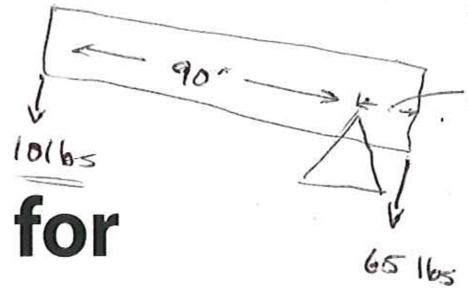


A Balancing Act for Dobsonian Telescopes

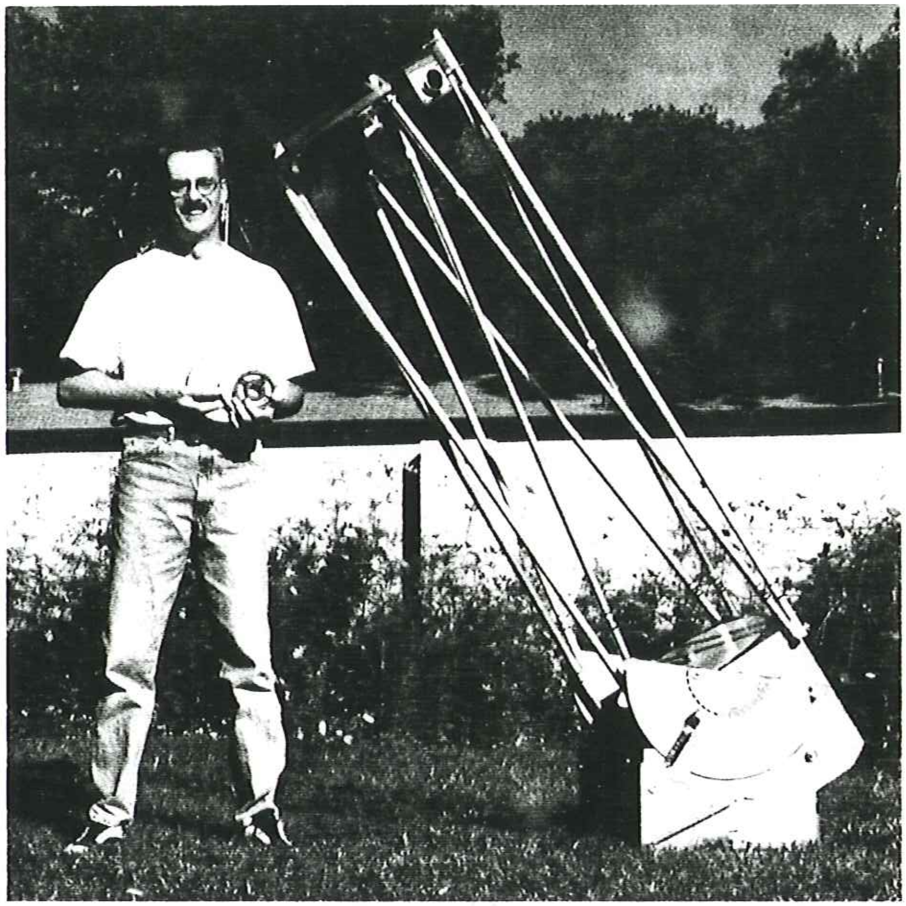
Achieve perfect balance using springs instead of heavy counterweights.

By Tom Krajci

MANY OF US DREAM OF building large-aperture, lightweight telescopes. Such instruments can easily be transported to dark-sky sites for awe-inspiring deep-sky views. Cutting-edge amateur telescope makers, like Gary Wolanski (*S&T:* August 1999, page 128), are constantly incorporating new designs and materials to make ever-larger instruments more and more portable.

For a Dobsonian telescope to work properly it has to be balanced. However, given the layout of many of the new lightweight designs, every extra pound at the focuser end of the scope requires *five* pounds of extra weight at the mirror end. Obviously, unless the front of the scope is very light, or the back very heavy, some kind of balance problem is likely.

One of the design goals I had when constructing my 16-inch truss-tube Dobsonian was that it be transportable in my midsize car. This necessitated a low-profile rocker box and altitude bearing assembly. It was apparent early on that such a configuration would make it difficult to position the scope's center of gravity at the trunnion axis. To make matters worse, the upper end of my tube assembly turned out to be heavier than I had planned. It seemed as if I had painted myself into the proverbial corner.



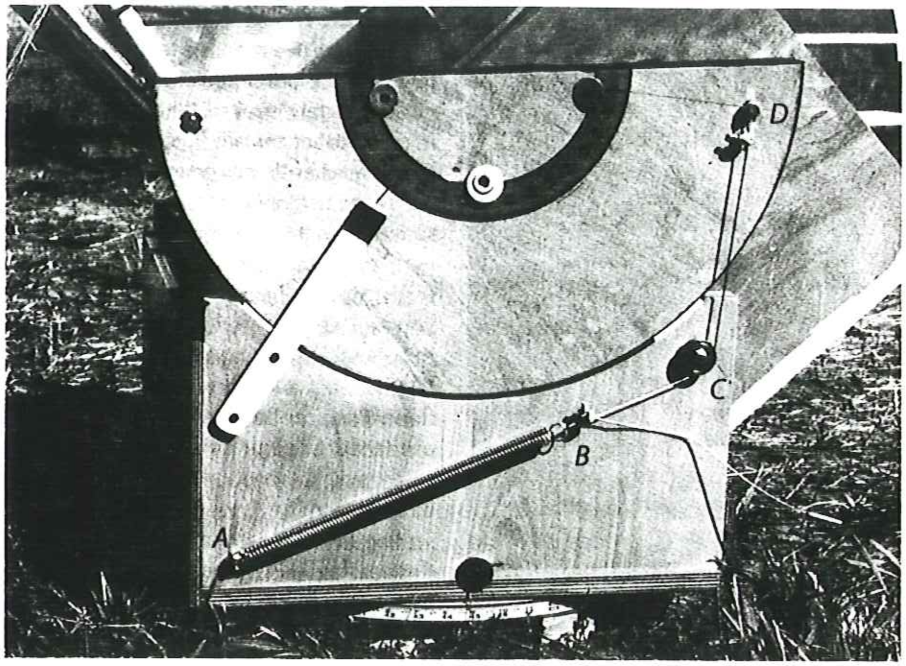
Author Tom Krajci holds the 15 pounds of counterweights that would have been needed to balance his 16-inch f/6 Dobsonian telescope if he had not implemented his virtual counterweight system. All photographs courtesy the author.

The Search for Solutions

To look at the situation from another angle, the real problem was that extra torque was being applied to the altitude trunnion by the imbalanced weight of the tube. What I wanted was a method of counteracting this torque without adding extra weight. Since I was obviously not the first telescope maker to run up against this problem, I didn't have to look far to find a variety of interesting solutions from those who had gone before me.

A search of the amateur literature turned up several interesting proposals. In the June 1981 issue of *Sky & Telescope* (page 549) Thomas Caudell advances the idea of counteracting telescope imbalance on a German equatorial mount by using a spring instead of counterweights. The principal shortcoming of this method is that torque generated by the spring varies linearly as it stretches, but the torque resulting from the imbalanced scope varies sinusoidally as the angle of the scope changes. However, as Caudell points out, one need not perfectly match the torque caused by the imbalance with that generated by the spring since in most cases friction in the telescope mount can handle the remaining imbalance. Thus, the idea of using springs had a lot of appeal.

In the Spring 1996 issue of *Amateur Astronomy* (page 50) Barry Peckham



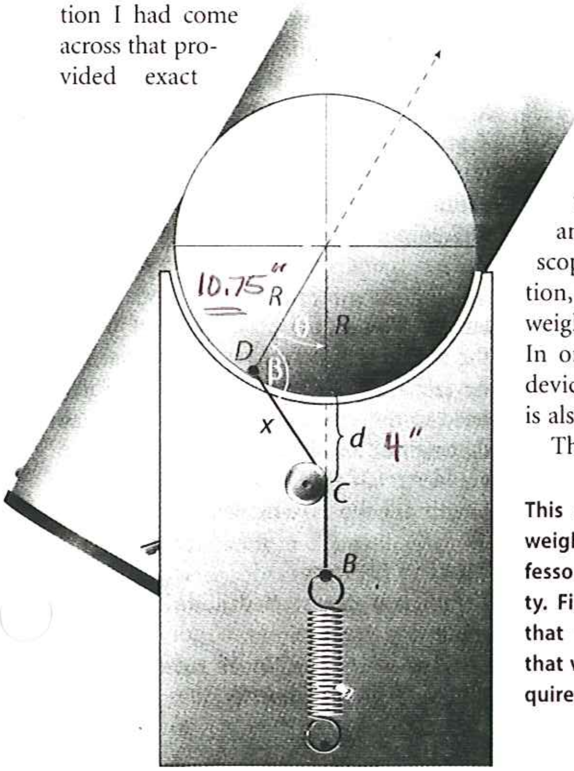
The spring counterweight system as applied to Tom Krajci's Dobsonian. *A* is the anchor point for the spring that is attached to a wire rope at *B*. The rope bears against the pulley at *C* before being attached to the telescope at *D*.

demonstrates that spring counterweights can work on a large Dobsonian to "fine-tune" the scope's balance, an idea that Chris Westland takes a step further in the Winter 1998 issue. Westland carefully analyzes the forces involved in an imbalanced telescope and shows that a specially designed cam, spring, cable, and pulley arrangement could allow a telescope to "defy gravity." This was the first solution I had come across that provided exact counterbalancing at all telescope elevations, but I was not eager to fabricate the necessary cam.

Posting a query regarding spring counterweights to the ATM e-mail list produced a number of solutions, including one by Stuart Field, a physics professor at Colorado State University. Field proposed the general layout of the spring counterweight system shown in the illustration below. A spring is fixed at one end, *A*, and is connected to a wire rope at its other end, *B*. The rope then passes around a pulley at *C* and is finally connected to the altitude bearing at *D*. Points *C*, *D*, and the center of the altitude bearing are collinear when the telescope points straight up and angle $\theta = 0°$. Thus θ is the angle of the scope as measured from its vertical position, so that the torque induced by any weight imbalance is proportional to $\sin\theta$. In order to balance properly, the spring device must provide a countertorque that is also proportional to $\sin\theta$.

The position of the attachment point (*A*) and the length of the wire rope need careful planning. If the rope is disconnected from point *D* and the spring is allowed to completely relax, the end of the rope should be at pulley *C*. With this adjustment we see that in attaching the spring to *D* we must pull the rope a distance x from the pulley, stretching the spring by an equal amount. When $\theta = 0°$, the spring is still stretched, but by a minimum amount where $x = d$. Since the force due to a spring is proportional to the amount it is stretched from its relaxed length, we can write $F = kx$, where F is the force applied to point *D* (as transmitted through the rope) and k is the *spring constant* — a measure of the stiffness of the spring.

Field's analysis shows that a combination of proper spring pretensioning, location of the attachment points, and pulley geometry can transform the spring's linear torque into the sinusoidal torque required. Here was a solution I could use! Unlike earlier spring counterweight solutions, this method exactly counterbalances the telescope at all altitudes. Best of all, it is simple — no specially made cams or exotic hardware are needed.

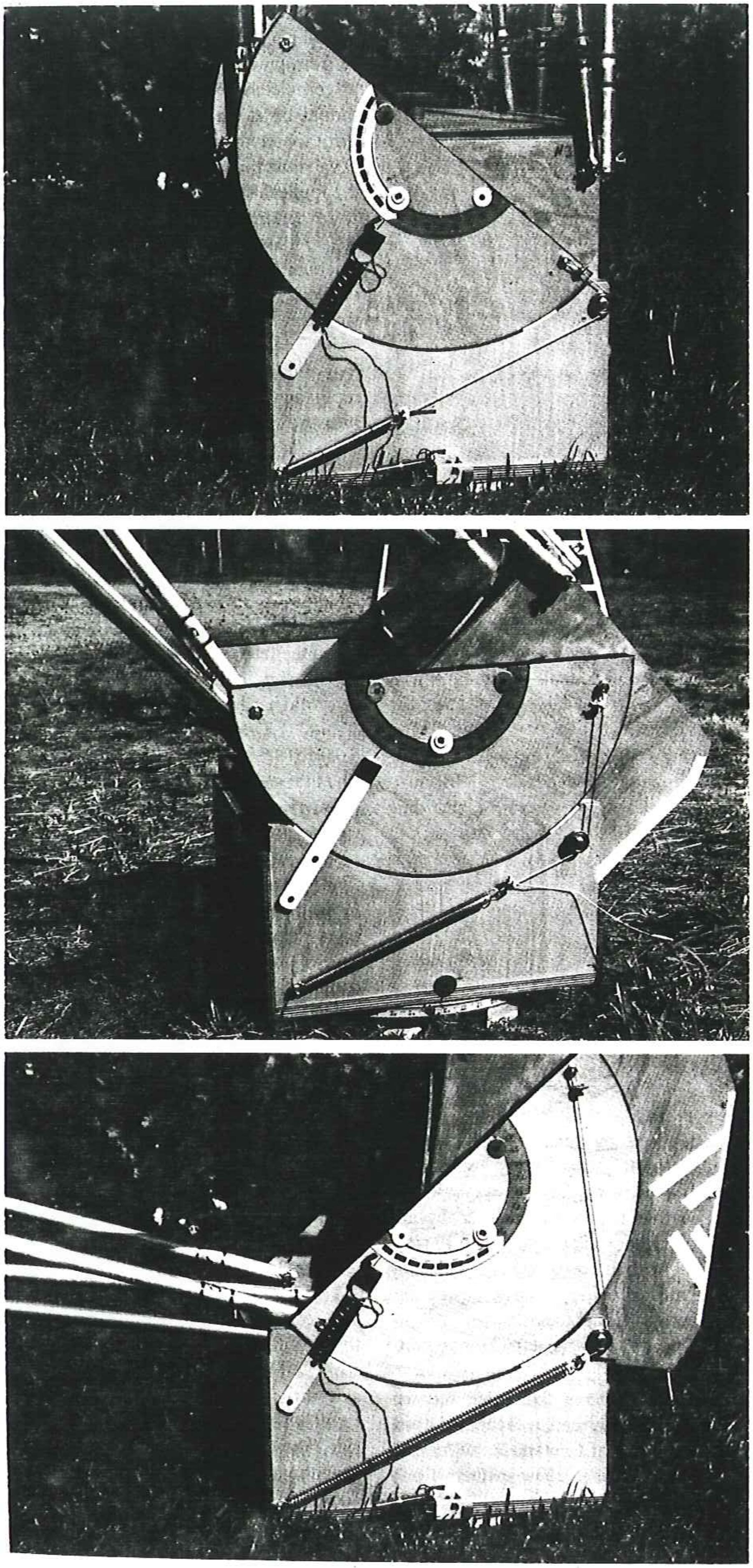


This schematic shows the spring counterweight system proposed by Stuart Field, professor of physics at Colorado State University. Field was able to show mathematically that this arrangement produces a torque that varies sinusoidally — exactly what is required to balance a telescope.

Springing into Action

The first step in implementing this virtual counterweight system is to determine the exact amount of imbalance in your telescope's tube assembly. An excellent book, *The Dobsonian Telescope* (Willmann-Bell, 1997) by David Kriege and Richard Berry, gives detailed instructions in chapter 3, page 59, on how to calculate the required counterbalancing. The method is pretty straightforward. All you need to know is how much the pieces weigh and how far they are from the desired balance point. For example, if your finderscope weighs 3 pounds and is positioned 60 inches away from the balance point, then it has a torque of 180 inch-pounds. To counter its weight you will need an equal amount of torque on the other side of the balance point. This could mean a 15-pound weight 12 inches from the pivot point, or a 7½-pound weight 24 inches from the balance point — the choice depends on the configuration of your particular scope. Add up all the inch-pounds on one side of the balance point and compare the result with what you have on the other side. The difference is the added counterweighting you need.

Since I was building my scope from scratch I knew the weight and position of all the components. However, if you al-



Tom Krajci's spring counterweight system is shown here in action. Note that when the telescope is pointed straight up, the spring is not completely recoiled. When the telescope is pointed horizontally *(bottom image)*, the spring reaches its maximum length. It is important to determine beforehand how far the spring can safely stretch.

ready have a completed tube assembly you can easily determine the amount of imbalance by laying your tube horizontally on top of a broom handle on the floor. Position the tube so that the center of the altitude trunnions is positioned directly over the broom handle. Use a scale and measure how nose-heavy the tube assembly is. Make note of the distance from the bearing axis to the scale and multiply the weight by that distance. For example, 3¾ pounds and 70 inches will give you 262½ inch-pounds of torque.

The next step is to acquire a spring and determine its spring coefficient *(k)* and stretch length. The value for *k* can be determined by hanging an object of known weight from the spring and measuring how far the spring stretches. Simply divide the weight by the stretch distance and you have *k* in pounds per inch. Some springs come "pretensioned" — their coils are tight against each other when the spring is relaxed. With such springs you need to initially add enough weight to extend the spring a small amount from its retracted position. Now you're set to find *k* as before; just don't count this first weight in your calculation. I used two identical, pretensioned springs on my telescope, each with a *k* value of approximately 1.13 pounds per inch. I also had to keep spring tension above a minimum of 4 pounds to keep the springs from fully retracting. Since both springs worked together, in tandem, they provided a total *k* of 2.26 pounds per inch.

The second spring parameter you have to determine is maximum safe stretch length. This is the point beyond which the spring will permanently deform and never return to its original length. You'll need to test one spring to destruction to determine this. The springs I purchased could stretch about 18 inches before deforming. I chose 16 inches as a safe limit.

Making It Work

Before you can start drilling holes and mounting springs, it's a good idea to make a scale drawing of your setup so that you can determine values for *R* (see the illustration on page 131) and d to make sure that your rocker box is large enough to accommodate the length of the fully stretched spring. R normally can't be larger than the radius of your altitude bearings and d can't be too large or you'll need to build a larger rocker box. (As a starting point, I recommend that R be no more than 80 percent of your altitude bearing's radius and that d be approximately 35 percent of R.)

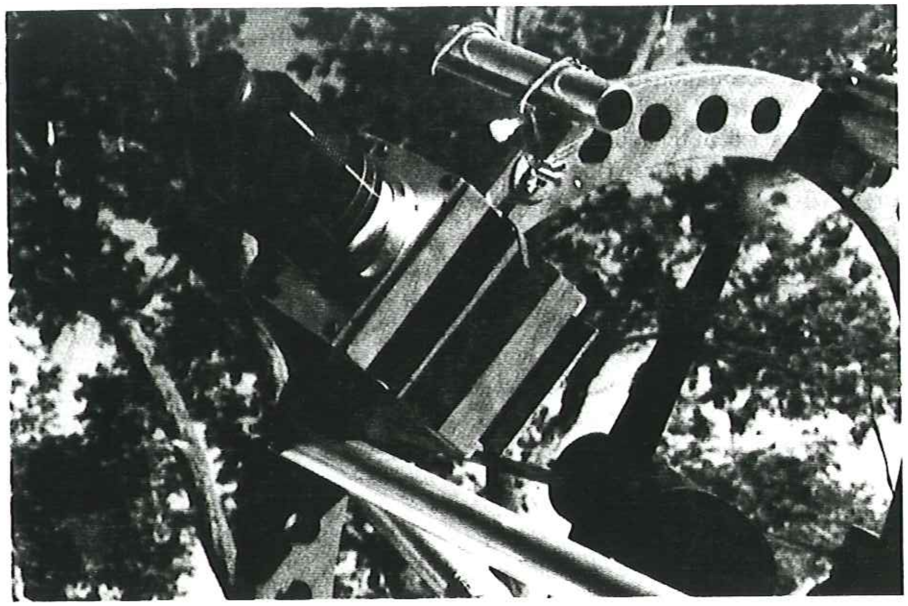
Field's analysis shows that the spring will generate a maximum torque that is equal to $kR(R + d)$. With my scope I needed 264 inch-pounds to properly balance the tube. The maximum total length the spring will need to stretch is approximated by $R + 2d$. With the spring I had chosen, this length could not exceed 16 inches. The maximum amount of stretch room you need on your rocker box is approximated by $R + d$. I had about 12 inches of available stretch room on my rocker box with a diagonal spring placement.

Arriving at a working solution is a classic case of solving multiple equations that contain several variables. The best strategy is to try to vary only one parameter at a time. If you have already chosen your spring and built your rocker box, then you just need to find values for d and R that produce the torque needed to balance your scope while staying within the spring safety and stretch-room constraints described above.

To avoid having to play around with a lot of numbers, I put together a spreadsheet to test various combinations and found many possible solutions for d and R. I settled on R as 9¼ inches and d as 3½ inches. This generated a torque value of 266½ inch-pounds — within 1 percent of my required value! Further analysis showed that the spring would have to stretch a maximum length of 15¾ inches (just under my safety limit) and that I needed 12 inches of stretch room in my rocker box. With this information I was finally ready to build my spring counterbalance system.

The pictures on page 132 show my results. On opposite sides of the rocker box are identical counterbalance devices that share equally in providing the necessary torque. Each spring is attached to a wire rope that passes around a pulley wheel. All parts were obtained from a local hardware store.

Since my telescope is balanced for heavy, 2-inch eyepieces, what do I do when I use lighter, 1¼-inch eyepieces?



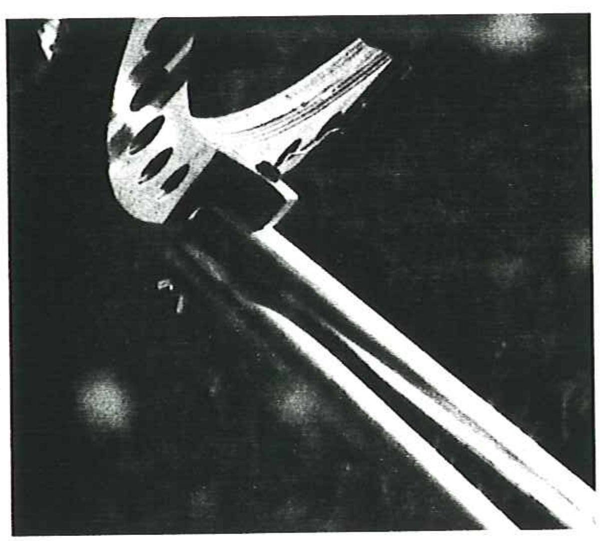
In order to minimize the amount of counterbalancing needed, it is important to ensure that the instrument's spider-cage assembly is as lightweight as possible. Krajci's fondness for his heavy 2-inch Nagler eyepiece meant that some counterweighting would be necessary in spite of his lightweight upper-tube design.

Simple. I temporarily disconnect one of the two springs. Since both springs together counterbalance about 3¼ pounds of excess weight in the upper end of my tube, using only one spring results in almost a 2-pound change in torque — the difference between my heaviest and lightest eyepieces. Another solution would be to make the distance of the attachment point (*D*) adjustable to allow for a range of maximum spring torques.

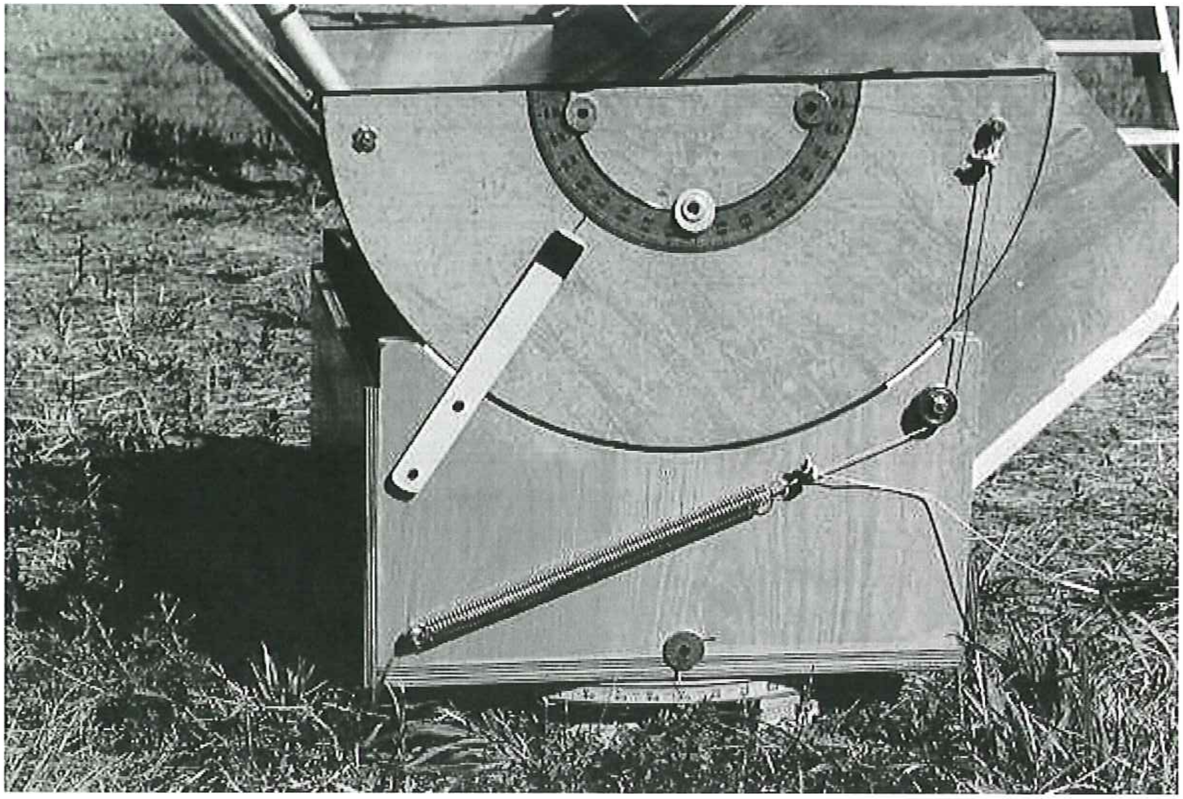
If this all sounds too good to be true, you should be aware that the design does have its limitations. A spring counterweight system does not change the center of gravity — my scope is still front-heavy. If the center of gravity is too far forward, the instrument could become unstable and in extreme cases even tip over! These potential problems are worst when the telescope tube is horizontal. I have noticed my scope is slightly less stable when aimed near the horizon than when pointed near the zenith, but this effect is hardly objectionable.

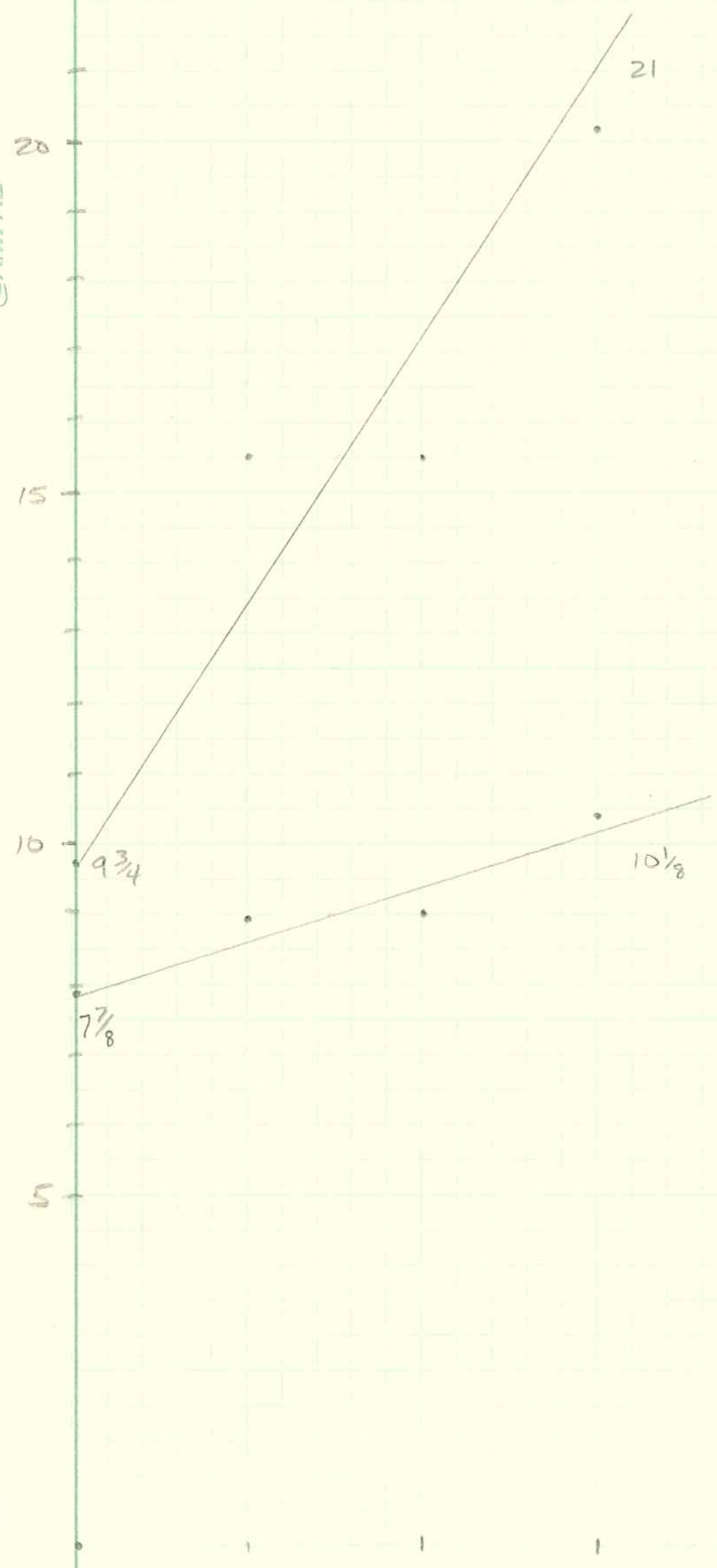
This spring-counterweight system will not be needed on every Dobsonian telescope, but for those trying to design lightweight, compact instruments it may make the difference between a scope that can be transported to a dark site and a scope that has to stay at home.

One way of minimizing the weight of the diagonal cage of a truss-tube Dobsonian is to eliminate the heavy clamping mechanisms favored by many telescope makers. Krajci's simple solution is effective and lightweight. Note the single ring of plywood that holds the whole upper cage together.



TOM KRAJCI *is an avid amateur astronomer and telescope builder. Additional aspects of his scope can be seen at http://coeweb1.gsu.edu/spehar/FOCUS/Astronomy/krajci/krajci.htm. He invites reader inquiries by writing krajcit@3lefties.com, or 1688 Cross Bow Circle, Clovis, NM 881101.*





$$K = \frac{21 - 9.75}{3} = 3.75 \ \frac{\text{lbs}}{\text{in}}$$

$$K = \frac{10.125 - 7.875}{3} = .43 \ \frac{\text{lbs}}{\text{in}}$$

Force	k	d	R	
513.8086	3.75	4	9.875	
502.7344	3.75	4	9.75	4
491.7773	3.75	4	9.625	
480.9375	3.75	4	9.5	
470.2148	3.75	4	9.375	
459.6094	3.75	4	9.25	
449.1211	3.75	4	9.125	
438.75	3.75	4	9	

504.5508	3.75	3.75	9.875	
493.5938	3.75	3.75	9.75	3 3/4
482.7539	3.75	3.75	9.625	
472.0313	3.75	3.75	9.5	
461.4258	3.75	3.75	9.375	
450.9375	3.75	3.75	9.25	
440.5664	3.75	3.75	9.125	
430.3125	3.75	3.75	9	

499.9219	3.75	3.625	9.875	
489.0234	3.75	3.625	9.75	3 5/8
478.2422	3.75	3.625	9.625	
467.5781	3.75	3.625	9.5	
457.0313	3.75	3.625	9.375	
446.6016	3.75	3.625	9.25	
436.2891	3.75	3.625	9.125	
426.0938	3.75	3.625	9	

495.293	3.75	3.5	9.875	
484.4531	3.75	3.5	9.75	3 1/2
473.7305	3.75	3.5	9.625	
463.125	3.75	3.5	9.5	
452.6367	3.75	3.5	9.375	
442.2656	3.75	3.5	9.25	
432.0117	3.75	3.5	9.125	
421.875	3.75	3.5	9	

490.6641	3.75	3.375	9.875	
479.8828	3.75	3.375	9.75	3 3/8
469.2188	3.75	3.375	9.625	
458.6719	3.75	3.375	9.5	
448.2422	3.75	3.375	9.375	
437.9297	3.75	3.375	9.25	
427.7344	3.75	3.375	9.125	
417.6563	3.75	3.375	9	

486.0352	3.75	3.25	9.875	
475.3125	3.75	3.25	9.75	3 1/4
464.707	3.75	3.25	9.625	
454.2188	3.75	3.25	9.5	
443.8477	3.75	3.25	9.375	
433.5938	3.75	3.25	9.25	
423.457	3.75	3.25	9.125	
413.4375	3.75	3.25	9	

481.4063	3.75	3.125	9.875	
470.7422	3.75	3.125	9.75	3 1/8
460.1953	3.75	3.125	9.625	
449.7656	3.75	3.125	9.5	
439.4531	3.75	3.125	9.375	
429.2578	3.75	3.125	9.25	
419.1797	3.75	3.125	9.125	
409.2188	3.75	3.125	9	

476.7773	3.75	3	9.875	
466.1719	3.75	3	9.75	3
455.6836	3.75	3	9.625	
445.3125	3.75	3	9.5	
435.0586	3.75	3	9.375	
424.9219	3.75	3	9.25	
414.9023	3.75	3	9.125	
405	3.75	3	9	