

# Tubes for Reflecting Telescopes

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## INTRODUCTION

It is no secret that many amateur telescopes take excessive time to equalize with the surrounding air, or cool down, so to speak. It is important to remove heat from components within the telescope to allow air in the optical path to stabilize. Even external parts, such as the mount, pier and surface area, will cause unwanted heat to enter into the telescope tube and spoil the stable air in the optical path. So, it is desirable to equalize the inside of the tube with the surrounding air as soon as possible.

In our atmosphere cooler air tends to drop towards the ground because it is denser, therefore heavier than warm air. When cool air descends, often down through a telescope tube, it mixes with rising warm air to cause turbulence in the optical path and form what some telescope designers refer to as "thermal cells." Because the density of air varies with temperature and the refractive index of air varies with its density, these "thermal cells" act like lenses floating around inside the tube. The result is similar to the effects of bad "astronomical seeing."

For serious planetary observers a portable telescope is usually not important. However, deep sky telescope user's desire portability and weight becomes an important design constraint. Another major concern is keeping the optics from losing collimation when moving the telescope around. The cost of materials is important when considering telescope design and while materials such as paper or fiberglass may seem to be cheaper than steel or aluminum this author found the opposite to be true.

This article will point out methods to reduce weight and annoying tube currents for both types of telescopes, and to reduce the overall cost of the telescope construction. However, a important rule to remember that we all subscribe to: the KISS rule -- **K**ee**P** **I**t **S**imple, **S**tupid.

## TUBE DIAMETER, LENGTH and VIGNETTING

After the amateur telescope maker (ATM) or assembler determines the purpose for their Newtonian telescope one of the first considerations is the primary mirror aperture and focal length. Typical deep sky observers would desire a short focal length and large aperture telescope whereas a planetary observer would like a longer focal length and large aperture telescope. In either case when selecting a tube the first consideration is the dimensions of the primary mirror cell and finding a suitable tube with an inside diameter that will accommodate the cell.

**NOTE:** Many of the parts used to build the telescopes described in this article were available in the past from Kenneth F. Novak & Co. Unfortunately, Kenneth passed away in 2004 and his company is no longer in business. Too bad, his superb and inexpensive telescope parts were widely used in the ATM world. At any rate this article will feature his component designs and dimensions because they are close to or similar to other commercially available parts.

An ATM could go all out and fabricate every component or, as most of us do, pick those items we can make and those we purchase in the a very limited commercial market. When buying ready made components a wide variety component designs and dimensions are available and usually these items are made to fit a variety of telescope tubes and can be shimmed to fit most available tubes. Some machining may be necessary as well.

When placing the focuser on the tube it should be far enough away from the front entrance to prevent direct light from entering the eyepiece the tube end. This is not a big problem for focusers with a high profile and long draw tube; however, low profile focusers may be short enough allow direct light from the tube entrance to enter into the focuser tube. A rule of thumb for ATM'ers is to extend the tube entrance from the focuser a few inches from the secondary mirror to the tube entrance (**DF**), typically 6" and then one must also allow a few inches from the primary face to the rear end of the tube (**DR**) to accommodate the primary thickness, mirror cell with collimating adjustments and mounting plate.

Then we must determine the inside diameter of the tube; however, this will be predicated upon those available on the open market. Commercially made telescope components are usually sized to fit their mirror cells or close to their competitors' parts, so some shimming or machining will be necessary by using simple hand tools. In my case, as an amateur telescope assembler (ATA), telescope design came first then a local fabrication shop rolled and welded an aluminum tube to fit my specifications. In most cases you will most likely have to find a tube that is close to your design and deal with changes later.

One must allow for proper air flow through the telescope tube to keep "tube currents" (heated air from the tube walls) from entering the optical path. A general rule for 6" to 10" reflectors is to add at least ½-inch clearance around the primary mirror, or the aperture plus one inch for the tube inside diameter. For 12" to 14" reflectors this clearance should be increased to at least 1 inch, or 2 inches plus aperture would be applicable. Of course, an open truss system is probably best for larger instruments from 15" and up. We must also consider the space from the primary face to the rear end of the tube and this can vary from 3 to 6 inches depending on the primary diameter and mirror cell design. A typical 6" mirror is 1 inch thick and a mirror cell with collimating bolts can take up 2 inches of space, so the distance from the primary face to the end of the telescope tube would be 3 or 4 inches.

As an example we will design a 6-inch f/4 with a 1.75-inch clear aperture secondary and after looking around publications find that a Parks 7" inside diameter (I.D.) fiberglass tube will be suitable for this project. The tube walls are 5/16<sup>th</sup>-inch thick rendering the outside diameter (O.D.) to be 7.0" + 2 \* 0.3125" or 7.625". In our junk box we find a nice 1.5" fully racked in focuser to use and adding 0.25" to allow for variations in eyepiece field stop positions, the distance from secondary to focal plane (*l*) will be  $T / 2 + \text{focuser height} = 7.625" / 2 + 1.5" + 0.25" = 5.5625"$  inches. We now can calculate the linear image diameter (*i*) of our optics setup using the equation:

$$i = (F \text{Sec} - l D) / (F - l).$$

In this case:  $i = (24 * 1.75 - 5.5625 * 6) / (24 - 5.5625) = 0.4678"$ . To find the telescope true field (**TF**) calculate then:  $\arctan (i / F)$ , where *i* is the image linear diameter, *F* the primary focal length, so  $\text{TF} = \arctan (0.4678 / 24) = 1.117\text{-degrees}$ .

Now to select the length of the tube given a 1.5" focuser with a 7.625" O.D. tube, then the distance from the primary face to the secondary face is 24" - 5.5625" = 18.4375" and adding 3" for DR plus 6" for DF the overall length of the tube will be 18.4375" + 3" + 6" = 27.4375 inches. From experience in ATM'ing we know that it is possible that the tube entrance could possibly cause vignetting of the final image, so a neat equation for calculating the minimum tube diameter is as follows:

$$MTD = 2 * D2E * \tan (TF / 2) + D + .5 ,$$

where MTD is minimum tube diameter, D2E is the distance from the primary mirror face to the front end of the telescope tube, TF is the true field, D is the primary diameter [McCluney].

For this 6" f/4 telescope the D2E would be 24.4375", so MTD = 2 \* 24.4375 \* Tan(1.117/2) + 6 + 0.5 = 6.9763". In this case the 7" I.D. tube diameter will not vignette the final image. A larger secondary, say 1.83", would require the inside diameter of the tube to be increased.

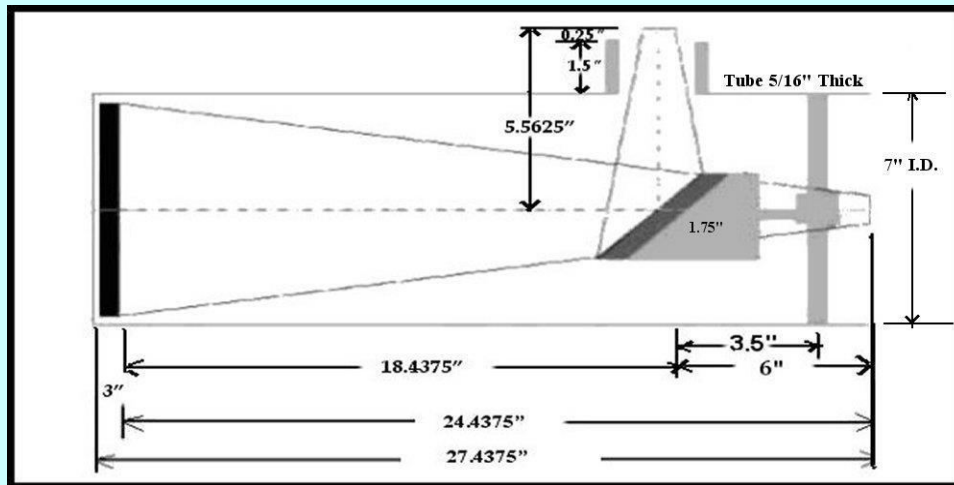


Figure 1. The minimum tube diameter is determined by  $MTD = 2 * D2E * \tan (TF / 2) + D + 0.5$  where the distance (D2E) is from the primary mirror face to the end of the telescope tube.

## SIMPLE TRUSS TUBE

Perhaps the best telescope system is the Simple Truss tube that combines lightweight, rigidity and excellent thermal stability. While this system appears to be more complex than the traditional "closed" tubular enclosure it is really quite easy to build. To use the traditional tubular system one must find a commercial company that supplies telescope tubes or have a local machinist construct one at a considerable expense. A case in point is the truss tube for my 16" f/6.9 Newtonian telescope that weighs only 109 pounds; the same telescope in a 1/8-th. inch thick closed-in aluminum tube would weigh 154 pounds.

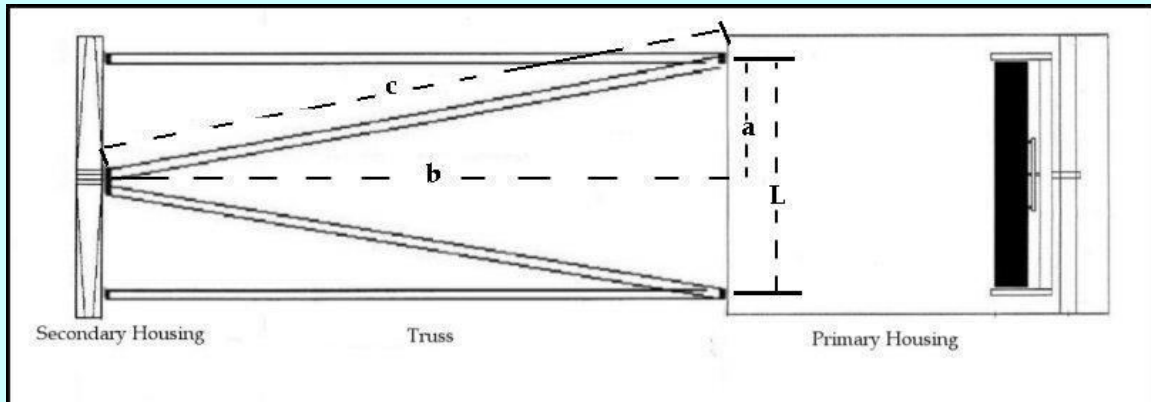


Figure 2. A typical Simple Truss tube arrangement.  $L = r \sin(\theta/2)$ , where  $\theta = 90^\circ$ ,  $c = \sqrt{a^2 + b^2}$

The components in a typical Simple Truss tube can be found at a local hardware store and can be constructed using ordinary hand tools. A typical Dobsonian telescope is usually made from plywood and aluminum truss tubes. For those who use an equatorial mount then the primary housing can be made from a *Sonotube* concrete forming tube, aluminum or fiberglass. This section is usually short and the diameter can be a little larger than usual for good air flow and it will not increase the secondary to focal point distance. The secondary housing can be made from wood or an aluminum ring from a local machinist or even found in local junk yards. Many of the ATM'ers in my area visit salvage yards close to airports where aircraft parts can be found that are less costly than having them made. Several of the telescopes I made have machined titanium jet engine rings and other parts found at a salvage yard. The web site gives detailed instructions on [Building a Truss Tube Telescope](#). The *Serrurier truss* is described; however, the basics are covered to build any truss tube system.



Figure 2a. Photograph of 16-inch f/6.9 Newtonian Reflecting Telescope simple truss tube assembly being constructed on author's patio. A chain link fence post to be fitted into two plywood circles and components were then assembled in turn to complete telescope. Open tube truss system design reduces weight by 50%.

The truss section can be covered with a shroud that can be made at home using *Rip Stop Nylon* fabric found in some local department stores or custom made shrouds from several Internet web sites. One shroud I made shrank when the air temperature dropped, so I found the best material was from JoAnn's Fabrics that would not change shapes with temperature changes. A shroud is not necessary in small telescopes; however, larger ones may need one to keep out body heat entering the optical path from the observers standing on a ladder.

## TUBE MATERIALS

Another reason some telescopes take longer to cool down is that telescope tubes are often made of the wrong material. Fiberglass, plastic, Formica, and other insulating materials store heat and are slow to radiate this energy to the outside air. Insulating materials, such as paper and fiberglass, tends to hold heat longer and radiated very slowly. Unfinished paper tubes are not much of a problem; however, when they are painted they soak up more paint than other materials and begin to store heat.

Fiberglass has two properties that deal with heat. First, it tends to hold heat longer than metallic materials and second it tends to pass more Infrared Radiation (Sunlight) through than metallic tubes. Sunlight will heat the interior of the telescope and that tends to prolong cooling. Furthermore, unlike metal, insulating materials are usually porous, soak up paint, and may require several coats to produce a satisfactory finish. This adds to the weight. Remember that paint was invented to be an insulator.

Metals, such as steel and aluminum, radiate and lose heat faster. Also, metal tubes are lighter than fiberglass and painted paper tubes as discussed later in this article.

### **Several interesting articles on wooden telescope tubes:**

Wooden Telescope: <http://www.woodentelescope.com/WoodenT/WoodenT.html>

My Delmarva Mirror's new home (Tim Parker):

<http://www.cloudynights.com/ubbthreads/showflat.php/Cat/0/Number/3739110/page/1/view/collapsed/sb/5/o/all/fpart/1/vc/1>

## WEIGHT AND RIGIDITY

Telescope tubes made from insulating materials are heavier because they are intrinsically weaker and have to be thicker than metal to provide the necessary strength to keep optical components in place. Aluminum is nearly twice as stiff and nearly three times as strong as fiberglass. Steel is approximately three times stronger than aluminum, but nearly three times heavier. However, aluminum is more rigid than steel -- an important ingredient to maintain the shape of the telescope tube.

Heavier may not be better. A lightweight tube assembly mounted onto a heavy, stable mount has certain advantages. First, a lighter tube tends to vibrate at a higher frequency than heavier tubes. Usually, higher frequency oscillations result in lower amplitudes; that is, the telescope will not oscillate with large swinging motions. A heavy tube tends to oscillate at lower frequencies but will take longer to dampen out. We must reach a compromise and select the right materials that

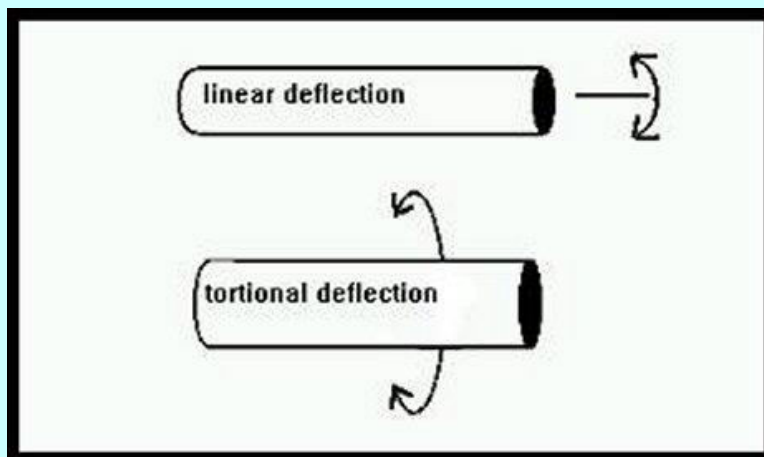


offer high frequency oscillations if disturbed and will expel heat as fast as possible. When selecting materials we must ask some important questions about the conditions we live in and what we expect from our instrument. What material is best suited for telescope tubes?

Several quantities will be necessary to calculate how rigid our telescope tube will be. Three important quantities to measure the density (weight) and modulus of elasticity (E) resistance to bending are listed in table I.

**Table I. Density and modulus of elasticity (E) of the three tube materials listed.**

MATERIAL	DENSITY	E
	In/lb <sup>3</sup>	10 <sup>6</sup>
Aluminum ( <i>al</i> )	0.098	10
Fiberglass ( <i>fg</i> )	0.065	3.45



**Figure 3. Simple illustration of the two elements to consider when selecting shaft sizes, linear deflection and torsional deflection**

At this point we will need to know the weight for each material per inch, so we first find the square area of the tube per inch from:

$$\pi(R^2 - r^2),$$

where R is tube outside diameter and r is the tube inside diameter and  $\pi$  is 3.14159

We then multiply that times the length of the tube and the weight can be found by multiplying the total area of the tube by the density of the tube material. As an example, this author's 12.5-inch f/7.04 Newtonian telescope has a 15" OD x 14.875" ID x 92" long aluminum tube, so the density from Table I is 0.098 lb/in<sup>3</sup> and the weight:

$$\pi(7.5^2 - 7.4375^2) = 2.93297 \text{ in}^2 \times 92" \times 0.098 \text{ lb/in}^3 = 26.4 \text{ lbs.}$$

A fiberglass tube with the same dimensions would weigh:  $2.93297 \times 92'' \times 0.065 \text{ lb/in}^3 = 17.5$  lbs; However, in order for a fiberglass tube to be as strong as aluminum tube the wall thickness will have to be 2.9 times thicker than aluminum. The closest commercially available tube sold by a well known company is 16.3125'' OD x 15.875'' ID x 92''. So this tube weighs:

$$\pi(8.15625^2 - 7.9375^2) \times 92'' \times 0.065 \text{ lb/in}^3 = 66.2 \text{ lbs}$$

Therefore, the fiberglass tube weighs – *two and a half times heavier* – than an aluminum tube.

## THERMAL STABILITY

Do we want a material that stores heat? One that slowly releases heat into the optical path during observing periods or do we want a material that radiates heat into the optical path or out into space? Materials are described by their thermal properties as well as the strength and rigidity. Many of the materials used for telescope construction are insulators, some radiators.

Heat waves cause turbulence within a telescope tube and interfere with the optical path. This causes the image to blur and move about. If this process is long lasting, for hours, then very little useful observing will take place until the tube stabilizes with outside air. Therefore, it stands to reason that the faster we rid the tube of heat, the quicker we can begin useful observations.

There are three processes of heat transfer at work within the components and materials of a telescope tube:

- 1) **Conduction** : When energy is transferred directly from a hot body to cooler body due to the temperature difference between them. As the telescope tube begins to cool when exposed to the night air, heat will transfer from some tube components to others, such as the walls of the tube to the secondary mirror support arms and then to the holder and mirror itself.
- 2) **Convection** : A typical example of convection is when hot air is moved from one part of a telescope tube to the other end by airflow. Because the telescope is usually pointed up, warm air rises towards the open top through the optical path. As heat enters the secondary system it rises in the optical path and this rising column of warm air will appear in the eyepiece similar to smoke rising from a fire.
- 3) **Radiation** : This is when energy (heat) transmission is through space from hotter body to a cooler body. The Sun radiates heat. Telescope materials and components radiate heat to other components from the upper side of tube outside into space (up). The lower side into the tube will radiate to the upper walls, and so on.

One must also be aware that various materials expand and contract at different rates. For instance, the thermal coefficient for aluminum is from 10 to 18 millionths of an inch per degree Fahrenheit. Fiberglass is can be from 3.3 to 8.2 millionths of an inch per degree Fahrenheit. If one uses a typical aluminum primary cell in aluminum tube expansion and contraction will be very similar [Cox, 1973]. However, an aluminum cell in a fiberglass tube will tend to loosen up as the temperature drops. Collimation problems may exist under these conditions.

## TUBE COLOR

A major aspect in stabilizing temperatures in a telescope is the color and thickness of the coating on the outside of the tube. A white or brightly colored tube may look very nice; however, heat (Infrared Radiation) is reflected into the black walls of the interior of the tube by bright commercially available coatings and causes the air to become unstable. If one remembers the theory of thermodynamics (the black body radiation part) then it would seem apparent that it is the best to paint the outside of a telescope tube black! Heat will tend to radiate from the black surface faster than from a white surface. Heat will radiate from a black (high emissivity) surface faster than it will radiate from a shiny (low emissivity) surface. That doesn't mean that a telescope painted black will always have significantly better radiation exchange with its environment than one painted white. The amount of radiative energy (heat) exchanged between two surfaces depends on: the temperature difference of the two surfaces; the emissivity (blackness) of the surfaces averaged over wavelengths at the peak of the appropriate blackbody curve; and the relative angular extent (view factor) of the surfaces.

In visible light, black surfaces absorb and re-radiate heat much more efficiently than white or reflective surfaces. Light from the sun --- with a 5000 K blackbody peak at a wavelength of 0.5 microns --- provides the standard reference against which we define colors. However, our common sense definitions of black and white may fail us at other wavelengths appropriate to different blackbody temperatures. Normal telescopes have temperatures around 260-300 K and thus have the peak of their blackbody radiated energy at wavelengths around 10 microns --- in the so-called "thermal infrared". Essentially all painted surfaces appear "black" (high emissivity) at a wavelength of 10 microns, so any painted telescope tube will radiate effectively to its surroundings regardless of the color of the paint. Typically, only metallic surfaces have low emissivity in the thermal infrared.

The nature of white is to reflect energy, and black absorbs energy. More energy (light and heat) is reflected from a shiny white surface than from a dull black one. However, because paint is not a perfect reflector, Infrared Radiation (I.R.) will leak through and slowly heat the telescope even if it is housed in an observatory or covered with some material in the outdoors under the Sun. At night, when the air is cooler, we want to remove the heat as fast as possible, so, if the outside of the tube is painted with I.R. reflecting white paint, where does this radiation go? Yes, inside through the black painted inside of the tube!

It may be a good idea first to paint the inside the tube (IR reflecting) titanium white then apply a light coat of flat black over the white paint. The white paint would reflect I.R. to the outside of the tube and of course the black reduces light scattering inside. Remember though, paint is an insulator and should be applied with the least amount of coats as possible on the outside of the tube. One might find it useful to black anodize a small aluminum telescope tube. A tube made this way is black through and through. Given the need to channel heat from within the tube to the outside air a bare aluminum lightly coated with black paint may be the best solution.

For general use, the outside of the tube may be painted any color which suits the taste of the owner. The painted surface will radiate to the sky and eventually cool below the surrounding air temperature. Telescope tubes, and indeed the whole earth, radiate heat to the cold sky because the night sky has an effective temperature of around 235 K. The sky would be much colder if it were not for the so-called "greenhouse gases" in the atmosphere which block many infrared wavelengths. The effective temperature of the sky varies with location and season. Deserts and high mountains tend to have colder skies because there is less water vapor to block the thermal infrared radiation. External surfaces of telescopes or domes which cool below the ambient air



temperature can have two unwanted effects. They can collect dew which then drips on the optics, or they can create plumes of cold air (cooled by conduction from the surface) which negatively effect seeing in the same way that plumes of hot air do. At least a little bit of cooling by radiation to the sky is desirable as it compensates some of the excess heat which may be stored in the mass of the telescope structure.

For telescope tubes or domes which are exposed to direct sunlight during the day, TiO<sub>2</sub> (titanium dioxide) white paint is a very effective coating. This special paint does the best job of reflecting away solar radiation during the day. TiO<sub>2</sub> white paint appears quite "black" at thermal infrared wavelengths so it radiates well to the sky at night. About 20 years ago, astronomers with white domes began to notice excess seeing caused by air cooled by being in contact with the radiatively cooled dome surface. Measurements of the inside of my 12.5" f/30 and f/7 telescopes have shown that a TiO<sub>2</sub> painted surface may be as much as 6 K below the surrounding air temperature. To bring the tube back into equilibrium with the nighttime air, we need a coating which has low emissivity at thermal infrared wavelengths. An example of such a coating is the shiny aluminum tape which is seen on many newer telescopes and domes. Note that the shiny aluminum surface actually gets hotter than the white surface in the daytime because it cannot easily radiate away the solar heat that it does absorb. These telescopes compensate for this effect by having very lightweight domes which don't hold much heat after the sun goes down.

Interesting article, "Black Coatings to Reduce Stray Light," Tutorial by Bernie Outram:  
<https://wp.optics.arizona.edu/optomech/wp-content/uploads/sites/53/2016/10/Black-Coatings-to-Reduce-Stray-Light.pdf>

## COOLING FANS

A theoretical laminar flow of light air through the tube will help remove warm air from the inside walls and telescope components. It is easier to remove hot air than it is to replace it with cold air, an old engineering trick we learned early days of computer cabinet design.

However, a laminar flow is only possible if the air induced into the system is undisturbed, so a telescope with components will not be easy to produce a smooth airflow through it. Any induced airflow through the tube must be low velocity to avoid air current a fluctuation called eddies. Cold air is denser than warm air and will settle down from the top of the tube to the bottom. Warm air also rises from the bottom to the top. Turbulence occurs when the two mixes and the optical path is effected.

Some telescope makers install several 12VDC fans with low CFM (cubic feet per minute) flow placed in the primary end of the tube will supply airflow up towards the front of the tube. This will help cool the primary mirror, since a major source of tube currents originate there, and help provide the laminar flow at the walls of the tube [Adler, 2002]. Since there is very little space between the primary mirror/cell and the walls of the tube, fans can be installed at a 45-degree angle to the rear of the tube so that air flows up the tube in a spiraling motion.

The fans also can be installed to exhaust warm air out the rear end of the tube and works well in most cases. Dobsonians with the primary mirror end closed may require this method. Remember, warm air rises and flows upward through the tube, not down and out the back. The direction of flow is dependent on the condition where the telescope is used. In warm (hot) climates fans are usually used to cool components and can be directed upward through the tube. However, in

cooler (cold) climates fans are better used to off air out from the bottom end. There is even talk that some makers are installing fans to blow air across the primary face though a hole in the side of the telescope tube. This is well worth experimenting with.

A note on optical windows: they are fine for small or short scopes, but they tend to prevent ventilation. So, unless those diffraction spikes really upset the observer and cause mental unsuitability it is advisable to leave the telescope tube open at both ends at least.

Several interesting articles on the use of fans to reduce "tube currents" in a telescope:

Attaching a cooling fan to Newtonian: <http://www.deepskywatch.com/Articles/rear-fan-newtonian.html>

Beat the Heat: Conquering Newtonian Reflector Thermals: <http://garyseronik.com/?q=node/55>

Cooling a 10" Newtonian: <http://www.acquerra.com.au/astro/cooling/index.html>

Pesky Tube Currents: [http://www.alpo-astronomy.org/jbeish/Peaky\\_Tube\\_Currents.pdf](http://www.alpo-astronomy.org/jbeish/Peaky_Tube_Currents.pdf)

Telescope Optics Topics: <http://www.fpi-protostar.com/bgreer/index.htm>

### TELESCOPE STORAGE

Finally, Infrared Radiation from the Sun will pass through most observatories to heat the tube and components in the telescope. To shield the instrument from heat waves a multipurpose silver tarp can be used to cover the instrument when not in use. The author uses a heavy duty Silver Tarp (Northern Hydraulics, Inc., Burnsville, MN) that has a U.V. absorbing coating to prevent deterioration by the Sun (~\$11- \$20). Remember, that an air space between the telescope and the tarp also helps keep the instruments cooler. I have found it also blocks IR and keeps my telescopes at ambient temperature even in the bright Florida Sunlight.

For mirror storage and/or shipping a wooden or heavy cardboard box is useful. Below is a photo of an old 16" magnetic tape shipping container with disks of thin Styrofoam and a sheet of cotton glued to 1/8th-thick Plexiglas disk accompanied by tissue paper and Styrofoam disk and sheets for the side, plus soft rubber forms for the mirror side.



LEFT: 16" magnetic tape shipping container. RIGHT: 1) container top, 2) two thin sheets of Styrofoam (with a place for secondary mirror and holder, 3) Sheet of cotton glued to 1/8th-thick Plexiglas disk, 4) tissue paper and 5) bottom of container with Styrofoam bottom, side sheets and three soft rubber forms (gray).

## DISCUSSION

By now the reader may question the methods suggested in this article. Why do so many commercial telescope makers use a different approach to their telescope tube designs? In my opinion they do not like to change production techniques and parts availability. Besides, a nice brilliant white fiberglass telescope tube really looks great!

The information herein does not fit all circumstances. I have talked with telescope makers who have not had good results with metal tubes even using cork liners. Also, self-adhesive [flocking material](#) can be a great method to line the inside of the telescope tube. This deserves more study. There is nothing wrong with paper or wooden tubes, if treated correctly. Carbon fiber tubes are lightweight and may not hold heat as fiberglass materials do, this also deserves more study. The treatment will add to the weight and difficulty in construction in many cases. Some of the newer composite materials may be even better than any material discussed in this article, however, the author has no experience with them.

For a detailed analysis of mechanical design in telescope making check [this site out](#). Certainly one of the most comprehensive and helpful analyses of telescope design can be found in Bob Lombardi's Internet book **Mechanical Design of Telescopes for the Amateur** and should be required reading for the advanced ATM'er [*Lombardi*, 2008].

My telescope making experience was in the warm climate of south Florida, so maybe this author missed something along the way. It may be just a matter of degree, no pun intended, how much heat transfers throughout the telescope tube and its surroundings. On occasions when the temperature reached 50 degrees or so, when the wind was still, something not common in Florida, my telescope produced more than usual tube currents.

Reversing the fans seemed to help. Since my fans were installed to cool the primary and were not used while observing, maybe heat in the tube just would not rise out of the entrance. So, the fans were changed to take out the heat from the bottom with improved performance. At any rate, tube material and colors are important in telescope design. One should experiment -- the telescope maker's creed! This paper discusses issues that were omitted from the previous articles that were published by this author with additional input from other ALPO members will be included (*Beish*, 1995, *Beish*, 2000). It is time for an update.

After replacing the heavy 16-inch I.D. by 53" long fiberglass tube with a thin wall (0.060) aluminum tube that was rolled and welded by a local business. I then painted the inside IR blocking titanium white and then applied a 1/8th-inch cork liner (purchased from a local hardware store) with the recommended glue; then painted the cork flat black. The outside was first sprayed with a light coat of Zinc chromate-based primer then lightly with flat black. The original aluminum end ring and Cassegrain primary cell and back plate was used to form the tube. The rack & pinion focuser, primary cell, secondary holder, spider, and tube counterweight set were purchased from Kenneth F. Novak & Co. and a 2.00-inch, 7.5X secondary for this telescope were made by our local optician, Richard Fagin, resulting in a 12.5" f/30 Classical Cassegrain.

Before the fiberglass tube with aluminum one this telescope would take 1.5 to 2 hours to really cool down and be ready for use. After opening the observatory roll-off roof and removing the

dust caps this telescope would be used right away and all the heat plumes from the internal components were gone. Also, a small fan was mounted near the back next to the mirror cell. To eliminate vibrations the fan was attached to the telescope tube using 3" rubber inner tube.

While at an astronomical meeting I "talked telescopes" with Bob Cox and he mentioned that he was an engineer, so we hit it off well and talked for a long time about tube currents and optical tube design. He told me that I should follow my experience in engineering and use physics to redesign my Cassegrain. In other words, replace the heat storing fiberglass with a heat radiating tube.

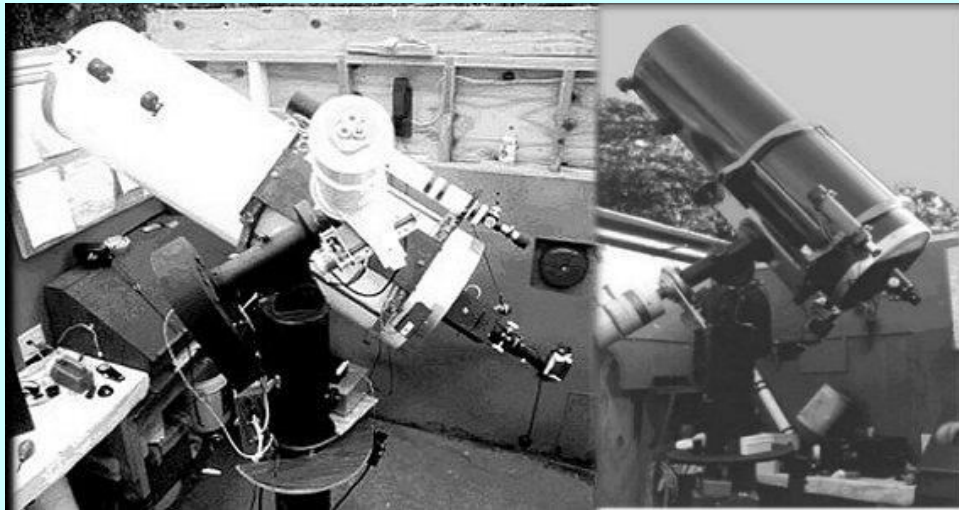


Figure 4. LEFT: My first 12.5-inch  $f/16.5$  Classical Cassegrain telescope design and RIGHT: modified to  $f/30$  with cork-lined, black aluminum tube.

We have discussed some of the bad aspects of tubes made from paper, fiberglass and so on. Moreover, we have discussed some good aspects in thin skinned, metal tubes with a light coat of flat black paint. Metals, such as steel, brass, or aluminum, are conducting materials and radiate energy. When exposed to the night air, metal tubes will immediately begin to radiate heat energy into space (straight up into the sky) and transfer heat into the surrounding air. Heat also radiates through to the inside walls of the tube. A thin sheet of material such as cork glued to the inside walls will insulate the interior of the tube from the outside heat. When cork is painted flat black its rough surface helps reduce light scatter -- an added benefit.

## Interesting Protostar Documentation downloads

Secondary Installation (Protostar): <http://www.fpi-protostar.com/ftp/instman.pdf>

Cassegrain secondary Installation (Protostar): <http://www.fpi-protostar.com/ftp/cassin02.pdf>

Flocking Installation (Protostar): <http://www.fpi-protostar.com/ftp/fbinst.pdf>

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