

# Improving the Thermal Properties of Newtonian Reflectors – Part 2

Some simple strategies and modifications will help eliminate the dreaded “thermal boundary layer” and allow your scope to perform at its best. [By Bryan Greer](#)

LAST MONTH I described the kinds of thermal problems Newtonian reflectors suffer from, and how to detect them. In this installment I will tell you how they can be minimized so that your telescope will regularly live up to its potential.

## Thin Is In

It turns out that the thickness of the Newtonian primary mirror is the dominant factor in determining how closely the optics will track the falling ambient temperature. This is actually good news for owners of big Dobsonian telescopes. If only the *mass* of the mirror were important, they would have little prospect for improvement – even a relatively thin 20-inch-diameter (51-centimeter) primary is a hefty piece of glass!

To demonstrate this point, look at the main graph on the facing page, which shows how 1-inch-thick Pyrex blanks of different diameters cool; notice how similar the curves are. Another way to demonstrate the importance of thickness is by measuring the cooling rates for mirrors of the same diameter but of different thickness. For mirrors 2 inches thick or more, it is common to find temperature differences exceeding 3°C (5.4°F) well into an observing session when the ambient air temperature is falling at a brisk rate.

Looking at the cooldown curves in the smaller graph on the facing page, it's obvious that thinner mirrors cool more rapidly than thicker ones. This is certainly important, but there is a second, more subtle point to take note of – a mirror that cools quickly also tracks the ever-changing



In producing the data used in this article, the author tested many different mirror blanks and fans, some of which are shown here. Suitable DC fans are available in a variety of sizes and flow capacities. The small fan held here is a good choice for 6-inch Newtonians because it causes minimal vibration, consumes little power, and yet provides sufficient cooling for a mirror this size.

BRYAN GREER

A mirror's thickness trumps its diameter when it comes to determining how quickly it will reach optimal performance (blue zone). Three 1-inch-thick mirrors with different diameters were tested to produce the main graph. Note how similar their cooling profiles are.

*Inset:* When two 10-inch mirrors of different thicknesses are compared, the thermal advantage of the thinner substrate becomes obvious. (No fans were used in these tests.)

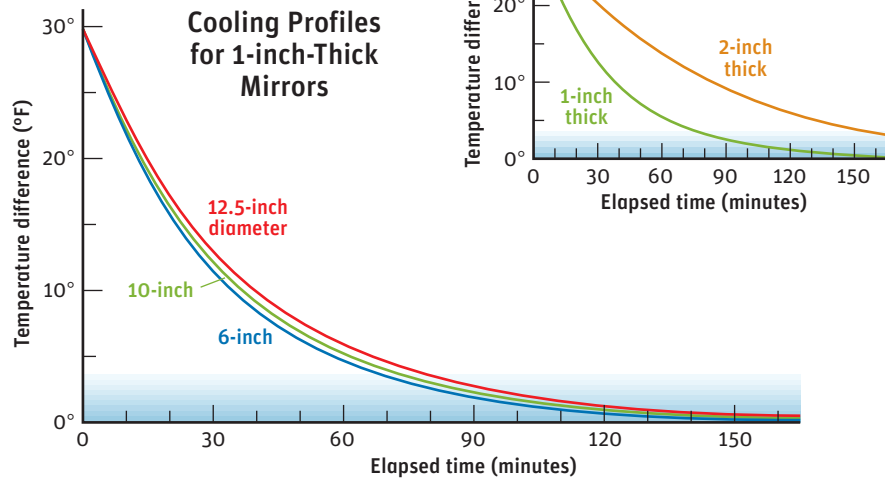
ambient air temperature more closely. All these graphs suggest that ultrathin mirrors are the way to go. In fact, computer modeling shows that mirrors  $\frac{1}{2}$  inch (13 millimeters) thick remain acceptably free of boundary-layer problems for most geographical locations with a  $2^\circ$  to  $4^\circ\text{C}$  per hour temperature drop.

However, don't order up your new ultrathin mirror quite yet — high-quality thin mirrors are difficult to fabricate and require more sophisticated support cells so that the optics don't sag under their own weight. Yet given the important thermal benefits of thin mirrors, perhaps it's time to start thinking about Newtonian optics differently. If one considers the effort and cost involved in producing a high-

This large Dobsonian employs a number of important features to reduce mirror cooldown times. Not only is the rear surface of the thin primary mirror completely exposed; it has no fewer than four fans blowing air at it. Even the 8-inch finderscope has a cooling fan!



S&T: GARY SERONIK



quality apochromatic refractor lens that has not one but often *six* surfaces, the expense of first-rate optics is put into better perspective. Perhaps we should stop thinking of the Newtonian design only as a cheap alternative to refractors and start giving it the kind of attention needed to fully exploit the design's capabilities. More-sophisticated support cells and costly mirrors might be justified if the extent of the potential optical rewards were more fully appreciated.

#### Fans to the Rescue

So far we've been addressing cooldown only in passive terms — the mirror, sitting in the bottom of its tube, is left to release its stored heat as conditions allow. But there are *active* strategies too, usually involving using one or more inexpensive fans to speed up mirror cooldown. While it isn't news that fans can improve the performance of Newtonian reflectors, there is still some uncertainty as to how best to use them. How big a fan do I need? Where do I put it? The answers largely depend on the scope's size, configuration, and even the owner's observing habits, to some degree.

Fans can have two useful effects, and in some cases they occur simultaneously. First, they increase the speed of the air moving over the mirror's surface, which significantly increases the rate of heat transfer from the glass to the air. This, in turn, eventually reduces the temperature difference ( $\Delta T$ ) and the strength of the boundary layer. This benefit can be gained if fans blow air at either the front or the rear of the mirror — or both.

In addition to cooling the mirror more quickly, when air-flow is directed at the front of the mirror (as advocated by Alan Adler in his January 2002 article, "Thermal Management in Newtonian Reflectors"), the moving air also has the potential to actually change the boundary layer — usually scrambling it into a much finer structure. In the presence



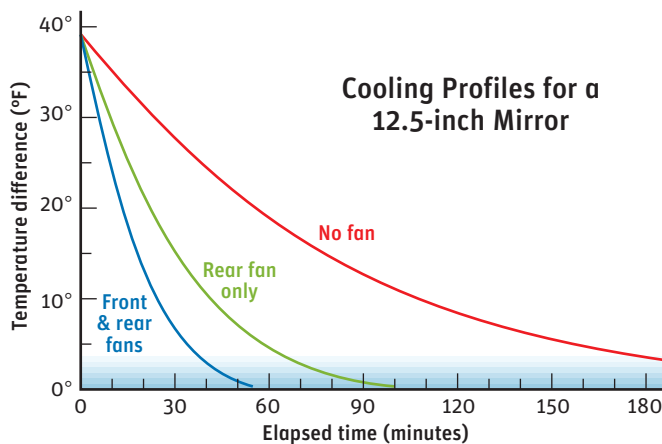
S&T: GARY SERONIK

Associate editor Gary Seronik's 6-inch Newtonian utilizes a  $\frac{1}{2}$ -inch computer "cpu" fan to keep its primary mirror at the ambient air temperature. The fan blows air across the face of the mirror, and air exits the opposite side of the tube through three 1-inch holes.

## ■ amateur telescope making

of a strong boundary layer, this will almost immediately sharpen fine image detail. Keeping both benefits in mind can steer you toward the most practical and effective fan-placement strategy for your particular scope.

My outdoor cooling tests show that with mirrors having thicknesses less than about 1½ inches, it is possible to maintain a sufficiently small  $\Delta T$  with a fan blowing air at only one side of the mirror. Practical considerations usually mean this will be the rear surface, since, for most small- and medium-size Newtonians, it is a relatively simple task to add a single fan behind the mirror cell. After turning on the fan, it usually takes only 30 minutes or less to reduce  $\Delta T$  to the point where the boundary layer is essentially eliminated. For owners of small and even medium Dobsonians, this may be one of the most cost-effective modifications possible. While some small further improvement can be gained by also adding a frontal fan, they are not essential if you're willing to wait just a few minutes for the rear-mounted fan to do its job. The important thing is not to let the added complexity of adding a frontal fan (which usually requires more tinker-



Thick mirrors benefit from having fans blowing on both the rear and front faces. Using front and rear fans, this 12.5-inch diameter, 2-inch-thick Pyrex mirror cools to near equilibrium twice as fast as it would with a single fan.



The author cools his 8-inch Newtonian with a 19-cubic-foot-per-minute (cfm) fan mounted on a piece of plastic that attaches to the telescope with three elastic hair bands that loop over screws on the outside of the telescope tube. These provide a good way to avoid vibration problems and make it easy to install, remove, or even reverse the fan.

ing to mount) keep you from adding any fans at all!

As the graph at left shows, mirrors thicker than 1½ inches will benefit from having fans cooling both the front and rear surfaces, though it's worth emphasizing that even rear cooling alone is still far better than having no fans at all. When the thickness of the glass exceeds 2 inches, fan cooling from one side alone will not remove a sufficient amount of heat for the mirror to adequately track the falling air temperature.

### Avoiding Bad Vibes

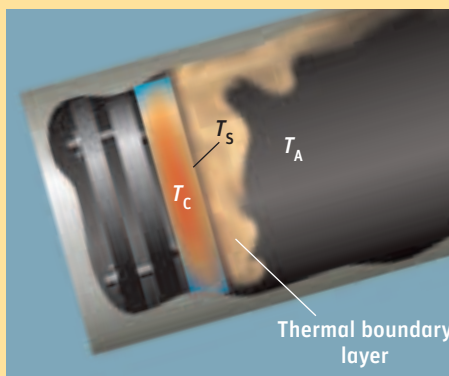
So what is the price paid for adding fans to your telescope? The only performance downside is the potential for introducing image-harming microvibration. Fortunately, this problem can be avoided by taking care how the fans are installed. The best way to mount them is by using heavy-duty

## Understanding Heat Transfer

The accompanying diagram shows a telescope mirror in the process of reaching equilibrium with the surrounding air. For the mirror to cool down, its stored heat must travel through two distinct mediums — glass and air. First, heat within the mirror must be transported to the surface of the glass via *conduction*. The difference in temperature between the mirror's warm center ( $T_C$ ) and cooler surface ( $T_S$ ) drives this heat-energy flow. Next, the cooler ambient air ( $T_A$ ) will absorb heat from the glass surface and carry it away by *convection*. This results in the formation of the *thermal boundary layer*. As heat is released, the temperature difference between the center of the glass and the air surrounding the mirror decreases. If there is no temperature difference

( $\Delta T = 0$ ), there will be no boundary layer and no resulting image degradation.

With these processes in mind, it's easier to understand why design changes that either



(a) increase the rate of heat transfer from the middle of the glass to the surface, (b) decrease the amount of heat stored within the glass, or (c) increase the rate of heat transfer from the glass surface to the surrounding air will decrease  $\Delta T$ , and thus the boundary-layer strength. The rate with which heat will flow through the glass is a function of the material's *thermal conductivity*, which we can't change if we use conventional mirror substrate materials such as Pyrex or plate glass. Fortunately, we can control the other two factors — we can decrease the amount of stored heat by using thinner mirrors and by storing the telescope outdoors, and we can greatly improve the rate of heat transfer from the surface of the mirror by forcing air to flow over it with a fan.

rubber bands or miniature bungee cords. But if you mount the fans directly to the telescope (even with foam gasket materials), microvibration can turn up in the image. This should be viewed as intolerable — there is no point in trading one image-degrading problem for another.

Unless they are severe, microvibration problems can go unnoticed because their effects (though very real) are not immediately obvious when you are viewing the Moon or a planet. The definitive test is to examine a bright star at high enough magnification to actually see the Airy disk. This requires at least 40× per inch of aperture (for example, more than 300× for an 8-inch reflector). You will also need an evening of steady skies, since poor seeing makes it difficult to view the Airy disk. Center the star and turn your fan on and off while you carefully examine the Airy disk. There should be no swelling of the Airy disk or other changes in its appearance when you switch the fan on. Owners of large Newtonians may have to resort to using an artificial star to test for vibrations. In such scopes, the Airy disk is just a fraction of an arcsecond in angular size, and atmospheric conditions frequently make it hard to see. Fortunately, an artificial star can be made with a simple shiny Christmas-tree ornament and a flashlight, as described in H. R. Suiter's book, *Star Testing Astronomical Telescopes* (Willmann-Bell, 1994).\*

#### Going with the Flow

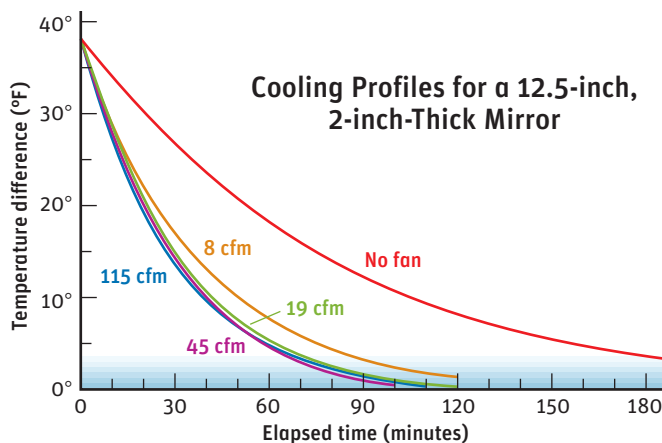
Determining how much fan cooling power you need is a straightforward engineering problem. Fans are rated by the volume of air they can move in a given amount of time. Most often the units are cubic feet per minute (cfm). One way to determine how much airflow is required is to measure and plot cooling curves for a range of fans. As the fans become more powerful (or more of them are used), eventually a point is reached where the cooling rate no longer improves significantly. This happens when the airflow is at a level where the maximum rate of heat transfer by convection has been reached, and transporting the remaining heat from inside the mirror to its surface becomes the heat-transfer bottleneck. At this point, adding more fan capacity will just increase the vibration and noise, and consume more power with no cooldown gains.

I've tested some common mirror sizes

---

\*Available from Sky Publishing.

## ■ amateur telescope making



This graph for a 12.5-inch-diameter, 2-inch-thick Pyrex mirror shows that using fans rated at more than about 20 cfm results in negligible improvements. However, these tests also show that just about *any* amount of forced airflow is very helpful. (For these tests air was blown at the rear of the mirror only.)

with a variety of fans, and the results are shown in the table below. These experimentally derived values need not be strictly adhered to, as an important finding of my tests is that just about any amount of forced airflow results in big improvements.

While using a fan to blow against the surface of the mirror is the most efficient cooling method, it may be advantageous to reverse the fans in some applications so that they draw air past the mirror instead. If you observe in a dusty location, drawing air in from the top of the tube and extracting the warm air out the bottom can reduce the accumulation of dirt on your mirror. However, if you go this route, close off the mirror end of the tube except for the hole for the fan. This ensures that most of the air is actually coming from within the telescope and not just being endlessly recirculated around the fan housing.

Finally, under most conditions fans should be left running for the whole observing session (which makes a vibration-free installation that much more critical). While fans significantly reduce the initial cooldown time, the real payoff comes when they are left running and drive the  $\Delta T$  down as close to zero as possible and keep it there throughout the night. A properly designed fan system that satisfies the airflow values given in the table will

accomplish this.

For large Newtonians, or situations where the initial  $\Delta T$  is great (such as during cold winter months), another strategy that works well is to set up a temporary additional fan to blow cool air down the front of the telescope tube while you are setting up your equipment. This will shorten the initial cooldown period, and since no viewing can be done with a fan in front of the scope, the vibration of this extra fan does not matter, so an ordinary household fan can be used. Once you're ready to begin observing, move this fan out of the way, but continue to use your regular fan.

While the majority of amateurs using fans report noticeable performance improvements, occasionally I will run into a nonbeliever. This usually isn't due to the person's lack of observing skills, but to their observing *habits*. Frankly, the benefits of fan-cooling Newtonians are most noticeable in planetary and lunar observing. Viewing the planets is the toughest test for any telescope because you are working with high magnifications and often trying to resolve very delicate low-contrast details. If galaxies and nebulae are your primary interests, the improvements are admittedly more subtle. That said, I've rarely run into an amateur astronomer who actually *avoids* looking at the planets, so I suspect the majority of Newtonian owners will find their efforts to make these thermal improvements handsomely rewarded. Certainly, given the minimal costs in time and money, there is a great deal to gain and very little to lose. \*

### Pyrex Mirror Cooldown Tests

Diameter (inches)	Thickness (inches)	Airflow requirement (cubic feet per minute)
6	1	10–15
8	1.6	15–20
10*	1.75	15–25
12.5*	2.0	20–30
16*	2.0	30–45

\* Benefits from fans providing listed airflow on both front and rear surfaces.

BRYAN GREER is a mechanical engineer, telescope maker, and the man behind the company ProtoStar. He is a frequent guest speaker at star parties. More of his telescope research can be found at [www.fpi-protostar.com/bgreer](http://www.fpi-protostar.com/bgreer).