Thermal Management In Newtonian Reflectors

The full potential of your Newtonian can be realized with only a small investment of time and money. | **By Alan Adler**

For years reflecting telescopes have taken a back seat to refractors for high-magnification views of planets and double stars. The reflector's central obstruction is most often blamed for this shortfall. However, a strong body of theoretical and experimental evidence has shown that central obstructions of 15 percent (perhaps even as high as 20 percent) of the diameter of the primary mirror are *not* visually detectable. Another often-cited scapegoat is surface accuracy. Although errors on reflector optical surfaces must be one-fourth those of refractors to achieve the same results, such accuracy is quite common in good reflectors.

So what's holding back well-made reflectors? I am convinced that it is not a central obstruction, and it's not optical quality — the problem is heat waves off the mirror surface. This layer of warm air behaves like a weak lens of very poor quality right in front of the mirror. I believe this is the main reason reflectors have always been regarded as poor cousins to refractor telescopes.

Taking the Heat from Your Mirror

Thermal management in your reflecting telescope can yield astonishing improvements in resolution and contrast. And it's easy and inexpensive to implement. My interest in thermal management began when *S&T* associate editor Gary Seronik played me a video made by Bryan Greer that showed heat waves slowing rising from the front surface of a 6-inch mirror. Greer's pioneering schlieren studies of heat waves (*S&T:* September 2000, page 125) revealed an important fact that was new to me at the time: heat waves were most prominent on the front surface of the mirror, not in the tube. It was then I realized that the popular term "tube currents" has misled telescope makers searching for a solution — the problem is

Alan Adler's 8-inch f/6 Newtonian is a marvel of refinement. It features a flex mirror (see the November 2000 issue, page 131) and the active cooling scheme described in this article. The author discovered that only by managing the instrument's thermal issues does the primary mirror perform to its potential. Except where noted, all images courtesy Alan Adler.

severe even with *no* tube. What is more, light must pass through these heat waves twice (before hitting the primary and again on its return journey), and the aberrative refraction of the two passes is additive.

Several months later I acquired first-hand experience with the image degradation that results from thermal problems. I had just completed my flexed-mirror Newtonian telescope (*S&T:* November 2000, page 131), and though the mirror had bench-tested beautifully, at 300× in good seeing I saw sharp stars surrounded by extraneous flares and sometimes even double images. It was time to try a fix.

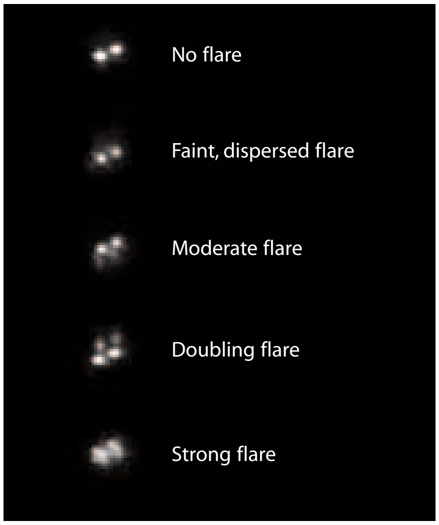
Fanning the Flames

Greer's studies showed that heat waves were present even when the mirror temperature was only 2°F warmer than the ambient air temperature. I decided that cooling the mirror might not be the complete solution and sought ways to directly homogenize the air mass in front of the mirror. I soon discovered that William H. Pickering had successfully done this. He describes his use of a fan in the original *Amateur Telescope Making, Book Two*, page 610 (page 9 of Volume 2 in the 1996 Willmann-Bell edition). In that same book (page 619, page 354 in the new edition) A. V. Goddard encouragingly wrote, "The effect was like blowing away a fog, and the detail, even with 600 diameters, was very clear. Since then, I have found the fan so far ahead of any other method that I always use it."

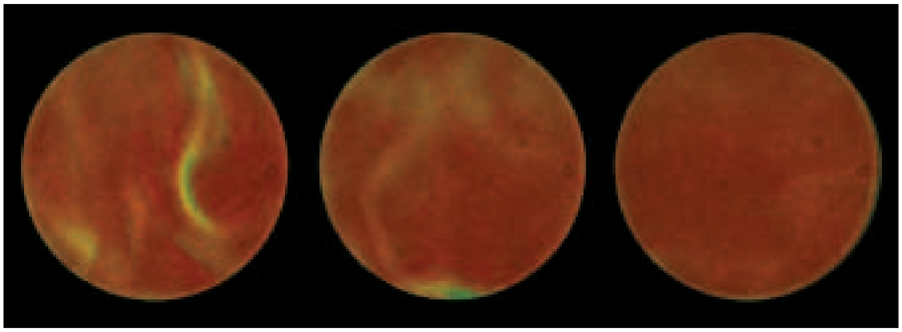
My first fix was a 3-inch-diameter fan behind the mirror. The idea was to draw air down the tube and wash the front of the mirror, but the improvement wasn't as great as I'd hoped. Interestingly, it took about 30 seconds for the fan benefits to fully take effect. These improvements were accompanied by a slight inward focus shift. When I conferred with Greer he said that he had seen the same shift, which is due to thinning of the layer of warm air in front of the mirror.

On another night when my mirror was about 15°F warmer than the air, I discovered that my fix wasn't good enough — the fan couldn't cope with such a great temperature difference, though leaving it on did eventually cool the mirror and reduce thermal effects to a manageable level.

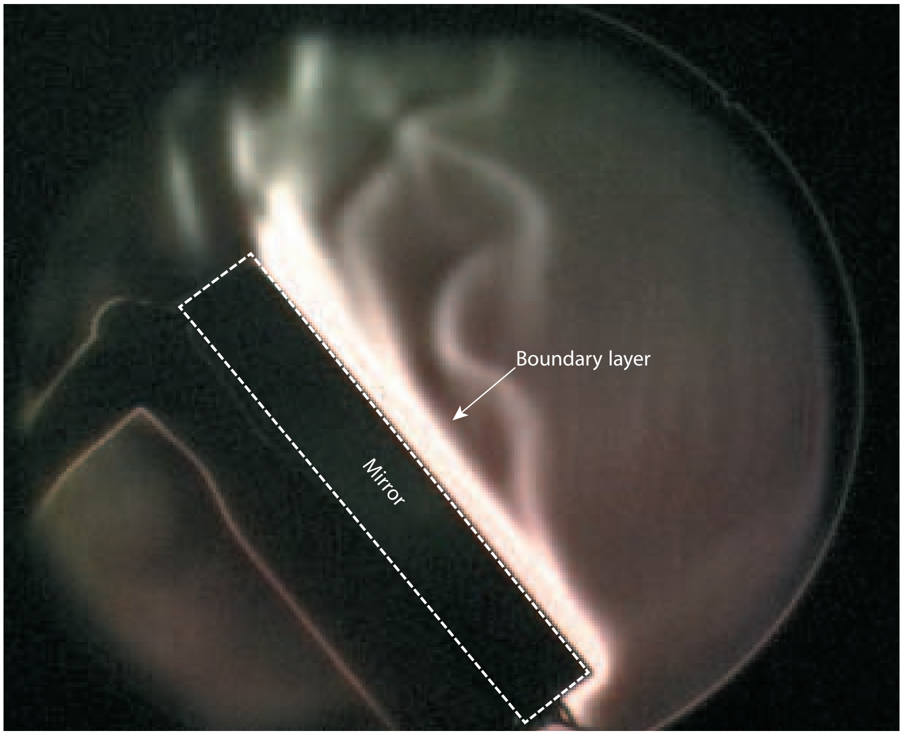
Next (with some trepidation) I cut a 3-inch-diameter hole in the side of my tube, adjacent to the mirror front, and mounted a fan so it was blowing straight across the face of the mirror. Star testing showed an improvement over the previous configuration, but when the temperature differences were high I still saw some image flare. I tried adding a diverter to induce cyclonic airflow on the front of the mirror, but this only reduced air ve-



This unretouched sequence of photographs shows the image of the double star Zeta Aquarii (which has a separation of only 2″) being affected to varying degrees by thermal distortion in the author's 8-inch telescope. These images were obtained within a single two-minute period.



Right, above: **This sequence of rainbow-schlieren images shows a mirror slowly cooling by 14°F (8°C) over two hours. Wavefront errors show as yellow and green, while red indicates unaltered returning light rays.**



BRYAN GREER (2)

Right: **In the past, tube currents (warm air rising up the length of the telescope tube) were thought to be the principal thermal problem in reflectors. Thanks to the efforts of Bryan Greer and the author, it now seems clear that the "boundary layer" of warm air directly in front of the primary mirror is the culprit. Greer's schlieren-shadowgram image of a warm 6-inch mirror shows this image-degrading layer plainly.**

Left: **Although telescope-cooling fans have traditionally been mounted behind the primary mirror (if they're used at all), the author's tests show that a fan positioned on the side of the tube blowing air across the face of the primary mirror is much more effective at cooling the mirror and breaking up the heat waves. The wire hanging from the bottom of a fan leads to a speed control that can be operated while viewing through the scope's eyepiece.**

Above: **Directly opposite the location of the cooling fan is a series of exhaust holes that allow warm air to exit the tube and get out of harm's way. The total area of these holes should roughly equal the area of the fan.**

locity and diminished the effectiveness of the fan. I even added another fan behind the mirror and ran both at once. The second fan didn't make much difference.

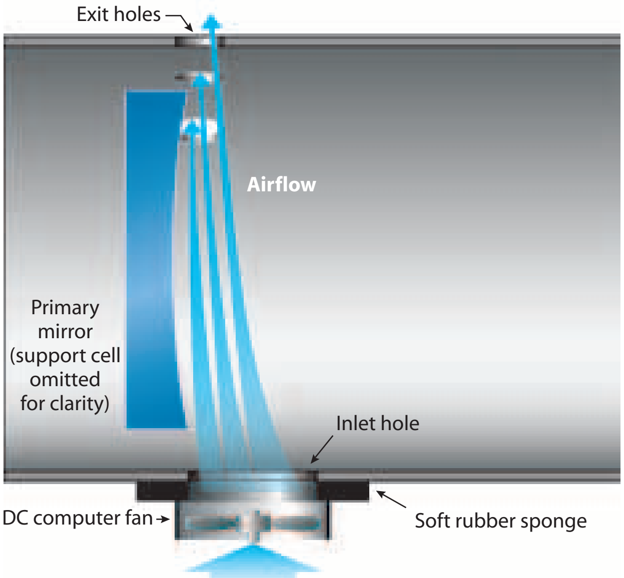
Last, I cut a row of five 1⅛-inch-diameter exit holes on the side of the tube, opposite the fan. This was inspired by Richard Berry, who advocated getting heat out of the scope via the shortest route. This proved to be the best configuration yet and is still in use a year later. My research and experience have shown that blowing directly on the front of the mirror works best both to cool the mirror and to homogenize heat waves. For large mirrors (12-inch and up), multiple fans are probably the best solution. I recommend directing them at the front of the mirror to maximize the mixing of thermals in the optical path.

Mirror Cooling

Some amateurs use fans that blow on the back of the mirror. Although intended to cool the mirror, in most scopes some air flows around the mirror and helps mix the thermals on the front surface. Regardless of whether the fan blows against the back of the mirror or draws air down the tube past it, this placement is not as effective as having the fan blow air across the mirror's face because the air velocity is much lower — the result of the fan's output being spread over a larger cross-section of flow.

In addition, the scope tube aligns the air movement from a rear-mounted fan into a laminar flow. The aligned airflow strikes the mirror and diverges radially outward. This radial part is the only useful component of the flow, but it's much slower than the cross-flow of a side-mounted fan. Furthermore, the rear-mounted fan provides virtually no airflow at the center of the mirror, which (in aerodynamic parlance) is called the *stagnation point.* Amateur astronomers often think laminar flow is essential for a sharp image, but turbulent flow (directly off the fan) is not only far more effective in homogenizing the heat waves in front of the mirror, but it also cools the mirror more rapidly because it is more effective at transferring heat.

I've done quite a lot of study and experimentation directed toward mirror cooling. Obviously if the mirror temperature is very close to the ambient air temperature, heat waves will not be present. So cooling the mirror to match the outside air temperature is our goal. How long this takes (or even if it is possible or not) for a given telescope can be calculated using the information contained in the box on page 136. These calculations are also automated for you in the program I've written, COOL.EXE, available for free download at SkyandTelescope.com/resources/software/cool.html. It's a simple DOS program, easy to run on any PC. It produces a



This schematic shows the placement of the fan and exhaust holes in the author's 8-inch Newtonian. Note that the exhaust holes are offset slightly toward the rear of the tube. This is to ensure that the flow opposite the fan has to scrub the mirror in order to reach the exhaust holes.

curve like the one shown at right.

When considering cool-down curves, keep in mind that any temperature difference *(ΔT)* greater than about 1.5°F will produce enough heat waves to degrade the image quality at high magnification. However, with a fan blowing on the mirror front, good image quality is possible with differences of up to about 10°F.

The program illustrates the futility of fanless Newtonians. Consider the small graph on this page for a 2.5-inch-thick mirror, which might be found in a 15-inch telescope. Note that *ΔT increases* as the night air cools. As this graph shows, the ambient drop is 2°F per hour. That's typical for much of the U.S., but in the dry southwest evening 10°F per hour is often seen. You don't want to see the "no fan" graph for that!

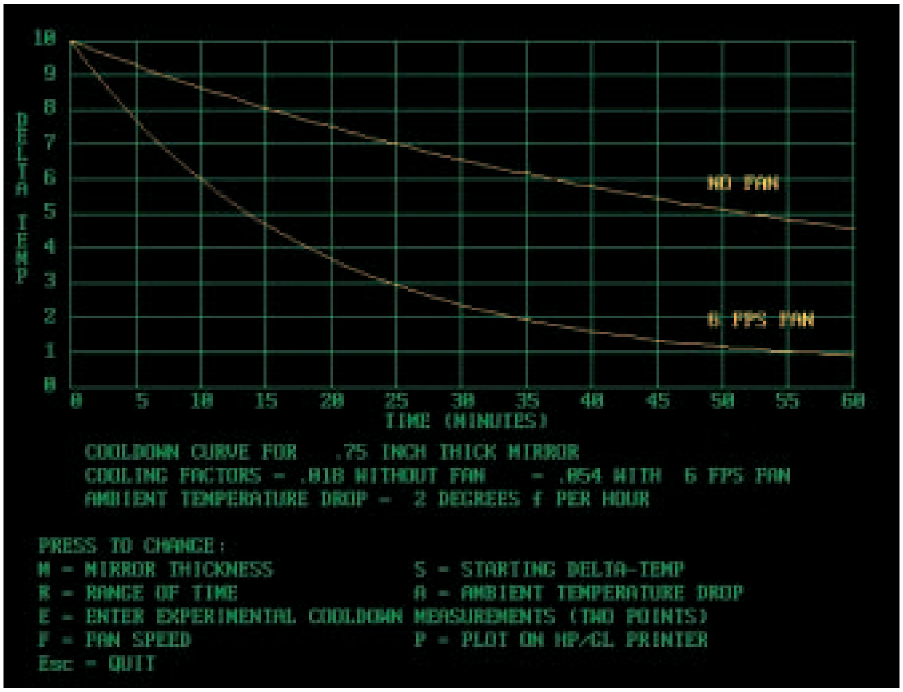
Fan Vibration and Isolation

I've wrestled with the problem of fan vibration a fair amount, though others have noticed very little or no vibration at all. Nonetheless, it is worth checking for and minimizing — there's no point in trading one form of image degradation for another. Fan vibration makes stars appear elongated at high magnification.

To cure these vibration effects, I have experimented with fan quality and found that some fans run much more smoothly than others. Out of more than a dozen fans that I have tried, my best results have been with 3-inch, medium-speed Sanyo fans. I was told by fan manufacturers that sleeve-bearing fans vibrate less than ball-bearing fans. However, I've tested many of each type and found the opposite to be true.

Mount the fan on soft sponge rubber — material that features a sluggish rebound. Highly resilient mounting material can actually magnify vibration. Some have had good success with self-adhesive Velcro strips or mounting fans with rubber bands.

Controlling the fan speed with a potentiometer (variable resistor) can also help, since most fans vibrate worst when running at their highest speed. I normally turn my fan on at full speed when I set up. Later, if I see vibration at high magnification, I reduce the fan speed until the image settles down. Even a modest airflow will do wonders for the image quality. I leave the fan on for the whole observing session to maintain image quality in the falling ambient air temperature.



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COOLDOWN CURVE FOR   .75 INCH THICK MIRROR
COOLING FACTORS - .018 WITHOUT FAN    - .054 WITH  6 FPS FAN
AMBIENT TEMPERATURE DROP -  2 DEGREES f PER HOUR

PRESS TO CHANGE:
M - MIRROR THICKNESS                S - STARTING DELTA-TEMP
R - RANGE OF TIME                   A - AMBIENT TEMPERATURE DROP
E - ENTER EXPERIMENTAL COOLDOWN MEASUREMENTS (TWO POINTS)
F - FAN SPEED                       P - PLOT ON HP/GL PRINTER
Esc - QUIT
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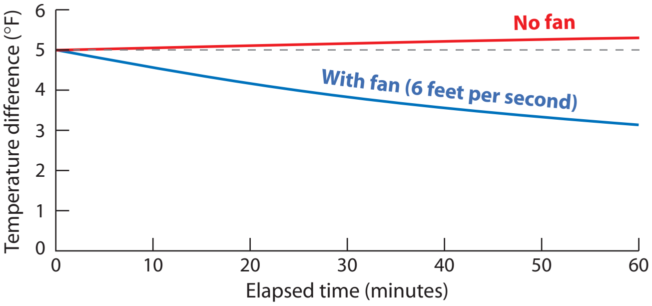
***Above:* The author's computer program COOL.EXE allows experimentation and shows the effects of different thermal situations. In this example, a 0.75-inch-thick mirror obviously benefits from the use of a fan, as it cools nearly 9°F in an hour. *Below, right:* This graph, made with data generated by COOL.EXE, shows how a 2.5-inch-thick mirror might not be able to keep up with the falling night air temperature even when it starts out only a few degrees warmer than ambient. Notice how the *ΔT* (temperature difference) of the uncooled mirror actually increases over time because the night air temperature is falling faster than the mirror temperature.**



Effects of Mirror Material

Over the years there has been a lot of discussion regarding the cooldown properties of two common mirror glasses: Pyrex and plate glass. Pyrex has about 10 percent lower specific gravity and about 10 percent lower specific heat than plate. These attributes combine to give it about 20 percent lower heat capacity for a given thickness. This means that, all other things being equal, Pyrex will cool 20 percent faster than plate glass. But the greatest benefit of Pyrex is probably realized only during final figuring, when its much lower thermal expansion makes it less touchy to work with.

While we're on the subject of heat capacity, don't forget that the added thermal mass of counterweights located right behind the mirror (common in Dobsonians and reflectors on split-ring equatorial mounts) will keep your mirror warm much longer. With Dobsonians, I'd recommend relocating them to the outer sides of the tube or mirror box.

The Proof Is in the Viewing

The disappointing resolution of large reflectors has led to a commonly accepted belief that the optimum aperture for high magnification is in the 10- to 12-inch range. The argument has been that the greater resolution offered by larger-aperture telescopes means that they are more adversely affected by seeing conditions than smaller instruments. But now that Bryan Greer has shown us that the most troubling seeing occurs in the first inch of air in front of the mirror, I'll go out on a limb and predict that with proper thermal management, amateurs will find that big scopes can perform well more often than is generally believed.

The benefits of thermal management

Thermal Math

Although most readers will find the COOL.EXE program the easiest way to analyze various telescope configurations, the following formulas can also be used to predict or analyze cooling.

I derived this first formula from an expression created by Isaac Newton in 1701:

$$\Delta T = \Delta T_O \, (1 - z)^N$$

where ΔT is the temperature difference between mirror and air after N minutes, ΔT_O is the temperature difference at start, and z is a cooldown factor for a given mirror and flow.

Note that the rate of change is proportional to the temperature difference. This means that the cooling rate is fastest when the mirror is hot and tends to level off as the mirror temperature approaches the air temperature — as evidenced by the graphs.

The value for z is approximately equal to $0.0045\ (V + 3)\ /\ \textit{Thickness}$, where V equals the velocity of flow over the mirror (zero for no fan) in feet per second (fps) and *Thickness* equals the mirror thickness in inches.

I've measured z for the following:

z = 0.010 for an 8-inch diameter, 1.35-inch-thick mirror without a fan (I measured the same z for both a bare mirror and when it was placed in a 10-inch-diameter tube).

z = 0.017 for the above configuration and a 6-fps (30 cubic feet per minute) fan mounted behind the mirror and drawing air down the tube.

z = 0.030 for the same mirror and tube with a 6-fps fan blowing across the mirror front.

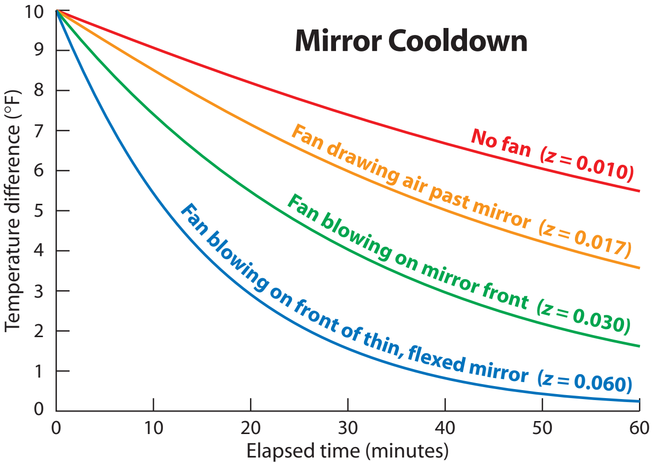
z = 0.060 for my 8-inch-diameter 0.65-inch-thick flexed mirror with the same side fan and tube.

z = 0.010 for my Celestron 8-inch f/6 Star Hopper Dobsonian with no fan. (Although this mirror is relatively thin, its heavy aluminum cell retains sufficient heat to make its cooldown similar to a 1.35-inch-thick mirror.)

The larger the value for z, the more rapid the cooldown. This is well illustrated by the graph at left. You can determine the z value for your telescope by measuring its cooldown at two different times using the following formula:

$$z = 1 - (\Delta T / \Delta T_O)^{(1/N)}$$

where N is the number of minutes between the two temperature readings.



***Left:* The effects of different cooling strategies are shown in this graph made with the same formulae incorporated into COOL.EXE.**

are most obvious when the seeing is good. I recall that on the night of June 10, 2001, during the recent Mars apparition, the seeing was especially steady. I set up my 8-inch at Lick Observatory, outside the dome of the famed 36-inch refractor, and was enjoying the best view of Mars I'd ever had. There were about 20 local amateurs in the dome. Someone wandered by and took a look at Mars in my scope and exclaimed, "Wow, that's the best I've ever seen it. Is this a reflector? I didn't think reflectors could do this well." Before I knew it, the word got out, and a steady stream of people started pouring out of the dome looking for "that scope with an outstanding view of Mars."

It is little wonder that these and many others who have looked through my scope have been surprised and impressed. It is not an exaggeration to say that the scope now works like a big refractor but with perfect color correction. You too can enjoy these benefits — all for about $20 and a few hours of work.

Alan Adler *lives in Palo Alto, California. He is a lecturer in mechanical engineering at Stanford University, owner of Superflight Inc. (makers of the Aerobie flying ring), and has about 35 U.S. patents to his name.*