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Seamless Frusta Creation for Stray-Light Management in Optical Devices

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Seamless Frusta Creation for Stray-Light Management in Optical Devices

ABSTRACT

Optical devices such as luminance meters and digital cameras used for light measurement often suffer from stray light corrupting the accurate measurement of light particularly when they are used to measure dark areas of high-contrast scenes. A method of controlling the stray light is provided using gloss-black frusta. Methods to create seamless frusta from plastic sheets are described and their use is described.

1. INTRODUCTION

Management of stray light in optical measurement devices is often handled by the use of matte-black surfaces and baffles in attempts to absorb the stray light from corrupting the measurement. We have found in numerous applications that the use of gloss-black frusta (a frustum is a cone with its tip cut off) can do a better job of managing stray light than matte-black surfaces.[1,2] Rather than trying to absorb the light on the material surface, we attempt to control and direct the light so that it is ultimately absorbed owing to multiple bounces. This report discusses the methods and apparatus we use to create seamless single-piece frusta from plastic sheets. Methods to create frusta from sheets of plastic (having seams where the edges are connected) are discussed in a separate paper.

Consider Fig. 1 where we show a luminance meter being used to measure the luminance of a dark rectangle on a white screen of a flat panel display (FPD). Two types of masks are shown in Fig. 1, a flat matte-black mask and a gloss-black frustum mask. Only if the flat mask is placed in direct contact with the screen and if the distance between the pixel surface and the front surface is small (on the order of a millimeter or so), can the flat mask provide a better stray light control than the frustum mask. However, whenever the front surface of a FPD is touched, particularly for many liquid-crystal displays (LCDs), there may be a danger of changing the characteristics of the display by the mechanical force or by heating the pixel surface. Either way, in many applications, it is usually not desirable to touch the surface we are trying to measure. Thus, we assume that we will always use a mask that is not touching the display surface. Even if the flat mask has a very dark matte surface with a diffuse reflectance of less than 5%, there is some light scattered into the measurement area. With some very high contrast FPDs this small amount of light can corrupt the correct measurement of black—hence, the usefulness of the frustum mask. The surfaces are gloss black so that any light from the white areas is reflected away from the measurement area. In addition, any light entering through the aperture of the frustum is reflected away from the luminance meter. Further advantages over a flat mask are as follows: (1) The diffuse reflectance of a good gloss-black material can be much less than 1 %, and (2) the frustum material's distance to the surface is not constant as in the case of a flat mask. With the frustum, as you move away from the hole along the surface of the frustum you also move further away from the surface being measured. There is very little light scattered in the direction of the measurement region—the dark rectangle in Fig. 1. In fact, depending upon the configuration and size, in some instances the greatest corruption from the frustum mask comes from scattering off the edge of the frustum aperture.

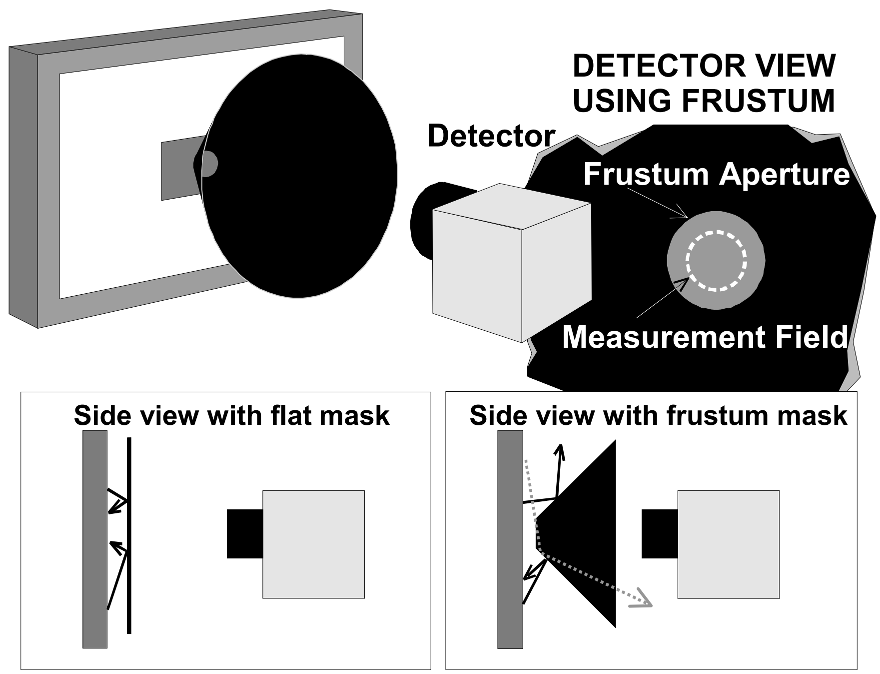


Fig. 1. Comparison of a matte -black flat mask with a gloss-black frustum mask.

In using any aperture mask, flat or frustum, it is essential that the mask not interfere with the measurement by cutting into the rays of light that are contributing to the measurement. In Fig. 2 we show that the mask aperture can be placed too close to the detector whereby it obscures some of the light that should be measured. The maximum distance z_{max} allowed based upon the diameter of the measurement field, u, the acceptance area diameter of the detector, w, the distance of the detector from the display, d, and the aperture diameter of the frustum, s, is given by

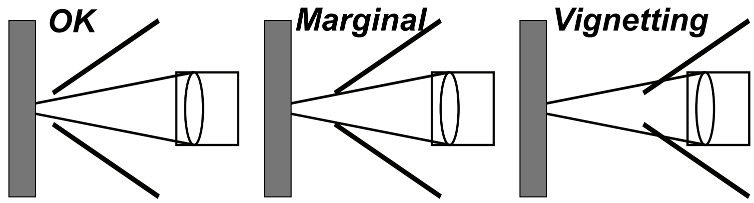


Fig. 2. *Frustum placement can cause vignetting.*

$$z_{max} = d\,\frac{s-u}{w-u}\,, \tag{1}$$

see Fig. 3. Note that the acceptance area is not always the full diameter of the lens depending upon the optical configuration of the detector being used. For example, a charge-coupled-device (CCD) camera (with a photopic correction filter) may be using a standard 35 mm photography lens that is stopped down so that the acceptance area of the lens is considerably smaller than the maximum lens diameter.

In general, large frusta used to make routine measurements can be cut from gloss-black plastic sheets such as vinyl plastic that are available from plastic suppliers. The advantage is that they are already glossy. The disadvantage is that they are not well suited for small work or where the frustum will be inserted into a tube. The frusta detailed here are fashioned from plastic sheets that offer the advantage of being seamless and can be created with cylindrical ends to easily be positioned in tubes for mounting. They can be made very small and in a variety of shapes, not just round. The disadvantage is that in the heat-forming process we often lose any original glossiness of the plastic sheeting employed, resulting in the need to paint the frustum with a gloss-black paint. While painting and drying, the frusta will have to be placed in a dust-free area to avoid accumulating light-scattering particles, as much as possible. In what follows we certainly do not claim that we have found the best way to make these seamless frusta. This is simply a documentation of what we have done to achieve our needs.

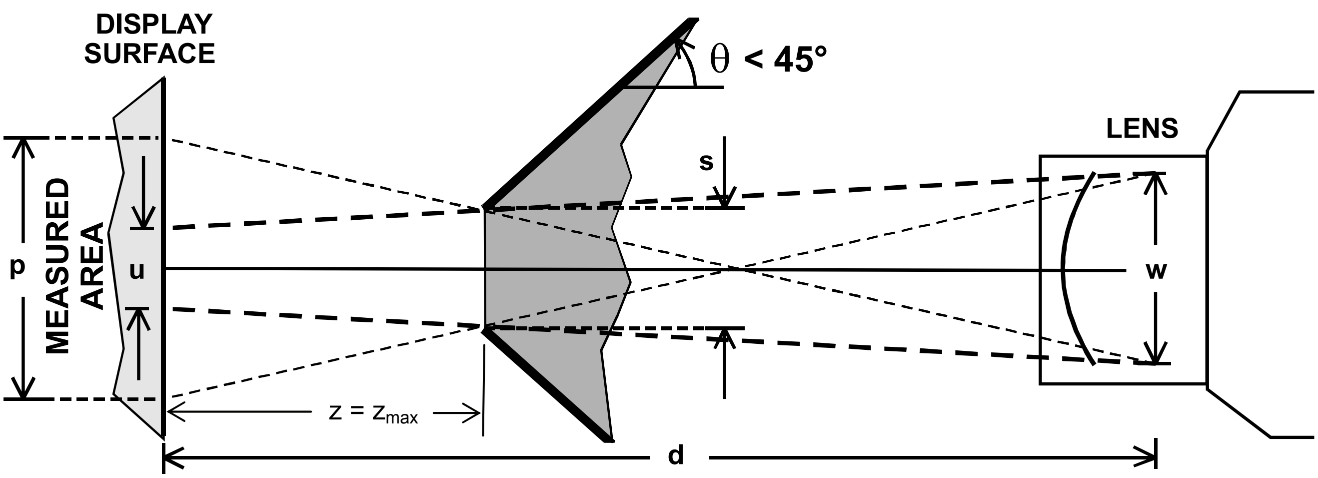


Fig. 3. *Detector configuration with frustum mask. The frustum aperture diameter is* s*, the acceptance area of the detector is* w*, the measurement field is* u*,* z *is the distance of the frustum from the display, and the light that can possibly contribute by directly scattering into the lens is denoted by* p*.*

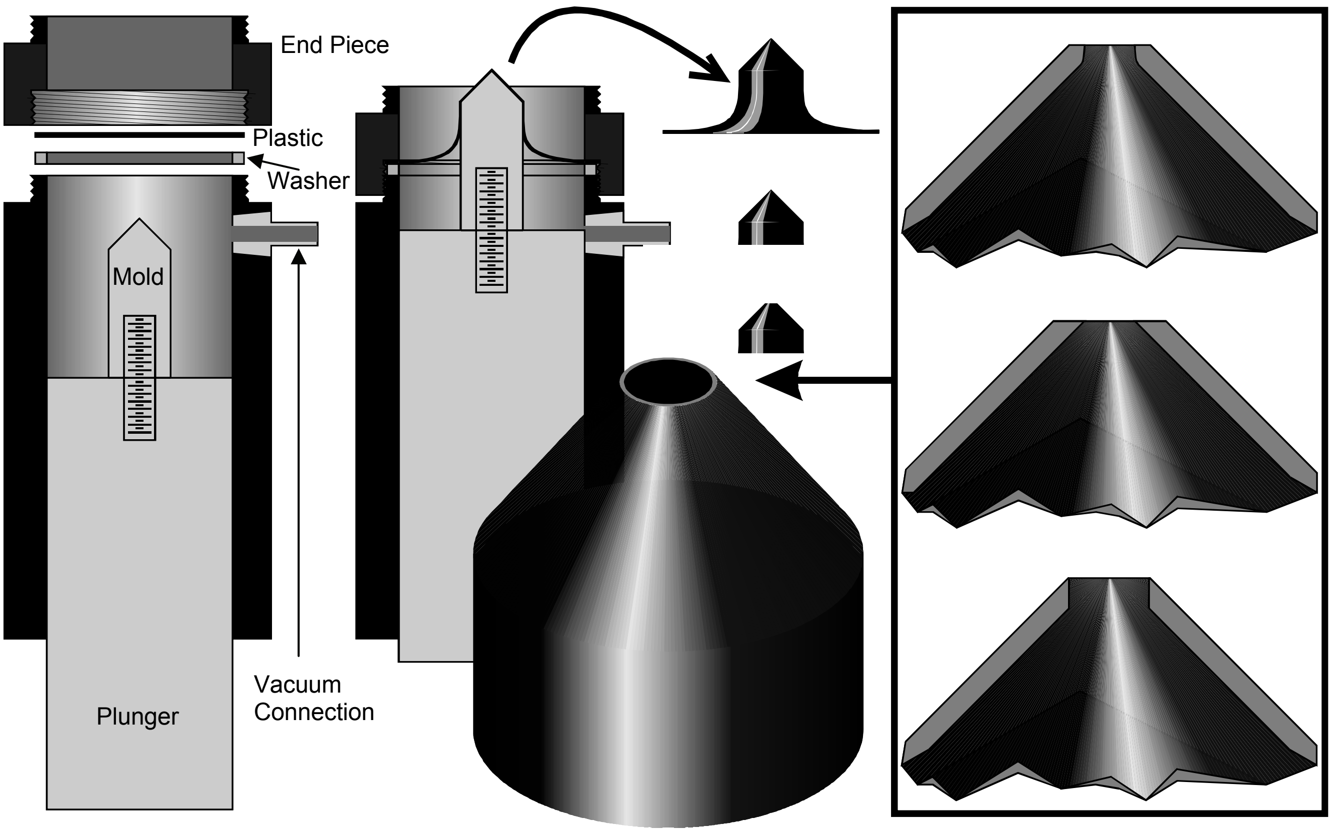


Fig. 4. Vacuum forming apparatus to create small seamless frusta. Examples of frusta aperture treatments are shown in the inset.

2. VACUUM FORMATION OF SMALL FRUSTA

In Fig. 4 we show an apparatus to create small seamless frusta. The cross section shows a solid cylinder, the plunger, that freely slides within a hollow cylinder. The end of the hollow cylinder accepts a threaded ring end piece to clamp the thin plastic material (see, for example, the T-mount hardware available from Edmond Industrial Optics[3]). Here are the steps for making small frusta:

1. Cut gloss-black vinyl plastic 0.25 mm (0.010 in) thick is cut into a disk and clamped at the top of the hollow cylinder with the end piece (a ring washer may be needed to hold the plastic securely in place as shown in the figure).
2. Attach the fitting at the side of the cylinder to a running vacuum pump through a closed valve.
3. Screw the frustum mold to the top of the plunger. Note that the tip of the mold must be slightly rounded or it can puncture the plastic.
4. Insert the plunger (with mold) into the cylinder and hold the mold below the surface of the plastic. Hold the cylinder and plunger with one hand.
5. Heat the plastic with a hot-air gun (held by your other hand) until it appears quite flexible. Pay attention to the plastic near the wall of the outer cylinder, which tends to be cooler. You will have to get the feel of how much the plastic needs to be heated for different size and shape molds.
6. Once the plastic is judged to be sufficiently hot, quickly place the hot-air gun down, open the vacuum valve, and at the same time quickly push down on the cylinder so that the plunger presses the mold up through the plastic. If the plastic is too hot, the vacuum can rip a hole in the side of the plastic. The plastic will cool quickly once in contact with the mold.
7. Gently remove the plastic from the cylinder and off the mold—the plastic can be quite thin and may tend to grasp the mold.
8. Carefully trim off all excess plastic from the shaped cone with scissors.

Note that a variety of different shapes can be created using different molds. It is not necessary to confine ourselves to a 45° frustum (apex angle of 90°) nor even to a round cross section. We have made rectangular cross-section as well as very narrow frusta using this device with appropriately shaped molds.

After the cone is created and the excess plastic is cut away, the frustum aperture is created. For these small cones, it is usually sufficient to hold the cone with your fingers at the tip and rotate a drill of desired diameter using gentle pressure to make the hole. After the rough hole is created, you can shape it as desired using a razor knife under a low-power microscope (this may try your patience).

The edge of the hole can be fashioned in various ways: Three types of frustum hole shapes are shown on the right of Fig. 4. Visualize each of the frusta being used with the detector at the bottom and the source of light at the top. The top hole treatment of Fig. 4 is a compromise between the bottom two types of holes. The middle hole treatment minimizes the reflection off the interior edge of the hole into the detector, and the bottom hole treatment minimizes the reflection off the trimmed hole back to the source.

Sometimes the cone will not retain its gloss surface after all this abuse. To freshen up the surface, especially the region of the aperture and for small frusta, try painting it with a 50 % diluted oil-base high-gloss black paint (it may not need to be diluted depending upon the thickness of the paint employed). Get the blackest paint you can get because the diffuse reflectance for even black gloss paints can vary (for example, we have successfully used Benjamin Moore Black #133−80 Impervo Alkyd High Gloss Metal & Wood Enamel; hobby-shop model paints may also be good candidates, also black fingernail polish can work). If the plastic material is stretched quite a bit it can become semi-transparent and will definitely need to be painted to be useful. Painting can also help to smooth out any rough edges remaining from cutting and shaping the hole at the tip.

If the small frusta are to be used as inserts inside a tube, the mold can be machined a little smaller than the inner diameter of the tube so that the finished frusta will slide fit inside the tube. Depending upon how rugged you intend the structure to be, you can secure such small frusta using gloss-black paint. Watch for light leaks around the outer diameter of the frustum within the tube. For more secure mountings, epoxy may be required or black silicone rubber sealant (available from hardware stores). Gloss-black paint can be used to eliminate any stray light around the edges of the frusta. Figure 5 shows a narrow-frustum stray-light-elimination-tube (NFS) containing three inserted frusta and a tip made from a narrow frustum. The device is approximately 3.8 cm in diameter.[4,5]

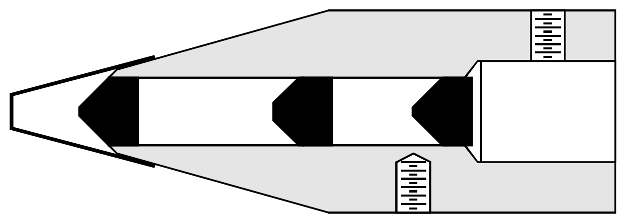


Fig. 5. *Small frusta shown used in a luminance probe for high-contrast measurements on displays.*

3. LARGE FRUSTUM FORMATION TOOLS

The machine drawings of the larger frustum formation apparatus are found through the remainder of the document. These are identified by name rather than figure number. They are the drawings supplied to the machinists and serve to provide an example of the apparatus that can be employed; they are drawn to scale (1 in = 2.54 cm). (Again, there are likely many better ways to create these seamless frusta, we are simply describing our methods here to distribute ideas. The figures show nominal values.)

The formation of larger-diameter frusta is similar to the creation of small frusta, but the vacuum is not used to propel the plunger into the quasi-melted plastic (at least for the apparatus detailed here). The mold is attached to the plunger disks. The disks are separated by a threaded hexagonal standoff (commercially available), and the plunger rod is an appropriate length of optical-component mounting rod (or aluminum rod with internally threaded end). Because the plunger disks are not good vacuum seals, the vacuum may be turned on during the heating (we use a 1/8 NPT Swagelok connector for 1/4 in [6.4 mm] tubing). It serves to help remove the air from the space around the mold when the mold is pushed into the hot plastic sheet. The outer cylinder is held by one hand with the plunger post resting on a table so that the mold is sufficiently below the plastic sheet. Once the plastic is sufficiently heated the outer cylinder is moved rapidly downward pushing the heated plastic onto the mold. In heating the plastic with the hot-air gun, it is important to be sure the outer diameter of the plastic near the walls of the cylinder are sufficiently heated. Thicker vinyl plastic is used having a thickness of 0.75 mm (0.030 in). Square sheets of plastic at the diameter of the outer cylinder wall may be used; it is not necessary to be disk shaped. Not all the six screws need to be used to clamp the plastic with the clamping flange, often two will work.

Once the cone is fashioned, the excess outside plastic must be trimmed off and the aperture must be cut. Two ways are provided to do this:

1. Often when making these frusta, you get focused on cleaning off the outside excess plastic first (because it is so ugly), and then cutting the center hole. The excess plastic material on the outside can be cut off by cutting a small hole in the tip of the cone so that the molded plastic can be held by the appropriate Frustum Trimming Holder (FTH) whereby the excess plastic can be cut off in a lathe (the FTH is mounted on the Mandrel). Then the Mounting Disk can be attached to the Mandrel by either a Blunt or Pointed Cone Support of the proper size using a threaded stud. The Beveled Clamping Flange of the proper size can then be attached to the Mounting Disk to hold the frustum in place to cut out the properly sized hole in a lathe. It is important to be careful of the shanks of the screws mounting the Beveled Clamping Flange because they represent a hazard to the lathe operator. The Pointed Cone Support allows you to support the thinner molded material sometimes encountered. You may be cutting into the Pointed Cone Support when making the hole. The Blunt Cone Support may be used with thicker molded plastic and permits greater flexibility in machining the edges of the aperture of the frustum.

2. If for some reason you wish to not use the Cone Support to cut the hole, the Clamping Flange can clamp the outer excess of the cone to the Mounting Disk whereby the position of the cone will have to be adjusted so that it is lined up with the rotation axis of the lathe. The center hole can then be cut in the cone. The resulting frustum can then be clamped in the FTH and the outer excess removed. This method requires that the cone material after molding be relatively firm.

Figure 6 shows a cone mold that has been shaped with rounded edges to avoid ripping the hot plastic during the molding process. Also, the outer diameter of the mold is adjusted so that the resulting frustum will slide-fit into a specific tube that is used to create a stray-light-elimination tube (SLET). These frusta may be mounted within tubes using black paint, epoxy, or black silicone rubber sealant as with the smaller versions described in Section 2. Attention must always be given to light leaks around the outer diameter of the frusta.

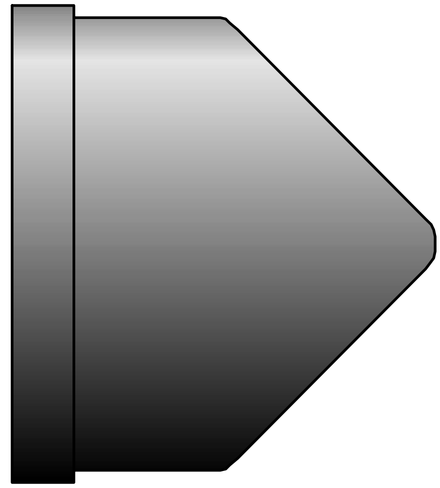


Fig. 6. *Cone mold with rounded edges to create frustum to fit the interior of a specific tube.*

In Fig. 7 we show a SLET assembled with two frusta where a luminance meter is measuring the luminance of a small area (measurement field) on a FPD. The interior of the SLET tube and the frusta surfaces are all gloss black. Grays are used in Fig. 7 to show the configuration of the frusta. The rays that contribute to the measurement extend from the bezel holding the lens—the acceptance area of the luminance meter—to the measurement field on the FPD. The rays that could corrupt the measurement extend from the lens bezel to the outer diameter of the interior frustum. Those lines hit the end frustum where no specular reflections will occur coming from the FPD being measured. Except for the circular interior edges of the two frusta used, there will be little stray light to corrupt the measurement; so if the FPD were displaying a black square (larger than the end frustum aperture) on a white field, we would be able to make an accurate measurement of that black region despite the surrounding white field.

It is anticipated that using gloss-black interiors coupled with gloss-black frusta will permit optical configurations to be used that reduce the stray light contamination experienced with the use of only matte-black surfaces. For example, in Fig. 8 we show a possible use of this idea with a telescope. Should better stray light elimination be needed, more frusta can be added. Looking down the SLET with you eye will reveal any reflections that my need to be further controlled.

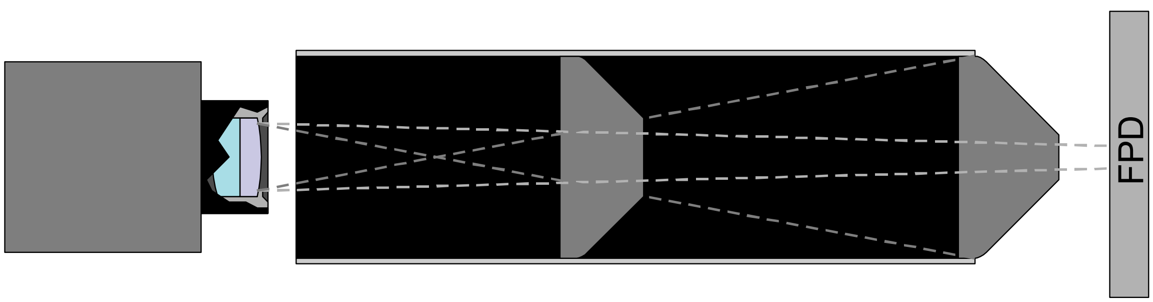


Fig. 7. *Luminance meter with stray-light-elimination tube (SLET) assembled with two frusta.*

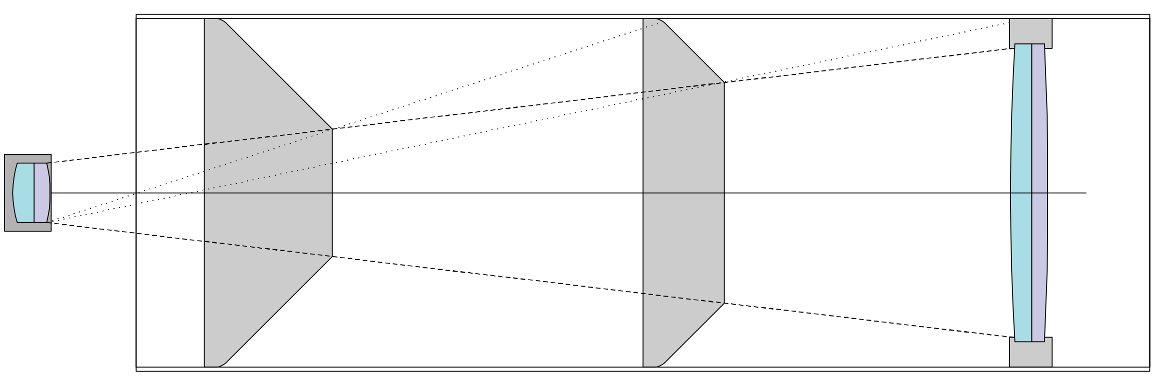
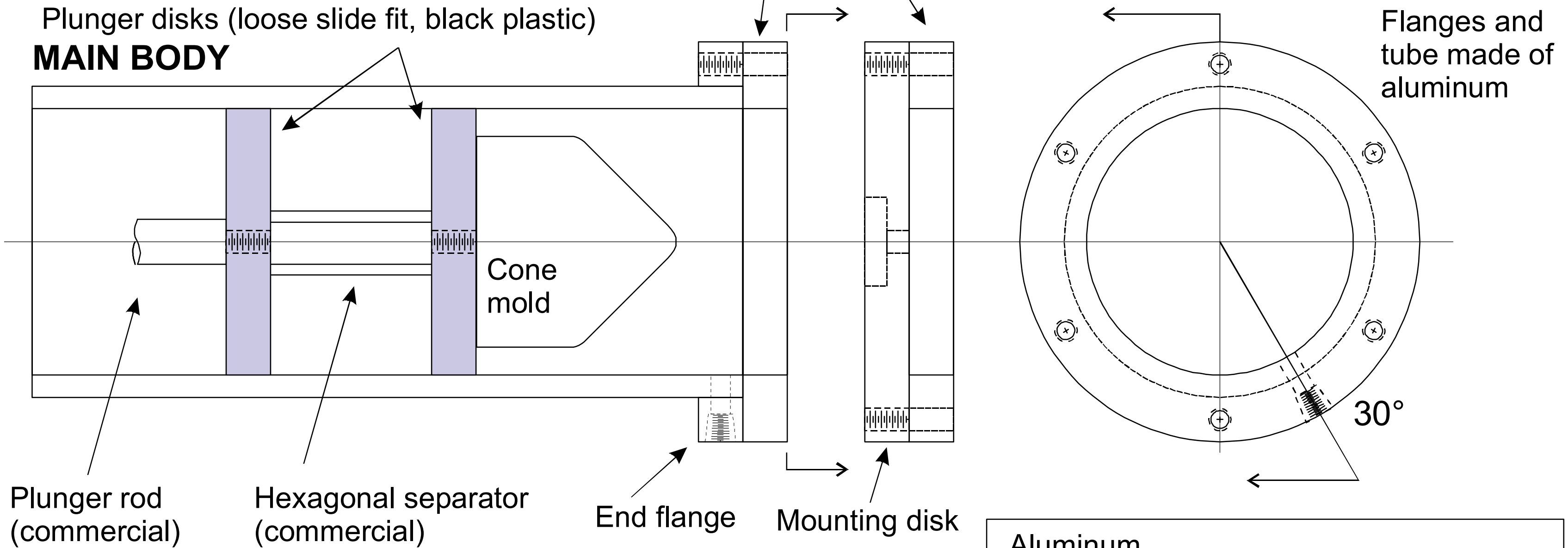
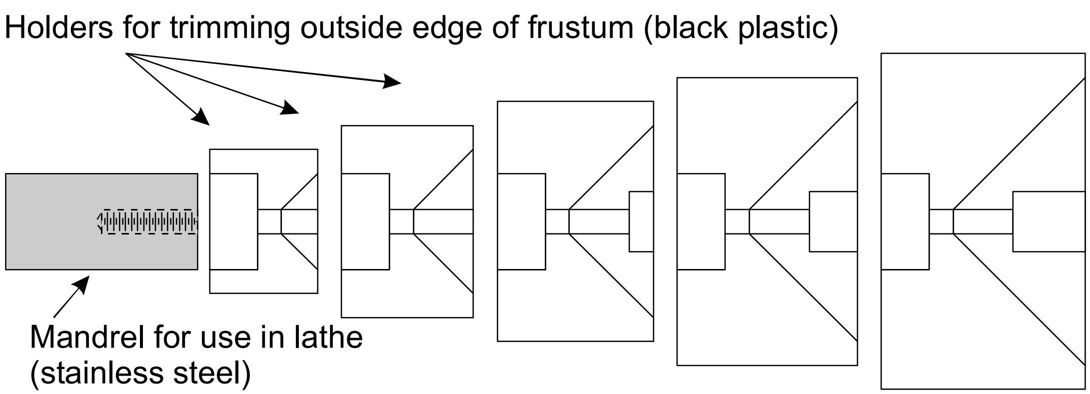


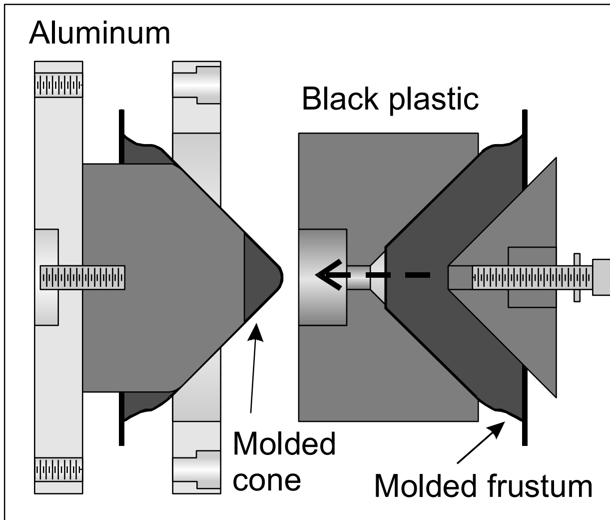
Fig. 8. *Schematic of a telescope using gloss-black frusta and a structural tube with a gloss-black interior. Dashed lines show the rays contributing to the image. Dotted lines depict the obscuring of light accomplished by the frusta.*

FRUSTUM MAKER: *OVERVIEW OF PROJECT*

Metric Conversion: 1 inch = 2.54 cm, replace 1/4-20 threads with M6.







Cross-section of assembled units for hole cutting and edge trimming

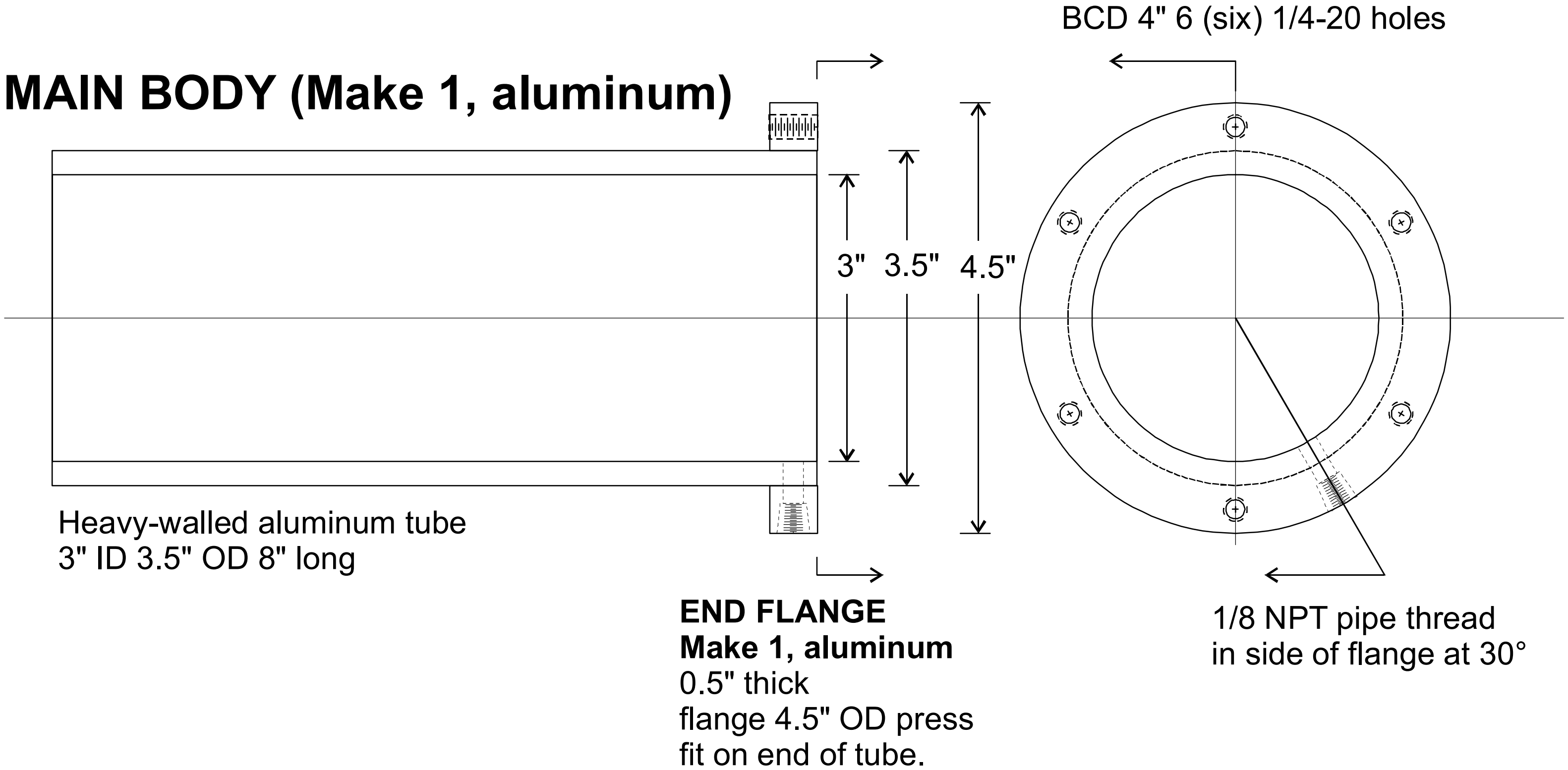
Usage: *A thin plastic disk (0.030") is placed between the end flange and clamping flange. The plastic disk is heated almost to melting using a hot-air gun. Then the cone mold is pushed upwards to form the sheet of plastic to the mold (vacuum assist can be included). The resulting molded cone is held against the mounting disk or mold to create the frustum hole. The frustum is placed in a trimming holder for removal of the outside edge of the frustum.*

FRUSTUM MAKER (3" ID): MAIN BODY

Drawn to scale at 2:1

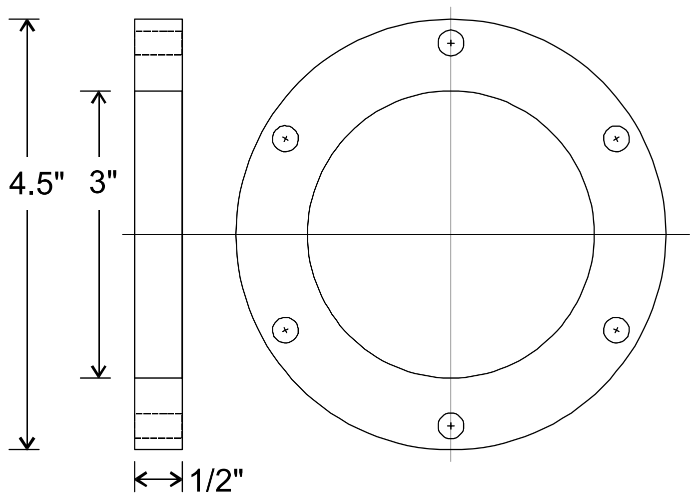
Metric Conversion: 1 inch = 2.54 cm, replace 1/4-20 threads with M6.

MAIN BODY (Make 1, aluminum)

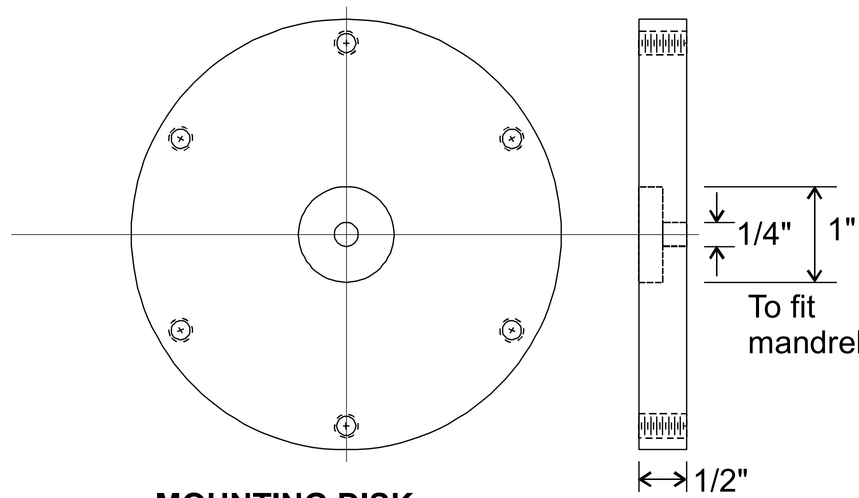


FRUSTUM MAKER (3" ID): MISC. PARTS

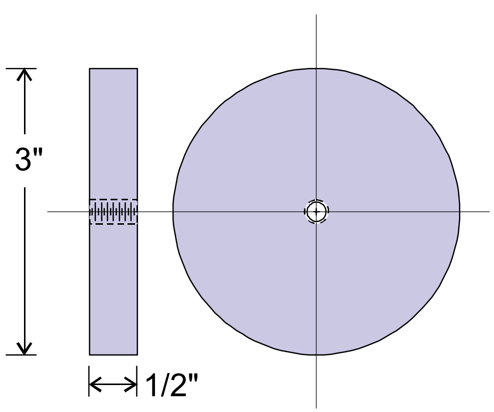
Drawn to scale at 2:1 *Metric Conversion: 1 inch = 2.54 cm, replace 1/4-20 threads with M6.*



CLAMPING FLANGE
(Make 2, aluminum)
4.5" OD, 3" ID. 1/2" thick
BCD 4", 6 (six) 17/64" holes



MOUNTING DISK
(Make 1, aluminum)
BCD 4", 6 (six) 1/4-20 holes
1" OD 1/4" deep countersink for mandrel
1/4" OD hole in center, 1/2" thick



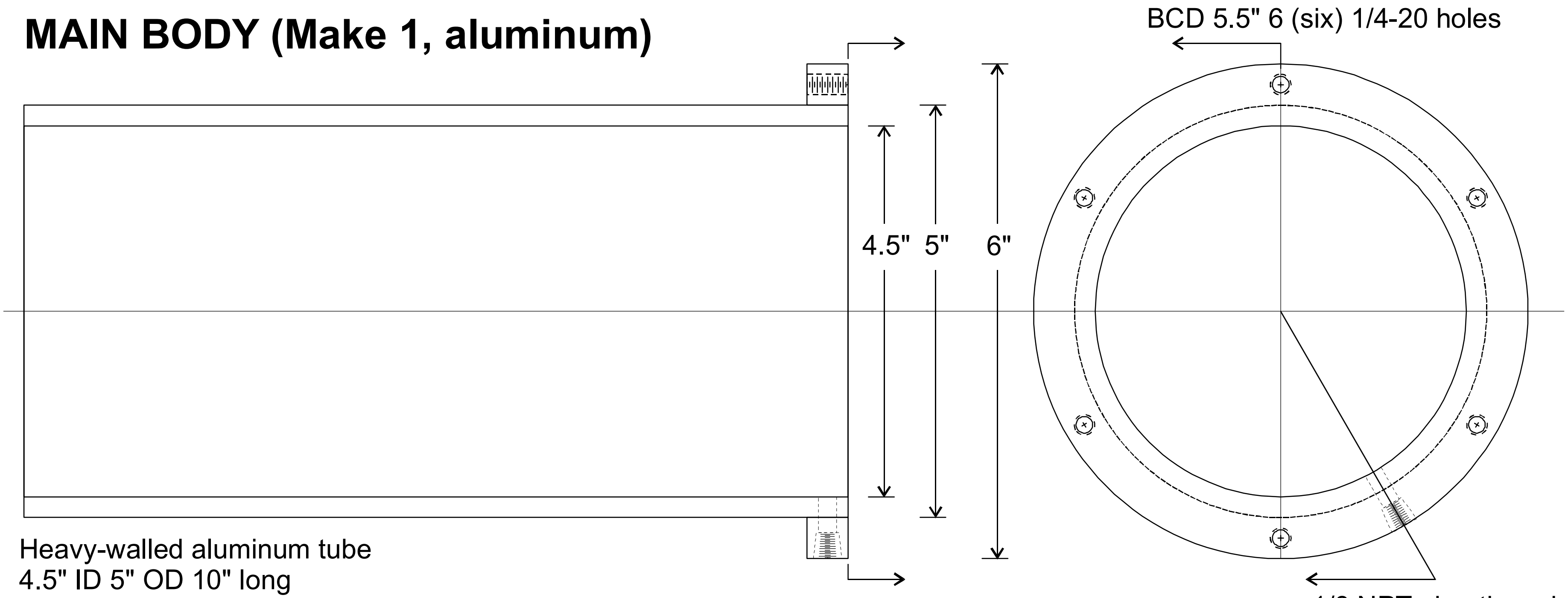
PLUNGER DISKS – (Make 4, Black Delrin)
1/2" thick, 3" OD nominally–must be an easy slide fit through main tube. 1/4-20 tapped hole must be centered accurately and tapped perpendicularly to the surface (e.g., tap in lathe, not by hand).

FRUSTUM MAKER (4.5" ID): MAIN BODY

Drawn to scale at 2:1

Metric Conversion: 1 inch = 2.54 cm, replace 1/4-20 threads with M6.

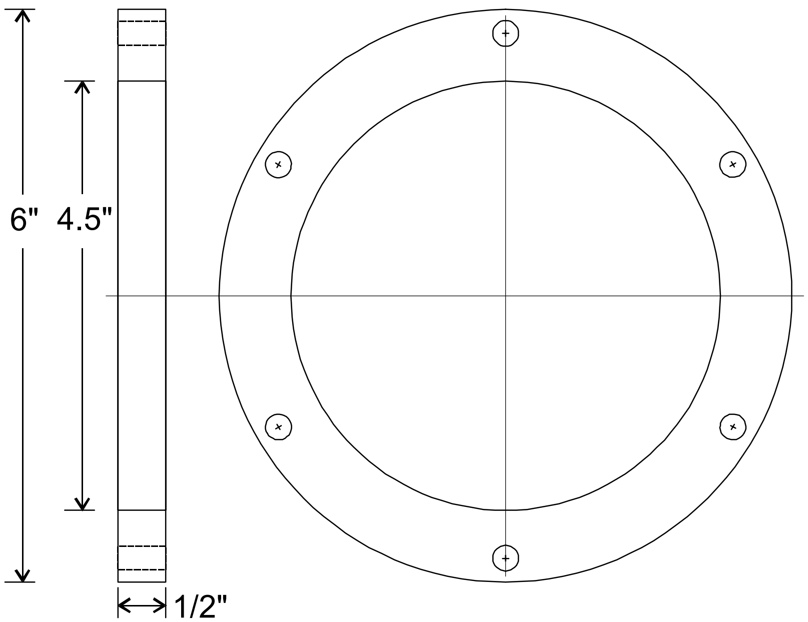
MAIN BODY (Make 1, aluminum)



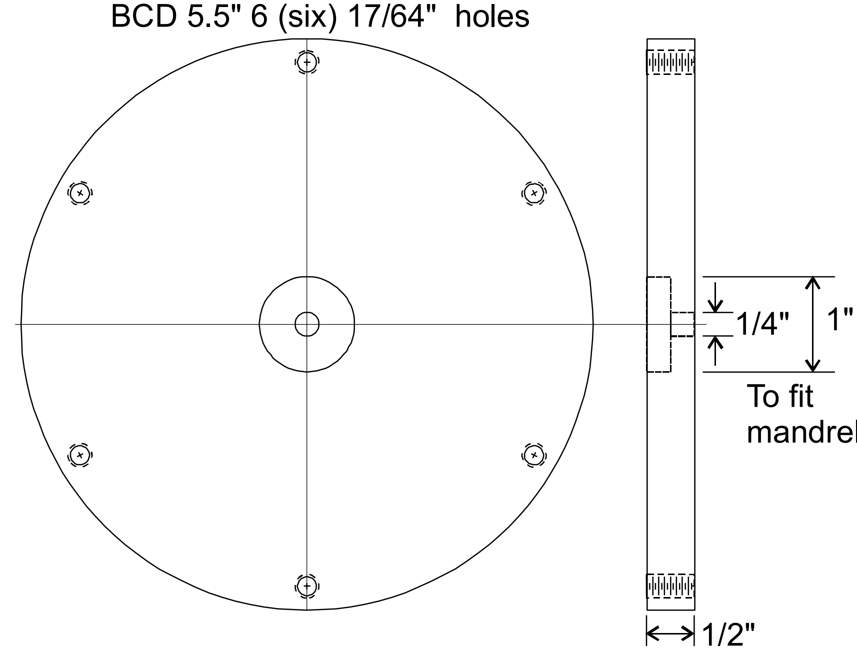
END FLANGE (Make 1, aluminum)
0.5" thick
flange 6" OD
press fit on end of tube.

FRUSTUM MAKER (4.5" ID): MISC. PARTS

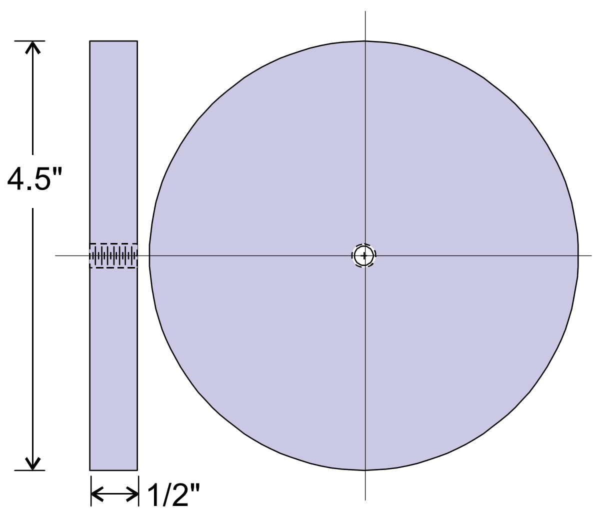
Drawn to scale at 2:1



CLAMPING FLANGE (Make 2, aluminum)
6" OD, 4.5" ID, 1/2" thick, BCD 5.5", 6 (six) 17/64" holes



MOUNTING DISK (Make 1, aluminum)
BCD 5.5", 6 (six) 1/4-20 holes
1" OD 1/4" deep countersink for mandrel
1/4" OD hole in center, 1/2" thick



PLUNGER DISKS – (Make 4, Black Delrin)
1/2" thick, 4.5" OD nominally–must be an easy slide fit through main tube. 1/4-20 tapped hole must be centered accurately and tapped perpendicularly to the surface (e.g., tap in lathe, not by hand).

Metric Conversion: 1 inch = 2.54 cm, replace 1/4-20 threads with M6.

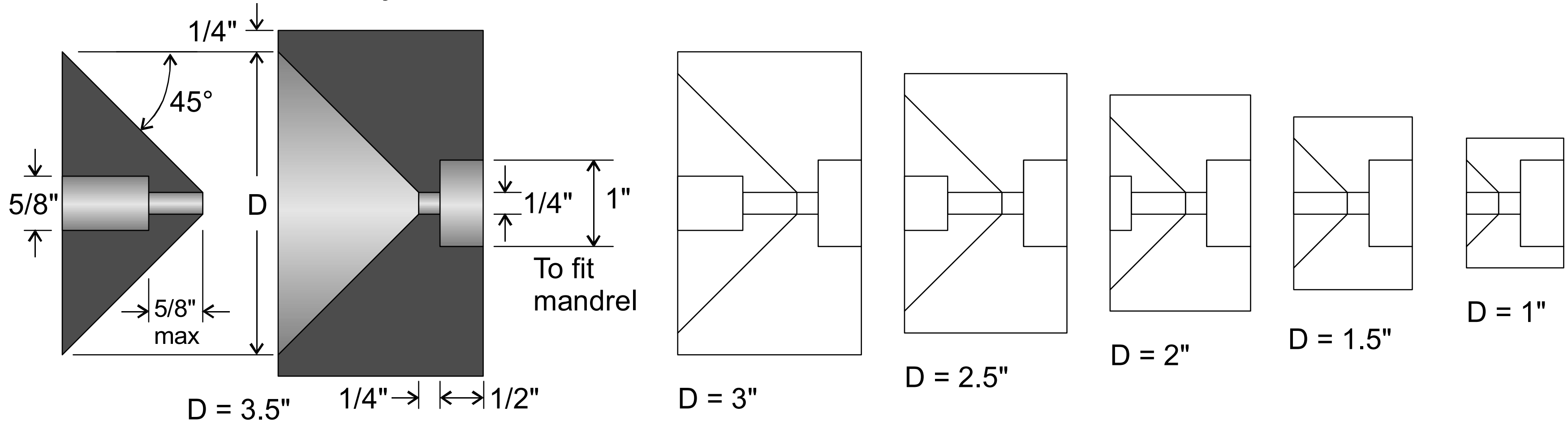
FRUSTUM MAKER: HOLDERS & MOLDS

Drawn to scale at 2:1 *Metric Conversion: 1 inch = 2.54 cm, replace 1/4-20 threads with M6.*

FRUSTUM TRIMMING HOLDERS

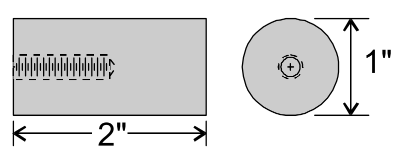
Make 1 each, black Delrin: D = 3.5", 3", 2.5", 2", 1.5", 1" (six units total of different sizes)

Cross-section of round objects, all cuts centered on axis



MANDREL

Make 2, stainless steel

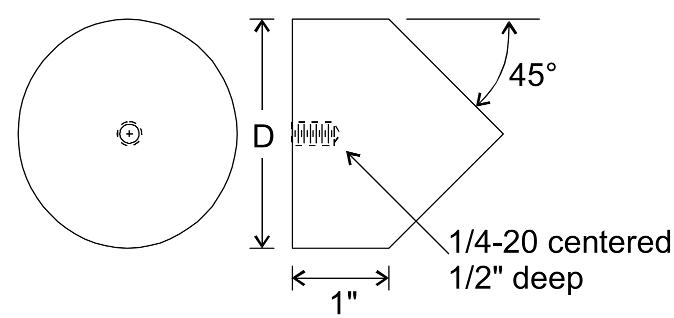


1.000" (+0, -0.002) diameter,
2" long, 1/4-20 hole 3/4" to 1" deep
at center and on axis.

CONE MOLDS

Material: Black Delrin:

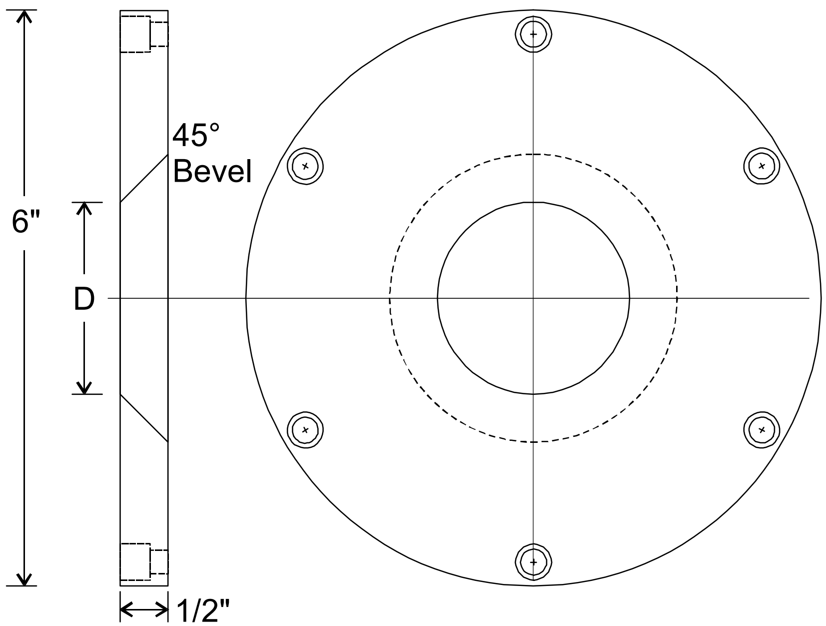
Diameter D	Number to Make
2"	4
3"	4
4"	2

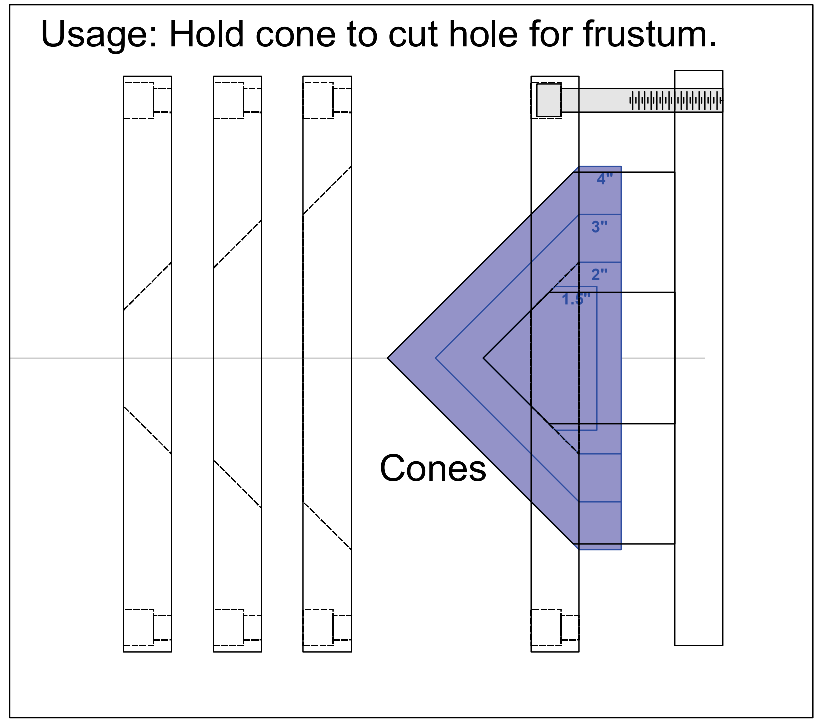


FRUSTUM HOLE-CUTTING JIG

Drawn approximately to scale at 2:1

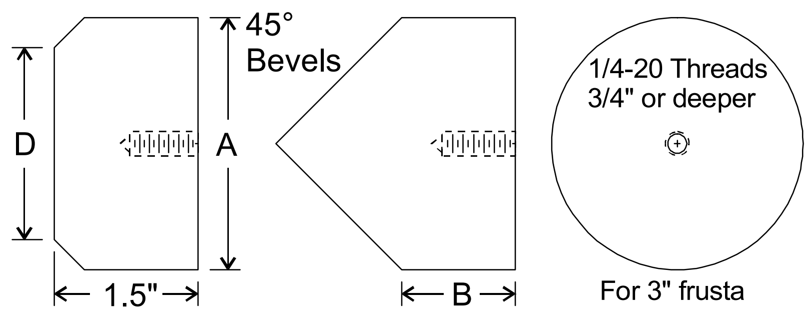
Metric Conversion: 1 inch = 2.54 cm, replace 1/4-20 threads with M6.



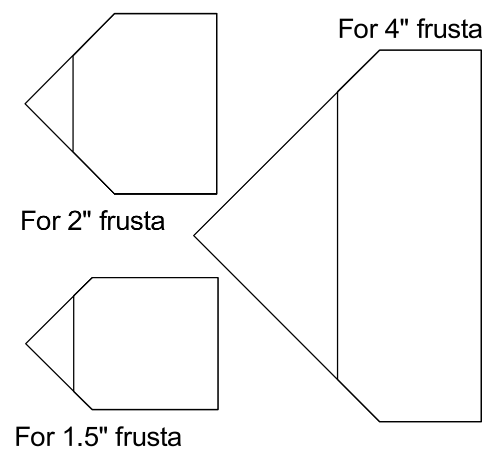


BEVELED CLAMPING FLANGE
Make 1 each size from aluminum
D = 1.060", 2.060", 3.060" (+0.020 -0) (three flanges total)
6" OD, 1/2" thick, BCD 5.5", 6 countersunk holes for 1/4-20 allen head cap screws (0.375" to 0.400" diameter hole for head)

BLUNT & POINTED CONE SUPPORT
Make 1 blunted, 2 pointed each size from black Delrin
(four sizes needed, 12 pieces, see table)



Sharpness of tip is not important.



D	A	B
1.050"	1.375"	1.312"
1.050"	1.875"	1.062"
2.050"	2.625"	1.187"
3.050"	3.875"	1.062"

Tolerances:
D +0.010 -0"
A +0 -0.050"
B +0 -0.050"

REFERENCES

Any NIST publication cited here should be available at ftp.fpdl.nist.gov/pub. Also see www.fpdl.nist.gov.

[1] P. A. Boynton and E. F. Kelley, "Accurate Contrast-Ratio Measurements Using a Cone Mask," 1997 Society for Information Display (SID) Symposium, Digest of Technical Papers, May 11-16, 1997, Boston, MA, Sec 32.1, pp. 823-826 (May 1997).

[2] P. A. Boynton and E. F. Kelley, "NIST Stray Light Elimination Tube Prototype," NISTIR 6861, March 2002.

[3] Certain commercial equipment, instruments, materials, systems, and trade names are identified in this paper in order to specify or identify technologies adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the systems or products identified are necessarily the best available for the purpose.

[4] Edward F. Kelley and Aldo Badano, "Characterization of Luminance Probe for Accurate Contrast Measurements in Medical Displays," NISTIR 6974 (National Institute of Standards and Technology Interagency Report) 15 pages, March 2003.

[5] J. W. Roberts and E. F. Kelley, "Measurements of Static Noise in Display Images," Proceedings of the SPIE V4295B-27, Electronic Imaging Symposium, San Jose, CA, pp. 211-218, January 23, 2001.