radius of curvature sphere. Because the difference in the radii of curvature, R_s and R_t is large, the double curvature must be generated during the last stage of fine grinding. For this purpose, long unidirectional grinding strokes are performed with the mirror on top of a full-sized grinding tool. This shortens the mirror's radius of curvature in the chosen direction.

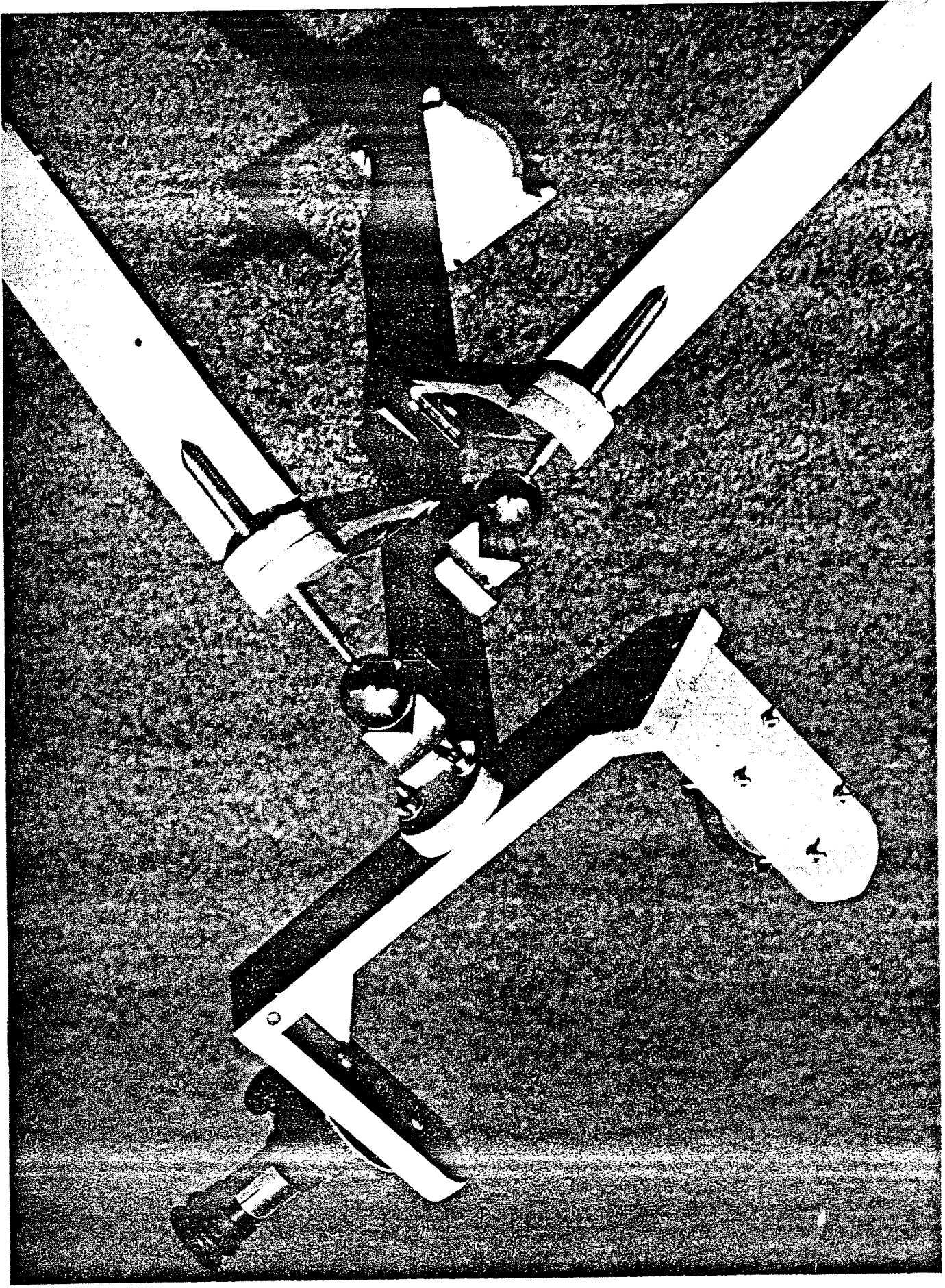
This process is very similar to traditional grinding except that the well-known sequence of events happens unidirectionally. Namely, a deep excavation in the center of the mirror is made using a long stroke, and then the rest of the surface is made uniform in curvature by reducing the stroke length. In fact, for this surface smoothing, you can perform normal grinding strokes in all directions doing only translational movements.

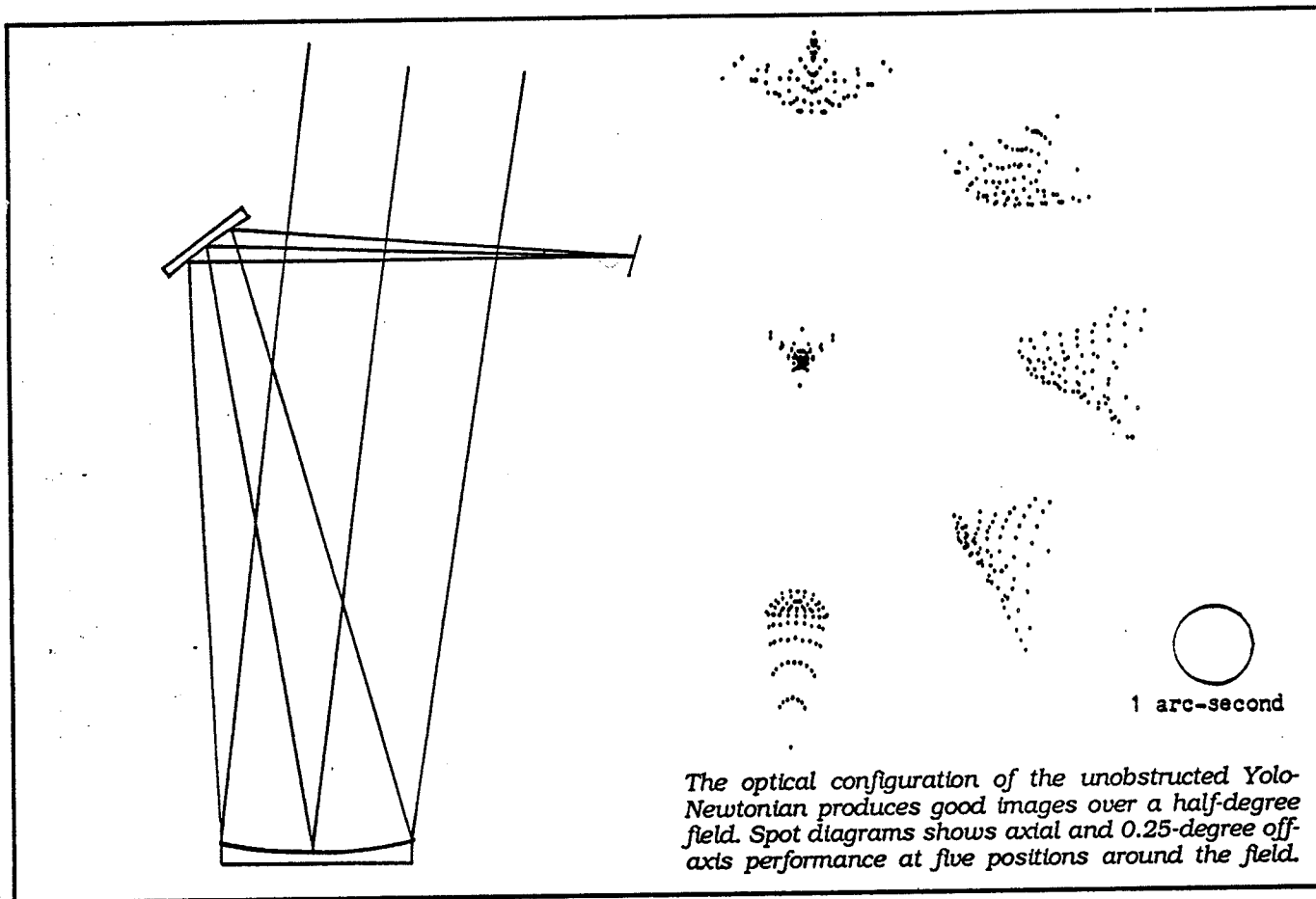
In my article in *TM*#37, I suggested a double four-bar linkage to constrain the rotation of the grinding or polishing tool, but the entire process can be done by hand. For this optical system the difference in sag of the two principal sections is so large that maintaining the parallelism between tool and mirror to within a few degrees becomes important. One can easily feel the effects of a small rotation in the grinding or polishing movements, and eventually one learns to direct his or her hands very precisely. Because the surface has two perpendicular planes of symmetry, you can rotate the mirror 180 degrees once in a while.

To monitor the generation process, I painted the mirror surface with a China marker, a waxy type of pencil. After removing the excess paint by scraping it with a razor blade dragged almost parallel to the blank, the surface became shiny enough to reflect light and made an optical test possible. The appearance of a ground surface before and after the scraping is illustrated in the photo.

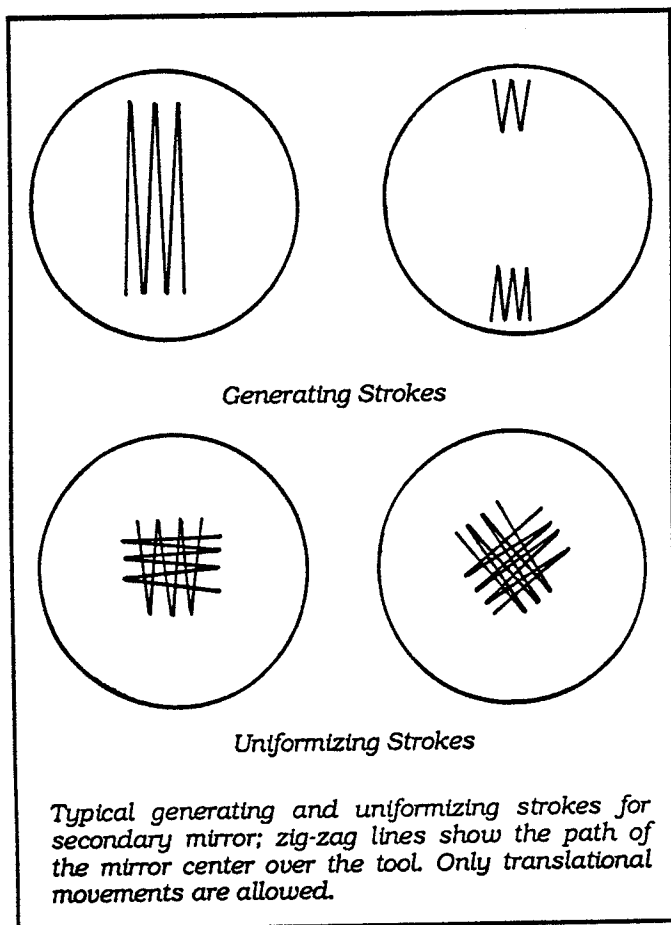
You can null test the mirror at its conjugate foci, but I tested the secondary using the aluminized primary

This novel optical design on its novel mounting makes for a very unusual-looking telescope. The Yolo-Newtonian offers an unobstructed aperture and an optical system consisting of just two elements.





The optical configuration of the unobstructed Yolo-Newtonian produces good images over a half-degree field. Spot diagrams show axial and 0.25-degree off-axis performance at five positions around the field.



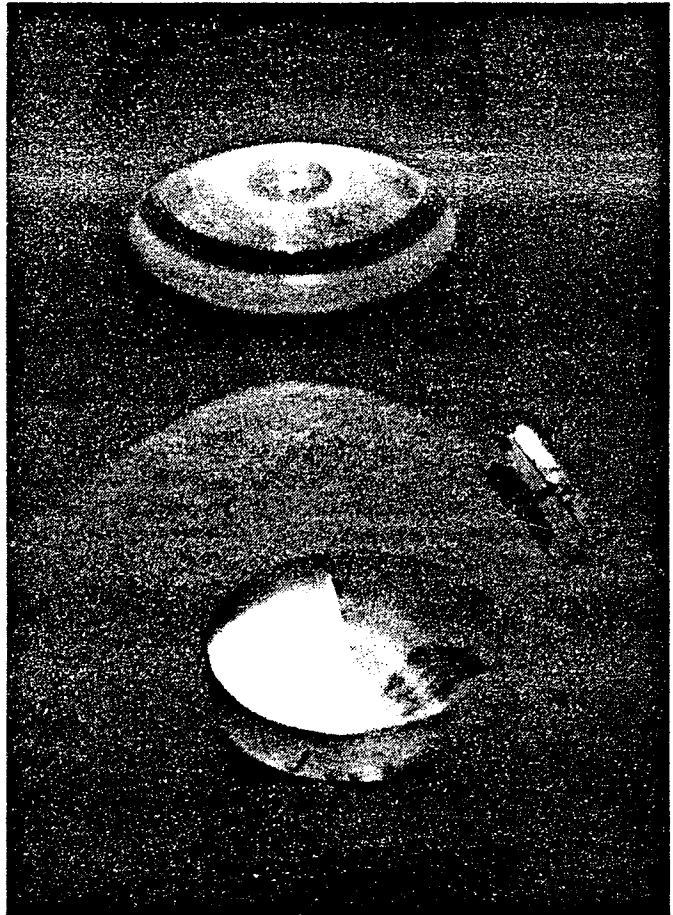
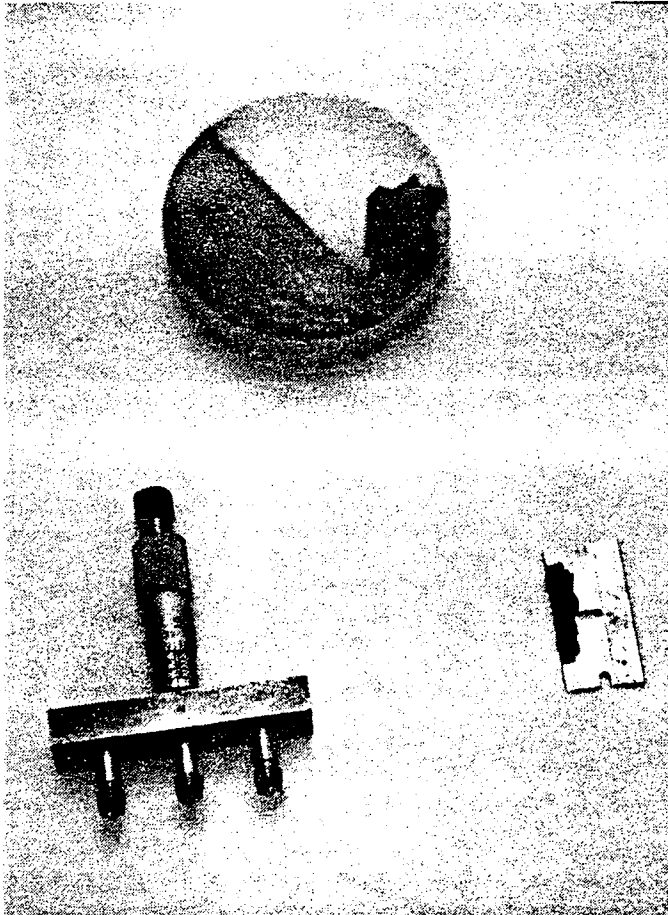
mirror. I prefer the test in which the secondary is placed at a specific angle with respect to the axis of the aluminized primary mirror because of the reduced test distances.

The purpose of these tests is to verify that no astigmatism is present when the secondary is tilted by the angle α , as calculated using the formula given in the above-mentioned article. These tests insure that the appropriate difference in curvature has been generated. The astigmatism can be detected by looking at the image of a point source with an eyepiece or by projecting the image on a fine ground glass.

Once the double curvature is generated, make a full-sized polishing lap and polish the secondary in a manner similar to the polishing of a standard mirror but doing only translational polishing movements. Either one of the methods mentioned can be used for the final test of the secondary. The second method using the primary is not a null test, and some residual coma will be observed. However, a smooth surface must be obtained.

The blank for my secondary is 3 inches in diameter, considerably oversized to allow for a turned-down edge. This problem could easily result if significant movements of rotation happen during the polishing. The clear aperture of the secondary is elliptical as in a regular Newtonian. The smaller diameter, that is, Φ_s , is the one used in the calculations. The large diameter, without considering the field size, is given approximately by $\sqrt{2} \cdot \Phi_s$.

The curvature of the starting long radius sphere was measured with a two-leg spherometer. The sag to measure was so small, about 0.001 inches, that a verification was necessary. This was done during the test in which the primary was used. Knowing the radius of the



primary R_p , the power of the secondary,

$$P_s = 2 \cdot \cos(\alpha) / R_s,$$

the primary to secondary test distance q , and the secondary to test point distance s , you can find out the short radius of the secondary from the relation:

$$P_s = (1/s) - (1/(R_p - q)),$$

which is the well-known lens formula.

To recap, then, here are the steps you should follow in making the ellipsoidal secondary:

1. Use an oversize blank (3 inches) and fine-grind it to a sphere of radius R_t .

2. Grind in the short radius by doing long, unidirectional grinding strokes for 30 minutes, with the mirror on top. Occasionally rotate the mirror or tool a full 180° .

3. Uniformize the surface by doing normal-length unidirectional strokes for 20 minutes.

4. Determine the difference in radii using either method. Method 1: Measuring the sag in the two principal meridians using a two-leg spherometer. Method 2: Coat the fine-ground surface with a waxy pencil, scrape off the excess with a razor blade, and determine the angle α at which you see no astigmatism.

5. Proceed toward the correct difference in radii, by repeating steps 2 through 4, until you see the correct sag in both meridians or until you see no astigmatism at the angle α specified by the design. Make sure the surface is uniform before proceeding.

6. Polish with a full-size polishing lap using translational strokes only; do not rotate the tool or mirror.

