THE UNIVERSITY OF ARIZONA

# Large Periscope System

## Proposal Including Optics and Mechanics

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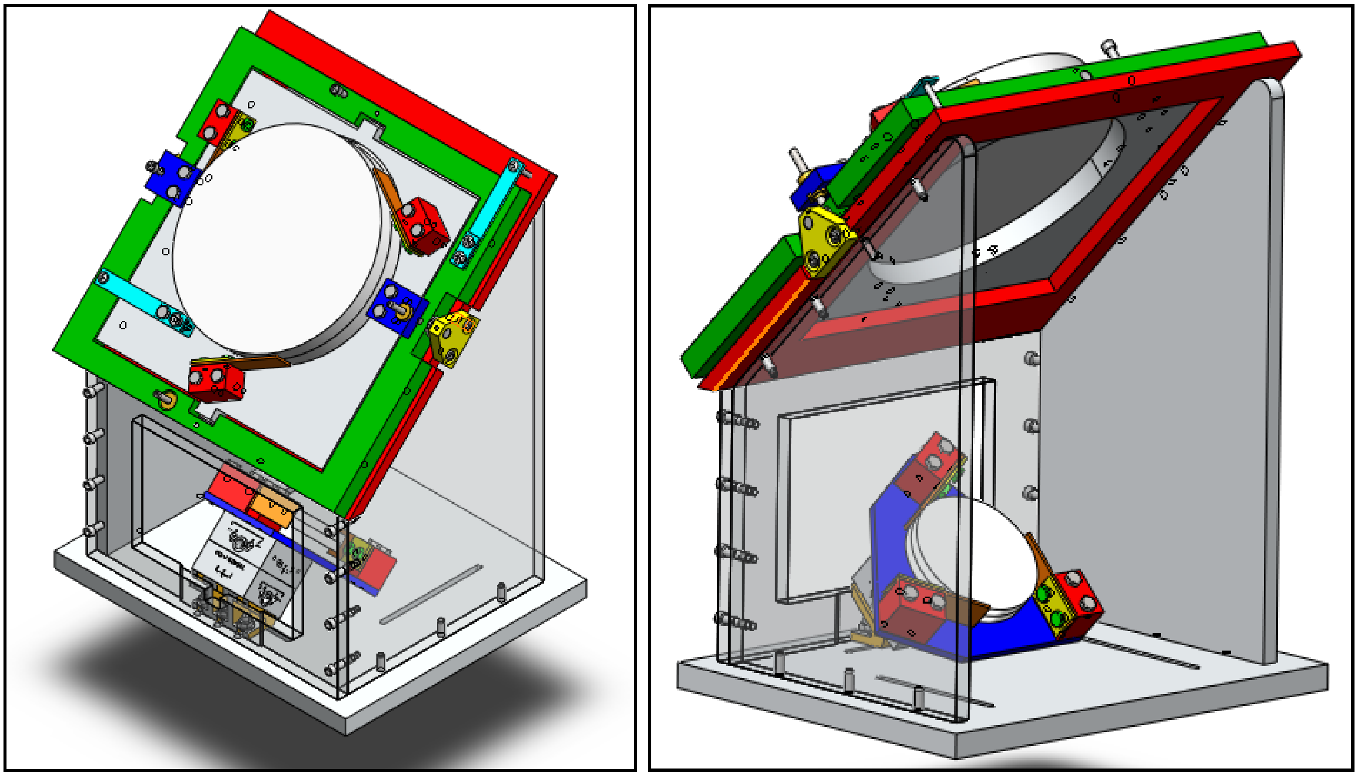


**Figure 1: System Layout. Note that all of the mechanical pieces are to be black anodized, and should not be the colors used for this document.**

Abstract: The final system implements the use of some off the shelf components, but the entire system is nearly fully custom. All of the customer's requirements were met and he is very happy with the final design.

### 1.1.1 Objective

Mount two large mirrors in a periscope orientation for folding the optical path behind a large refractive telescope with a large focal length.

### 2.1.1 Requirements and Design

The requirements from the customer are outlined below in Table 1.

| Requirements |
|---|
| 1. Telescope CA is 8” in diameter |
| 2. Top mirror must be centered at 15” in height |
| 3. System must have > 95% reflectivity at 850nm |
| 4. Each mirror cannot cause more than λ/10 rms wavefront error @ 850nm |
| 5. Top mirror at 45°, Bottom at -45° |
| 6. Angular adjustment accurate to 10μrad |
| 7. Operational Temperatures between 10C and 45C (24C build temperature) |
| 8. Cage stable to 200Hz |
| 9. Survive 20G shock load |
| 10. Mount periscope to Aluminum plate |
| 11. System must survive transportation with minimal adjustment |

Table 1: Requirements

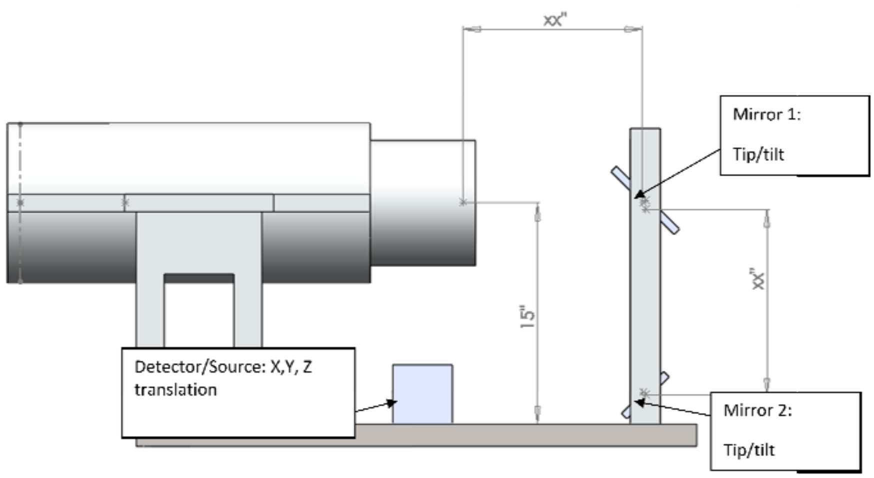



Figure 2: Sketch from customer.

Although the initial sketch from the customer appears to be simple, the final design of the system is extremely complex and requires much more time and thought than originally anticipated.

### 2.1.2 System Overview

The system is designed to meet all of the requirements as described in the table below.

| Requirement | How Requirement is Met | Section | Appendix |
|---|---|---|---|
| Diameter of Mirrors | Ray trace | 2.2.1 | - |
| Height of Mirrors | Geometrically attained with cage structure | 2.2.1 | - |
| <95% reflectivity | Dielectric coating from MellesGriot | 2.2.2 | - |
| λ/10 rms wavefront | Pitch polish surface, use flexure mounts, and 6:1 rule of thumb for mirrors | 2.2.3 | 1.1-1.3 |
| Operational Temperature | Use same material for all metal component, use flexible mounting system for mounting mirrors | 2.3.1-2 | 2.1,3.1,5.1 |
| Angle Adjustment of Mirrors | Kinematic mount adjustment with locking screws, pivots on high precision pins/sockets, preloaded with flexures | 2.4.2 | 4.1-4.2 |
| Transportation Survival | Lockable adjusters, adhesive area and thickness | 2.4.3 | - |
| Frequency analysis | Use fundamentals of frequency analysis, FEA of components to confirm hand calculations | 2.4.all | 2.1-2.4, 5.1 |
| Shock Survival | Shear stress equations to find appropriate bond area | 2.5.1 | 5.1 |
| Mounting to Al Plate | Use slots in base for easy positioning | 2.6.1 | - |

**Table 2: Table of Requirements and how they are met.**

*2.2.1 Mirror Size and Geometry*

The size of the mirror depends on the beam profile from the point source, which has an NA of 0.12. Below is a simple raytrace showing the beam profile on both mirrors. Notice that the top mirror must be about 7.934” in diameter, while the bottom mirror must be about 3.38” in diameter. The final design choice for the diameter of the mirror was to use a 8.5” diameter top mirror, and a 3.75” bottom mirror, which allows for errors outside 5% of each clear aperture. The thickness of both mirrors both follow the 6:1 aspect ratio rule of thumb, making the top mirror about 1.42” thick and the bottom 0.625” thick.

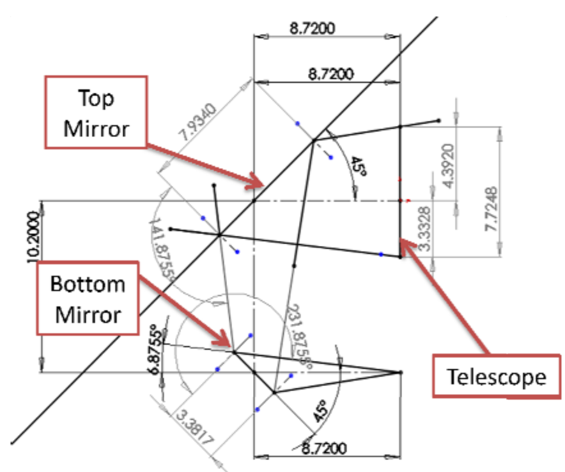



**Figure 3: Simple raytrace performed in SolidWorks.**

As seen below the basic cage system raises the mirror to the appropriate height and positions the mirror back into the periscope. Here I was actually able to increase the distance between the mirrors slightly to about 11.1inches. The slop in the diameter of the large mirror still captures all of the light with the change but a small cut had to be made in the gray plate to reduce the mechanical bottleneck on the clear aperture (see below).

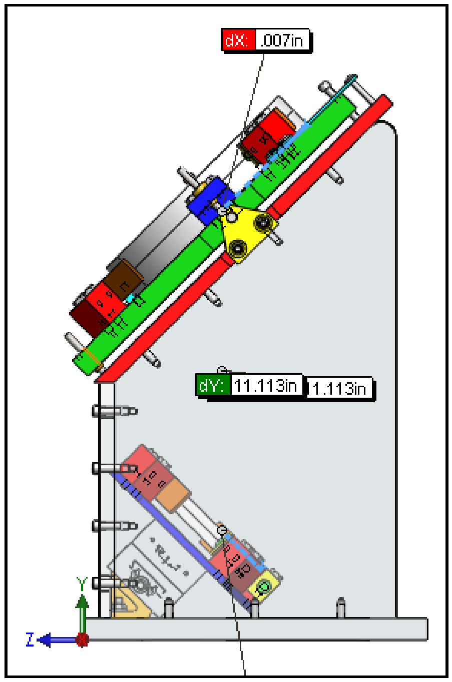



**Figure 4: Mechanical positioning of the mirrors.**

One other thing to notice in the above images is that the mirror does not make contact with the plates whatsoever. It is held about 1/4inch above the plate. The plate aperture does provide a sort of safety clip for the mirror because it is 1/4inch from the outer diameter of the mirror.

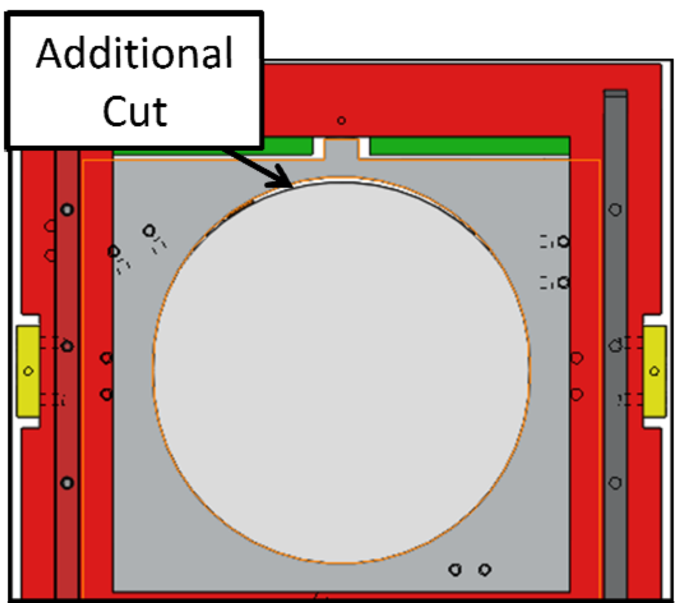



**Figure 5: Looking into the top mirror.**

As seen above the small cut only increases the aperture slightly, but because the reflectivity requirement is high for the mirror this means that the overall efficiency of the system needs to be high. Therefore, the cut is necessary.

*2.2.2 Reflectivity*

As seen below (Figure 4-5) the reflectivity curves for protected silver, protected aluminum, and the dielectric Mellesgriot custom coatings are significantly different. In particular, the aluminum mirror is below 95% reflectivity at $\lambda = 0.85\mu nm$. By contrast the protected silver mirror has well above 90% reflectivity at $\lambda = 0.85\mu m$, however the plots seen in Figure 1 are with normal incident light and in our application the mirror is held at 45°, therefore the mirror coating needs to consider this. The mirror will have a call out on its engineering drawing showing that it needs to be coated with the Mellesgriot MAXbright coating 003. Using this coating for both mirrors the system efficiency follows the simple equation: $0.978^2 = 95.6\%$.

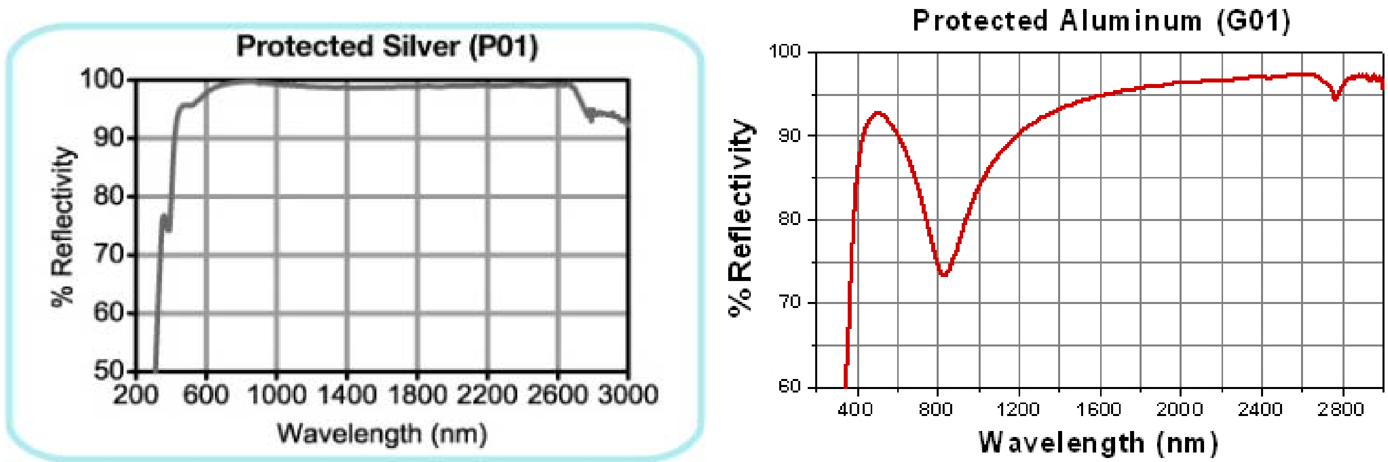



**Figure 6: Reflectivity from Thorlabs**

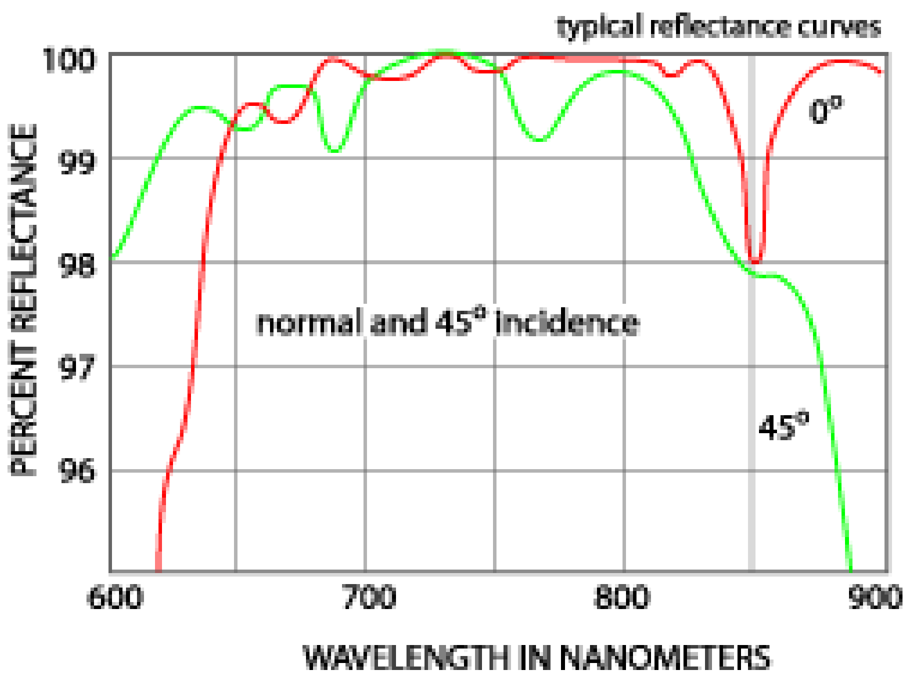



**Figure 7: Dielectric coating optimized for 45° angle of incidence. (Mellesgriot MAXBrite Coating 003)**

*2.2.3 Wavefront Error*

Here there are two main contributors to the wavefront error. I will handle this using an RSS breakdown for both mirrors. As seen below the breakdown only considers surface roughness error, and self-weight deflection. Thermal effects are not considered because the mirror will be mounted in a flexure system.

| Parameter | Allotment | Actual Value by Design |
|---|---|---|
| RMS Surface Error – Both Mirrors | 0.05λ | 3nm → 0.0035λ |
| Self-weight Deflection Error – Large Mirror | 0.05λ | 7.5nm → 0.009λ |
| Self-weight Deflection Error – Small Mirror | 0.05λ | 1.7nm → 0.002λ |

**RSS Nominal** → $\sqrt{4 * 0.05^2} = 0.1\lambda$

**RSS Actual** → $\sqrt{0.0035^2 + 0.0035^2 + 0.009^2 + 0.002^2} = 0.0104\lambda$

**Table 3: RSS Breakdown of wavefront error.**

As seen above the wavefront error is easy to obtain using standard rules of thumb for pitch polishing surfaces and 6:1 diameter to thickness aspect ratios.

*2.3.1 Thermal Considerations: Optical*

Fused silica is known to have a very low CTE (about 0.6ppm/°C), therefore the small change in temperature will not cause much of a change in the beam translation, so we don't have to worry about clipping the edges of the beam off. In addition, the mirror is held in a flexure mount system so there is no thermal induced stress in the mirror.

*2.3.2 Thermal Considerations: Mechanical*

To avoid any thermal stress in the mechanical components all parts are made of 6061 Aluminum. Therefore, the entire body will expand and contract uniformly. The only real area of concern may be in the expansion of the mirror and the induced stress on the flexures. This was observed to be ok in FEA analysis.

*2.4.1 Mechanical Design: Flexure*

The first item in the mechanical design was the flexure, seen below. Here, the mirror is bonded to the mirror with a small amount of epoxy. Three flexures are oriented at 120° with respect to each other for an even stress distribution. The flexure was designed to bend when the mirror expands and contracts from large temperature changes of 10C to 45C (see appendix A.5), and also have good resonant frequency characteristics (see appendix A.3). The final flexure design was used for both mirrors: the large mirror flexures were found to have a resonant frequency of about 440Hz, and the small mirror flexures were found to have a resonant frequency of 1500Hz.

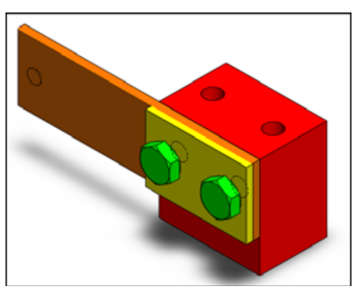


**Figure 8: Flexure Support Design.**

As seen above the flexure has bolts that connect the support plate (yellow) to the flexure, and then to the support block (red). This support block is first bonded to the mirrors edge and then bolted to the mounting plate which will attach to the cage support system (see figure below).

In addition, the green bolts cover holes that have a fairly loose clearance fit; the top holes have the same loose clearance. The reason for this is to reduce the torque induced in the flexure when the system is bolted down. Here the loose clearance holes allow the flexures to first be bonded to the mirror and then be loosely fit into the block holders, tightened to the blocks, and finally the blocks tightened to the plates. The clearance simply allows the flexure to move in place until the system is bolted down while minimizing any torques on the flexure.

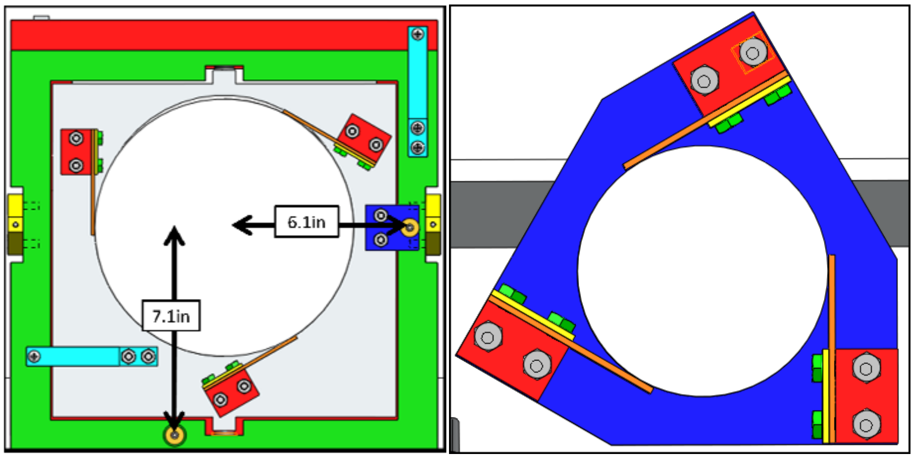



**Figure 9: Back of top mirror showing flexure attachment (left). Front of bottom mirror showing flexure attachment (right). Not to scale.**

Another important thing to note here is the orientation of the mirrors. This way of mounting the mirrors is not the optimal orientation, however the special considerations drive this geometry. Notice that if the top mirror is rotated in any way the size of the top plate increases which will increase the weight and decrease the resonant frequency of the cage system. Similarly the bottom mirror needs to be in its orientation to make it as close to the base of the periscope as possible so that the beam is folded up as much as possible.

One possible placement of the flexures would be to mount them such that the bottom of the mirror is supported by flexures positioned in the form of a v, and then have one flexure positioned horizontally on the top of the mirror. However, my design was based on the Yoder design of flexures, and the FEA analysis shows that the orientations shown have very little effect on the deflection of the mirror (see appendix A.1.2-3).

*2.4.2 Mechanical Design: Tip/Tilt Angle*

TOP MIRROR

The tip/tilt control of the top mirror is controlled by the custom two axis pivot mount design seen above in figure 7 and below. Here the turquoise flexures provide a preload while the 100tpi screws provide adjustment, and the 3/8” super smooth pins and super smooth sockets provide a tight clearance fit for resisting moments. The pins and sockets are also to be lubricated with silicon to allow smooth motion in the tight fit. In addition there are preload springs between the plates around the 3/8”pins that keep the plates from translating when rotated. Here the adjustment of the tip/tilt mount is accurate to about 4μrad for each direction (see appendix A.5.1). Also the mechanical tolerances on the 45° cut and bottom of the side pieces and the flatness of the base plate do not need to be very tight because of the range of the tip/tilt mount (found to be about ± 3°).

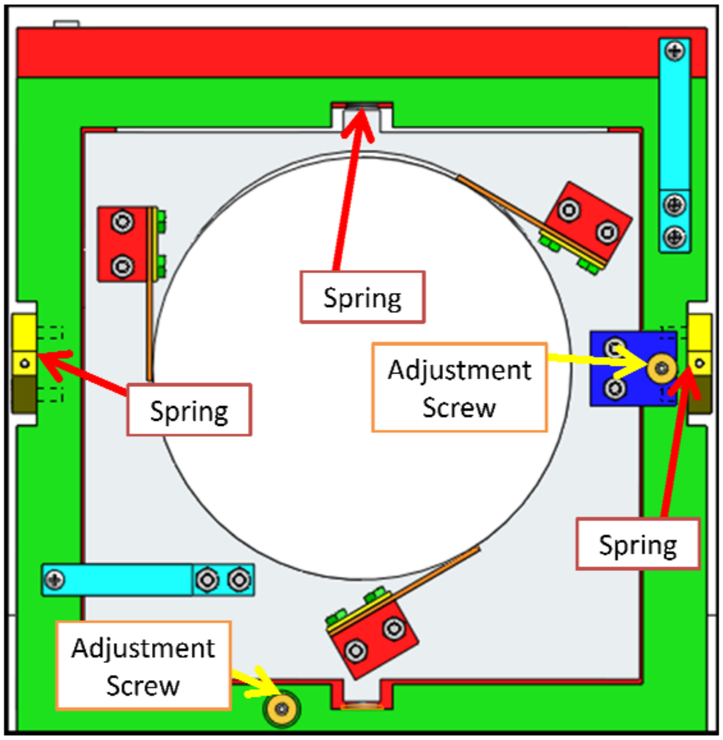


Figure 10: Back of top/large mirror – locking screws not shown.

As seen above the top mirror is mounted in a tip cell but the tilt is reliant on the plate that interfaces the cell and the cage assembly. Here the green plate is connected to the red plate with the small yellow pieces that bolt down and provide a pivot point – the gray pin (see figure below).

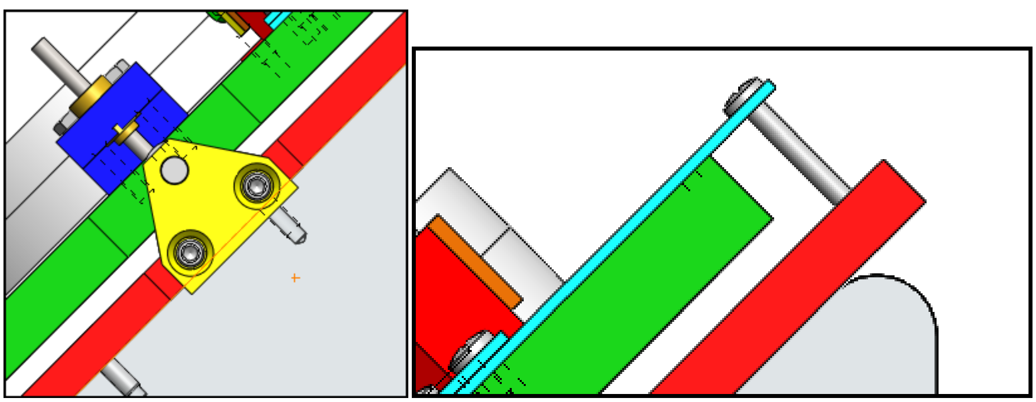


Figure 11: Interface between the green and red plates. Left - adjustment screw. Right – flexure (note that the flexure is normally bent upwards in the preloaded condition.

As seen above the tip/tilt relies on the adjustment of the 100tpi screws and the preload of the turquoise flexures. Also note that the adjustment screws and locking screens are mylar padded to reduce lurching when adjusting. These flexures do not need to have great consideration given because they are only used to preload temporarily – however the preload force can be adjusted by adjusting the length of the gray screw in the turquoise flexure for a desired stiffness. Once the periscope is aligned the locking screws can be tightened down to stabilize the system (see figure below).

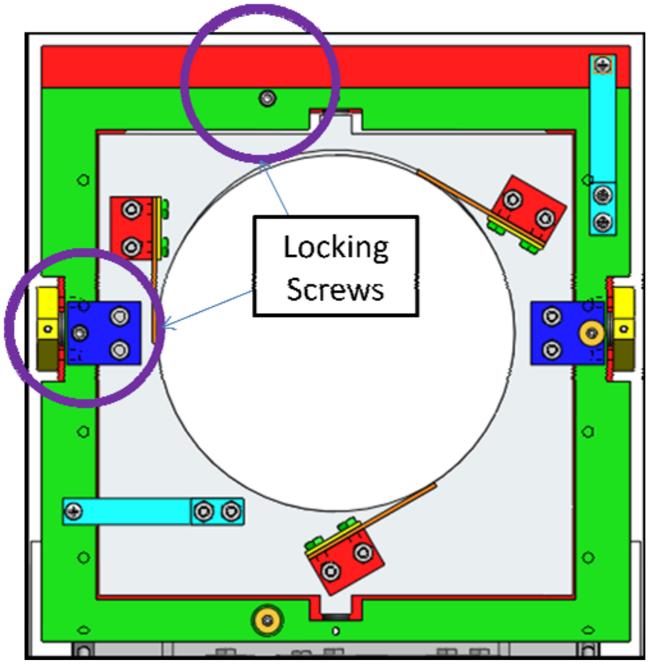



Figure 12: Top Plate with locking screws shown.

As seen above the locking screws are place directly across from the adjustment screws to relieve the moment imposed on the pins during adjustment. The large distance may cause a slight bending moment in the metal components, however I expect these to be negligible because the grey and green plates are 0.5" thick aluminum. If in doubt, caution should be taken when locking the adjustment in place so as not to bend the grey and green plates.

BOTTOM MIRROR

For the bottom mirror tip/tilt control is performed with goniometers that are mounted on a right angle bracket. The goniometers and right angle bracket are available from Newport (GON-65L/U – goniometers, and model 360-45 – right angle bracket). The support system of the bottom mirror can be seen below. It should be noted here that the right angle bracket must be cut down to fit within the periscope.

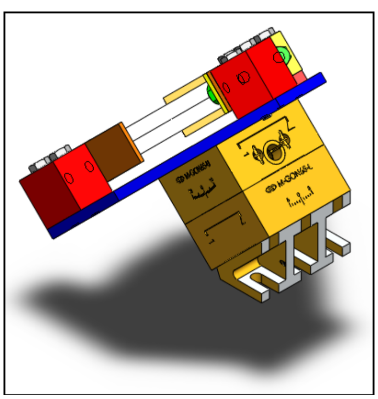



Figure 13: Mount of bottom mirror. Note that the angle bracket is cut off.

In the figure above the goniometers do have adjustment screws, but they are not shown in the model. Furthermore, the complex shape of the mounting plate (blue) for the bottom mirror lead me to perform an FEA analysis of the system for resonant frequency. Here I am using off the shelf components so I was not sure how they would perform; however, as seen below the resonant frequency exceeds the requirement of 200Hz (FEA showed 1200Hz). It should be noted however that the goniometers were modeled as a single block; they do not have all of their complex parts (see appendix A.3.2).

*2.4.3 Mechanical Design: Stability*

The system is designed to be somewhat stable for transportation by utilizing set screws on the axis pins for the top mirror rotation, and adhesive for the bottom mirror tip/tilt control. As seen below the tip/tilt has set screws that act as breaks when the mirror does not need to be adjusted. These set screws also prevent the pins from backing out when the position is set.

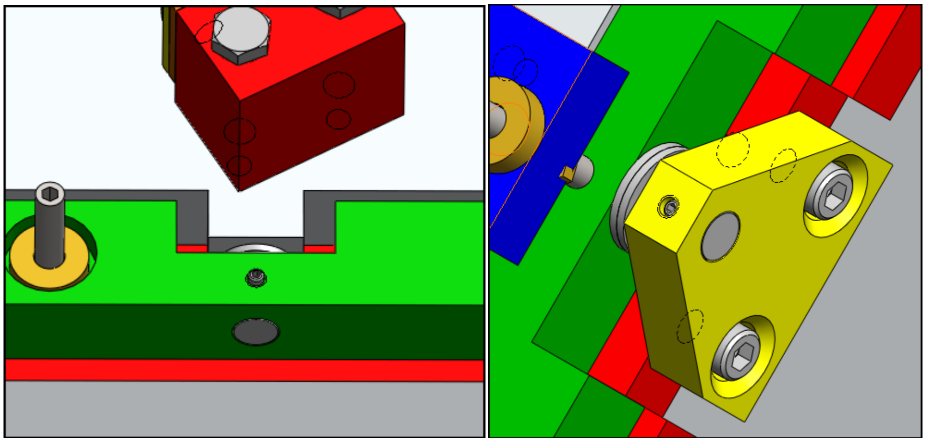
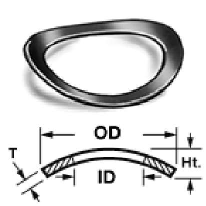


**Figure 14: Braking for axis pins.**

As seen above there is a gap between the plates (where the washers are). In actuality, the disk springs below will also fit into the gap providing a preload between the plates so that they do not shift around; between the two plates will be a washer and a disk spring. It should be noted that the bottom pin (shown above left picture) will only have washers, to reduce the resonant frequency from the load path; the top disk spring will preload the plates gray and green platens together vertically. For the horizontal axis there is no mass supported by the springs so there will be no resultant resonant frequency.

Disc Springs

2 products match your selections




| | |
|---|---|
| Type | Curved Disc Springs |
| System of Measurement | Inch |
| Fits Hole Size | 3/4" |
| Fits Rod Size | 3/8" |
| Minimum Inside Diameter | .395" |
| Maximum Outside Diameter | .735" |
| Thickness | .0160" |
| Overall Height | .086" |
| Load Range | 7 lbs. - 39.99 lbs. |
| Load | 12 lbs. |
| Load (7 lbs. - 39.99 lbs.) | 12 lbs. |
| Deflection at Load Range | .040" - .059" |
| Deflection at Load | .050" |
| Deflection at Load (.040" - .059") | .050" |
| Specifications Met | Not Rated |

**Figure 15: Disk Springs used for preload.**

In addition to the locking set screws the design also implements post adjustment locking screws as seen in figure 10 above. This provides stability during transportation in addition to stiffening the structure by relieving the preload turquoise flexures.

*2.5.1 Shock Loading – Bond Areas*

The shock loading of the system will have little effect on all of the mechanical connections in the periscope. The only area where we need to worry about the shock loading is in the bond for the mirror. Here the shear force on the bond was found to be only about 280psi per bond, which is well below the shear strength (4000psi from Yoder) of 3M 2214 – Gray (see appendix for data sheets). The small bond area also reduces the shear stress on the bond for the large change in temperature; thermal shear stress was found to be only about 1790psi (see appendix for details). The final bond dimensions were chosen to be 0.22” in radius and 0.003” thick. These parameters can be easily attained with shims and stencils.

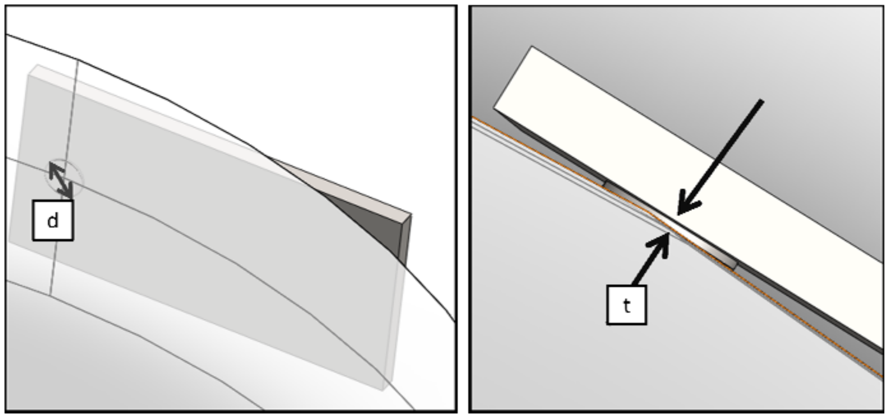



**Figure 16: Bond area close up. d = 0.44in, t = 0.003in. Not to scale.**

*2.6.1 Interface with Base Plate*

The system will interface with the customer’s aluminum base plate with the slots seen below. Here the flatness of the base plate for the periscope can be set to a standard tolerance because the mirror tip/tilt should be able to compensate for small assembly and manufacturing errors.

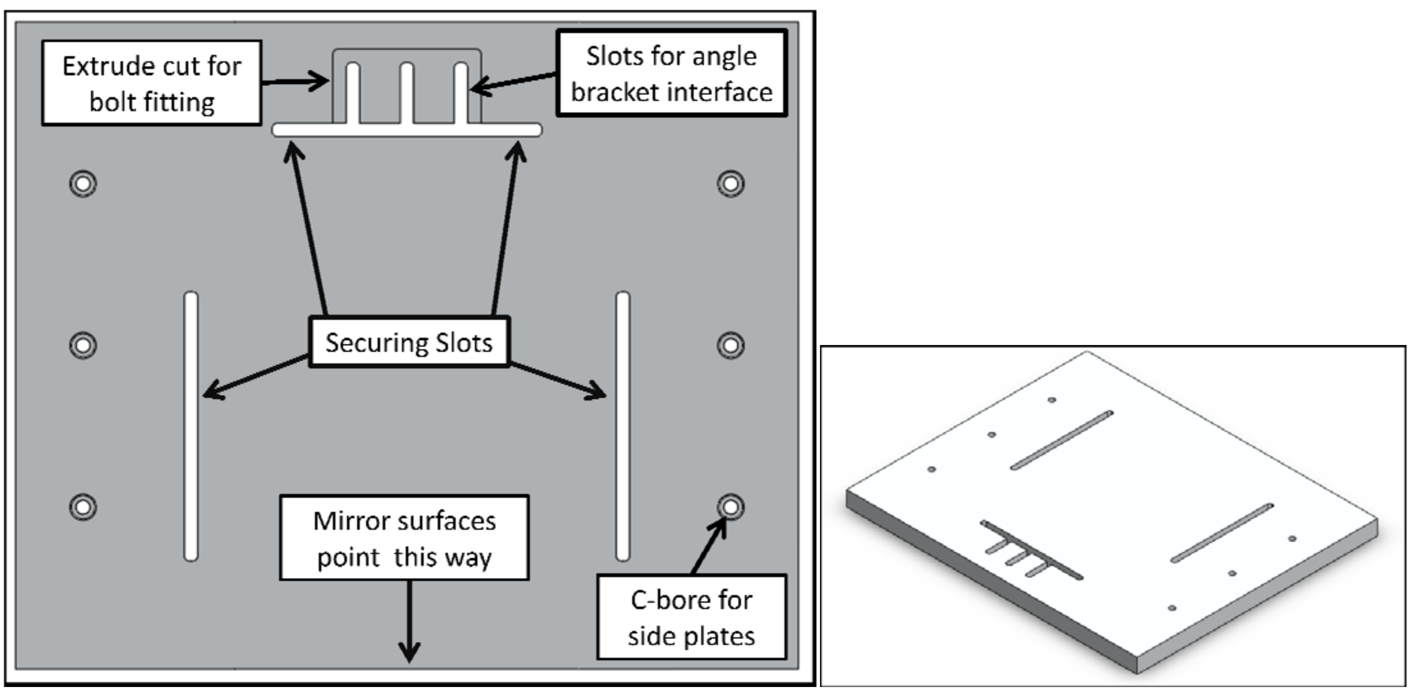



**Figure 17: Bottom of base plate (left). Iso of top of base plate (right).**

In the figure above it is important to note that the bottom surface of the base plate offers a flat interface to the customer's aluminum plate.

### *3.1.1 Assembly*

The assembly for the periscope is extensive as seen below. However, the system can be put together in sub assemblies and then pieced together entirely. Mirror handling should always be done with gloves – never touch the surface of the mirror.

Cage System:

1) Assemble the cage system including the bottom plate, the two side pieces, and the top plate (see figure below).
2) Only loosely attach the back support plate.
    a. It will need to be removed to attach the small mounted mirror.

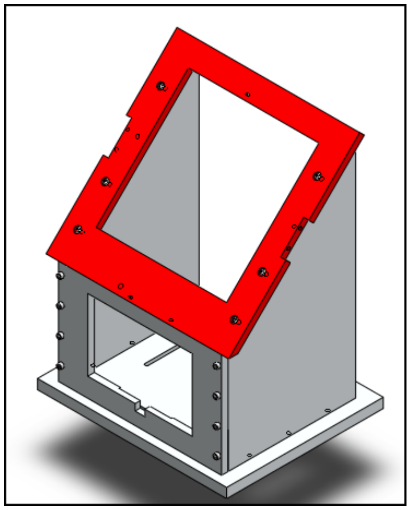


**Table 4: Cage System.**

Bottom Mirror

1) Assemble the goniometers and attach them to the 45° angle bracket.
    a. Set aside
2) Using spacers adhere the flexures to the mirror
    a. Make sure they are in the orientation shown below
3) Once the adhesive is set attach the mirror with flexures to the flexure support blocks (red blocks)
    a. Make sure the reflective side of the mirror points outwards
4) Place the yellow plates overtop the flexures and hand tighten bolts
5) Place the mirror with flexures on top of the blue plate as shown below.
    a. Check to ensure the blocks sit flat on the plate without assistance or force
        i. If the mirror does not sit flat do not force blocks down to the plate. Break the adhesive bond and reapply adhesive until the blocks sit flat.
        ii. Do not use shims underneath the blocks to make them sit flat
        iii. The flexures cannot have any torque in them.
6) Hand tighten the flexure blocks to the plate.
    a. Allow the flexures to wiggle into place as to reduce any torques on them
7) Tighten all bolts down with reasonable torque.

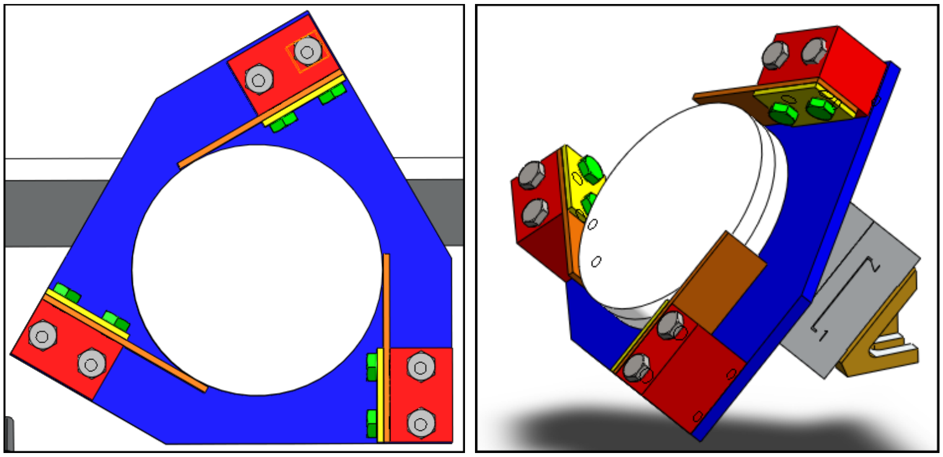


**Figure 18: Orientation of flexures (left). Finished product (right).**

Top Mirror:

1) Place the green plate and grey plat on a flat surface with the grey plate inside the green plate as depicted in the finished product.
2) Insert two washers in between the bottom pivot boss and the bottom pivot cutout
    a. Align to the pivot hole and insert 3/8” pin
        i. Be sure to lubricate pin and hole
    b. Screw in but do not tighten set screw
3) Insert one washer and one disk spring in between the top pivot boss and the top pivot cutout
    a. Align to the pivot hole and insert 3/8” pin
        i. Be sure to lubricate pin and hole
    b. Screw in but do not tighten set screw
4) Assemble adjustment block by inserting adjustment micrometer (right side blue block)
    a. Set aside
5) Assemble locking block by screwing in locking screw (do not tighten screw all the way down) (left side blue block).
    a. Set aside
6) Using spacers adhere the flexures to the mirror
    a. Make sure they are in the orientation shown below
7) Once the adhesive is set attach the mirror with flexures to the flexure support blocks (red blocks)
    a. Make sure the reflective side of the mirror points down through the mechanical aperture
8) Place the yellow plates overtop the flexures and hand tighten bolts
9) Place the mirror with flexures on top of the blue plate as shown below.
    a. Check to ensure the blocks sit flat on the plate without assistance or force
        i. If the mirror does not sit flat do not force blocks down to the plate. Break the adhesive bond and reapply adhesive until the blocks sit flat.
        ii. Do not use shims underneath the blocks to make them sit flat
        iii. The flexures cannot have any torque in them.
10) Hand tighten the flexure blocks to the plate.
    a. Allow the flexures to wiggle into place as to reduce any torques on them
11) Tighten all bolts down with reasonable torque.
12) Attach turquoise preload flexures as shown below
13) Insert second micrometer and locking screw (top ¼-20 tapped hole)

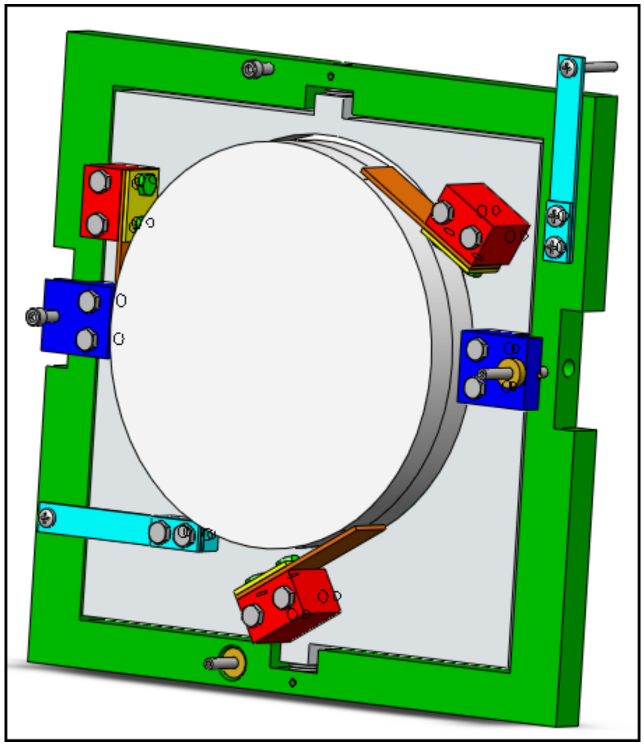


Figure 19: Final product.

Final Assembly

1) Remove the back plate from the cage structure and insert bottom mirror sub assembly.
2) Use back plate to position angle bracket by allowing them to be flush with one another. (see below).

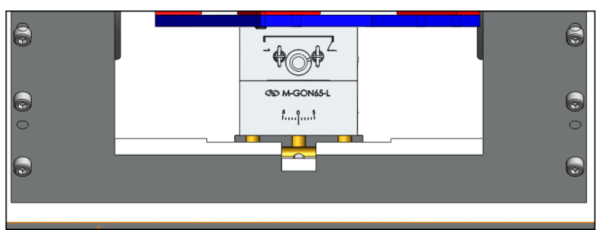



Figure 20: Fit of bottom mirror.

3) Remove back plate and bolt down angle bracket as shown below.

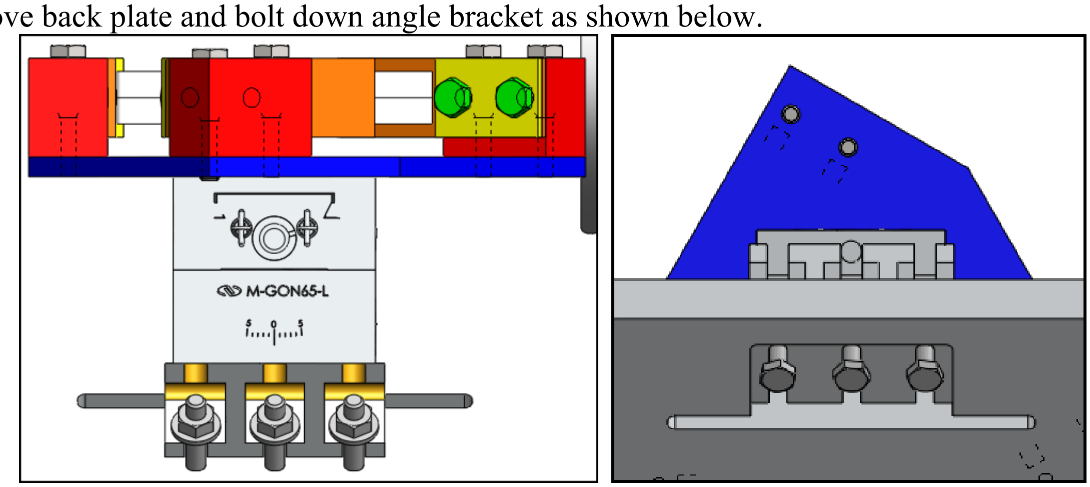



Figure 21: Left – top, Right - bottom

4) Bolt back plate back onto assembly and ensure the components fit.

5) Attach the yellow support triangles to the top plate of the cage assembly (red plate).
6) With a friend attach hold the top mirror in place while holding the washer and spring in place and inserting the pivot pin
7) Repeat 6 for both sides
8) Screw in set screws
9) Enjoy!

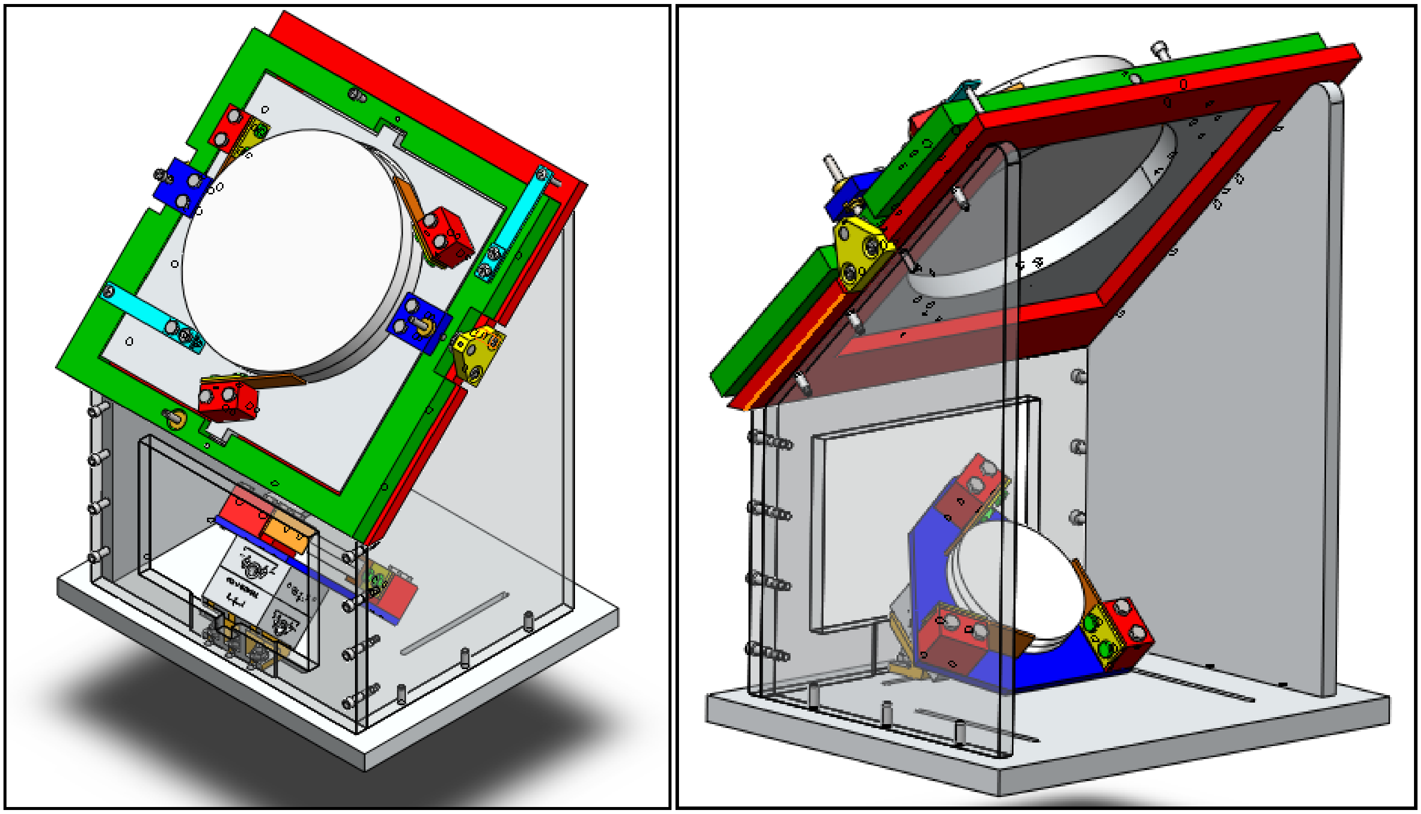


Figure 22: Finished Product

## APPENDIX A: Calculations

### *A.1.1 Wavefront Error: Surface Roughness*

For a mirror held at 45° to the incident beam surface roughness will cause an rms wavefront error described by the following:

**Equation 1: Wavefront Error**

$$\Delta W = (n-1)\ \Delta S * \cos(\theta)$$

Solving equation 2 above for ΔS or surface roughness we can assign an allowable rms wavefront error, and then specify surface roughness in the engineering drawings. However, normal pitch polished surfaces can easily attain 20Å rms, so I'll try that first.

**Equation 2: Wavefront Error Continued**

$$\Delta W = (-1-1) * 20\text{Å} * \cos(45) \cong 30\text{Å} = 3\text{nm}$$

Clearly a pitch polished surface will not cause any notable effect on the overall performance of the mirror if the mirror is pitch polished.

### *A.1.2 Wavefront Error: Self Weight Deflection of the Mirror*

The self weight deflection of the mirror will cause errors in the wavefront of the reflected beam. Vukabratovich gives the relationship of the mirror mounting type to the self weight deflection of mounted mirrors. The following properties for the fused silica substrate will be used for subsequent equations:

| Fused Silica Properties |
| --- |
| • Weight Density $\rho = 0.08 lb/in^3$ |
| • Elastic Modulus $E = 10.6x10^6\ lb/in^2$ |
| • Poisson Ratio $\nu = 0.17$ |
| • Coefficient of Thermal Expansion $\alpha = 0.55ppm/°C$ |

**Table 5: Properties of fused silica.**

For a mirror oriented at 45° relative to the optical bench, the self weight deflection is described by Vukabratovich (pg. 260 of his notes).

**Equation 3: Surface Deflection**

$$\delta_{pv} = 1.356\left(\frac{\rho r^4}{Eh^2}\right)(1-\nu^2)\cos(\theta)$$

**Equation 4: For the large mirror:**

$$\delta_{pv} = 1.356\left(\frac{0.08lb/in^3 * (4.25in)^4}{10.6 * 10^6 lb/in^2\ * (1.42in)^2}\right)(1-0.17^2)\cos(45) = 21.5nm$$

**Equation 5: PV to RMS**

$$\delta_{rms} = 0.25 * \delta_{pv} = 5.4nm$$

**Equation 6: Similarly for the small mirror:**

$$\delta_{pv} = 1.356\left(\frac{0.08lb/in^3 * (2in)^4}{10.6 * 10^6 lb/in^2\ * (0.66in)^2}\right)(1-0.17^2)\cos(45) = 9.3nm$$

**Equation 7: PV to RMS**

$$\delta_{rms} = 0.25 * \delta_{pv} = 2.3nm$$

This displacement directly affects the rms wavefront error of the incident beam. The rms wavefront error will be 2times the surface deflection error because the beam is reflected. So the wavefront will have about 11nm rms error for the large mirror and 4.6nm for the small mirror, this seems negligible.

*A.1.3 Wavefront Error: Self-weight Deflection of Mirror: FEA*

Below the mirror was analyzed in CosmosWorks to observe the surface deflection under gravity. Here the mirror was modeled to be bonded at three points around the outside cylindrical surface of the glass. The bond diameter was set at 0.2in and the bond thickness was the recommended bond thickness for adhesives by Yoder (0.003in – Yoder Opto-Mechanical System Design pg. 425). In the models, the mirrors were both held at 45° with fixed restraints on the bond areas. As seen below the rule of thumb for the thickness of the mirrors holds well in that the surface deformation is small. The top and bottom mirror are both held in the same orientation.

After FEA was performed in CosmosWorks the surface data for only y-displacements was imported into MatLab to determine the resultant rms wavefront error (see attached appendices for code). The code normalizes the surface error by removing tilts and shifts.

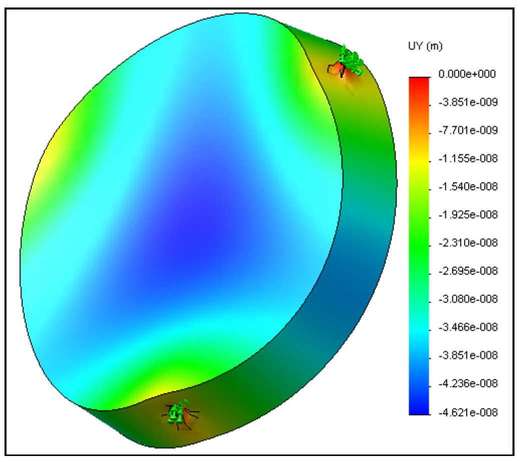
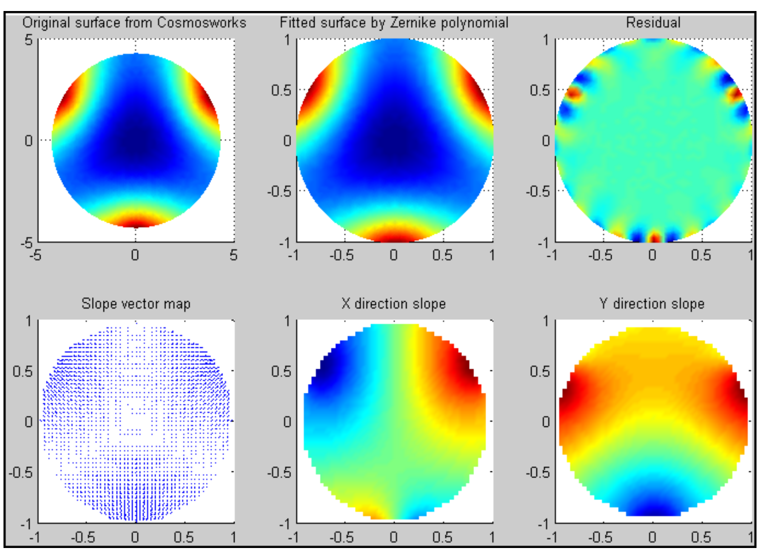



**Figure 23: Large Mirror Y-Displacement from self-weight deflection.**




| | |
|---|---|
| RMS_surface | 7.4902e-09 |
| Residual | <1310x1 double> |
| Rho | <1310x1 double> |
| Slope_PV | 7.6701e-08 |
| Slope_RMS | 3.2248e-08 |

**Figure 24: MatLab Results from FEA imported data.**

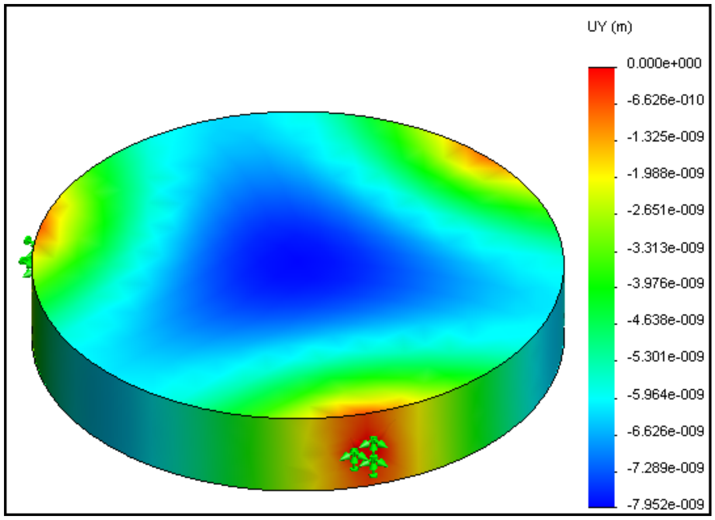



**Figure 25: Small Mirror Y-Displacement from self-weight deflection.**

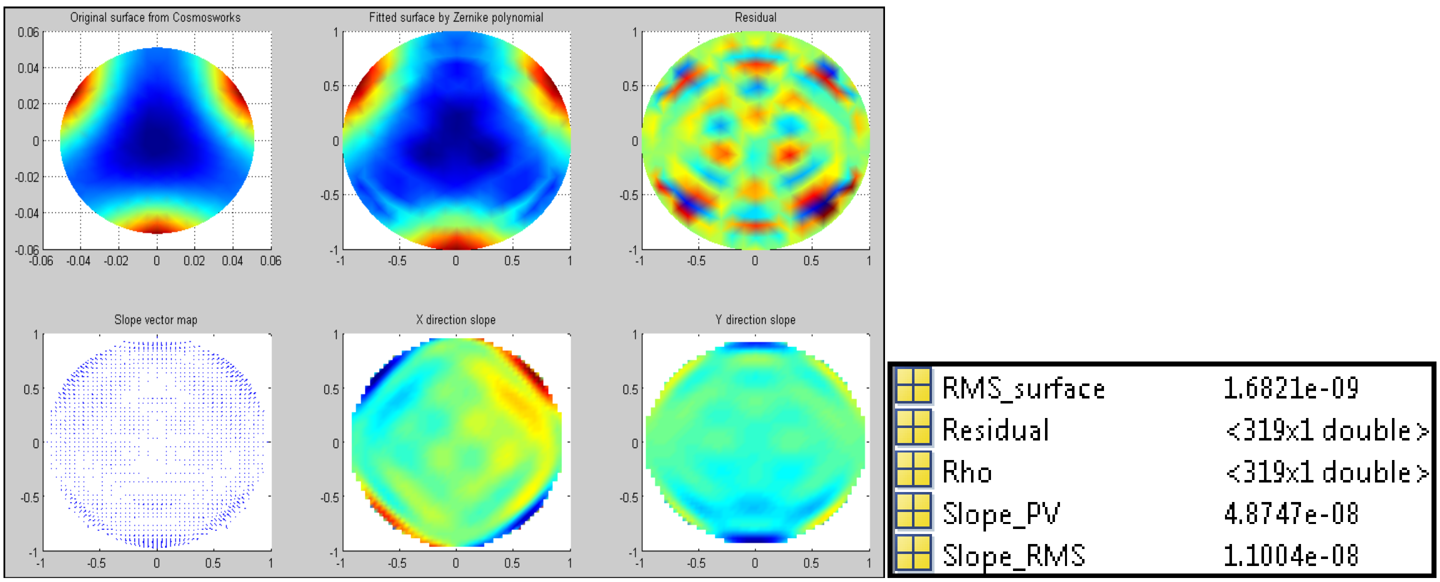



**Figure 26: MatLab Results from FEA imported data.**

As seen above the hand calculation from Vukabratovich and CosmosWorks seem to agree somewhat closely. Both data are within about 27% of each other – this could be related to the rms-pv rule of thumb conversion. This analysis confirms that the rms wavefront error from the self-weight deflection of the mirror is very small. Furthermore, the mirror is held in a flexure assembly that will have some compliance – therefore the self-weight deflection induced wavefront error should not increase in the flexure mount.

*A.2.1 Resonant Frequency: Flexures*

The resonant frequency of the flexure system will follow the simple equation $\omega = 1.875^2 * \sqrt{k/m}$, where k is the stiffness of the flexure system and m is the mass of the mirror.. The stiffness of a single flexure follows the equation below. However, after performing an FEA of the three flexures together with the mirror the results seemed to reflect a much more complex load path. So the flexure was made thicker and shorter to increase the resonant frequency two a factor of 2 larger than the requirement (for safety).

**Equation 8: Stiffness of a cantilever**

$$k = \frac{3EI}{L^2}$$

Vukabratovich states that the stiffness for a flexure mount system has the following stiffness parameters:

Equation 9: Radial Stiffness (Vuka pg. 259)

$$k_R = 3/2(k_{af} + k_{tf})$$

Equation 10: Axial Stiffness

$$k_A = 3k_{af}$$

And because my mirrors are held at 45° with respect to gravity my flexures will be compliant in both the axial and radial directions. However, because the radial stiffness of the flexures is much smaller than the axial stiffness of the flexure, the $k_R$ value will not change the result by any significant amount. The geometry seen below was used to calculate the second moment of inertia (figure 10)

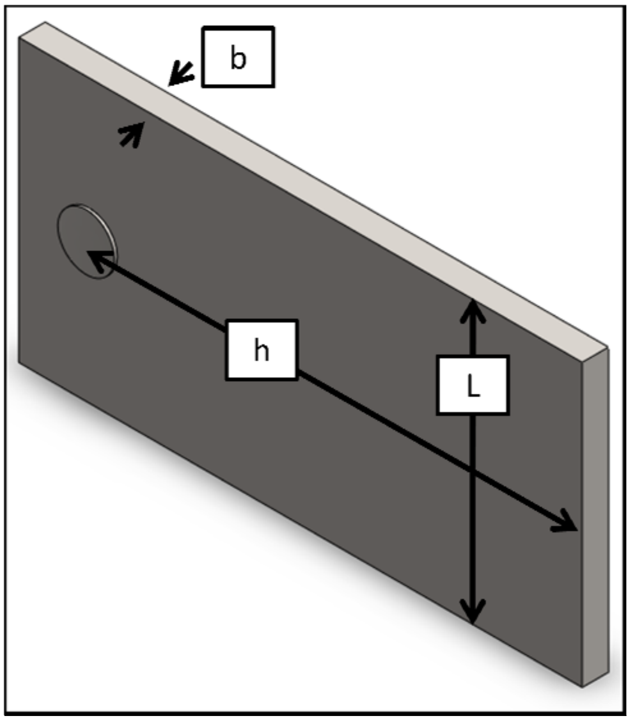



**Figure 27: Flexure Geometry**

Equation 11: Second Moment of Inertia

$$I_{af} = \frac{bh^3}{12} = \frac{0.094in * (1.75in)^3}{12} = 0.042in^4$$

Equation 12: Axial Stiffness

$$k_{af} = \frac{3 * 10^7 psi * 0.042in^4}{(1in)^3} = 1.26 * 10^6 lb/in$$

Equation 13: Resonant Frequency Large Mirror

$$\omega = 1.875^2 \sqrt{\frac{3 * 1.26 * 10^6 lb/in}{6.39lb}} = 2703.52rad/\sec \rightarrow 430.28Hz$$

Equation 14: Small Mirror

$$\omega = 1.875^2 \sqrt{\frac{3 * 1.26 * 10^6 lb/in}{0.6662lb}} = 8374.25rad/\sec \rightarrow 1332.8Hz$$

As seen below the FEA analysis of the flexure matches closely the calculated value. The value is slightly different because I did not consider the radial compliance of the flexures and the load situation is slightly more complex than a simple calculation. However, the hand calculation and FEA seem to agree well enough to use the flexure for a design choice.

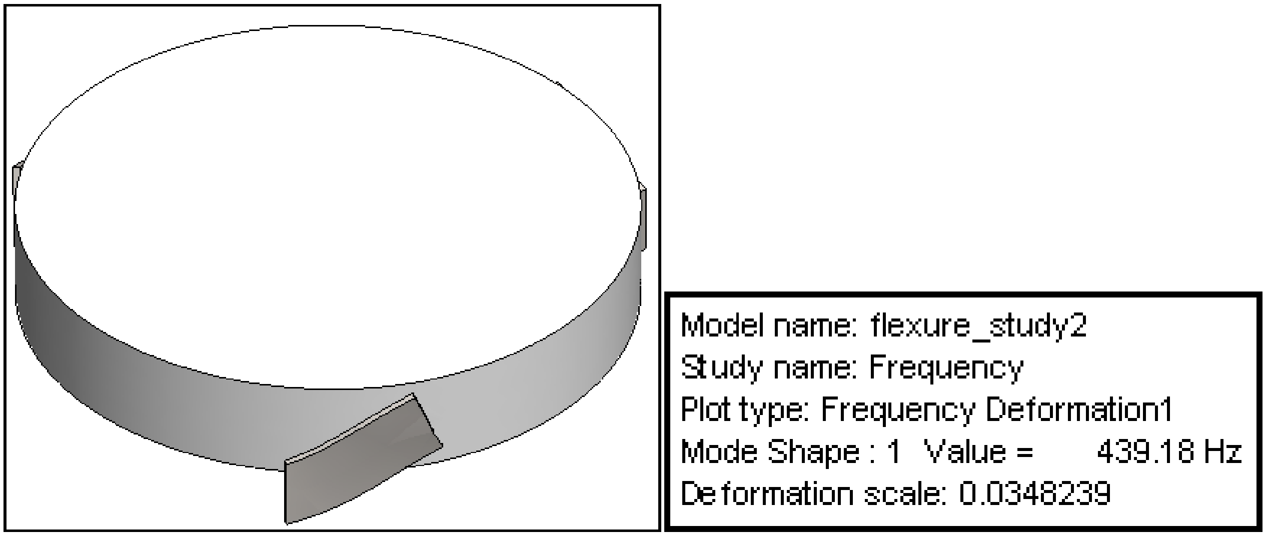



**Figure 28: Resonant Frequency of Flexure System: Large Mirror**

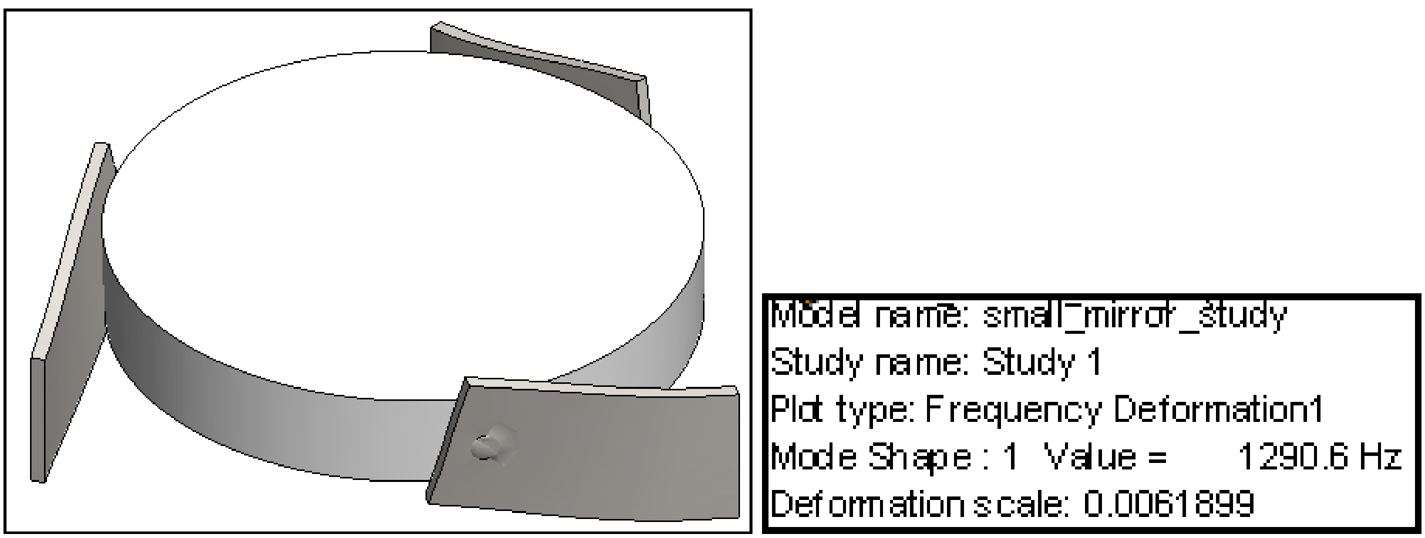



**Figure 29: Resonant Frequency of Flexure System: Small Mirror.**

*A.2.3 Resonant Frequency: Cage System*

The cage system resonant frequency is somewhat difficult to calculate because of its complex geometry, therefore I tried to design a cage that I felt would meet the resonant frequency requirement and ran an FEA analysis of it. The results showed that the cage system meets the requirement of 200Hz, but it was very close at 247Hz. After trying several geometries I could not come up with anything that had more than 300Hz – which involved several large cross section pieces. I did not choose to use the cross sections pieces because the cost to benefit ratio seemed high.

Below is the CosmosWorks analysis of the cage system for natural frequency. The green arrows show where the system is restrained, while the purple arrows show where the load from the top mirror assembly is applied. The top mirror assembly weighed about 16lbs. For the final design I have chosen to accept the 250Hz value as it does meet the minimum requirement.

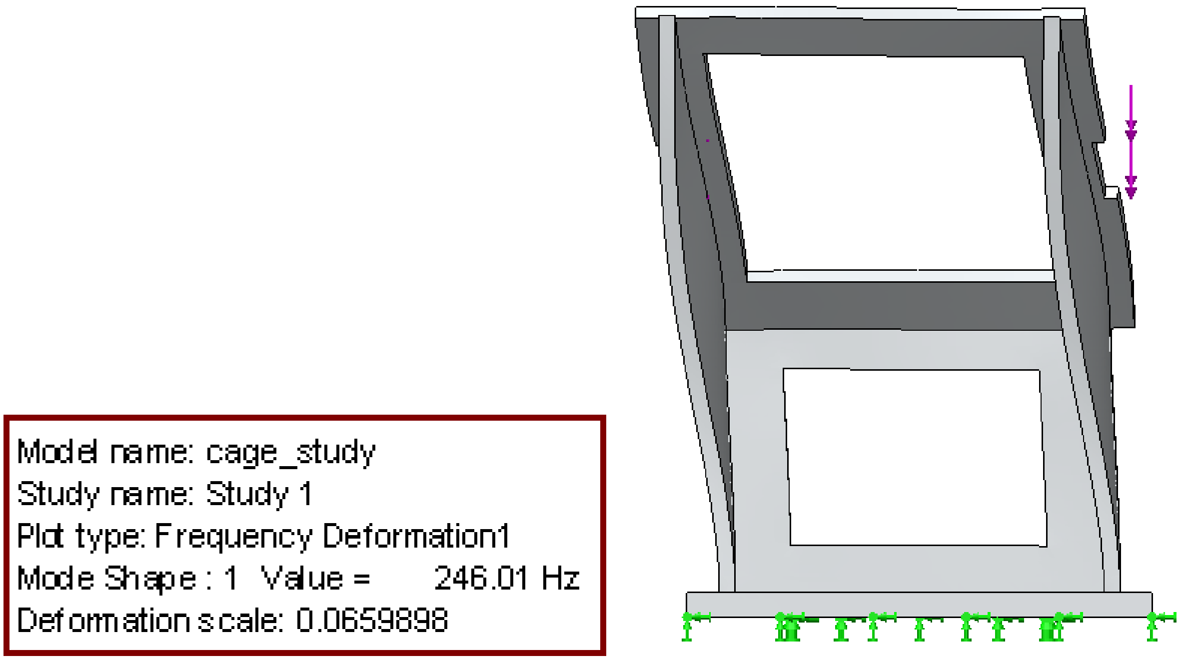



Figure 30: Resonant Frequency Study.

*A.2.4 Resonant Frequency: Bottom Mirror Support*

The complex shape of the mounting plate (blue) for the bottom mirror lead me to perform an FEA analysis of the system for resonant frequency. Here I am using off the shelf components so I was not sure how they would perform; however, as seen below the resonant frequency exceeds the requirement of 200Hz. It should be noted however that the goniometers were modeled as a single block; they do not have all of their complex parts.

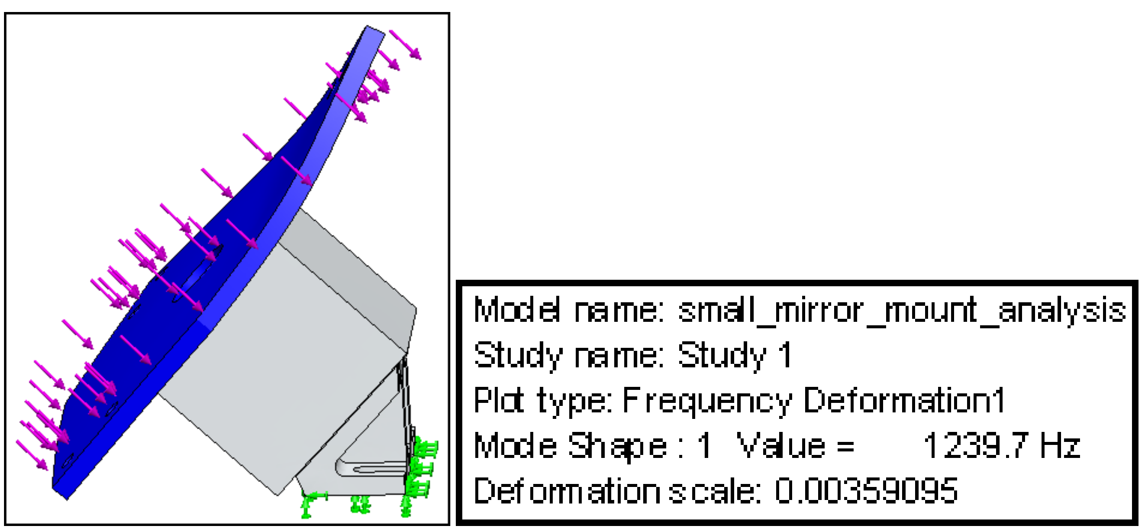



Figure 31: Resonant frequency of bottom mirror mount.

*A.3.1 Flexure Stress Analysis*

As seen below the flexures even when held fixed at the support point are still under the yield strength of aluminum. Here the three flexures and mirror were held in the same orientation as seen in the resonant frequency analysis. The smaller mirror analysis was not performed because the effect on the flexures will be proportional to the size of the mirror – the stress should be slightly less.

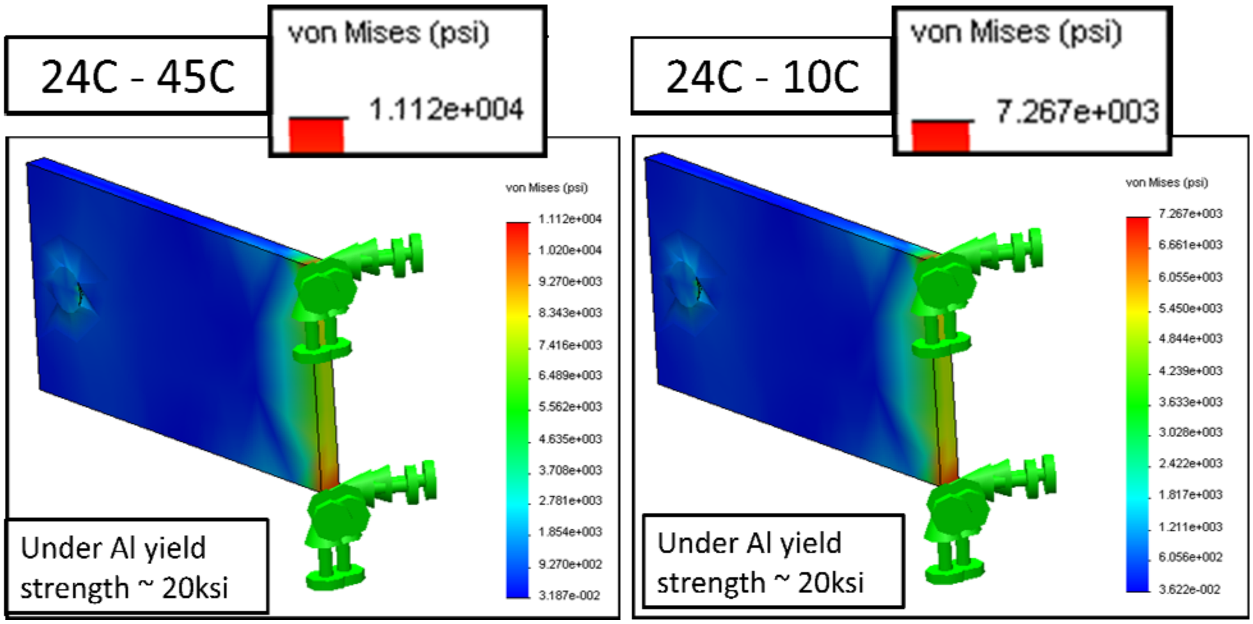



**Figure 32: Large mirror flexure analysis, mirror held at 45°, temperature and gravity applied.**

*A.4.1 Tip/Tilt: Large Mirror*

The kinematic mounting system has about 7µrad angular resolution based on the resolution of the 100tpi adjustment screw (0.7µm), and the distance to the axis of rotation of the adjustment screw. The geometry of the kinematic mount for the large mirror is shown below.

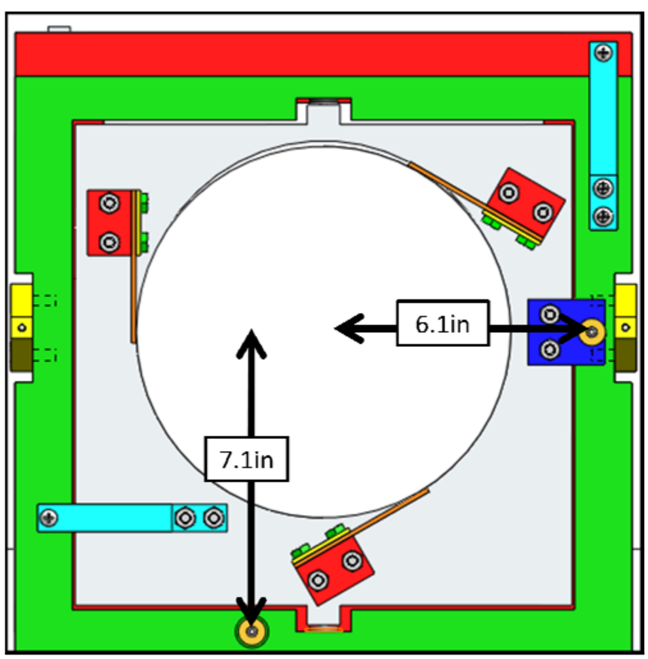



**Figure 33: Top view of kinematic mount. The distance shown is the distance from the 100tpi adjustment screw to the axis of rotation of the mount.**

The calculation of the angular resolution from the position of the adjustment screws is seen below. By using the high precision micrometer screws from Newport, the angular adjustment requirement is easily met. Note that the turquoise flexures provide the preload/reaction force to the micrometer motion, which stabilizes the system during adjustment. In addition, the adjustment of a tip/tilt causes a moment on the axis of rotation in the pins. However, the pins are designed to have tight clearance fit tolerances to resist this moment while still providing precise rotation. Silicon lubricant can be used to allow the plates to rotate about the pins, while the holes for the pins have 0.001in clearance from edge to edge. In addition, the pins and holes all have very smooth finishes of 32μin.

Equation 15: Angular Resolution: X

$$Angular\ Resolution = \operatorname{asin}\left(\frac{0.7\mu m}{6.1in}\right) = 4.5\mu rad$$

Equation 16: Angular Resolution: Y

$$Angular\ Resolution = \operatorname{asin}\left(\frac{0.7\mu m}{7.1in}\right) = 3.88\mu rad$$

Equation 17: Angular Range: X

$$Angular\ Range = \operatorname{asin}\left(\frac{0.3in}{6.1in}\right) = 2.82°$$

Equation 18: Angular Range: Y

$$Angular\ Range = \operatorname{asin}\left(\frac{0.3in}{7.1in}\right) = 2.42°$$

### *A.4.2 Tip/Tilt: Small Mirror*

The small mirror is mounted on a pair of goniometers that provide tip and tilt adjustment of the bottom mirror. Sometimes with goniometers travel can be an issue, so I recommended securing with epoxy after setting the appropriate angle. These goniometers have the following specifications:

- +/- 5deg travel
- Sensitive to 3arcsec

The angular travel is pleanty for loose tolerances on a 45° support plate and the 3arcsec sensitivity means that the goniometers can be adjusted accurately to within 14.5μrad. This of course does not meet the angular resolution requirement; however it can be made up for in the top mirror. Here the goniometers will cause some linear translation of the mirror when adjusted, therefore the tolerances on the angle of the supporting plate and the position of the supporting plate will be semi-tight.

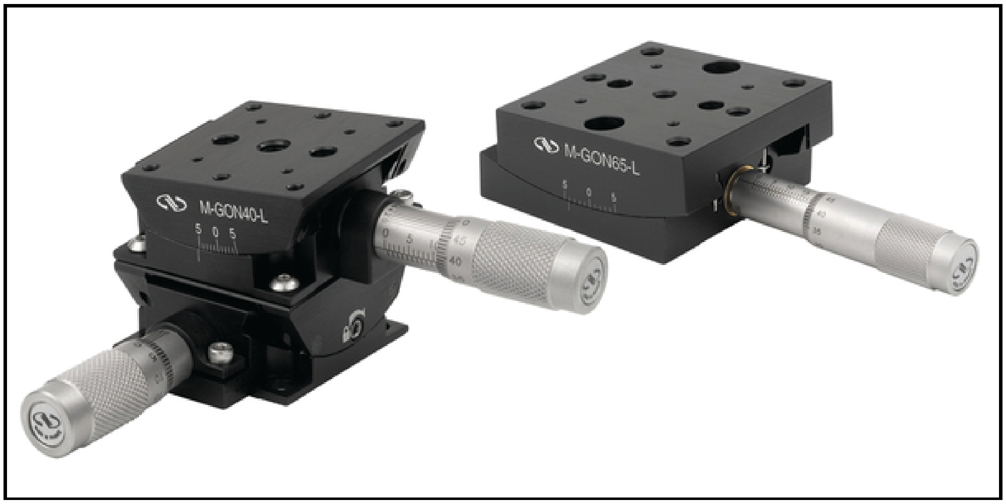



**Figure 34: Goniometer from Newport (GON-65L).**

*A.5.1 Bond: Glass to Flexure*

The bond thickness and area control is very important for ensuring that the mirror will not fall out of its mount. Here the first thing to consider is the resonant frequency of the bond. For a safe bond I will set the resonant frequency to 300Hz to surpass the 200Hz requirement. As seen below the resonant frequency will depend on the stiffness of the bond. See figure below calculations for illustration of bond placements. Below is a table of the important parameters for the calculation.

| Item | Value |
|---|---|
| 3M 2214 Shear Modulus | 150ksi |
| Weight of Mirror | 6.39lbs |
| Construction Temperature | 24C |
| CTE of Al | 23ppm/°C |
| CTE of Fused Silica | 7ppm/°C |

**Table 6: Important parameters for the adhesive**

**Equation 19: Resonant frequency**

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

**Equation 20: Shear stiffness of a bond**

$$k = \frac{GA}{t}$$

Setting the resonant frequency to 300Hz, using the standard recommended bond thickness of 0.003in, and using the rule of thumb for epoxy where G = 150ksi (value is not specified by 3M spec sheet), we can combine equations 19 and 20 and solve for the bond radius and see if the value gives shear stresses lower than the shear strength of 3M 2214.

$$300Hz = \frac{1}{2\pi}\sqrt{\left(150000psi * \pi * \frac{r^2}{0.003in}\right)(6.39/3)^{-1}}\text{ ; r = 0.22in}$$

**Equation 21: Shear stress from temperature change**

$$\tau = \frac{GA}{2t}(\alpha_1 - \alpha_2) * \Delta T$$

Plugging in the radius value from above we get a thermally induced shear stress of:

$$\tau = \frac{150000 * \pi * (0.22in)^2}{2 * 0.003in}(23 - 0.7) * \frac{10^{-6}}{C} * (45C - 24C) = 1788\text{psi}$$

Plugging in the radius value from above we get a shock loading induced shear stress of:

**Equation 22: Shear stress due to shock load**

$$F_{shear} = \frac{1}{3} * \frac{WG}{A} = \frac{1}{3} * \frac{6.39lb * 20}{\pi * (0.22in)^2} = 281lb$$

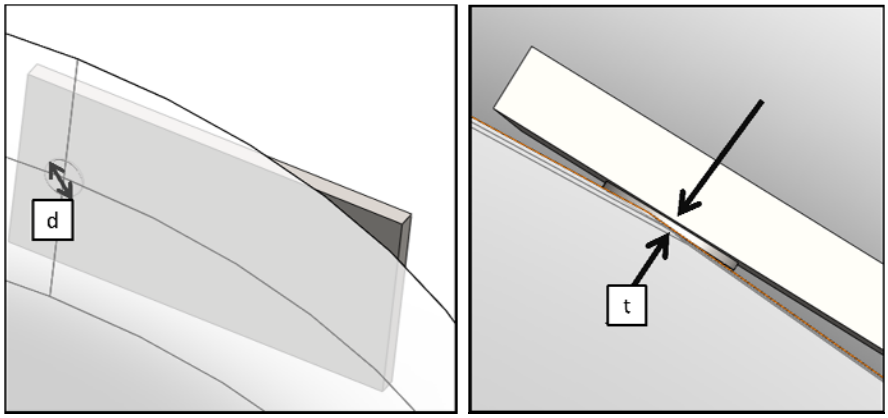



Figure 35: Bond area close up.

As seen above, only the large mirror is considered because it will have the harshest effect on the adhesive; the small mirror will use the same exact bond thickness and diameter. Furthermore, only the large temperature change between 45C and 24C is considered because it has a larger effect on the thermal induced shear stress in the adhesive (larger $\Delta T$).

APPENDIX B: Engineering Drawings and Attachments

Engineering Drawings are attached as follows. Note only custom parts have full drawings.

1. Complete System with BOM
2. Cage sub-assembly
    a. Base Plate
    b. Side Plate
    c. Back Plate
    d. Top Plate
    e. Pivot Triangle Support (yellow)
3. Bottom Mirror sub-assembly
    a. Angle bracket
    b. Support Plate
    c. Flexure Support Block
    d. Flexure
    e. Flexure Clamp
    f. Small Mirror
4. Top Mirror sub-assembly
    a. Outside Plate (green)
    b. Inside Plate (gray)
    c. Adjustment Block
    d. Locking Block
    e. Preload Flexure (turquoise)
    f. Pivot Pin
    g. Large Mirror

Procurement data sheets and are as follows:

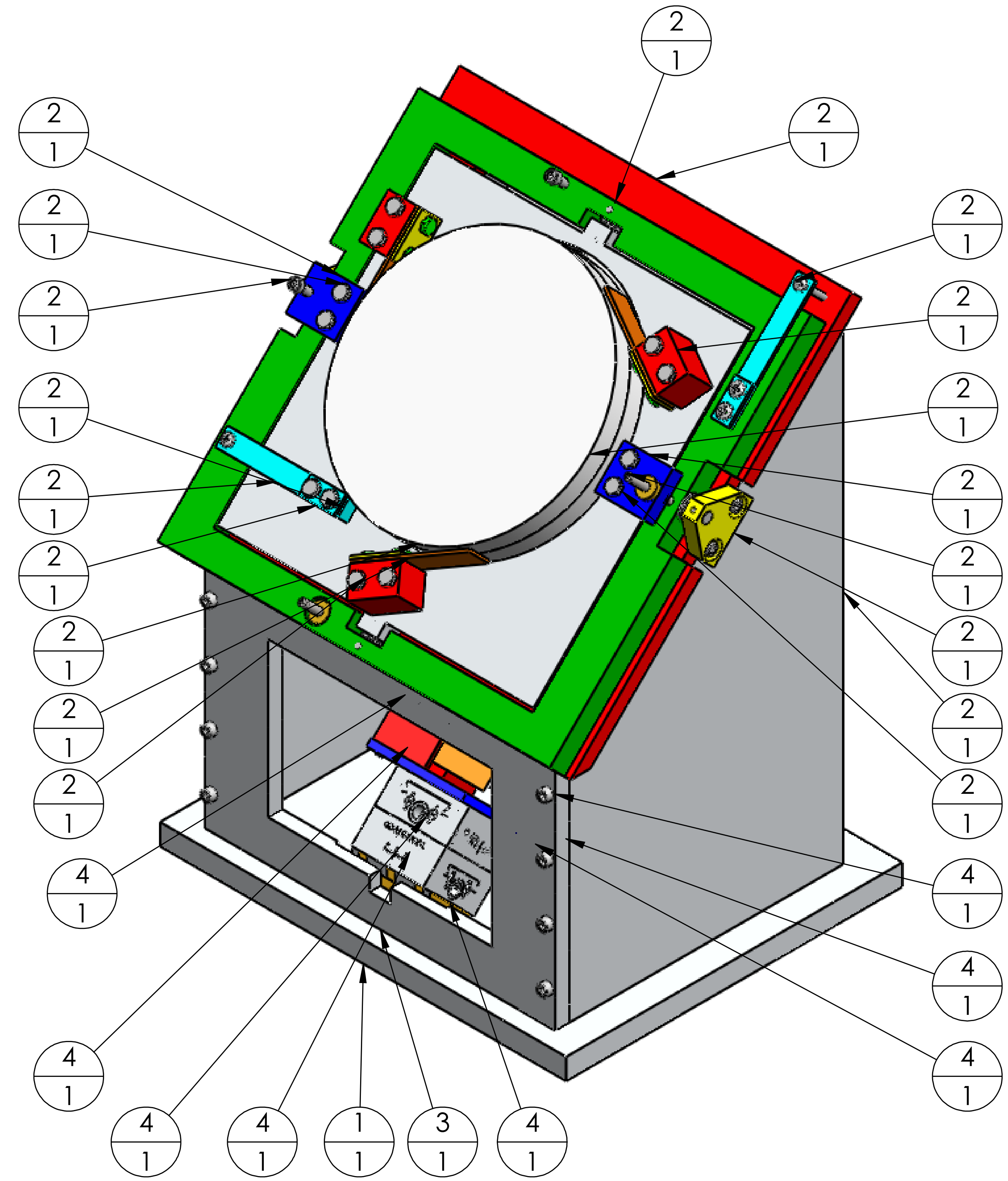
1. Newport Goniometers GON-65L/U
2. Newport Angle Bracket Model 360-45
3. Newport Micrometer AJS-1001H
4. MellesGriot Coating MAXBright Coating 003
5. Adhesive – 3M 2214 Gray – Scotch data sheet
6. Adhesive – 3M 2214 Gray – Yoder Table
7. Disk Springs – McMaster Carr

Attachments are as follows:

1. Won Hyun Park's Mirror Deflection Code

| ITEM NO. | PART NUMBER | QTY. |
|---|---|---|
| 1 | baseplate | 1 |
| 2 | LargeMirrorMountedAssembly | 1 |
| 3 | backplate_support | 1 |
| 4 | small_mirror_goniometer_bracket | 1 |
| 5 | SSFLATSKT 0.125-40x0.25-HX-N | 2 |
| 6 | SSFLATSKT 0.125-40x0.125-HX-N | 2 |
| 7 | Preferred Narrow FW 0.375 | 4 |
| 8 | HX-SHCS 0.25-20x0.75x0.75-N | 14 |
| 9 | HFBOLT 0.25-20x1.25x1.25-N | 2 |
| 10 | Hex Finished Bolt_AI | 1 |
| 11 | HX-SHCS 0.25-20x1.125x1.125-N | 5 |
| 12 | Socket Head Cap Screw_AI | 1 |
| 13 | Preferred Narrow FW 0.25 | 3 |
| 14 | MSHXNUT 0.250-20-S-N | 3 |

Only top level items shown in BOM.
Each sub assembly has indiviual BOM showing more components



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TOLERANCES:
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| MFG APPR. | | |
| Q.A. | | |

COMMENTS:

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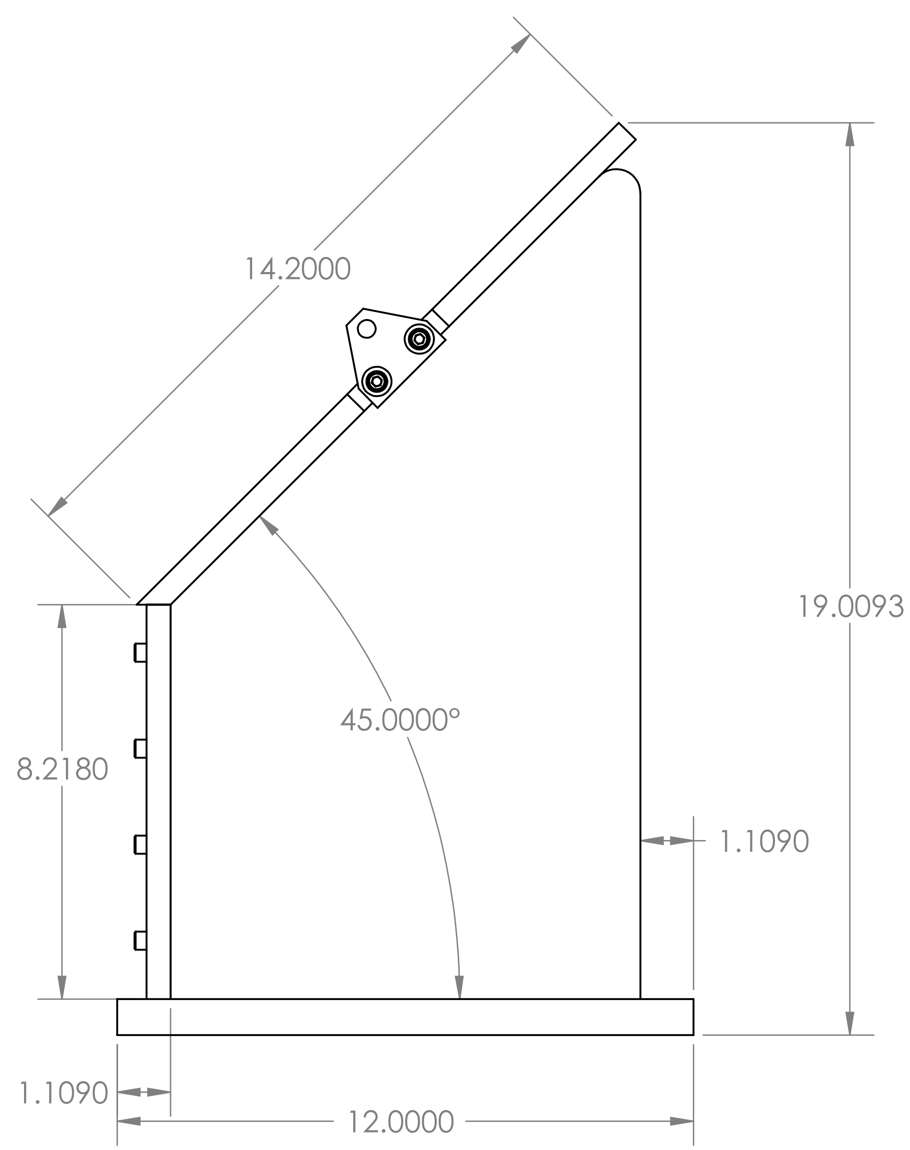
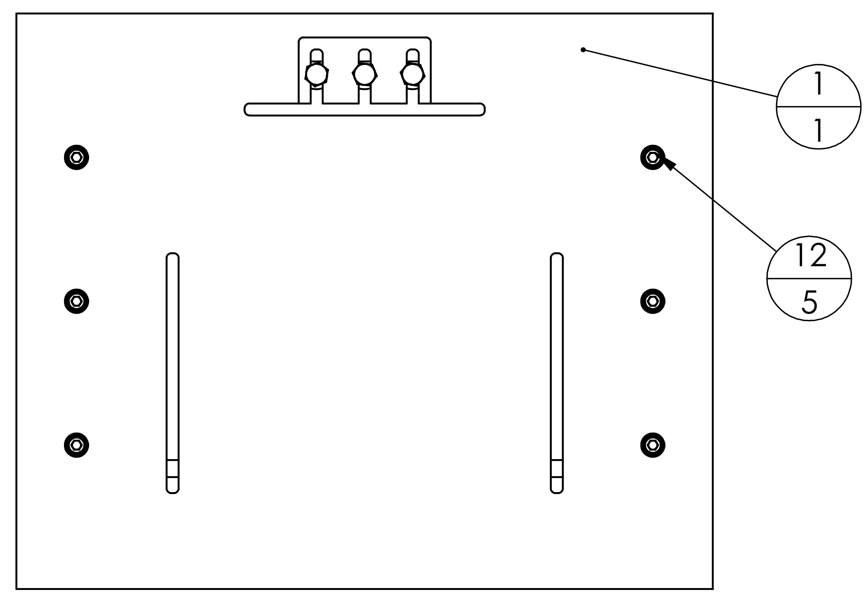
TITLE:
System w/BOM

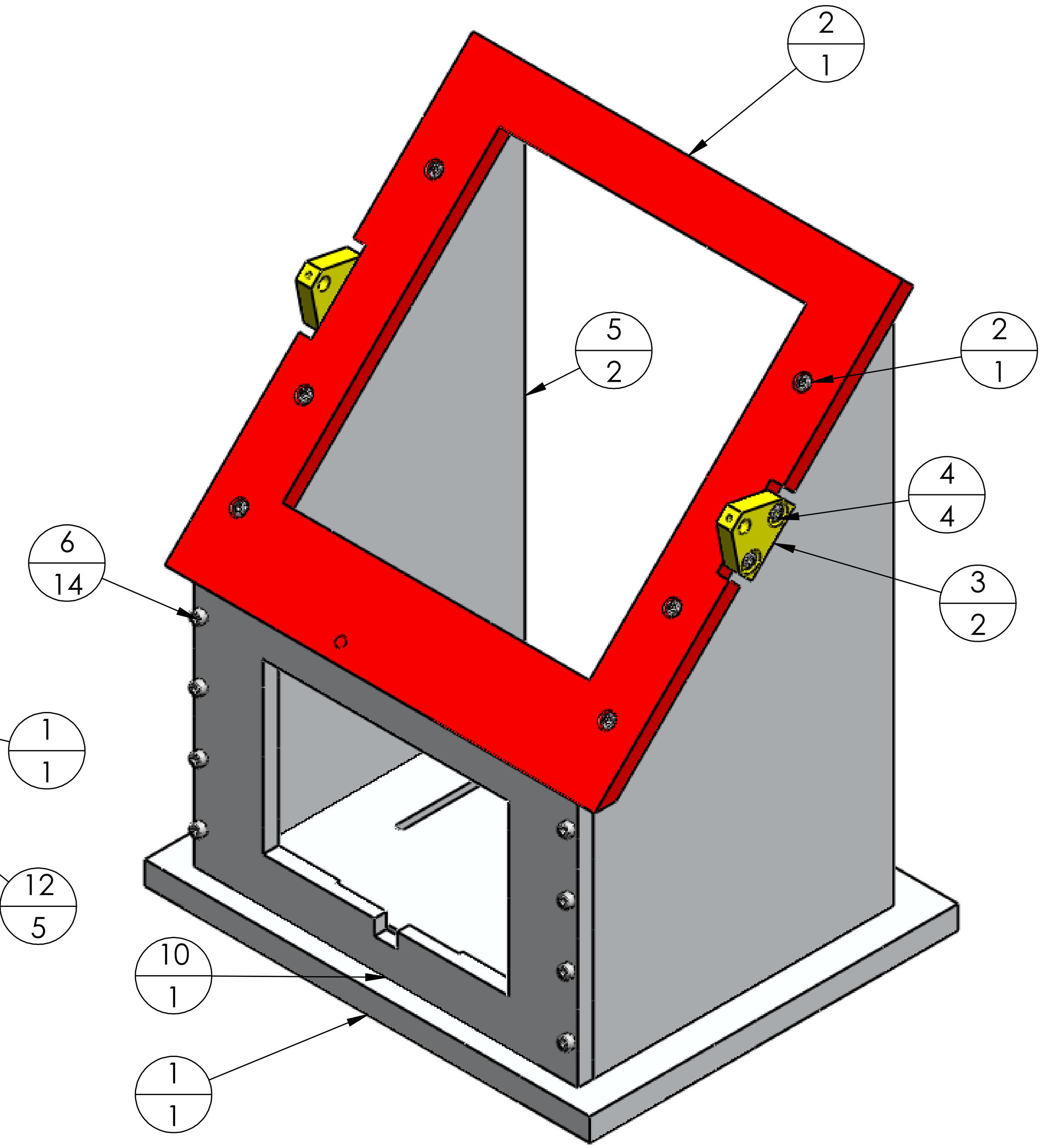
SIZE B | DWG. NO. | REV

SCALE: 1:12 | WEIGHT: | SHEET 1 OF 1

| ITEM NO. | PART NUMBER | QTY. |
|---|---|---|
| 1 | baseplate | 1 |
| 2 | bottom_kinematicmount | 1 |
| 3 | kinematic_assembly_connector | 2 |
| 4 | HX-SHCS 0.25-20x0.375x0.375-N | 4 |
| 5 | side | 2 |
| 6 | HX-SHCS 0.25-20x0.75x0.75-N | 14 |
| 7 | Hex Finished Bolt_AI | 1 |
| 8 | HFBOLT 0.25-20x1.25x1.25-N | 2 |
| 9 | Socket Head Cap Screw_AI | 1 |
| 10 | backplate_support | 1 |
| 11 | Preferred Narrow FW 0.25 | 3 |
| 12 | HX-SHCS 0.25-20x1.125x1.125-N | 5 |
| 13 | MSHXNUT 0.250-20-S-N | 3 |

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COMMENTS:

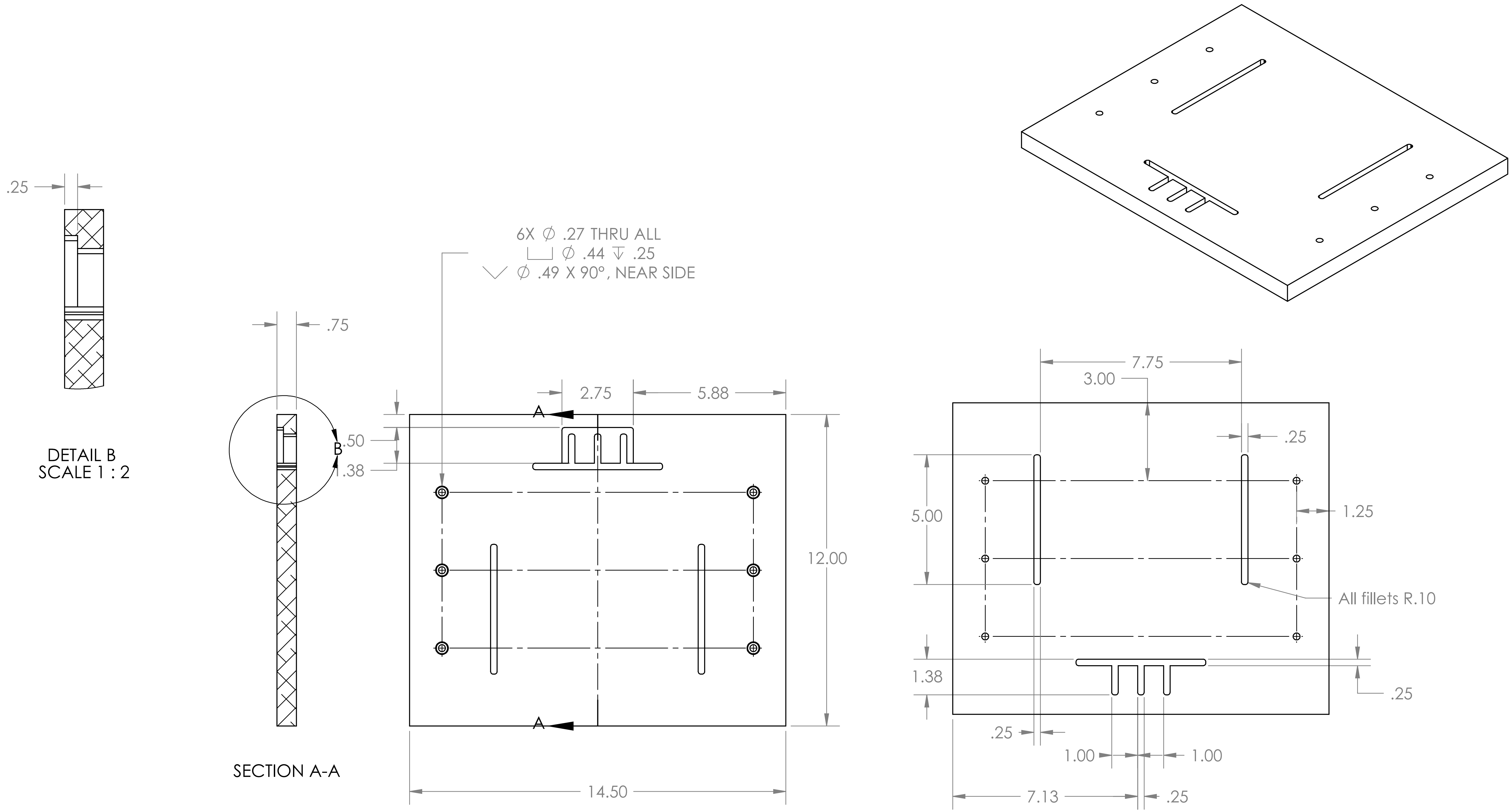
AVM OPTICAL

TITLE:

Cage

| SIZE | DWG. NO. | REV |
|---|---|---|
| B | | |

SCALE: 1:12 WEIGHT: SHEET 1 OF 1

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| MFG APPR. | | |
| Q.A. | | |

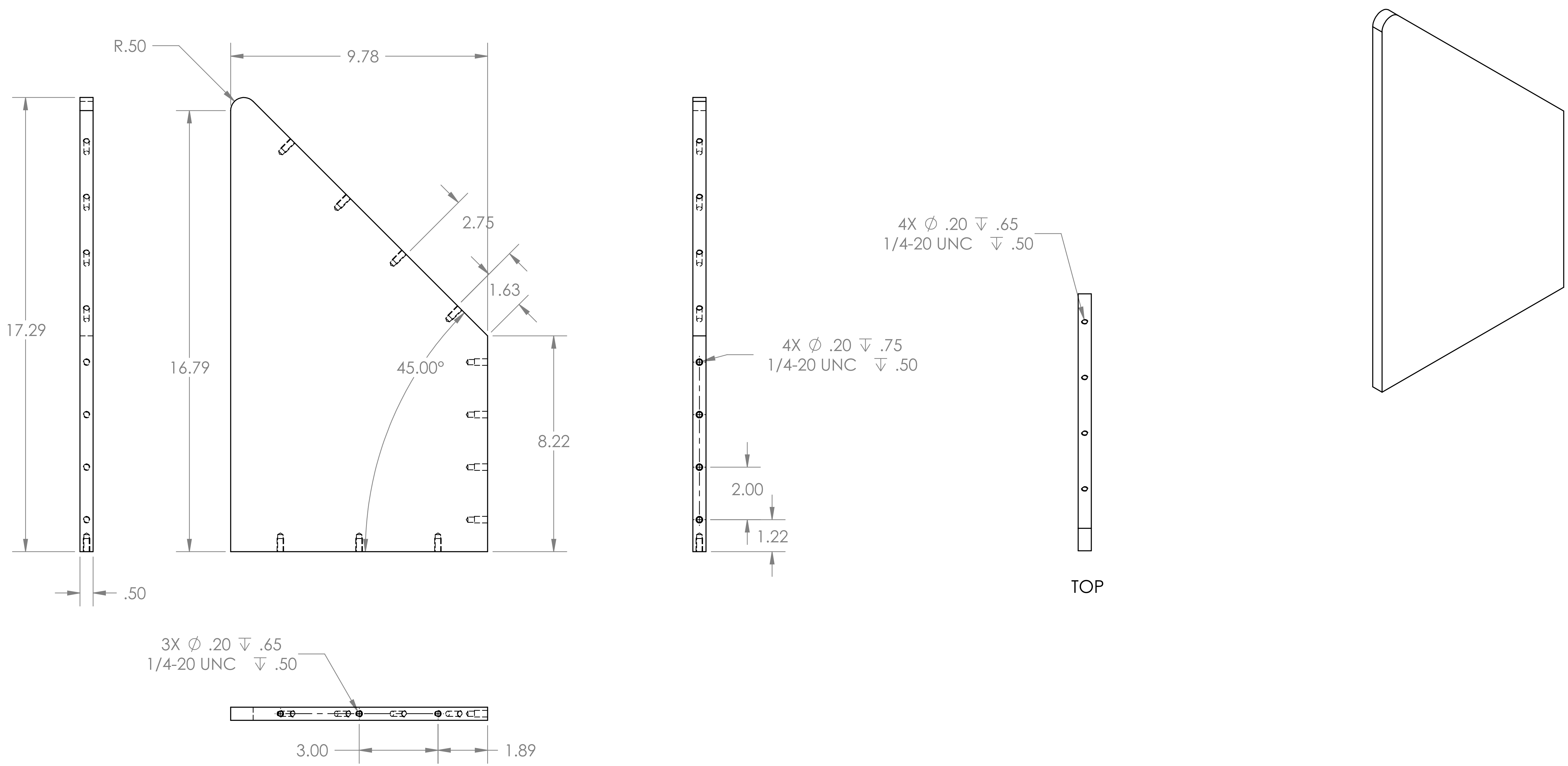
COMMENTS:

AVM OPTICAL

TITLE:

| SIZE | DWG. NO. | REV |
|---|---|---|
| **B** | Base Plate | |

SCALE: 1:4 WEIGHT: SHEET 1 OF 1

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MATERIAL

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| | NAME | DATE |
|---|---|---|
| DRAWN | | |
| CHECKED | | |
| ENG APPR. | | |
| MFG APPR. | | |
| Q.A. | | |

COMMENTS:

# AVM OPTICAL

TITLE:

## Side Piece

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| B | | |

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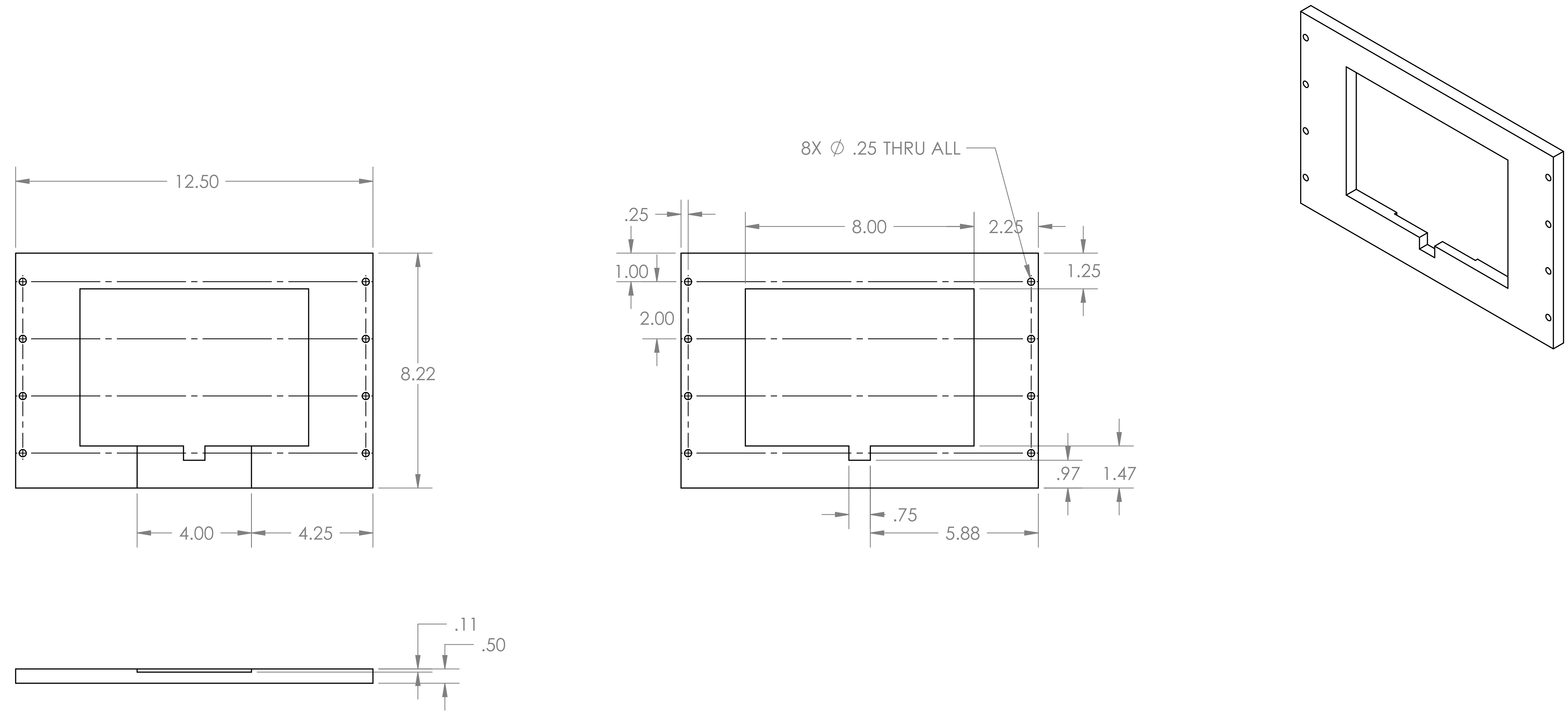


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TWO PLACE DECIMAL +-.15

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL

FINISH

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| | NAME | DATE |
|---|---|---|
| DRAWN | | |
| CHECKED | | |
| ENG APPR. | | |
| MFG APPR. | | |
| Q.A. | | |

COMMENTS:

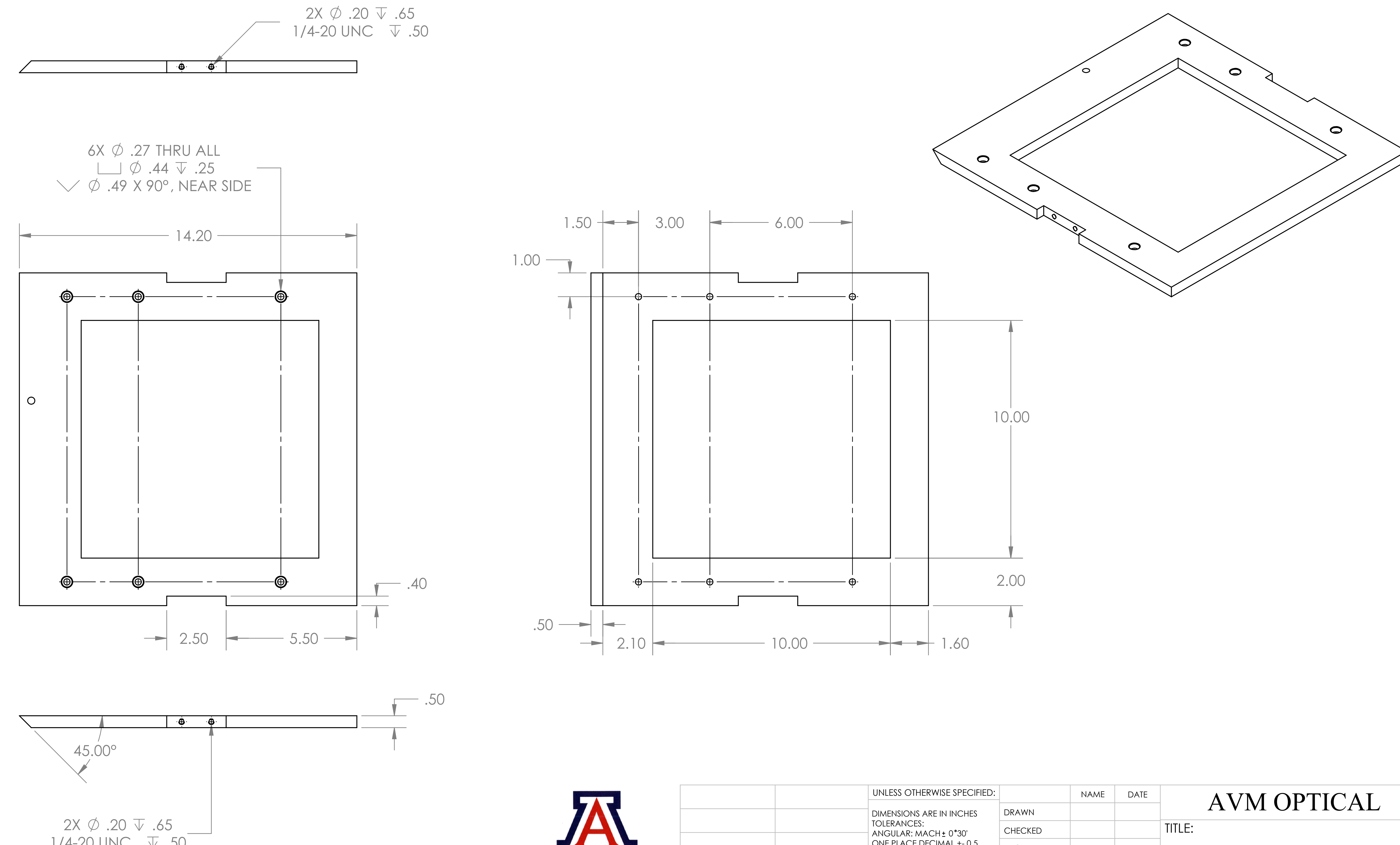
AVM OPTICAL

TITLE:

# Back Plate

SIZE **B** DWG. NO. REV

SCALE: 1:2 WEIGHT: SHEET 1 OF 1




AVM OPTICAL

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|---|---|
| NEXT ASSY | USED ON |
| APPLICATION | |

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TOLERANCES:
ANGULAR: MACH ± 0°30'
ONE PLACE DECIMAL +- 0.5
TWO PLACE DECIMAL +-.15

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL

FINISH

DO NOT SCALE DRAWING

| | NAME | DATE |
|---|---|---|
| DRAWN | | |
| CHECKED | | |
| ENG APPR. | | |
| MFG APPR. | | |
| Q.A. | | |

COMMENTS:

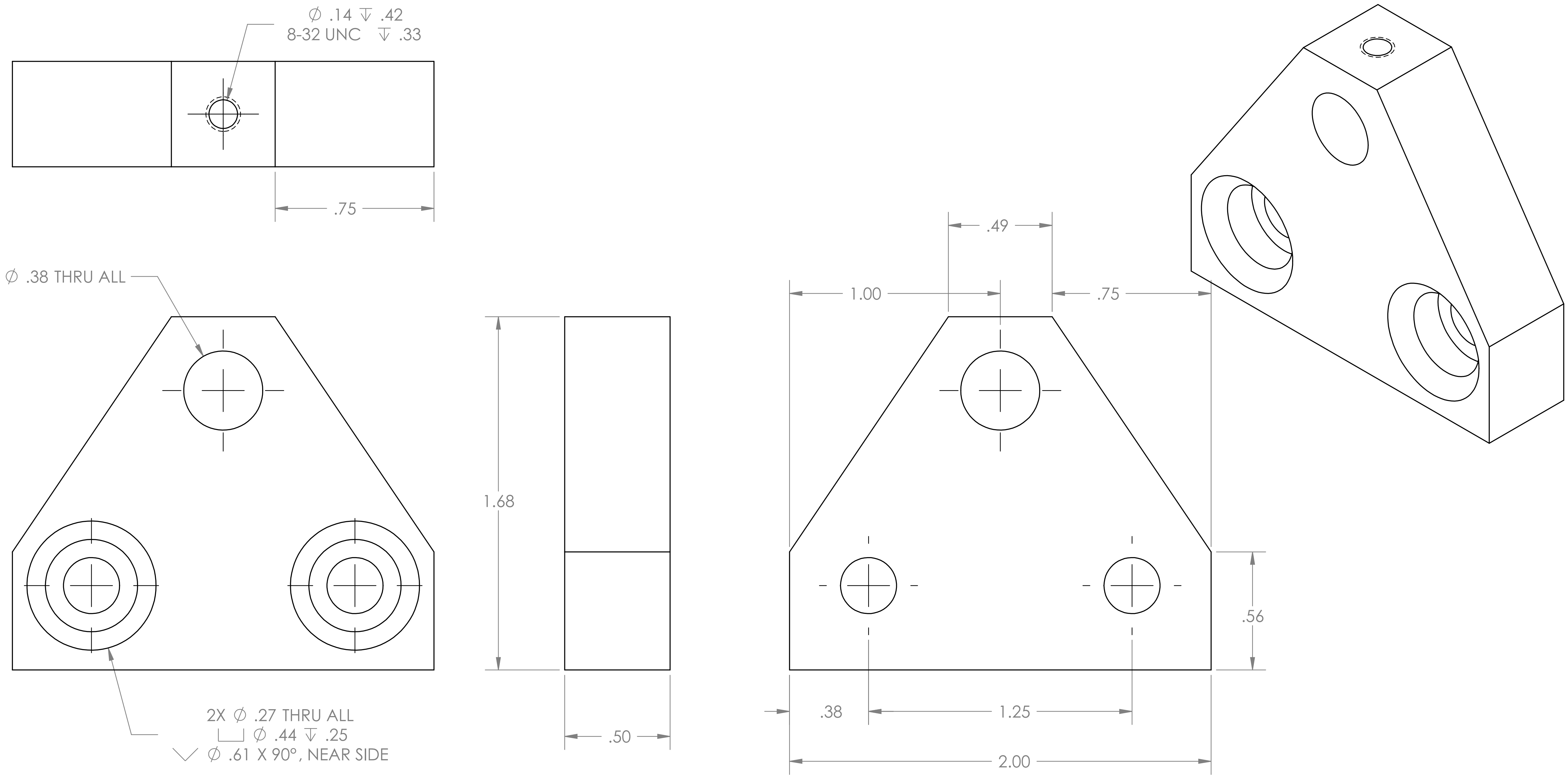
AVM OPTICAL

TITLE:

# Top Plate

| SIZE | DWG. NO. | REV |
|---|---|---|
| B | | |

SCALE: 1:4 WEIGHT: SHEET 1 OF 1




AVM OPTICAL

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| NEXT ASSY | USED ON |
|---|---|
| APPLICATION | |

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ± 0°30'
ONE PLACE DECIMAL +-.0.5
TWO PLACE DECIMAL +-.15

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL

FINISH

DO NOT SCALE DRAWING

| | NAME | DATE |
|---|---|---|
| DRAWN | | |
| CHECKED | | |
| ENG APPR. | | |
| MFG APPR. | | |
| Q.A. | | |

COMMENTS:

AVM OPTICAL

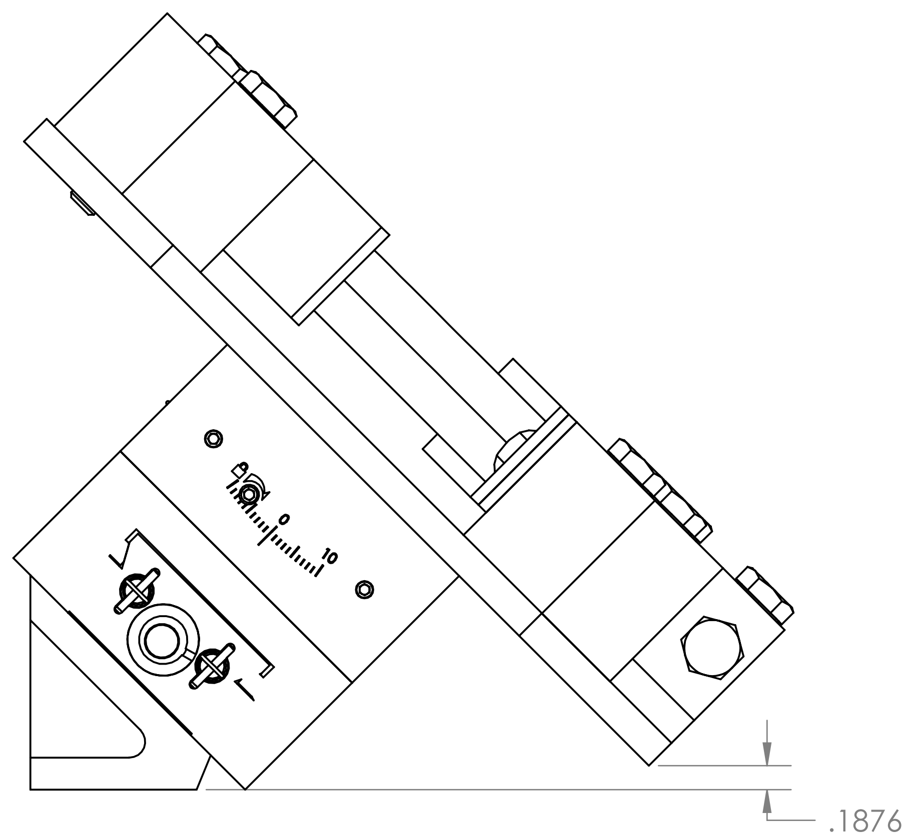
TITLE:

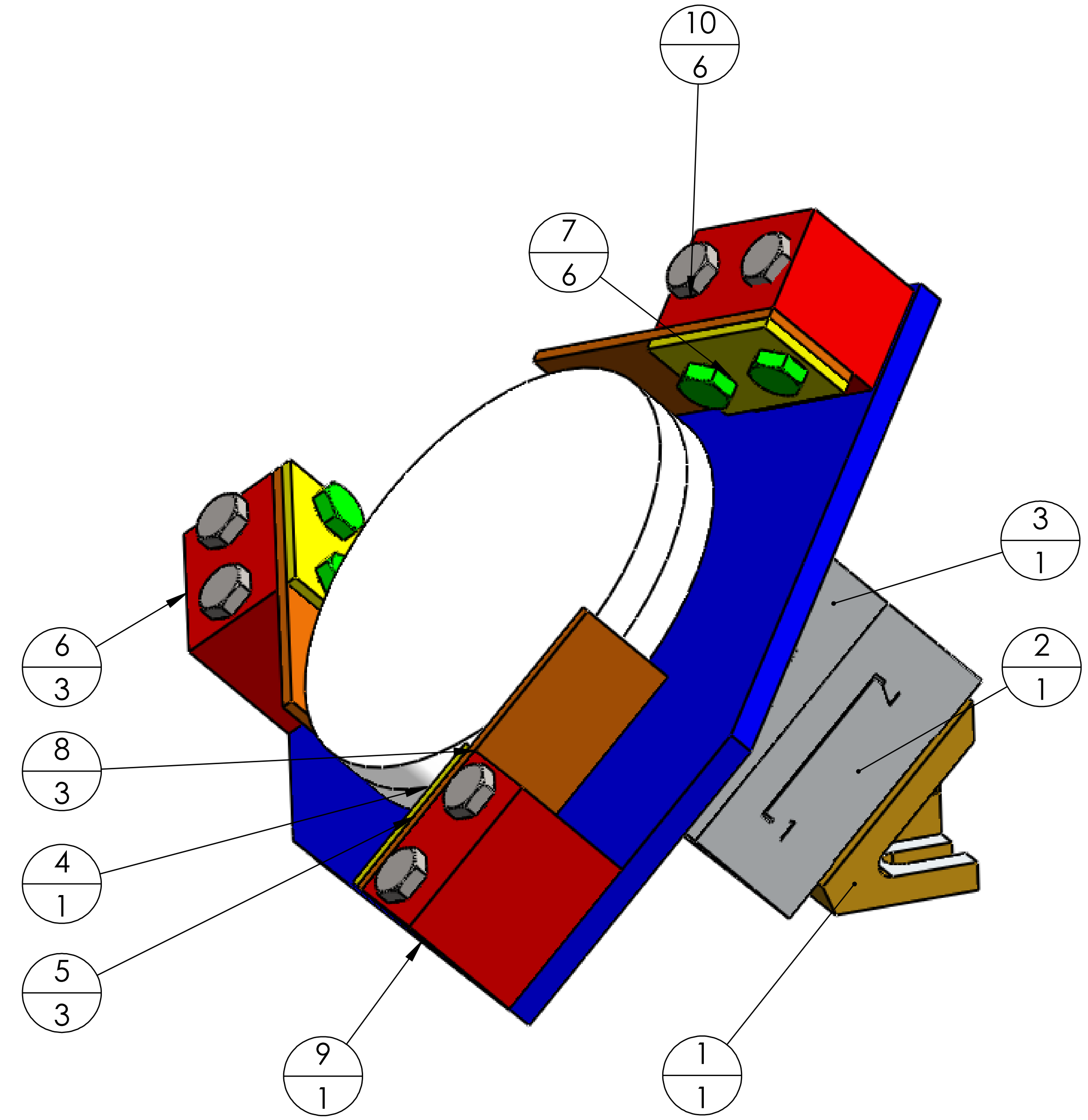
Pivot Tria Supp

SIZE **B** DWG. NO. REV

SCALE: 2:1 WEIGHT: SHEET 1 OF 1

| ITEM NO. | PART NUMBER | QTY. |
|---|---|---|
| 1 | Newport-360-45 | 1 |
| 2 | Newport-M-GON65-L | 1 |
| 3 | Newport-M-GON65-U | 1 |
| 4 | SmallMirror | 1 |
| 5 | loadingplate | 3 |
| 6 | small_mirror_flexure_mount | 3 |
| 7 | flexure_bolt_mount | 6 |
| 8 | small_extended_flexure | 3 |
| 9 | small_mirror_plate1 | 1 |
| 10 | HFBOLT 0.25-20x1.5x0.75-C | 6 |




AVM OPTICAL

PROPRIETARY AND CONFIDENTIAL



NEXT ASSY | USED ON

APPLICATION

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ± 0°30'
ONE PLACE DECIMAL +- 0.5
TWO PLACE DECIMAL +-.15

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL

FINISH

DO NOT SCALE DRAWING

| | NAME | DATE |
|---|---|---|
| DRAWN | | |
| CHECKED | | |
| ENG APPR. | | |
| MFG APPR. | | |
| Q.A. | | |

COMMENTS:

AVM OPTICAL

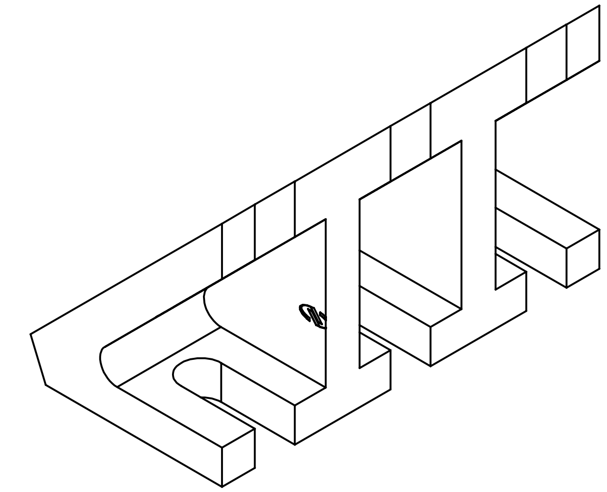
TITLE:

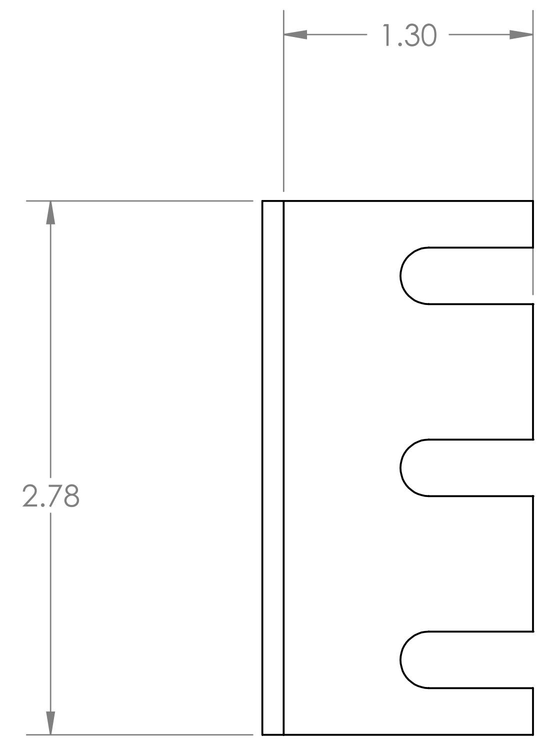
# Small Mirror Assm

SIZE **B** DWG. NO. REV

SCALE: 1:4 WEIGHT: SHEET 1 OF 1

ORIGINAL MODEL360-45 MUST BE CUT TO THE DIMENSION SHOWN BELOW






AVM OPTICAL

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| NEXT ASSY | USED ON |
|---|---|
| APPLICATION | |

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ± 0°30'
ONE PLACE DECIMAL +- 0.5
TWO PLACE DECIMAL +-.15

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL

FINISH

DO NOT SCALE DRAWING

| | NAME | DATE |
|---|---|---|
| DRAWN | | |
| CHECKED | | |
| ENG APPR. | | |
| MFG APPR. | | |
| Q.A. | | |

COMMENTS:

AVM OPTICAL

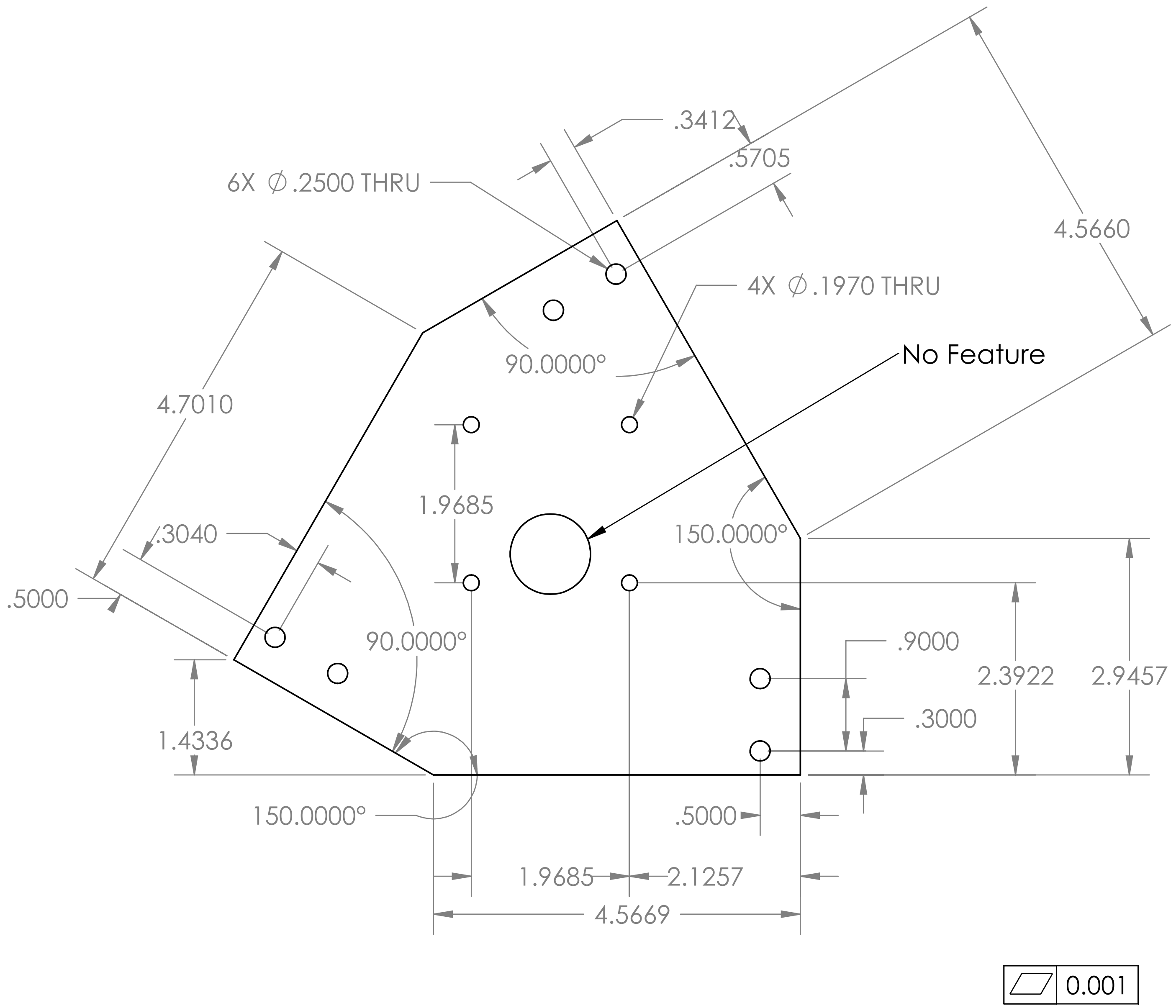
TITLE:

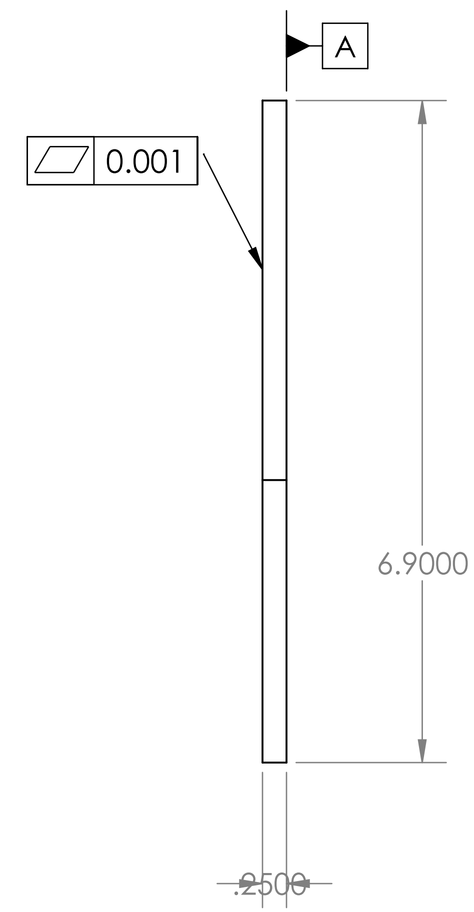
# NP-360-45 CUT

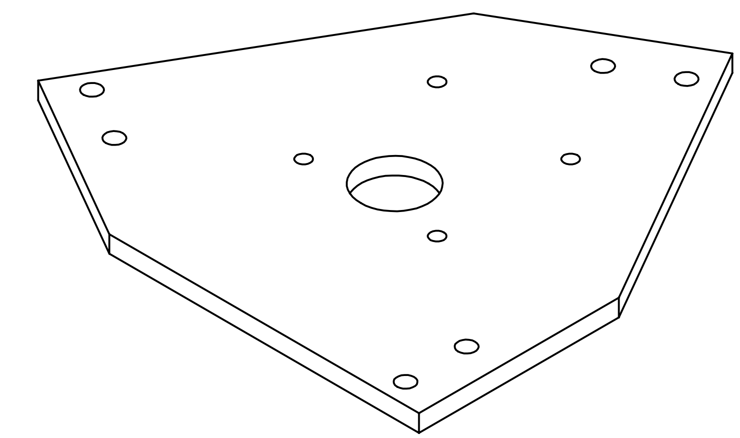
| SIZE | DWG. NO. | REV |
|---|---|---|
| B | | |

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

TIGHT TOLERANCES NEEDED FOR ACCURATELY MOUNTING FLEXURES



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NEXT ASSY | USED ON

APPLICATION

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ± 0.001°
3 PLACE DECIMAL +- 0.0050
4 PLACE DECIMAL +- 0.0015

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL

FINISH

DO NOT SCALE DRAWING

| | NAME | DATE |
|---|---|---|
| DRAWN | | |
| CHECKED | | |
| ENG APPR. | | |
| MFG APPR. | | |
| Q.A. | | |

COMMENTS:

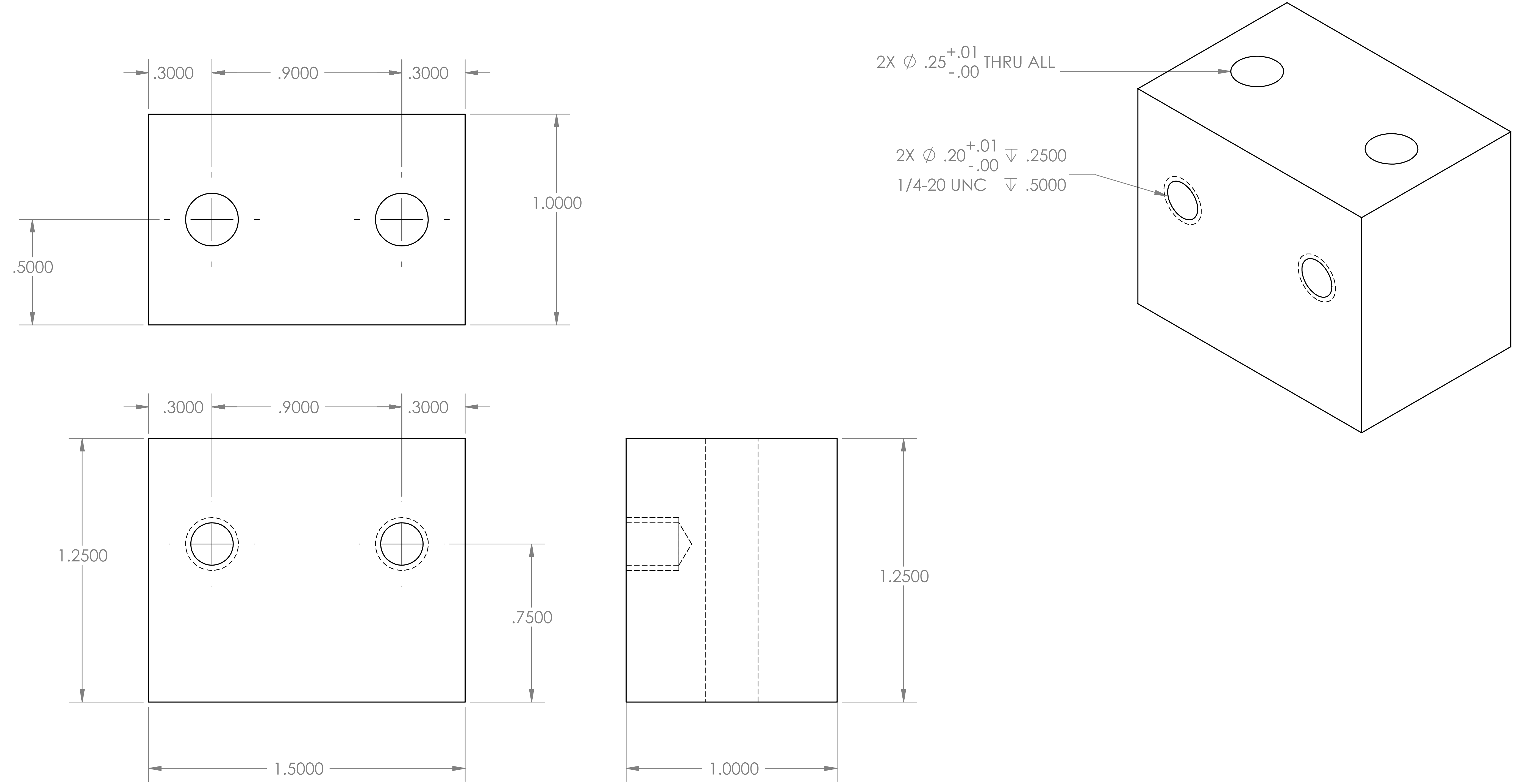
AVM OPTICAL

TITLE:

SM Support Plate

SIZE B | DWG. NO. | REV

SCALE: 1:2 | WEIGHT: | SHEET 1 OF 1




AVM OPTICAL

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| | |
|---|---|
| NEXT ASSY | USED ON |
| APPLICATION | |

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ± 0.001°
3 PLACE DECIMAL +- 0.005
4 PLACE DECIMAL +-.0015

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL

FINISH

DO NOT SCALE DRAWING

| | NAME | DATE |
|---|---|---|
| DRAWN | | |
| CHECKED | | |
| ENG APPR. | | |
| MFG APPR. | | |
| Q.A. | | |

COMMENTS:

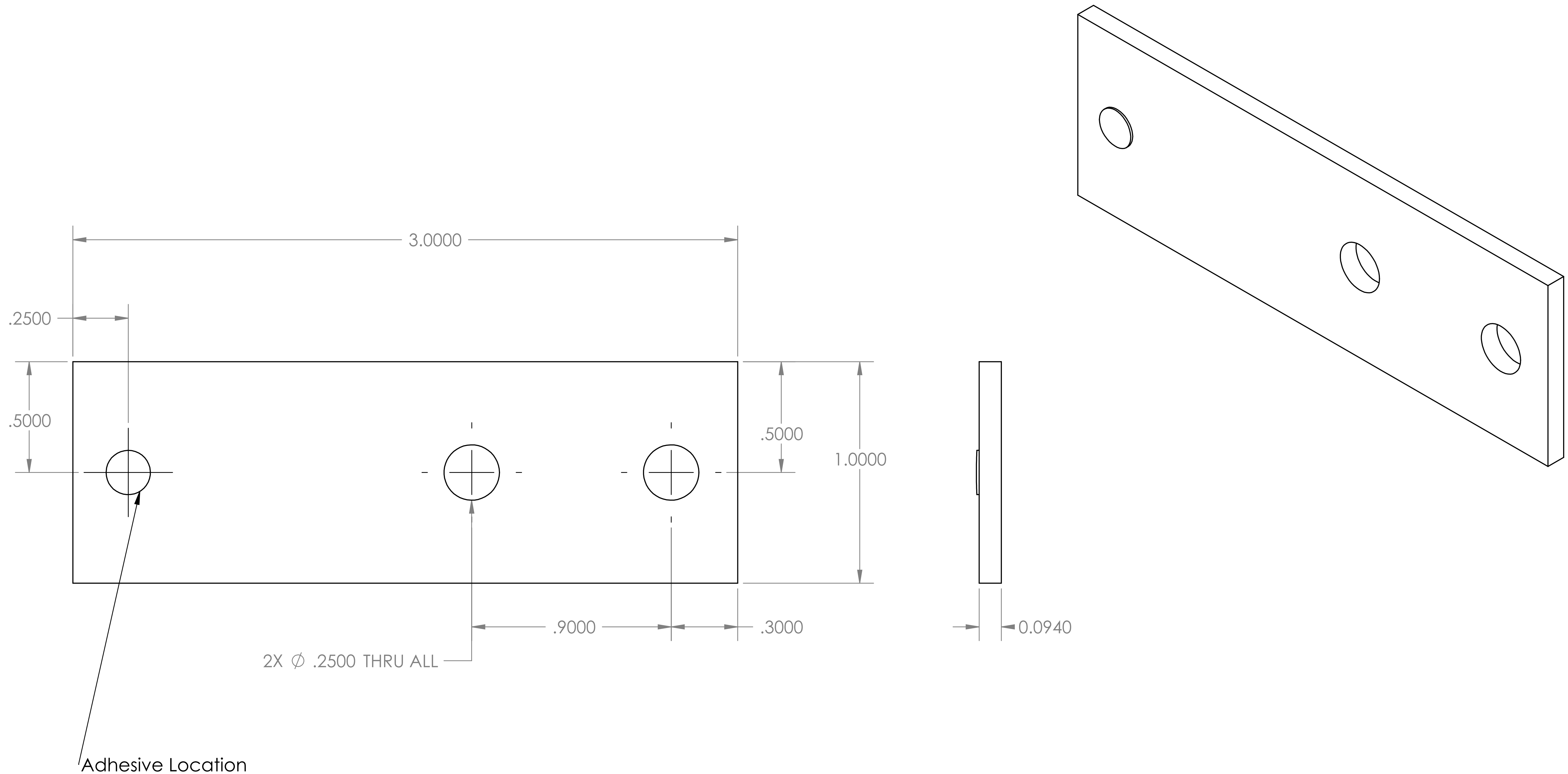
# AVM OPTICAL

TITLE:

## Flexure Block

| SIZE | DWG. NO. | REV |
|---|---|---|
| **B** | | |

SCALE: 2:1 | WEIGHT: | SHEET 1 OF 1

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|---|---|
| APPLICATION | |

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DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ± 0.001°
3 PLACE DECIMAL +- 0.005
4 PLACE DECIMAL +-.0015

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL

FINISH

DO NOT SCALE DRAWING

| | NAME | DATE |
|---|---|---|
| DRAWN | | |
| CHECKED | | |
| ENG APPR. | | |
| MFG APPR. | | |
| Q.A. | | |

COMMENTS:

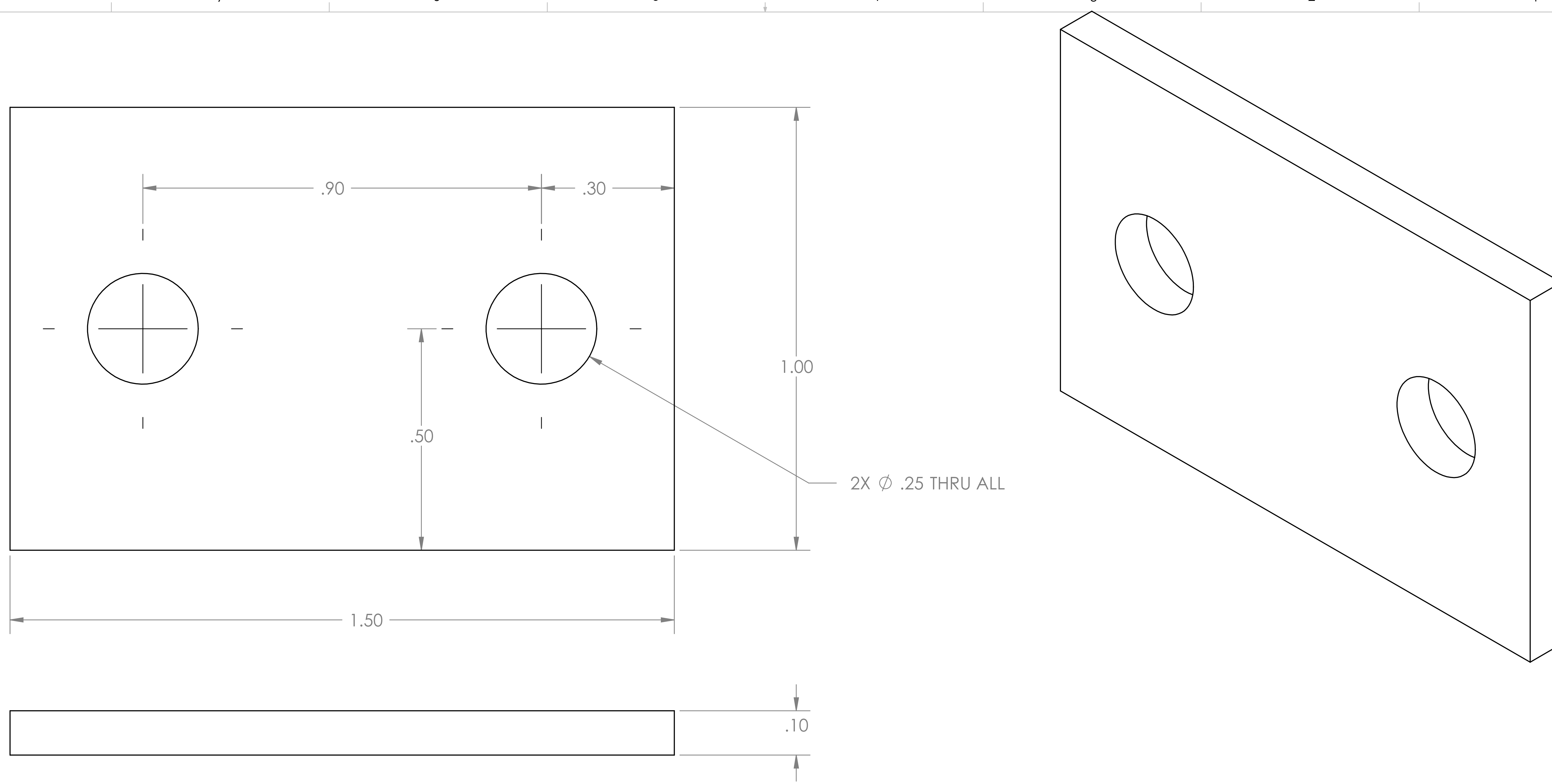
AVM OPTICAL

TITLE:

Flexure

| SIZE | DWG. NO. | REV |
|---|---|---|
| B | | |

SCALE: 2:1 WEIGHT: SHEET 1 OF 1




AVM OPTICAL

**PROPRIETARY AND CONFIDENTIAL**



| NEXT ASSY | USED ON |
|---|---|
| APPLICATION | |

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ± 0°30'
ONE PLACE DECIMAL +- 0.5
TWO PLACE DECIMAL +-.15

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL

FINISH

DO NOT SCALE DRAWING

| | NAME | DATE |
|---|---|---|
| DRAWN | | |
| CHECKED | | |
| ENG APPR. | | |
| MFG APPR. | | |
| Q.A. | | |

COMMENTS:

AVM OPTICAL

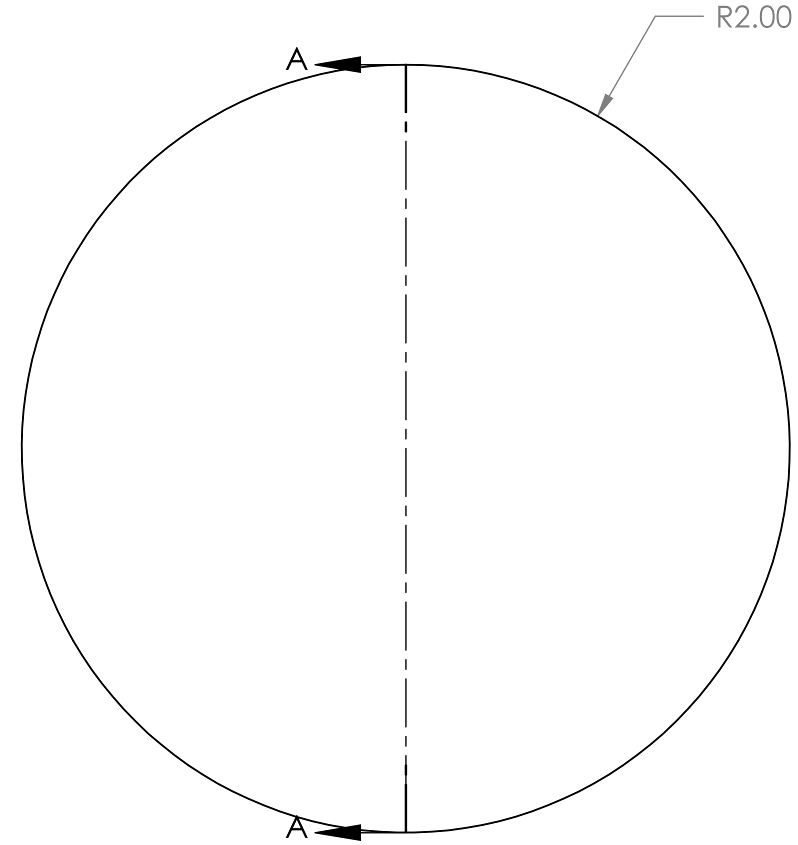
TITLE:

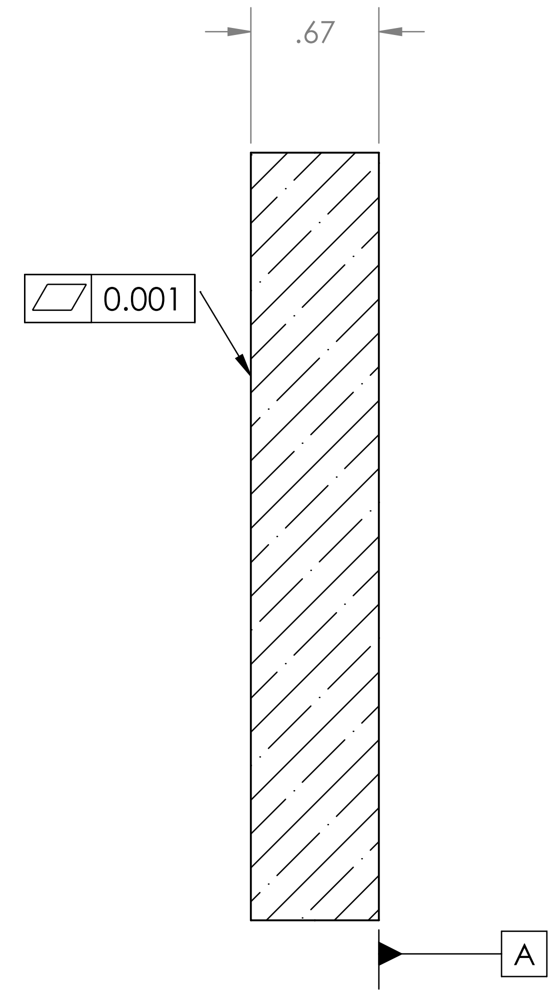
# Flexure Clamp

| SIZE | DWG. NO. | REV |
|---|---|---|
| B | | |

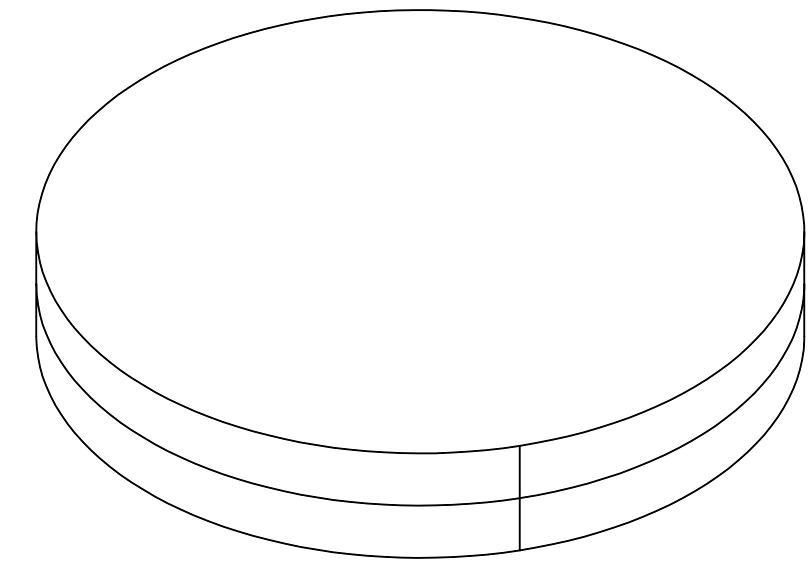
SCALE: 4:1 | WEIGHT: | SHEET 1 OF 1

- PITCH POLISH SURFACE TO 20ANG
- COAT WITH MELLESGRIOT COATING 003
- CA IS 95% OF THE LENS DIAMETER




SECTION A-A



AVM OPTICAL

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|---|---|
| APPLICATION | |

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TOLERANCES:
ANGULAR: MACH ± 0.001°
2 PLACE DECIMAL +-0.05
3 PLACE DECIMAL +- 0.005
4 PLACE DECIMAL +-.0015

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL

FINISH

DO NOT SCALE DRAWING

| | NAME | DATE |
|---|---|---|
| DRAWN | | |
| CHECKED | | |
| ENG APPR. | | |
| MFG APPR. | | |
| Q.A. | | |

COMMENTS:

AVM OPTICAL

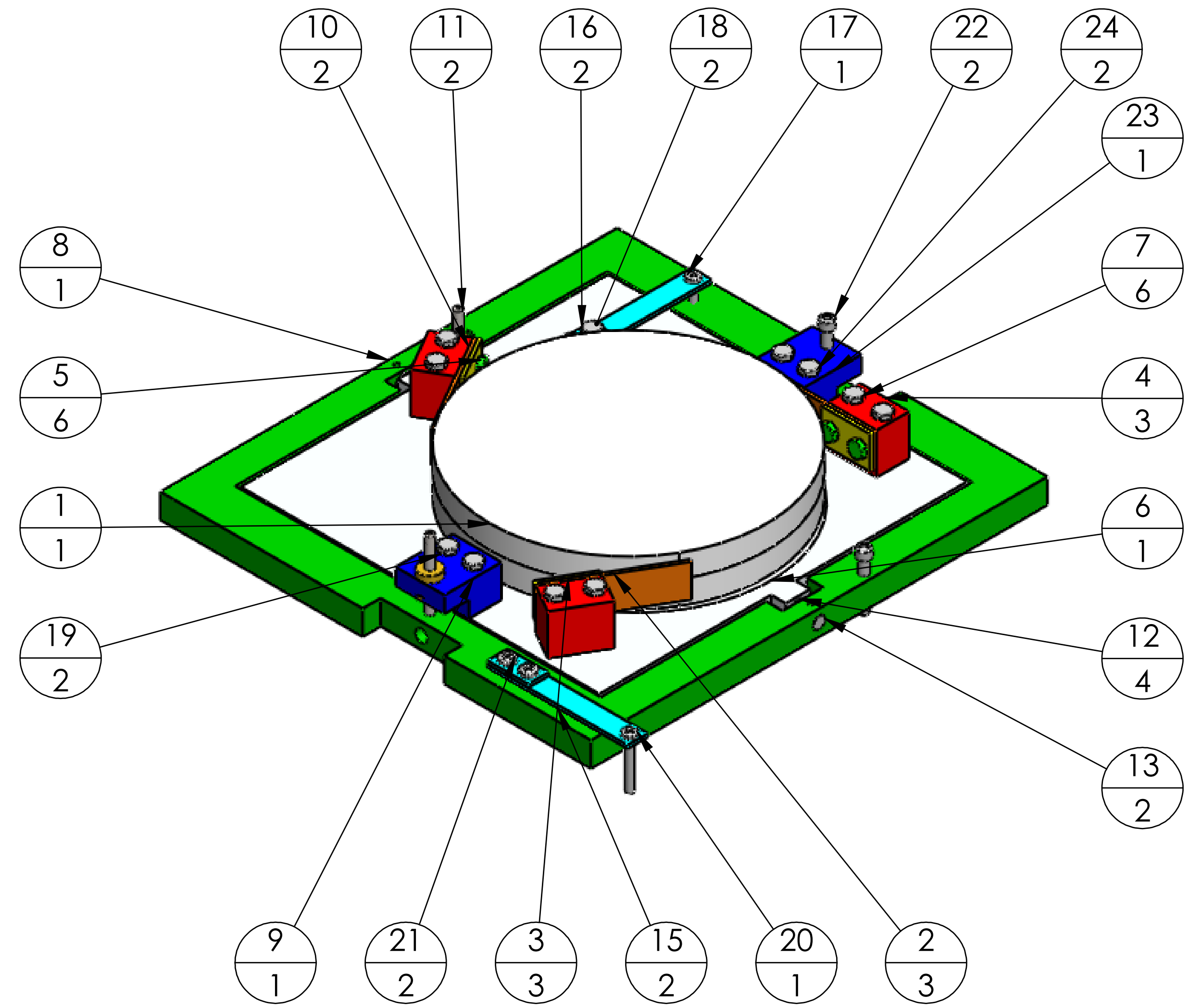
TITLE:

Small Mirror

SIZE **B** DWG. NO. REV

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

| ITEM NO. | PART NUMBER | QTY. |
|---|---|---|
| 1 | Large Mirror | 1 |
| 2 | extended_flexure | 3 |
| 3 | loadingplate | 3 |
| 4 | small_mirror_flexure_mount | 3 |
| 5 | flexure_bolt_mount | 6 |
| 6 | largemirrorbackplate | 1 |
| 7 | HFBOLT 0.25-20x1.75x0.75-C | 6 |
| 8 | Kinematicplate | 1 |
| 9 | adjustmentblock | 1 |
| 10 | micrometer | 2 |
| 11 | 100tpi_screw | 2 |
| 12 | Preferred Narrow FW 0.25 | 4 |
| 13 | DPM 0.1875x1.125 | 2 |
| 14 | preload_base | 1 |
| 15 | preload_flex | 2 |
| 16 | preload_top | 2 |
| 17 | CR-BHMS 0.19-24x0.75x0.75-N | 1 |
| 18 | HFBOLT 0.25-20x0.875x0.875-C | 2 |
| 19 | HFBOLT 0.25-20x1.25x0.75-C | 2 |
| 20 | CR-BHMS 0.19-24x1.5x1-N | 1 |
| 21 | CR-BHMS 0.216-24x0.5x0.5-N | 2 |
| 22 | HX-SHCS 0.25-20x1.5x1-N | 2 |
| 23 | lockblock | 1 |
| 24 | HFBOLT 0.25-20x1.25x1.25-N | 2 |

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NEXT ASSY | USED ON

APPLICATION

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ± 0°30'
ONE PLACE DECIMAL +- 0.5
TWO PLACE DECIMAL +-.15

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL

FINISH

DO NOT SCALE DRAWING

| | NAME | DATE |
|---|---|---|
| DRAWN | | |
| CHECKED | | |
| ENG APPR. | | |
| MFG APPR. | | |
| Q.A. | | |

COMMENTS:

AVM OPTICAL

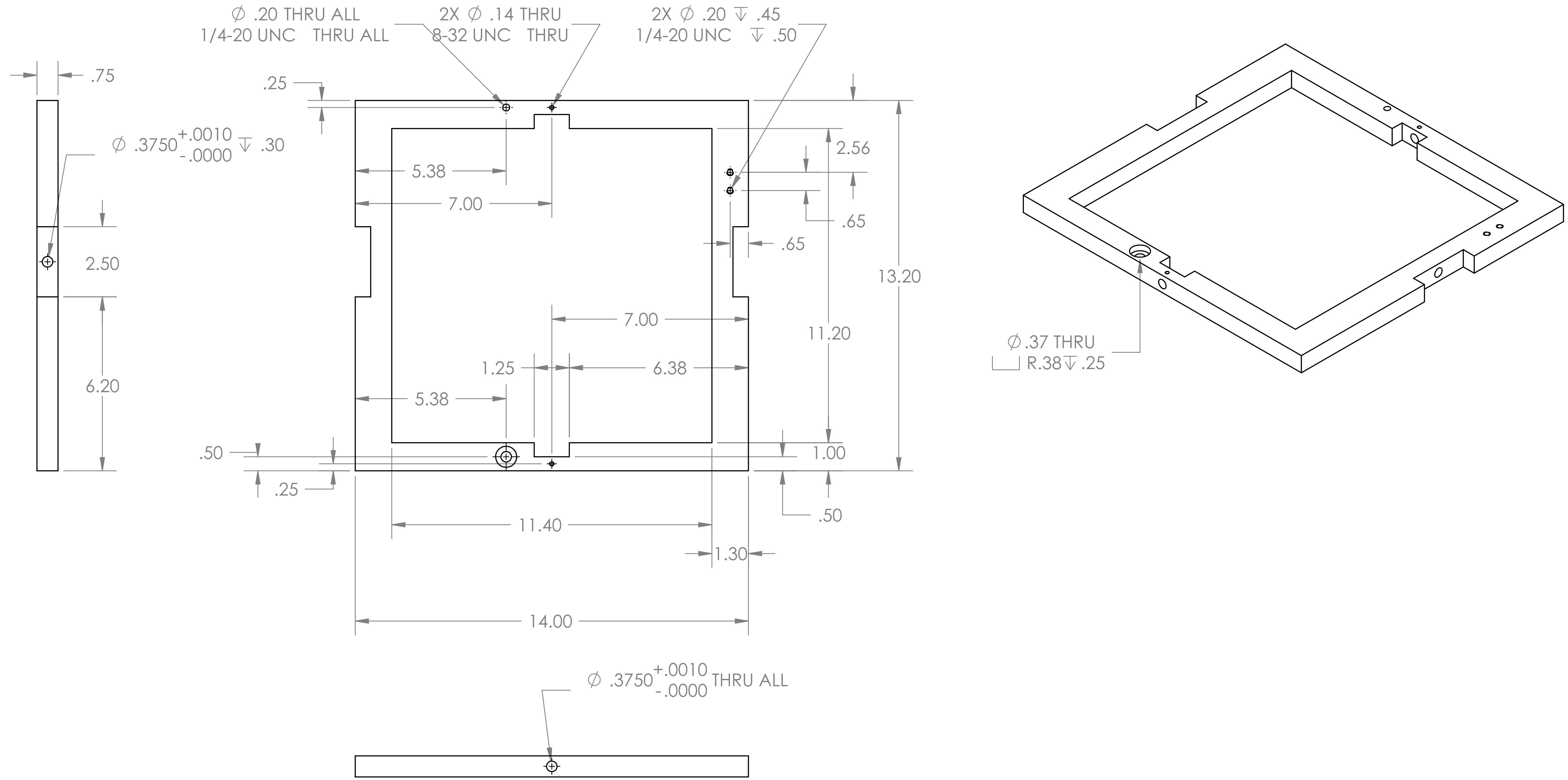
TITLE:

Top Mirror Assm

SIZE B | DWG. NO. | REV

SCALE: 1:4 | WEIGHT: | SHEET 1 OF 1

- 3/8" HOLES MUST BE GROUND TO 32MICRONS ROUGHNESS

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| NEXT ASSY | USED ON |
|---|---|
| APPLICATION | |

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TOLERANCES:
ANGULAR: MACH ± 0°30'
ONE PLACE DECIMAL +- 0.5
TWO PLACE DECIMAL +-.15

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL

FINISH

DO NOT SCALE DRAWING

| | NAME | DATE |
|---|---|---|
| DRAWN | | |
| CHECKED | | |
| ENG APPR. | | |
| MFG APPR. | | |
| Q.A. | | |

COMMENTS:

AVM OPTICAL

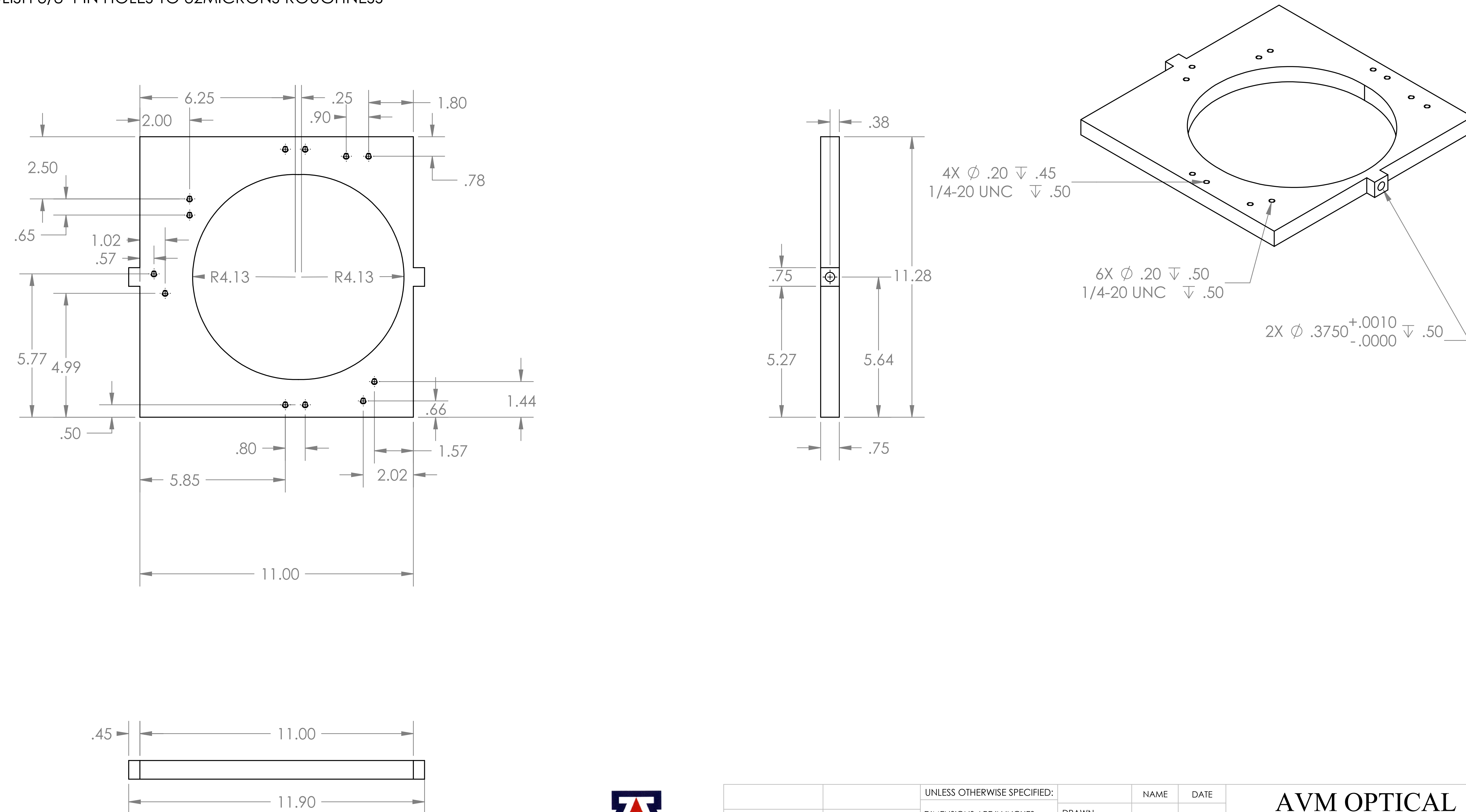
TITLE:

# Outside Plate

| SIZE | DWG. NO. | REV |
|---|---|---|
| B | | |

SCALE: 1:4 WEIGHT: SHEET 1 OF 1

POLISH 3/8" PIN HOLES TO 32MICRONS ROUGHNESS




AVM OPTICAL

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|---|---|
| APPLICATION | |

UNLESS OTHERWISE SPECIFIED:

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TOLERANCES:
ANGULAR: MACH ± 0°30'
ONE PLACE DECIMAL +- 0.5
TWO PLACE DECIMAL +-.15

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL

FINISH

DO NOT SCALE DRAWING

| | NAME | DATE |
|---|---|---|
| DRAWN | | |
| CHECKED | | |
| ENG APPR. | | |
| MFG APPR. | | |
| Q.A. | | |

COMMENTS:

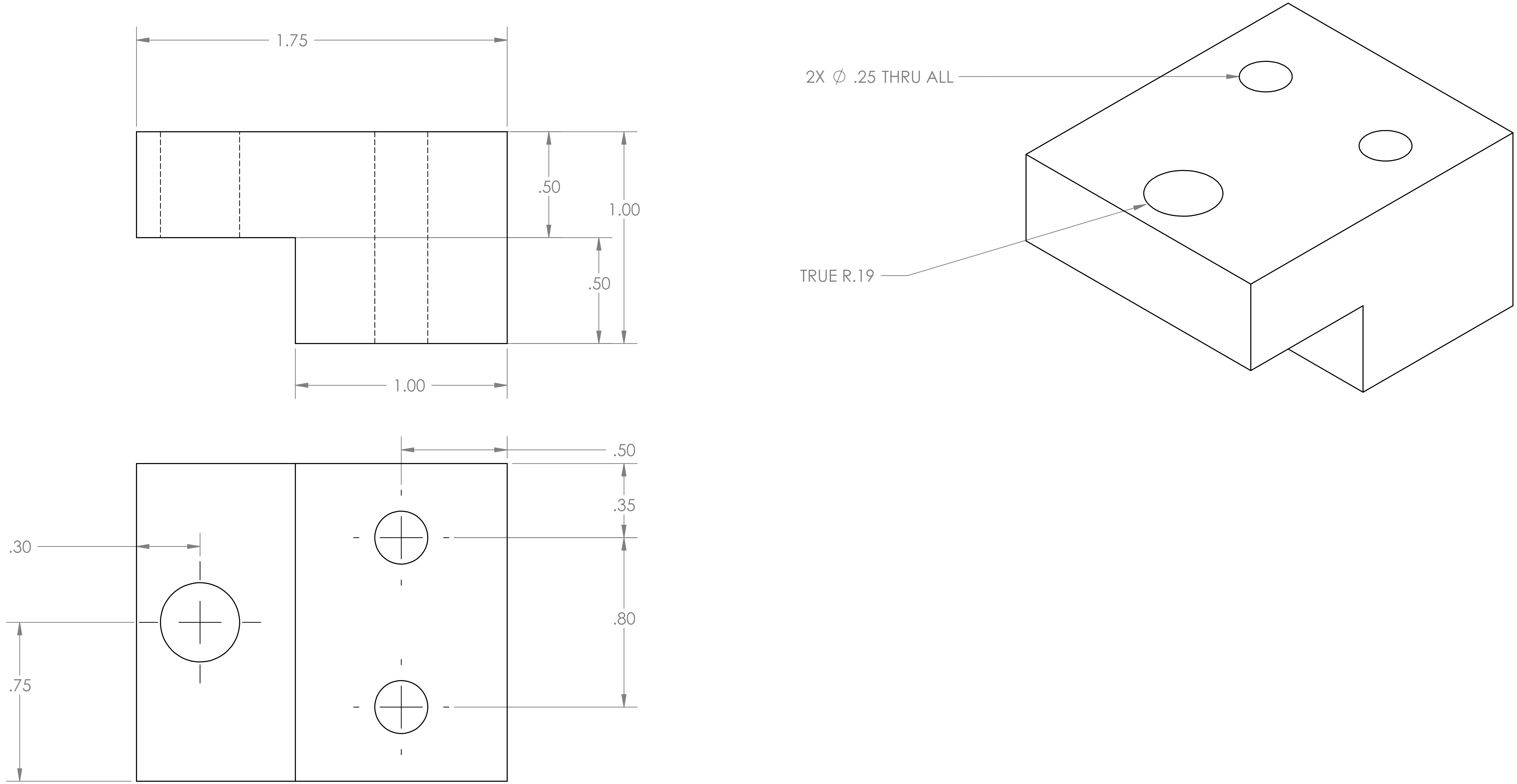
AVM OPTICAL

TITLE:

Inside Plate

SIZE **B** DWG. NO. REV

SCALE: 1:4 WEIGHT: SHEET 1 OF 1




AVM OPTICAL

**PROPRIETARY AND CONFIDENTIAL**



| | |
|---|---|
| NEXT ASSY | USED ON |
| APPLICATION | |

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ± 0°30'
ONE PLACE DECIMAL +- 0.5
TWO PLACE DECIMAL +-.15

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL

FINISH

DO NOT SCALE DRAWING

| | NAME | DATE |
|---|---|---|
| DRAWN | | |
| CHECKED | | |
| ENG APPR. | | |
| MFG APPR. | | |
| Q.A. | | |

COMMENTS:

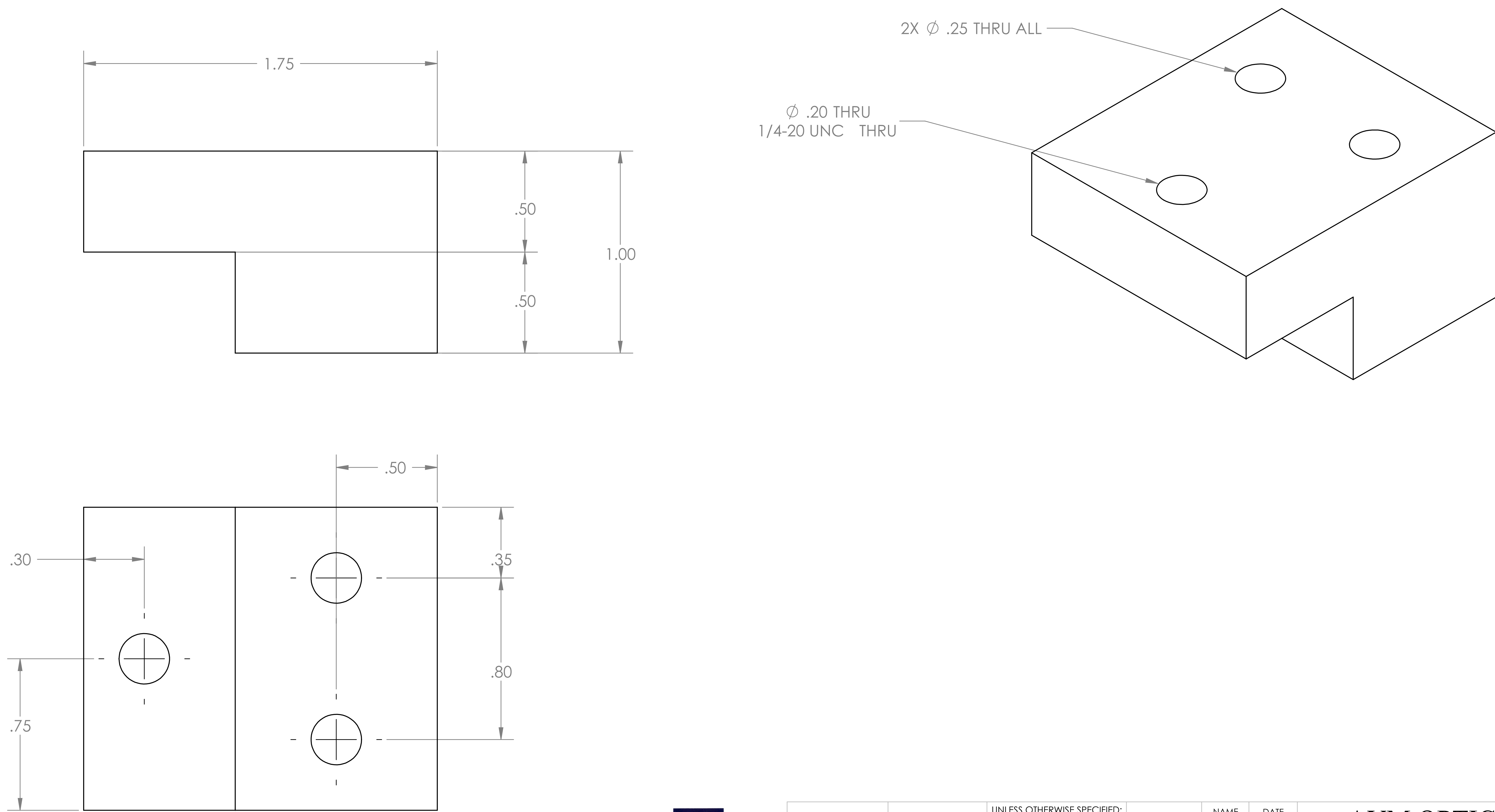
# AVM OPTICAL

TITLE:

## Adj Block

| SIZE | DWG. NO. | REV |
|---|---|---|
| **B** | | |

SCALE: 2:1 | WEIGHT: | SHEET 1 OF 1

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| | |
|---|---|
| NEXT ASSY | USED ON |
| APPLICATION | |

UNLESS OTHERWISE SPECIFIED:

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TOLERANCES:
ANGULAR: MACH ± 0°30'
ONE PLACE DECIMAL +- 0.5
TWO PLACE DECIMAL +-.15

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL

FINISH

DO NOT SCALE DRAWING

| | NAME | DATE |
|---|---|---|
| DRAWN | | |
| CHECKED | | |
| ENG APPR. | | |
| MFG APPR. | | |
| Q.A. | | |

COMMENTS:

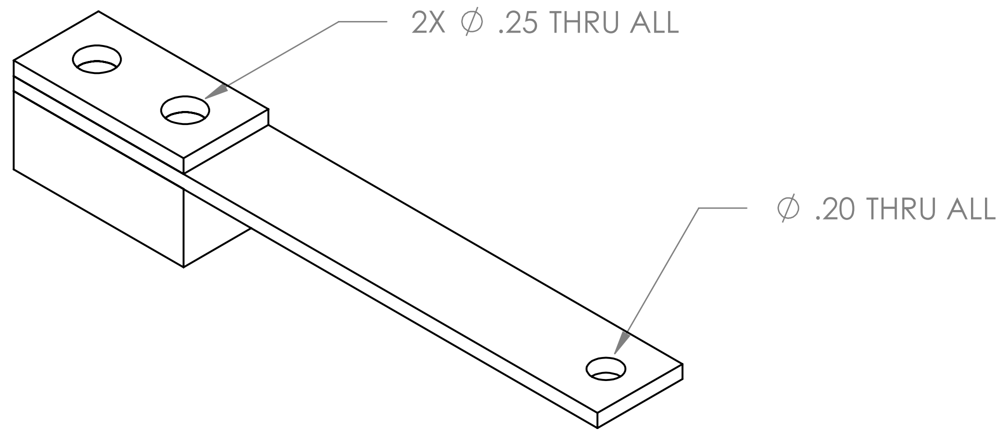
AVM OPTICAL

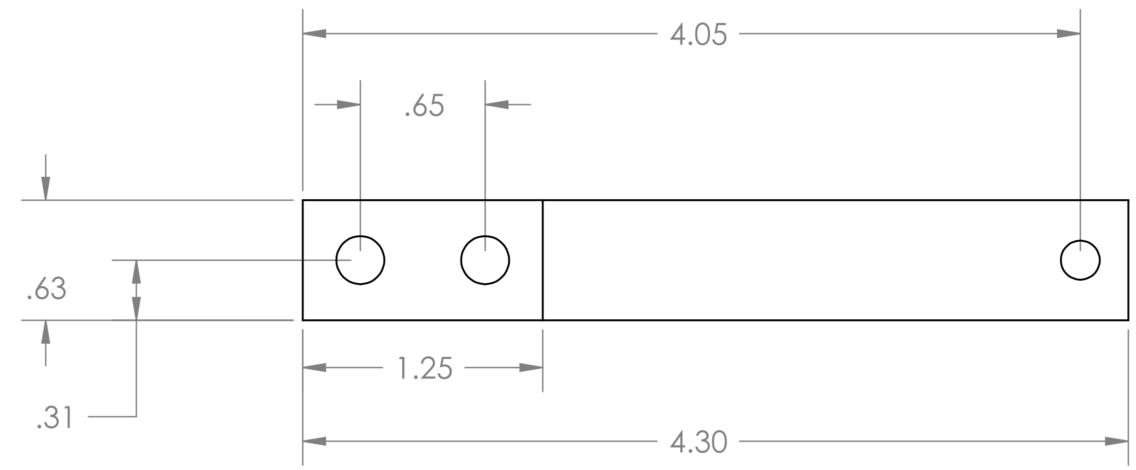
TITLE:

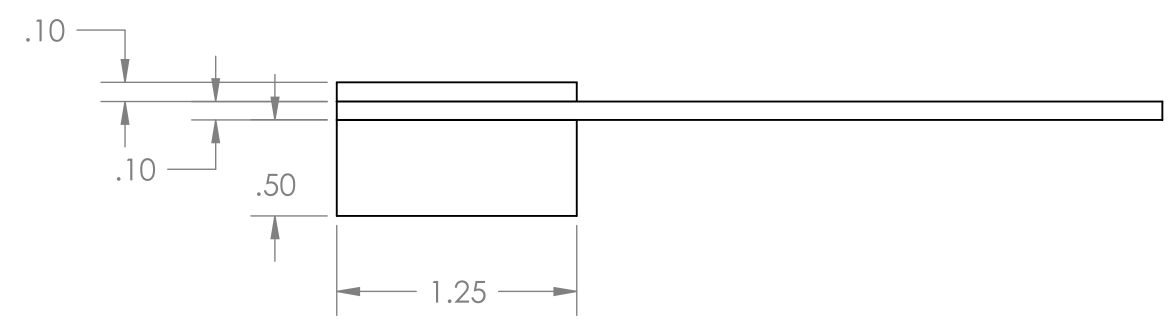
Lock Block

| SIZE | DWG. NO. | REV |
|---|---|---|
| B | | |

SCALE: 2:1 WEIGHT: SHEET 1 OF 1




AVM OPTICAL

**PROPRIETARY AND CONFIDENTIAL**



| NEXT ASSY | USED ON |
|---|---|
| APPLICATION | |

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ± 0°30'
ONE PLACE DECIMAL +- 0.5
TWO PLACE DECIMAL +-.15

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL

FINISH

DO NOT SCALE DRAWING

| | NAME | DATE |
|---|---|---|
| DRAWN | | |
| CHECKED | | |
| ENG APPR. | | |
| MFG APPR. | | |
| Q.A. | | |

COMMENTS:

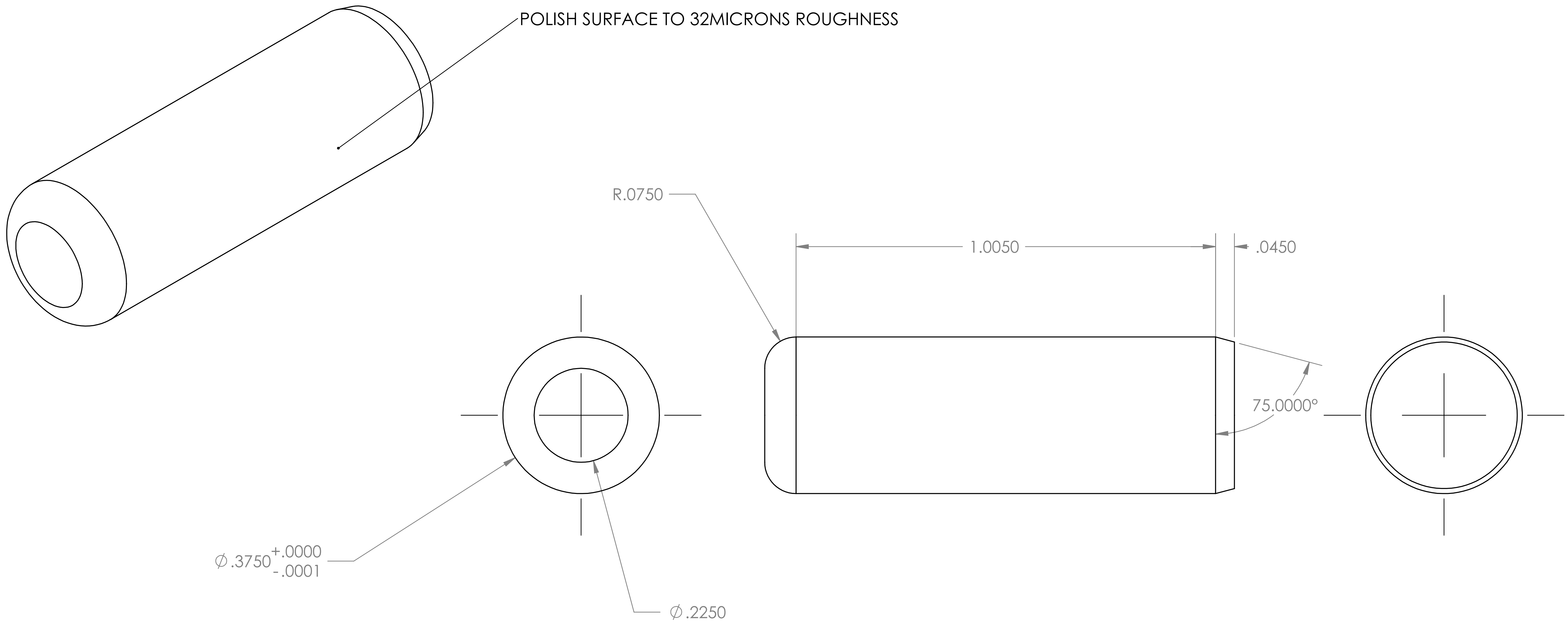
AVM OPTICAL

TITLE:

# Preload Flexure

SIZE **B** DWG. NO. REV

SCALE: 1:1 WEIGHT: SHEET 1 OF 1




PROPRIETARY AND CONFIDENTIAL



NEXT ASSY | USED ON

APPLICATION

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ± 0.001°
3 PLACE DECIMAL +- 0.005
4 PLACE DECIMAL +-.0015

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL

FINISH

DO NOT SCALE DRAWING

| | NAME | DATE |
|---|---|---|
| DRAWN | | |
| CHECKED | | |
| ENG APPR. | | |
| MFG APPR. | | |
| Q.A. | | |

COMMENTS:

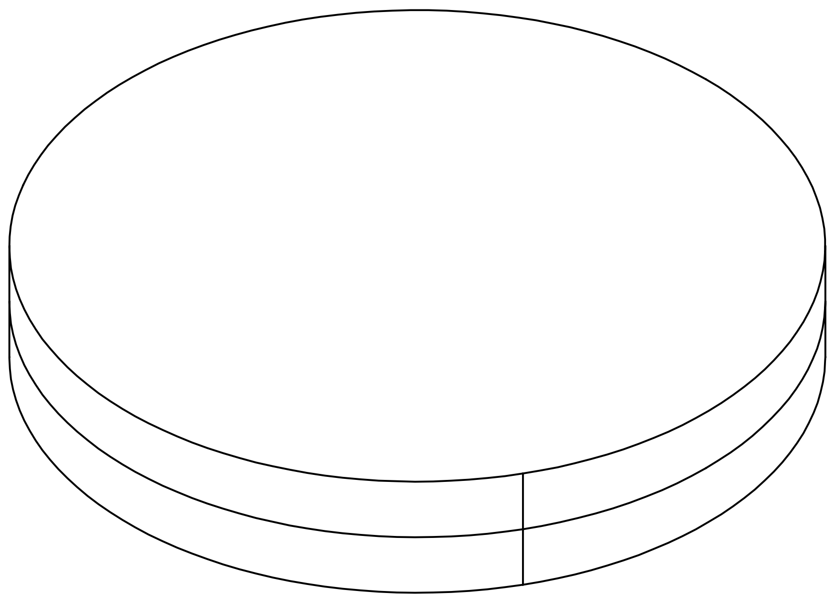
AVM OPTICAL

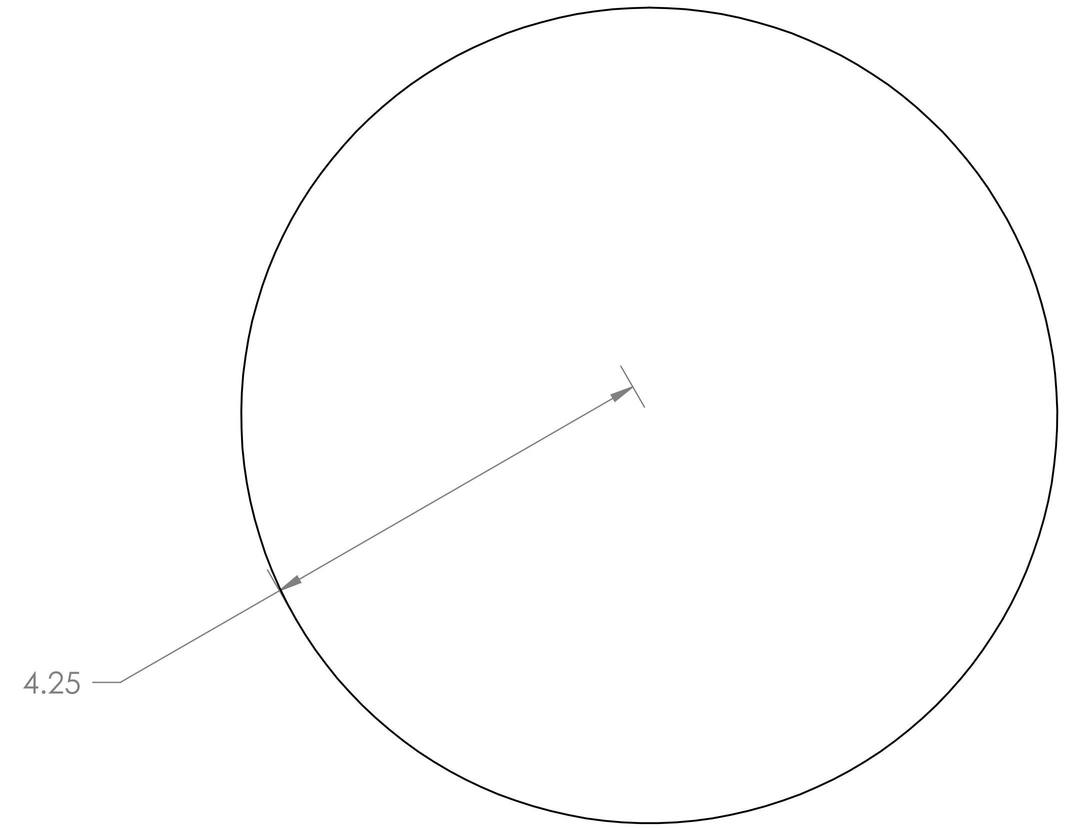
TITLE:

# Pin

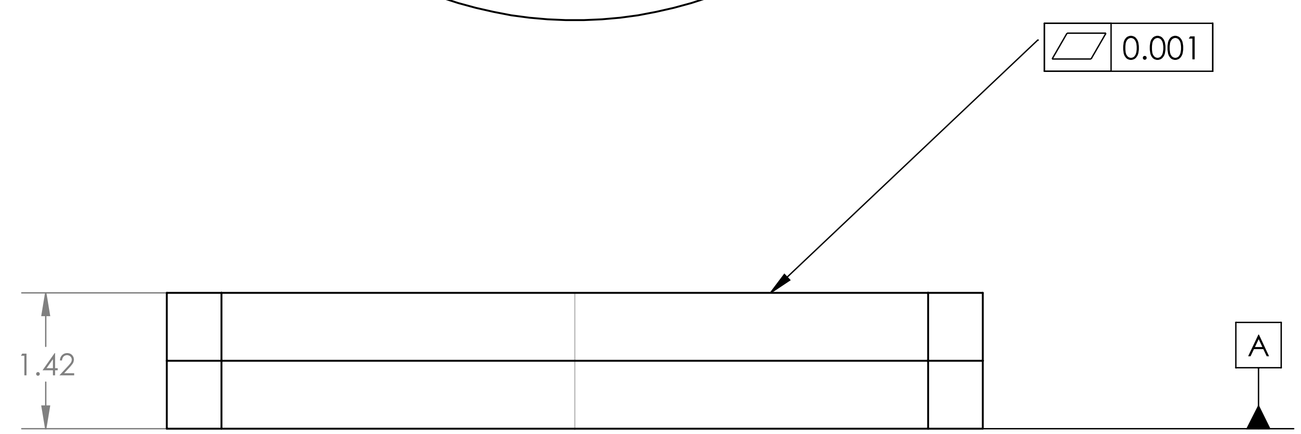
SIZE **B** DWG. NO. REV

SCALE: 4:1 WEIGHT: SHEET 1 OF 1






- PITCH POLISH SURFACE TO 20ANG
- COAT WITH MELLES GRIOT COATING 003
- CA IS 95% OF DIAMETER




AVM OPTICAL

**PROPRIETARY AND CONFIDENTIAL**

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

| NEXT ASSY | USED ON |
|---|---|
| APPLICATION | |

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ± 0.001°
3 PLACE DECIMAL +- 0.005
4 PLACE DECIMAL +-.0015

INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5

MATERIAL

FINISH

DO NOT SCALE DRAWING

| | NAME | DATE |
|---|---|---|
| DRAWN | | |
| CHECKED | | |
| ENG APPR. | | |
| MFG APPR. | | |
| Q.A. | | |

COMMENTS:

# AVM OPTICAL

TITLE:

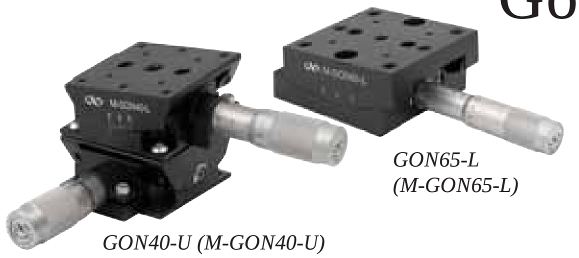
## Large Mirror

| SIZE | DWG. NO. | REV |
|---|---|---|
| **B** | | |

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

GON Series

# Goniometers



GON65-L
(M-GON65-L)

GON40-U (M-GON40-U)
GON40-L (M-GON40-L)

- Up to ±10° of rotation with secure locking mechanism
- Interchangable manual or motorized drives
- Stackable with common rotation point for two orthogonal axes
- Patented design (U.S. Patent 6,601,524)

Goniometers rotate an object about a point located over the center of the top platform and the rotation point is unobstructed by the goniometer itself. GON Series Goniometers utilize an actuator-driven precision dovetail slide. A precision adjustment screw, a micrometer, or a motorized actuator can drive them.

The GON40 Goniometers have ±5° of rotational motion when used with a 13 mm travel actuator. The GON65-U upper goniometer has ±10° of rotational motion when used with a 25 mm travel actuator, and ±5° of motion when used with a 13 mm travel actuator. The GON65-L lower goniometer has ±5° of motion when used with a 25 mm travel actuator, and ±3° of motion when used with a 13 mm travel actuator. The motion on both goniometers can be securely locked using a hex screw on the side of the goniometer.

## Specifications

| | GON40 (M-GON40) | GON65 (M-GON65) |
|---|---|---|
| Material | Aluminum, black anodized | Aluminum, black anodized |
| Graduations | 1 ° | 1 ° |
| Sensitivity* | Upper, 8 arc sec;<br>Lower, 5 arc sec | Upper, 3 arc sec;<br>Lower, 2 arc sec |
| Load Capacity, Horizontal [lb (N)] | 5 (22) | 10 (45) |

* Angular sensitivity calculated assuming actuator sensitivity is 1 μm

## Ordering Information

| Model (Metric) | Description | Dimensions [in. (mm)] | Height [in. (mm)] | Rotation Axis Height [in. (mm)] | Travel |
|---|---|---|---|---|---|
| GON40-U<br>(M-GON40-U) | Upper<br>Goniometer | 1.57 x 1.57<br>(40 x 40) | 0.79<br>(20) | 0.59<br>(15) | ±5° with 13 mm actuator* |
| GON40-L<br>(M-GON40-L) | Lower<br>Goniometer | 1.57 x 1.57<br>(40 x 40) | 0.79<br>(20) | 1.38<br>(35) | ±5° with 13 mm actuator* |
| GON65-U<br>(M-GON65-U) | Upper<br>Goniometer | 2.56 x 2.56<br>(65 x 65) | 1.18<br>(30) | 1.97<br>(50) | ±5° with 13 mm actuator*<br>±10° with 25 mm actuator* |
| GON65-L<br>(M-GON65-L) | Lower<br>Goniometer | 2.56 x 2.56<br>(65 x 65) | 1.18<br>(30) | 3.15<br>(80) | ±3° with 13 mm actuator*<br>±5° with 25 mm actuator* |

* Actuator sold separately
U.S. Patents 6,601,524

## Recommended Actuators

| Manual Drives | Description | GON40 (M-GON40) | GON65 (M-GON65) | Travel (mm) | Sensitivity (μm) |
|---|---|---|---|---|---|
| AJS100-0.5 | Fine Adjustment Screw | • | • | 12.7 | 0.70 |
| AJS100-1 | Fine Adjustment Screw | | • | 25.4 | 0.70 |
| AJS127-0.5 | Fine Adjustment Screw | • | • | 12.7 | 0.6 |
| SM-13 | Micrometer | • | • | 13 | 1 |
| SM-25 | Micrometer | | • | 25 | 1 |
| HR-13 | High-Resolution Micrometer | • | • | 13 | 0.5 |
| **Motorized Drives** | | | | | |
| CMA Series | Motorized Actuator | • | • | 12.5–25 | 0.2–0.5 |
| LTA Series | Motorized Actuator | • | • | 25 | 0.05 |
| PZA12 | NanoPZ actuator, 12.5 mm travel | • | • | | 0.03 |

## Related Products

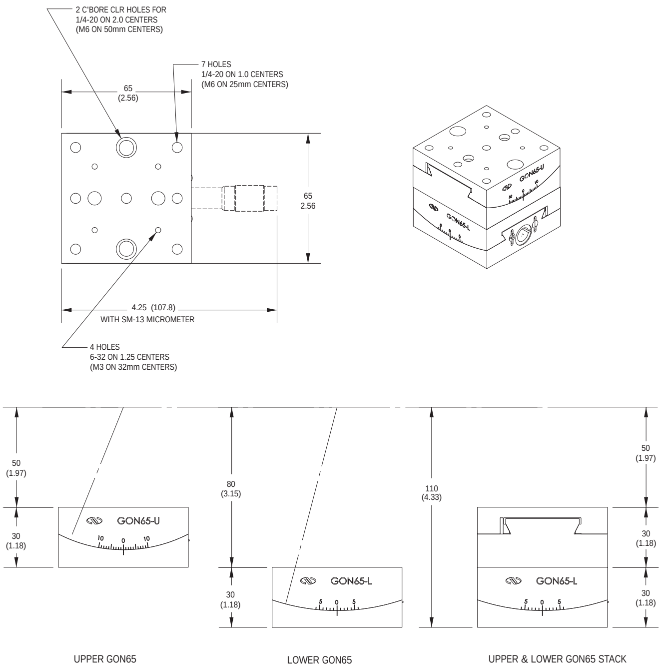
*Angle Brackets*

*SDS Linear Translation Stages (see page 881)*

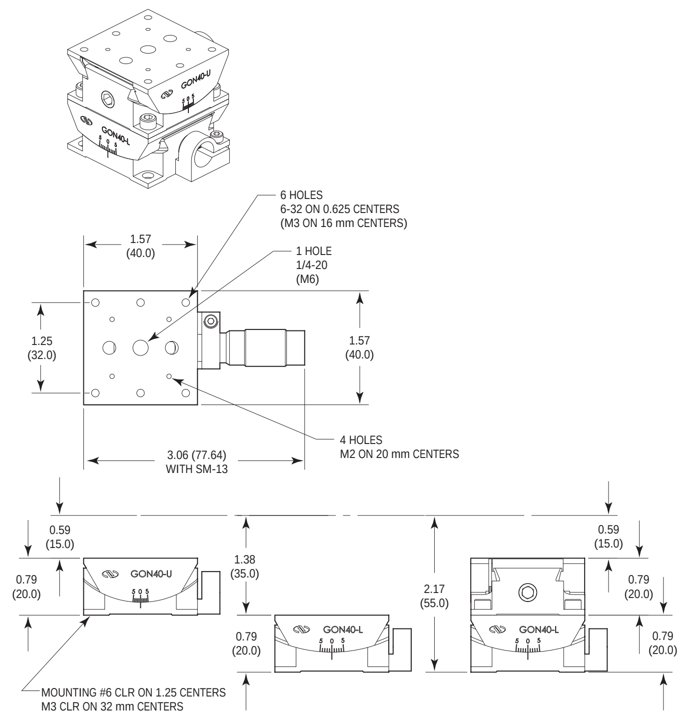
*RS40 with motorized GON40 stack using NanoPZ actuators*

CAD *See our website for CAD files*

## GON65 Series

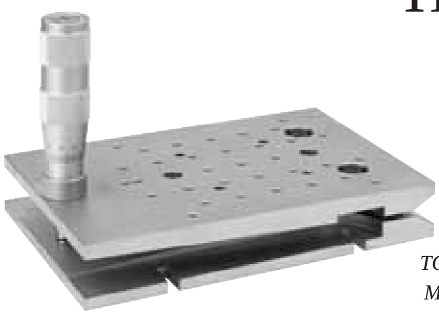



## GON40 Series




### TGN Series

# Tilt Platforms



*TGN80 (M-TGN80)*
*Micrometer included*

- Stainless steel construction
- Adjustment sensitivity to 1 arc sec
- ±2.86° adjustment range
- Load capacity to 176 lb (800 N)

For high-resolution alignment of components — especially large or heavy equipment — TGN Tilt Stages precisely control tilt for one rotational axis over a range of ±2.86°.

Mounting plates are fabricated from stainless steel for excellent rigidity and stability. The micrometer is preloaded for smooth, backlash-free motion. Adjustment sensitivity improves with larger size. The upper and lower surfaces are parallel when the micrometer reads 5.00.

Clearance holes in the top plate facilitate mounting of a wide range of components to the platform. TGN Series stages attach to tables and breadboards via clearance slots in the bottom plate.

## Specifications

| | TGN80 (M-TGN80) | TGN120 (M-TGN120) | TGN160 (M-TGN160) |
|---|---|---|---|
| Travel Range | ±2.86 ° | ±2.86 ° | ±2.86 ° |
| Resolution (arc sec) | 20.6 | 13.8 | 10.3 |
| Sensitivity (arc sec) | 2 | 1.5 | 1 |
| Max Centered Load [lb (N)] | 44 (200) | 101 (450) | 180 (800) |
| Weight [lb (kg)] | 2.6 (1.2) | 8.4 (3.8) | 18 (8) |

## Ordering Information

| Model (Metric) |
|---|
| TGN80 (M-TGN80) |
| TGN120 (M-TGN120) |
| TGN160 (M-TGN160) |

## Related Products

- UMR stages
- UTR stages
- MVN stages

CAD *See our website for CAD files*

## 360 Series

# Angle Brackets

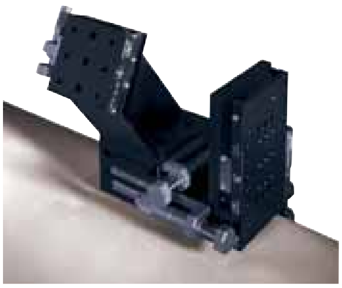

- Rigid, angled mounting brackets with slotted faces
- 30°, 45°, and 90° angle brackets
- Useful for building three-axis stage assemblies
- Orthogonal mounting platform for rod clamps

The 360 Series Angle Brackets are rigid, angled mounting plates with slotted faces. The 30, 45 and 90 degree angles are accurate to within ±2 arc min. Model 360-90 is useful for building 3-axis linear stage assemblies and as a platform with rod mounted components. Brackets may be combined to provide stable compound angle supports. Pairs of 360-30 or 360-45 brackets bolted together on hypotenuse faces provide coarse-adjustable height platforms of exceptional rigidity.

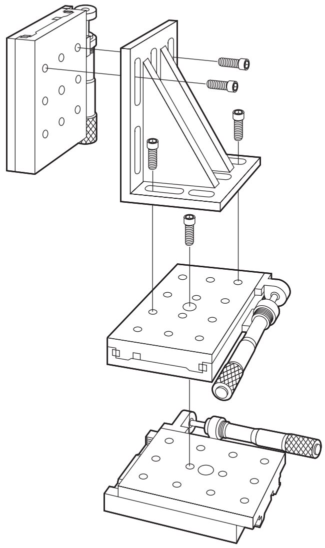
## Ordering Information

Availability – Guaranteed on select items @ newport.com

| Model (Metric) | Description |
|---|---|
| 360-30 | 30°/60° Angle Bracket |
| 360-45 | 45° Angle Bracket |
| 360-90 (M-360-90) | 90° Angle Bracket |

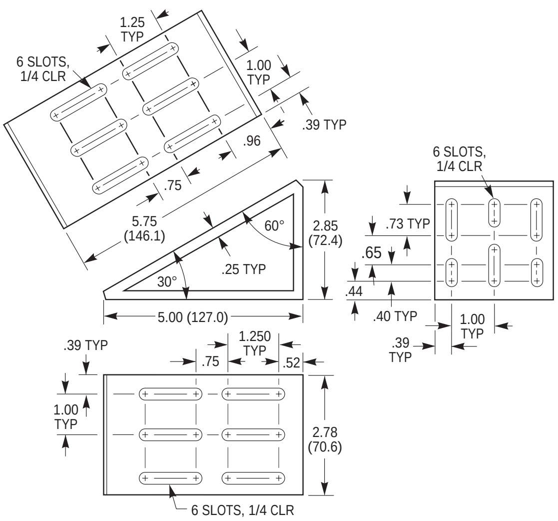


*OEM versions available.*

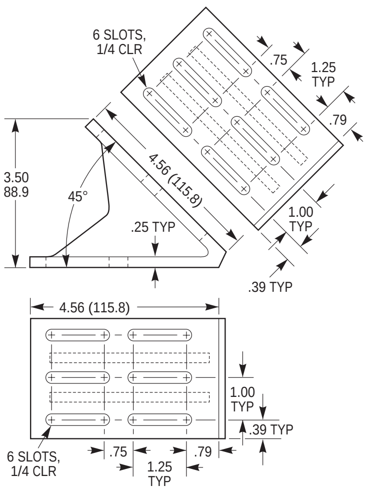


*Models 360-90 and 360-30 can be used to make long-travel XYZ stages using linear stages like our Models 423, 433, 443, 426 or 436.*

### Model 360-30

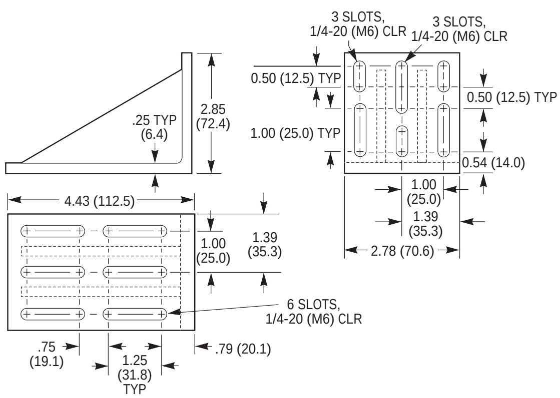



### Model 360-45




See our website for CAD files

### Model 360-90



AJS Series

# High-Precision Adjustment Screws

*AJS100-0.5*

*100 TPI Adjustment Screws* *AJS100-02H*

- Sub-micron sensitivity provided by 100 and 127 TPI screws
- Patented end lock that does not influence the screw position — a Newport exclusive
- Knobs with an integral hex hole allow increased sensitivity
- Please call us regarding custom OEM designs

AJS Series Adjustment Screws have precision rolled threads and proprietary lubrication for exceptionally smooth adjustment and higher sensitivity than standard micrometers. With sub-micron sensitivity, they are a cost-effective alternative to micrometers where position readout is not required. The standard 0.375 in. (9.5 mm) diameter collet allows them to be used with Newport optical mounts, stages, and most micrometer-compatible components. Our miniature series adjustment screws are ideal for OEM and custom mount applications and the 20 TPI coarse adjustment screws are useful for quick travel adjustment where high resolution is not required.

*AJS127-0.5H*

*127 TPI Adjustment Screws*

*AJS100-0.5K*

*AJS100-0.5H-NL*

*AJS100-0.5K-NL*

*100 TPI Adjustment Screws for Optical Mounts*

## Ordering Information

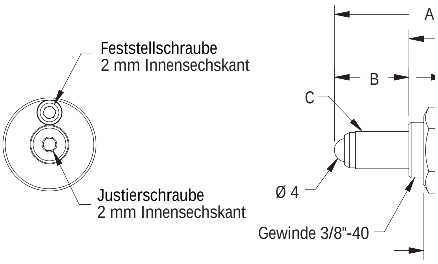
Availability – Guaranteed on select items @ newport.com

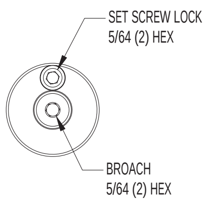
| Model | Thread | Drive | Lock | Travel [in. (mm)] | Sensitivity* (μm) | Load Capacity [lb (N)] |
|---|---|---|---|---|---|---|
| **127 TPI Adjustment Screws** | | | | | | |
| AJS127-02H | 1/4-127 (127 TPI) | Hex | End Lock | 0.25 (6.35) | 0.6 | 20 (90) |
| AJS127-0.5H | 1/4-127 (127 TPI) | Hex | End Lock | 0.5 (12.7) | 0.6 | 20 (90) |
| AJS127-0.5 | 1/4-127 (127 TPI) | Knob | Side Lock | 0.5 (12.7) | 0.6 | 20 (90) |
| **100 TPI Adjustment Screws** | | | | | | |
| AJS100-02H | 1/4-100 (100 TPI) | Hex | End Lock | 0.25 (6.35) | 0.7 | 20 (90) |
| AJS100-0.5H-NL | 1/4-100 (100 TPI) | Hex | No Lock | 0.5 (12.7) | 0.7 | 20 (90) |
| AJS100-0.5H | 1/4-100 (100 TPI) | Hex | End Lock | 0.5 (12.7) | 0.7 | 20 (90) |
| AJS100-0.5K-NL | 1/4-100 (100 TPI) | KD.75 Knob | No Lock | 0.5 (12.7) | 0.7 | 20 (90) |
| AJS100-0.5K | 1/4-100 (100 TPI) | KD.75 Knob | Side Lock | 0.5 (12.7) | 0.7 | 20 (90) |
| AJS100-0.5 | 1/4-100 (100 TPI) | Knob | Side Lock | 0.5 (12.7) | 0.7 | 20 (90) |
| AJS100-1H | 1/4-100 (100 TPI) | Hex | End Lock | 1.0 (25.4) | 0.7 | 20 (90) |
| AJS100-1 | 1/4-100 (100 TPI) | Knob | Side Lock | 1.0 (25.4) | 0.7 | 20 (90) |
| AJS100-2 | 1/4-100 (100 TPI) | Knob | Side Lock | 2.0 (50.8) | 0.7 | 20 (90) |
| **Miniature 100 TPI Adjustment Screws** | | | | | | |
| AJS8-100-02H | 8-100 (100 TPI) | Hex | Side Lock | 0.25 (6.35) | 0.7 | 10 (45) |
| AJS8-100-0.5H | 8-100 (100 TPI) | Hex | Side Lock | 0.5 (12.7) | 0.7 | 10 (45) |
| AJS8-100-0.5 | 8-100 (100 TPI) | Knob | Side Lock | 0.5 (12.7) | 0.7 | 10 (45) |
| AJS8-100-1 | 8-100 (100 TPI) | Knob | Side Lock | 1.0 (25.4) | 0.7 | 10 (45) |
| **20 TPI Adjustment Screws** | | | | | | |
| AJS20-0.5 | 1/4-20 (20 TPI) | Knob | Side Lock | 0.5 (12.7) | 4 | 20 (90) |
| AJS20-1 | 1/4-20 (20 TPI) | Knob | Side Lock | 1.0 (25.4) | 4 | 20 (90) |
| AJS20-2 | 1/4-20 (20 TPI) | Knob | Side Lock | 2.0 (50.8) | 4 | 20 (90) |
| **Accessories** | | | | | | |
| KD.37 | Small Knob | | | | | |
| KD.75 | Large Knob | | | | | |

* Sensitivity based on a 1° rotation of the adjustment screw

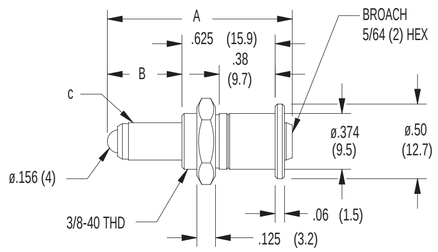
U.S. Patent 6,016,230

### Model AJS100-02H, -0.5H, -1H; AJS127-0.5H

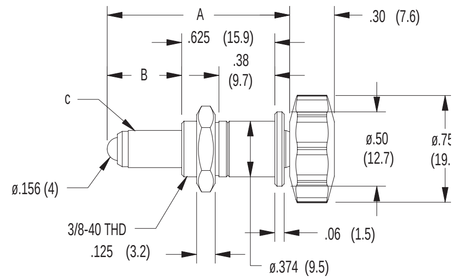


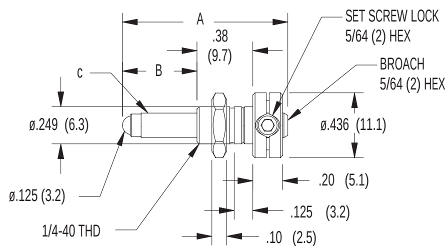

### Model AJS100-0.5H-NL



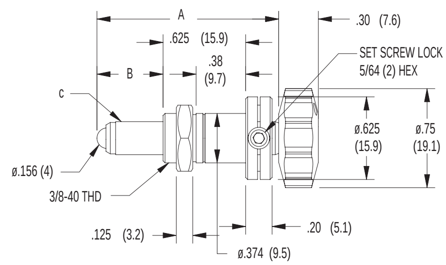

### Model AJS100-0.5K-NL



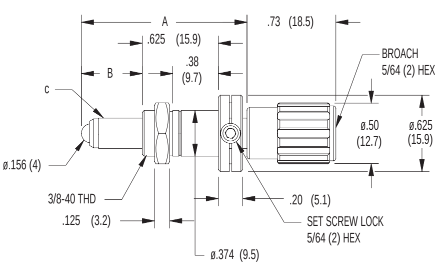

### Model AJS8-100-02H, -0.5H



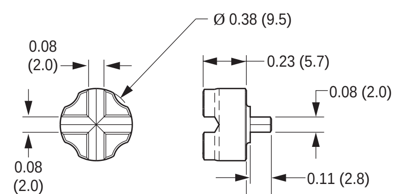

### Model AJS100-0.5K-NL



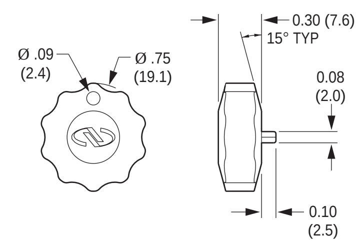

### Model AJS100-0.5, -1, -2; AJS127-0.5; AJS20-0.5, -1, -2




### Model KD.37



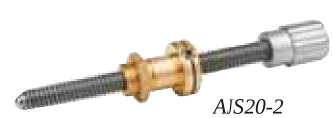

### Model KD.75




| | Dimensions [in. (mm)] | | Thread |
|---|---|---|---|
| Model | A | B | C |
| AJS127-02H | 1.23 (31.2) | 0.25 (6.4) | 1/4-127 (127 TPI) |
| AJS127-0.5H | 1.43 (36.3) | 0.50 (12.7) | 1/4-127 (127 TPI) |
| AJS127-0.5 | 1.41 (35.8) | 0.50 (12.7) | 1/4-127 (127 TPI) |
| AJS100-02H | 1.23 (31.2) | 0.25 (6.4) | 1/4-100 (100 TPI) |
| AJS100-0.5H-NL | 1.29 (32.8) | 0.5 (12.7) | 1/4-100 (100 TPI) |
| AJS100-0.5H | 1.43 (36.3) | 0.50 (12.7) | 1/4-100 (100 TPI) |
| AJS100-0.5K-NL | 1.27 (32.3) | 0.50 (12.7) | 1/4-100 (100 TPI) |
| AJS100-0.5K | 1.41 (35.8) | 0.50 (12.7) | 1/4-100 (100 TPI) |
| AJS100-0.5 | 1.41 (35.8) | 0.50 (12.7) | 1/4-100 (100 TPI) |
| AJS100-1H | 2.10 (53.3) | 1.00 (25.4) | 1/4-100 (100 TPI) |
| AJS100-1 | 2.10 (53.3) | 1.00 (25.4) | 1/4-100 (100 TPI) |
| AJS100-2 | 2.97 (75.4) | 2.00 (50.8) | 1/4-100 (100 TPI) |
| AJS8-100-02H | 0.88 (22.4) | 0.25 (6.4) | 8-100 (100 TPI) |
| AJS8-100-0.5H | 1.16 (29.5) | 0.50 (12.7) | 8-100 (100 TPI) |
| AJS8-100-0.5 | 1.16 (29.5) | 0.50 (12.7) | 8-100 (100 TPI) |
| AJS8-100-1 | 1.85 (47.0) | 1.00 (25.4) | 8-100 (100 TPI) |
| AJS20-0.5 | 1.41 (35.8) | 0.50 (12.7) | 1/4-20 (20 TPI) |
| AJS20-1 | 2.10 (53.3) | 1.00 (25.4) | 1/4-20 (20 TPI) |
| AJS20-2 | 2.97 (75.4) | 2.00 (50.8) | 1/4-20 (20 TPI) |

*AJS8-100-0.5H*

*100 TPI Miniature Adjustment Screws*



*AJS20-2*

*20 TPI Adjustment Screws*

*KD.37*

*KD.75*

*AJS8-100-0.5H*

*Knobs can be added to hex adjustment screws*

CAD *See our website for CAD files*

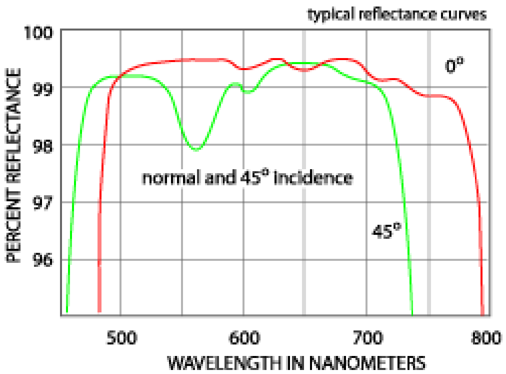
# High-Reflection Coatings

## MAXBRIte™ Coatings

MAXBRIte™ (multilayer all-dielectric xerophilous broadband reflecting interference) coatings are, without a doubt, the best broadband mirror coatings commercially available. The /001 coating covers the visible spectrum from 480 nm to 700 nm, the /003 is useful for diode laser applications from 630 nm to 850 nm, and the /009 coating offers enhanced blue response. They all reflect well over 98% of incident laser radiation within their respective wavelength ranges.

These coatings exhibit exceptionally high reflectances for both *s*- and *p*-polarizations. In each case, at the most important laser wavelengths and for angles of incidence as high as 45 degrees, the average of *s*- and *p*-reflectances exceeds 99%. For most applications, they are superior to metallic or enhanced metallic coatings.

### MAXBRIte™ Coating for 480 to 700nm (/001)

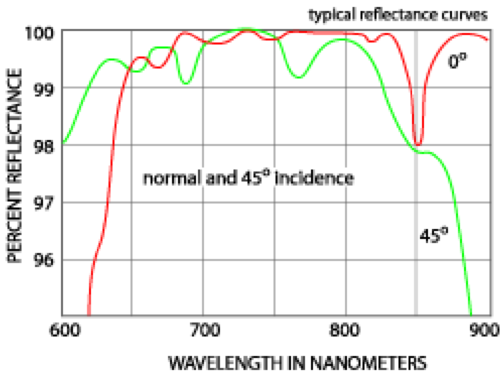



MAXBRIte™ /001 coating

- Exceptional reflectance for *s*- and *p*- polarization
- Excellent performance for common visible lines
- Suitable for external laser-beam manipulation and many instrument applications
- $R_{avg}$ > 98% from 480 to 700 nm
- Damage threshold: 0.92 J/cm$^2$± 10%, 10-nsec pulse (57 MW/cm$^2$) at 532 nm

The standard /001 coating is suitable for instrumental and external laser-beam manipulation tasks. It is the ideal choice for use with tunable dye and parametric oscillator systems. The structural design of this coating is such that flatness specifications as tight as l/10 can be maintained using low-expansion substrate materials.

### MAXBRIte™ coating for 630 to 850 nm (/003)

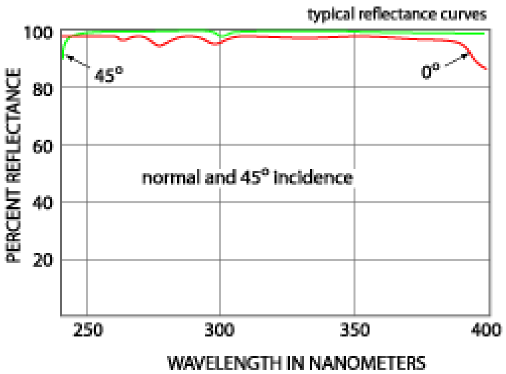


MAXBRIte™ /003 coating

- Useful with visible, near-infrared diode, and HeNe lasers Easily accommodates diode wavelength drift
- Ideal for pointing and alignment applications
- $R_{avg}$ > 98% from 630 to 850 nm
- Damage threshold: 0.92 J/cm$^2$± 10%, 10-nsec pulse (57 MW/cm$^2$) at 532 nm

The /003 coating covers all the important diode laser wavelengths from 630 to 850 nm; therefore, it can be used with both visible and near-infrared diode lasers. This broadband coating is ideal for applications employing nontemperature-stabilized diode lasers where wavelength drift is likely to occur. The /003 also makes it possible to use a HeNe laser to align diode systems.

### UV MAXBRIte™ coating for 245 to 390 nm (/007)

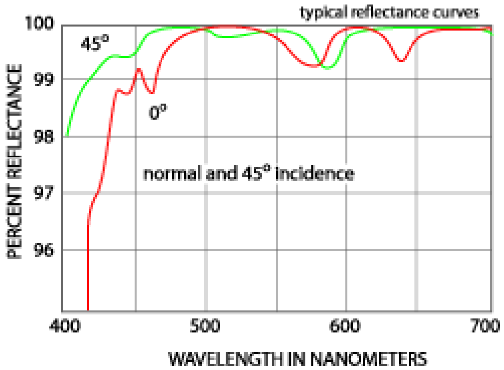


MAXBRIte™ /007 coating

- Excellent performance for excimer and YAG third- and fourth-harmonic lines, as well as broadband ultraviolet sources
- Superior reflectance from 0 to 45 degrees incidence for *s*- and *p*-polarizations
- $R_{avg}$ > 98% from 245 to 390 nm
- Damage threshold: 0.92 J/cm$^2$± 10%, 10-nsec pulse (57 MW/cm$^2$) at 532 nm

The /007 coating offers superior performance for ultraviolet applications. It is ideal for use with many of the excimer lasers, as well as the third and fourth harmonics of most solid-state lasers. It is also particularly useful with broadband ultraviolet light sources, such as mercury and xenon lamps. Due to mechanical stresses within this intricate coating, it is limited to substrates of l/4 figure or less.

### Extended MAXBRIte™ coating for 420 to 700 nm (/009)



MAXBRIte™ /009

- Wavelength range extended even farther than /001 MAXBRIte™
- Outstanding performance from 0 to 45 degrees incidence
- $R_{avg}$ > 98% from 420 to 700 nm
- Damage threshold: 0.4 J/cm$^2$± 10%, 10-nsec pulse (35 MW/cm$^2$) at 532 nm on silica substrate

The /009 extended-range coating offers superior response below 500 nm, and it is particularly useful for helium cadmium lasers at 442 nm, or the blue lines of argon-ion lasers. Like the /007, mechanical stresses in this complex coating limit its use to substrates of l/4 figure or less.

Because of the many applications for these superior coatings we stock a number of precoated substrates.

**MAXBRIte™ Coatings**

| Wavelength Range (nm) | Average Reflectance (%) | Angle of Incidence (degrees) | Damage Threshold | COATING SUFFIX |
|---|---|---|---|---|
| 480-700 | 98 | 0±45 | 0.92 J/cm$^2$ ± 10%, 10-nsec pulse (57 MW/cm$^2$) at 532 nm | /001 |
| 630-850 | 98 | 0±45 | 0.92 J/cm$^2$ ± 10%, 10-nsec pulse (57 MW/cm$^2$) at 532 nm | /003 |
| 245-390 | 98 | 0±45 | 0.92 J/cm$^2$ ± 10%, 10-nsec pulse (57 MW/cm$^2$) at 532 nm | /007 |
| 420-700 | 98 | 0±45 | 0.4 J/cm$^2$ ± 10%, 10-nsec pulse (35 MW/cm$^2$) at 532 nm on silica substrate | /009 |

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# Scotch-Weld™
## Epoxy Adhesives
### 2214 Regular • 2214 Hi-Dense • 2214 Hi-Flex • 2214 Hi-Temp 2214 Hi-Temp New Formula • 2214 Non-Metallic Filled

**Technical Data** **September, 1998**

(Supersedes March 1, 1992)

**Features**

- One part 250°F (121°C) curing 100% solids, paste consistency epoxy adhesives designed for bonding metals and many high temperature plastics such as fiberglass reinforced plastic, polyester, polysyphenylene sulfides and phenolics.
- 2214 Regular is an aluminum filled general purpose product for use in applications where high strength bonds are needed in a temperature range of -67°F to 250°F (-53°C to 121°C).
- 2214 Hi-Dense is a deaerated version of 2214 Regular for use where a very dense, void free bondline is required.
- 2214 Hi-Flex is an aluminum filled, deaerated product for use where increased shock resistance and peel strength is required.
- 2214 Hi-Temp and Hi-Temp New Formula are aluminum filled, deaerated products for use where higher strengths are required between 180°F to 350°F (82°C to 177°C).
- 2214 Non-Metallic Filled is a non-metal filled version of 2214 Regular.

**Typical Uncured Physical Properties**

Note: **The following technical information and data should be considered representative or typical only and should not be used for specification purposes.**

| | 2214 Regular | 2214 Hi-Dense | 2214 Hi-Flex | 2214 Hi-Temp | 2214 Hi-Temp New Formula | 2214 Non-Metallic Filled |
|---|---|---|---|---|---|---|
| **Viscosity (Approx.) time to deliver 20 grams @ 50 psi thru a .104" orifice (seconds)** | 130 | 130 | 150 | 25 | 160 | 100 |
| **Viscosity (Brookfield)** | Because of Thixotropic paste nature of these products Brookfield viscosity will be over 1,000,00 cps. | | | | | |
| **Color** | Gray | Gray | Gray | Gray | Gray | Cream |
| **Base** | Modified Epoxy | Modified Epoxy | Modified Epoxy | Modified Epoxy | Modified Epoxy | Modified Epoxy |
| **Net Weight (lbs/gal)** | 12.0 | 12.6 | 12.0 | 12.0 | 13.8 | 9.6 |

# Scotch-Weld™
## Epoxy Adhesives
2214 Regular • 2214 Hi-Dense • 2214 Hi-Flex • 2214 Hi-Temp • 2214 Hi-Temp New Formula • 2214 Non-Metallic Filled

### Typical Cured Physical Properties

**Note: The following technical information and data should be considered representative or typical only and should not be used for specification purposes.**

| | 2214 Regular | 2214 Hi-Dense | 2214 Hi-Flex | 2214 Hi-Temp | 2214 Hi-Temp New Formula | 2214 Non-Metallic Filled |
|---|---|---|---|---|---|---|
| **Color** | Gray | Gray | Gray | Gray | Gray Brown | Cream to Tan |
| **Shore D Hardness (Approx.)** | 85 | 85 | 81 | 88 | 85 | 85 |
| **Elongation (Approx. %)** | <2 | <2 | 3 | 1 | 1 | <2 |
| **Ultimate Tensile (Approx. psi)** | 10,000 | 10,000 | 5,800 | 8,000 | – | 9,000 |
| **Modulus Elasticity (Approx. psi)** | 750,000 | 750,000 | 460,000 | 800,000 | – | 700,000 |

### Typical Thermal Properties (Cured)

**Note: The following technical information and data should be considered representative or typical only and should not be used for specification purposes.**

| | Thermal Conductivity (BTU/HR/FT2/°F/FT) | Coefficient of Thermal Expanse (in./in./°C) |
|---|---|---|
| 2214 Regular | .231 | 49 x $10^{-6}$ (between 0-80°C) |
| 2214 Hi-Dense | .231 | 49 x $10^{-6}$ (between 0-80°C) |
| 2214 Hi-Flex | .193 | 80 x $10^{-6}$ (between 0-80°C) |
| 2214 Hi-Temp | .189 | 48 x $10^{-6}$ (between 0-80°C) |
| 2214 Hi-Temp New Formula | .244 | 44 x $10^{-6}$ (between -60 - +80°C) |
| | | |

### Typical Electrical Properties (Cured)

**Note: The following technical information and data should be considered representative or typical only and should not be used for specification purposes.**

Dielectric Constant (1) **ASTM-D-150**
Dissipation Factor (2) **ASTM-D-150**

| **Power Range 1.00 KC Test Temperature** | | **73°F (23°C)** | **140°F (60°C)** | **194°F (90°C)** | **219°F (104°C)** |
|---|---|---|---|---|---|
| 2214 Regular | (1)<br>(2) | 10.5<br>0.126 | 11.1<br>0.463 | 16.7<br>0.346 | 24.0<br>0.515 |
| 2214 Hi-Dense | (1)<br>(2) | 10.5<br>0.126 | 11.1<br>0.463 | 16.7<br>0.346 | 24.0<br>0.515 |
| 2214 Hi-Flex | (1)<br>(2) | 11.3<br>0.037 | 13.9<br>0.075 | –<br>– | –<br>– |
| 2214 Hi-Temp | (1)<br>(2) | 6.2<br>0.021 | 7.6<br>0.023 | 7.8<br>0.025 | 8.0<br>0.025 |
| 2214 Non-Metallic Filled | (1)<br>(2) | 4.61<br>0.0135 | 4.96<br>0.0148 | –<br>– | –<br>– |
| 2214 Hi-Temp New Formula | (1)<br>(2) | –<br>– | –<br>– | –<br>– | –<br>– |
| Arc Resistance<br>Dielectric Strength | ASTM-D-495-61<br>ASTM-D-149 | | Surface Resistivity<br>Volume Resistivity | ASTM-D-257<br>ASTM-D-257 | |

### Typical Electrical Properties (Cured) *[continued]*

| | ARC Resistance (Seconds) | Dielectric Strength (Volts Per Mil Thickness) | | Surface Resistivity (500 Volts-DC) | Volume Resistivity (500 Volts-DC) |
|---|---|---|---|---|---|
| | | Volts/Mil | Sample Thickness Inches | Ohms/Square 73°F (23°C) | Ohms-CM 73°F (23°C) |
| 2214 Regular | 76 | 77 | 0.0366 | $9.8 \times 10^{12}$ | $2.8 \times 10^{13}$ |
| 2214 Hi-Dense | 76 | 77 | 0.0366 | $9.8 \times 10^{12}$ | $2.8 \times 10^{13}$ |
| 2214 Hi-Flex | 32 | 83 | 0.042 | $1.2 \times 10^{15}$ | $2.8 \times 10^{13}$ |
| 2214 Hi-Temp | 119 | 347 | 0.038 | $1.1 \times 10^{17}$ | $9.4 \times 10^{14}$ |
| 2214 Non-Metallic | 26 | 570 | 0.039 | – | $2.5 \times 10^{13}$ |
| | | | | | |

### Handling/Curing Information

**Directions for Use**

1. Warm products to room temperature before opening containers to restore proper application consistency and to prevent moisture condensation on adhesive surface.
2. For high strength structural bonds, paint, oxide films, oils, dust, mold release agents and all other surface contaminants must be completely removed. However, the amount of surface preparation directly depends on the substrates, the required bond strength, environmental aging resistance, and requirements determined by the user in light of the user's particular purpose and method of application. For specific surface preparations on common substrates, see the following section on Surface Preparation.
3. Use gloves to minimize skin contact. Do not use solvents for cleaning hands.
4. For maximum bond strength apply product evenly to both surfaces to be joined.
5. Join the adhesive coated surfaces and heat cure using the following bondline temperature and time for the specific product being used.

   Any of the following cure cycles will result in a full cure.

   | | |
   |---|---|
   | 2214 Regular<br>2214 Hi-Dense<br>2214 Hi-Flex<br>2214 Hi-Temp<br>2214 Non-metallic filled | 40 min @ 250°F (121°C)<br>10 min @ 300°F (149°C)<br>5 min @ 350°F (177°C) |
   | 2214 Hi-Temp New Formula | 60 min @ 250°F (121°C)<br>15 min @ 300°F (149°C) |

6. Keep parts from moving during cure. Contact pressure is necessary.
7. Cleanup can be accomplished with solvent such as 3M™ Scotch-Grip™ Solvent No. 3 or Methyl Ethyl Ketone.*

***Note:** When using solvents, extinguish all ignition sources and follow manufacturer's precautions and directions for use.

**Surface Preparation**

The following cleaning methods are suggested for common surfaces:

**Steel:**

1. Wipe free of dust with oil-free solvent such as Methyl Ethyl Ketone or chlorinated solvents.*
2. Sandblast or abrade using clean fine grit abrasives.
3. Wipe again with solvent to remove loose particles.

**Aluminum:**

1. Vapor Degrease – Perchloroethylene* condensing vapors for 5-10 minutes.
2. Alkaline Degrease – Oakite 164 solution (9-11 oz./gallon water) at 190°F ± 10°F (87°C ± 5°C) for 10-20 minutes. Rinse immediately in large quantities of cold running water.
3. Acid Etch – Place panels in their following solution for 10 minutes at 150°F ± 5°F (66°C ± 2°C).

| | |
|---|---|
| Sodium Dichromate | 4.1-4.9 oz./gallon |
| Sulfuric Acid, 66°Be | 38.5-41.5 oz./gallon |
| 2024-T3 aluminum (dissolved) | 0.2 oz./gallon minimum |
| Tap Water | Balance of volume |

4. Rinse – Rinse panels in clear running tap water.
5. Dry – Air dry 15 minutes; force dry 10 minutes at 150°F ± 10°F (66°C ± 5°C).
6. If primer is to be used, it should be applied within 4 hours after surface preparation.

**Plastics:**

1. Solvent wipe with Isopropyl Alcohol.*
2. Abrade using clean fine grit abrasives.
3. Solvent wipe with Isopropyl Alcohol.*

**Rubbers:**

1. Solvent wipe with Methyl Ethyl Ketone.*
2. Abrade using clean fine grit abrasives.
3. Solvent wipe with Methyl Ethyl Ketone.*

**Glass:**

1. Solvent wipe with acetone or Methyl Ethyl Ketone.*

**Note:** For glass applications which will be subjected to high moisture/humidity conditions, EC-3901 primer should be used to prime the glass.

***Note:** When using solvents, extinguish all ignition sources and follow manufacturer's precautions and directions for use.

**Application/Equipment Information**

These products may be applied by spatula, trowel, or flow equipment.

Dispensing equipment is available for intermittent or production line use. These systems are ideal because of their variable shot size and flow rate characteristics and are adaptable to most applications. For more information, contact your local 3M sales representative.

## Equipment Suggestions

**Note:** Minimum pumping temperature is 65°F (18°C) for all products.

**2214 Regular Production Extrusion Equipment**

| Pump | Ram | Hose | Flow Gun |
|---|---|---|---|
| Ratio 55:1 with a chopping check valve and priming piston, 8 in. air motor. 3.7 cu. in./cycle | Pneumatic type capacity-12 psi on material surface | Super high pressure with standard lining | High pressure type |

**Output based on 1/4" tip flow gun (material temperature 65°F [18°C]) (minimum pumping temperature is 65°F [18°C])**

| Hose Assembly | Material Pressure (psi) | (Output lbs./min.) |
|---|---|---|
| Length-20', I.D.-1/2" | 4800* | .36 |
| Length-20', I.D.-3/4" | 4800* | 1.0 |

**2214 Non-Metallic Production Extrusion Equipment**

| Pump | Ram | Hose | Flow Gun |
|---|---|---|---|
| Ratio 38:1 with a chopping check valve and priming piston | Pneumatic type capacity-10 psi on material surface | Super high pressure with standard lining | High pressure type |

**Output based on 3/8" tip flow gun-8" diameter air motor (minimum pumping temperature is 65°F [18°C])**

| Hose Assembly | Material Pressure (psi) | (Output lbs./min.) |
|---|---|---|
| Length-10', I.D.-3/4" | 3000 | 2.3 |
| Length-20', I.D.-3/4" | 3000 | 1.6 |
| Length-20', I.D.-3/4" +10, I.D.-1/2" | 3000 | 1.2 |
| Length-20', I.D.-1/2" | 3000 | .84 |

**2214 Hi-Temp Production Extrusion Equipment**

| Pump | Ram | Hose | Flow Gun |
|---|---|---|---|
| Ratio 40:1 with a chopping check valve and priming piston, 6 in. air motor. 2 cu. in./cycle | Pneumatic type capacity-12 psi on material surface | Super high pressure with standard lining | High pressure type |

**Output based on 1/4" tip flow gun (material temperature 65°F [18°C])**

| Hose Assembly | Material Pressure (psi) | (Output lbs./min.) |
|---|---|---|
| Length-20', I.D.-1/2" | 2400 | .4 |

**2214 Hi-Flex Production Extrusion Equipment**

| Pump | Ram | Hose | Flow Gun |
|---|---|---|---|
| Ratio 50:1 with a chopping check valve and priming piston, 6 in. air motor. 1.6 cu. in./cycle | Pneumatic type capacity-12 psi on material surface | Super high pressure with standard lining | High pressure type |

**Output based on 1/4" tip flow gun (material temperature 65°F [18°C]) (minimum pumping temperature is 65°F [18°C])**

| Hose Assembly | Material Pressure (psi) | (Output lbs./min.) |
|---|---|---|
| Length-20', I.D.-1/2" | 4000* | .2 |
| Length-20', I.D.-3/4" | 4000* | .6 |

**Equipment Suggestions *(continued)***

### 2214 Hi-Dense Production Extrusion Equipment

| Pump | Ram | Hose | Flow Gun |
|---|---|---|---|
| Ratio 55:1 with a chopping check valve and priming piston, 8 in. air motor. 3.7 cu. in./cycle | Pneumatic type capacity-12 psi on material surface | Super high pressure with standard lining | High pressure type |

**Output based on 1/4" tip flow gun (material temperature 65°F [18°C]) (minimum pumping temperature is 65°F [18°C])**

| Hose Assembly | Material Pressure (psi) | (Output lbs./min.) |
|---|---|---|
| Length-20', I.D.-1/2" | 4500* | .45 |

### 2214 Hi-Temp New Formula Production Extrusion Equipment

| Pump | Ram | Hose | Flow Gun |
|---|---|---|---|
| Ratio 55:1 with a chopping check valve and priming piston, 8 in. air motor. 3.7 cu. in./cycle | Pneumatic type capacity-12 psi on material surface | Super high pressure with standard lining | High pressure type |

**Output based on 1/4" tip flow gun (material temperature 65°F [18°C]) (minimum pumping temperature is 65°F [18°C])**

| Hose Assembly | Material Pressure (psi) | (Output lbs./min.) |
|---|---|---|
| Length-20', I.D.-1/2" | 4800* | .36 |

*These pressures will require a special consideration during hose selection. They are actual working pressures.

**Typical Adhesive Performance Characteristics**

**Note: All of the following data was developed using a cure cycle of 40 minutes @ 250°F (121°C) under 25 psi pressure except 2214 Hi-Temp New Formula which was 60 minutes at 250°F (121°C).**

### A. Aluminum Overlap Shear

Overlap shear strength was measured on FPL etched 1" wide by 1/2" overlap specimens. The bonds were made from 2 panels of 4" x 7" x .063", 2024 T3 clad aluminum bonded together and cut into 1" wide specimens. The separation rate of the testing jaws was .1"/minute. Tests similar to ASTM D-1002. (All data in psi).

| Test Temperature | 2214 Regular | 2214 Hi-Dense | 2214 Hi-Flex | 2214 Hi-Temp | 2214 Hi-Temp New Formula | 2214 Non-Metallic Filled |
|---|---|---|---|---|---|---|
| -67°F (-53°C) | 3000 | 3000 | 2500 | 2000 | 2800 | 3000 |
| 75°F (24°C) | 4500 | 4500 | 4000 | 2000 | 2800 | 4000 |
| 180°F (82°C) | 4500 | 4500 | 2000 | 3000 | 2800 | 4500 |
| 250°F (121°C) | 1500 | 1700 | 450 | 2500 | 2500 | 1500 |
| 300°F (149°C) | 600 | 600 | 300 | 2500 | 2000 | 600 |
| 350°F (177°C) | 400 | 400 | 250 | 900 | 1200 | 400 |

## Typical Adhesive Performance Characteristics *(continued)*

### B. Aluminum T-Peel

T-Peel bonds were measured on 1" wide specimens cut from two FPL etched 8" x 8" x .032" 2024 T3 clad aluminum panels bonded together. The separation note of the testing jaws was 20"/minute. Tests similar to ASTM D-1876. (All data in lbs./in. of width.)

| Test Temperature | 2214 Regular | 2214 Hi-Dense | 2214 Hi-Flex | 2214 Hi-Temp | 2214 Hi-Temp New Formula | 2214 Non-Metallic Filled |
|---|---|---|---|---|---|---|
| 75°F (24°C) | 5 | 5 | 10 | 2 | 2 | 7 |

### C. Steel Overlap Shear

Overlap shear strength was measured on 1" wide by 1/2" overlap specimens. These bonds were made on 1" x 4" x .035" thick cold rolled steel which was MEK solvent wiped prior to bonding. The separation rate of the testing jaws was .1"/min. Tests similar to ASTM D-1002. (All data in psi.)

| Test Temperature | 2214 Regular | 2214 Hi-Dense | 2214 Hi-Flex | 2214 Hi-Temp | 2214 Hi-Temp New Formula | 2214 Non-Metallic Filled |
|---|---|---|---|---|---|---|
| -67°F (-53°C) | 3000 | 3000 | 3500 | 1650 | 2000 | 3000 |
| 75°F (24°C) | 2500 | 2500 | 2500 | 2400 | 2500 | 2200 |
| 180°F (82°C) | 2000 | 2000 | 2000 | 2000 | 2000 | 2000 |
| 250°F (121°C) | 800 | 800 | 250 | 2000 | 2000 | 400 |
| 300°F (149°C) | 200 | 200 | 150 | 2000 | 2000 | 200 |
| 350°F (177°C) | 100 | 100 | 125 | 500 | 700 | 100 |

### D. Steel T-Peel

T-Peel bonds were measured on two 1" wide x 8" long specimens bonded together. These bonds were made on MEK wiped .035" steel. After bonding they were then pulled apart in 180° Peel at a jaw separation rate of 20"/in. rate. Tests similar to ASTM D-1876. (All data in lbs./in. of width.)

| Test Temperature | 2214 Regular | 2214 Hi-Dense | 2214 Hi-Flex | 2214 Hi-Temp | 2214 Hi-Temp New Formula | 2214 Non-Metallic Filled |
|---|---|---|---|---|---|---|
| 75°F (24°C) | 50 | 50 | 65 | 5 | 5 | 12 |

## Environmental Resistance

Note: **The following data is overlap shear after aging for 365 days in the specified environment. Tests were run on FPL etched aluminum and solvent degreased, sandblasted .035" thick cold rolled steel. Bonds and tests similar to ASTM D-1002. (All data in psi.)**

| | 2214 Regular | 2214 Hi-Dense | 2214 Hi-Flex | | 2214 Hi-Temp | |
|---|---|---|---|---|---|---|
| | Aluminum | Steel | Aluminum | Steel | Aluminum | Steel |
| Tap Water @ 75°F (24°C) | 4630 | 1620 | 4610 | 1900 | 3060 | 1580 |
| 100% relative humidity @ 120°F (49°C) | 1900 | 1910 | 1500 | 1800 | 3120 | 2090 |
| Ethyl Gasoline @75°F (24°C) | 4690 | 2310 | 5370 | 2410 | 2620 | 1870 |

**Storage and Shelf Life**

Store products at 40°F (4°C) or below for maximum storage life. Higher temperatures reduce normal storage life. Rotate stock on a "first-in-first-out" basis. All of these products have a shelf life of 12 months when stored in their unopened containers @ 40°F (4°C) or below.

**CAUTION:** Products are heat sensitive. Storage above 130°F (54°C) may cause an exothermic reaction resulting in evolution of excessive heat, noxious fumes, and possibly fire.

**Precautionary Information**

Refer to Product Label and Material Safety Data Sheet for Health and Safety Information before using the product.

**For Additional Information**

To request additional product information or to arrange for sales assistance, call toll free 1-800-362-3550. Address correspondence to: 3M Adhesives Division, 3M Center, Building 220-7E-05, St. Paul, MN 55144-1000. Our fax number is 651-733-9175. In Canada, phone: 1-800-364-3577. In Puerto Rico, phone: 1-787-750-3000. In Mexico, phone: 5-270-2180.

**Important Notice**

3M MAKES NO WARRANTIES, EXPRESS OR IMPLIED, INCLUDING, BUT NOT LIMITED TO, ANY IMPLIED WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE. User is responsible for determining whether the 3M product is fit for a particular purpose and suitable for user's method of application. Please remember that many factors can affect the use and performance of a 3M Adhesives Division product in a particular application. The materials to be bonded with the product, the surface preparation of those materials, the product selected for use, the conditions in which the product is used, and the time and environmental conditions in which the product is expected to perform are among the many factors that can affect the use and performance of a 3M product. Given the variety of factors that can affect the use and performance of a 3M product, some of which are uniquely within the user's knowledge and control, it is essential that the user evaluate the 3M product to determine whether it is fit for a particular purpose and suitable for the user's method of application.

**Limitation of Remedies and Liability**

If the 3M product is proved to be defective, THE EXCLUSIVE REMEDY, AT 3M'S OPTION, SHALL BE TO REFUND THE PURCHASE PRICE OF OR TO REPAIR OR REPLACE THE DEFECTIVE 3M PRODUCT. 3M shall not otherwise be liable for loss or damages, whether direct, indirect, special, incidental, or consequential, regardless of the legal theory asserted, including negligence, warranty, or strict liability.

ISO 9002

This Adhesives Division product was manufactured under a 3M quality system registered to ISO 9002 standards.

**For Additional Product Safety and Health Information,** See Material Safety Data Sheet, or call:

3M

**Adhesives Division**

3M Center, Building 220-7E-05
St. Paul, MN 55144-1000
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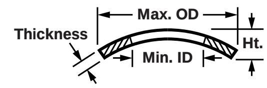
**TABLE 3.26**
**Typical Mechanical Characteristics of Representative Structural Adhesives**

| Material (Mfr. code)[a] | Recommended curing time at °C | Uncured Viscosity (cP) | Shear strength MPa (lb/in.$^2$) at °C | Temperature Range of Use (°C; °F) | CTE ($\alpha$) ($\times10^{-6}$/°C; $\times10^{-6}$/°F) | Joint Thickness (mm; in.) | Young's modulus $E$ (MPa; lb/in.$^2$) | Poisson's Ratio $\nu$ |
|---|---|---|---|---|---|---|---|---|
| **One-Part Epoxies** | | | | | | | | |
| 2214<br>Regular<br>Gray (3M) | 60 min at 121 | Thixotropic paste (aluminum filled) | 20.7 (3,000) at −55<br>31.0 (4,500) at 24<br>31.0 (4,500) at 82<br>10.3 (1,500) at 121<br>2.7 (400) at 177 | −53 to 121<br>(−67 to 250) | 49 (27)<br>at 0–80°C | | ~5170<br>(~7.5 × $10^5$) | |
| **Two-Part Epoxies** | | | | | | | | |
| Milbond<br><br>1:1 (bywt)<br>mix ratio (SO) | 3 h at 71<br><br>7 d at 25 | | 17.7 (2,561) at −50<br>14.5 (2,099) at 25<br>6.8 (992) at 70 | −54 to 70<br>(−65 to 158) | 62 at −54 to 20<br>72 at 20 to 70 | 0.381 ± 0.025<br>(0.015 ± 0.001) | 592 (8.6 × $10^4$)<br>at −50°C<br>158 (2.3 × $10^4$)<br>at 20°C | |
| 2216 B/A<br>Gray<br>2:3 (by vol.)<br>mix ratio (3M) | 30 min at 93<br>2 h at 66<br>7 d at 24 | ~80,000 | 13.8 (2,000) at −55<br>17.2 (2,500) at 24<br>2.7 (400) at 82<br>1.3 (200) at 121 | −55 to 150<br>(−67 to 302) | 102 (57) at 0 to 40°C<br>134 (74) at 40 to 80°C | 0.102 ± 0.025<br>(0.004 ± 0.001) | ~689<br>(~1.0 × $10^5$) | ~0.43 |
| 2216 B/A<br>Translucent<br>1:1 (by vol.)<br>mix ratio (3M) | 60 min at 93<br>4 h at 66<br>30 d at 24 | ~10,000 | 20.7 (3,000) at −55<br>13.8 (2,000) at 24<br>1.4 (200) at 82<br>0.7 (100) at 121 | −55 to 150<br>(−67 to 302) | 81 (45) at –50 to 30°C<br>207 (115) at 60 to 150°C | 0.102 ± 0.025<br>(0.004 ± 0.001) | (~6.9 × $10^4$)<br>(~1.0 × $10^5$) | ~0.43 |
| **Urethanes** | | | | | | | | |
| 3532 B/A<br>Brown<br>1:1 (by vol.)<br>mix ratio (3M) | 24 h at 24 | 30,000 | 13.8 (2,000) at −40<br>13.8 (2,000) at 24<br>2.1 (300) at 82 | | ~0.127 (~0.005) | | | |
| U-05FL off-white<br>2:1 (by vol.)<br>mix ratio (L) | 24 h at 25<br>& 50% RH | | 5.2 (7.50) at 25 | | | 0.076 to 0.229<br>(0.003 to 0.009) | | |

## Curved Disc Springs CAD

Curved disc springs are excellent for light loads in small spaces. Often used to reduce axial end play, they exert relatively light thrust loads. They're designed to fit standard rod and hole sizes. Package quantity is 10, unless noted.



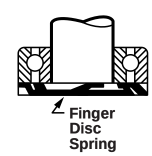

| Fits Hole Size | Fits Rod Size | Min. ID | Max. OD | Thickness | Ht. | High-Carbon Steel Defl. @ Load | Load, lbs. | | Per Pkg. | Type 301 Stainless Steel Defl. @ Load | Load, lbs. | | Per Pkg. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ¼″ | #5 | 0.135″ | 0.245″ | 0.0040″ | 0.049″ | 0.018″ | 0.80 | 9715K22 | $7.41 | 0.026″ | 1.00 | 9716K31 | $7.70 |
| 11/32″ | #8 | 0.174″ | 0.322″ | 0.0050″ | 0.064″ | 0.024″ | 1.21 | 9715K34 | 7.57 | 0.034″ | 1.50 | 9716K36 | 7.70 |
| ⅜″ | #8 | 0.174″ | 0.370″ | 0.0113″ | 0.039″ | 0.024″ | 9.00 | 9715K37 | 9.00 | 0.024″ | 9.00 | 9716K72 | 8.12 |
| 11/32″ | #10 | 0.203″ | 0.322″ | 0.0050″ | 0.053″ | 0.026″ | 1.12 | 9715K38 | 9.00 | 0.026″ | 1.12 | 9716K73 | 8.39 |
| ⅜″ | #10 | 0.200″ | 0.370″ | 0.0090″ | 0.047″ | 0.015″ | 3.45 | 9715K24 | 8.68 | 0.028″ | 4.50 | 9716K41 | 8.97 |
| 7/16″ | #10 | 0.200″ | 0.423″ | 0.0113″ | 0.047″ | 0.027″ | 9.00 | 9715K43 | 9.03 | 0.027″ | 9.00 | 9716K42 | 9.16 |
| 7/16″ | ¼″ | 0.269″ | 0.423″ | 0.0065″ | 0.070″ | 0.025″ | 1.39 | 9715K25 | 9.22 | 0.037″ | 1.75 | 9716K45 | 9.23 |
| 7/16″ | ¼″ | 0.269″ | 0.423″ | 0.0082″ | 0.055″ | 0.019″ | 2.50 | 9715K26 | 9.22 | 0.032″ | 2.50 | 9716K46 | 9.38 |
| ½″ | ¼″ | 0.265″ | 0.490″ | 0.0075″ | 0.091″ | 0.033″ | 2.50 | 9715K27 | 9.68 | 0.046″ | 3.50 | 9716K62 | 9.45 |
| ½″ | ¼″ | 0.265″ | 0.490″ | 0.0110″ | 0.063″ | 0.034″ | 7.00 | 9715K53 | 9.27 | 0.034″ | 7.00 | 9716K77 | 8.62 |
| 9/16″ | ¼″ | 0.265″ | 0.551″ | 0.0145″ | 0.060″ | 0.034″ | 14.00 | 9715K54 | 9.57 | 0.018″ | 8.66 | 9716K78 | 9.50 |
| 9/16″ | ¼″ | 0.265″ | 0.551″ | 0.0185″ | 0.052″ | 0.037″ | 21.00 | 9715K55 | 9.59 | 0.034″ | 21.00 | 9716K47 | 9.75 |
| ½″ | 5/16″ | 0.331″ | 0.490″ | 0.0075″ | 0.077″ | 0.028″ | 1.66 | 9715K48 | 9.38 | 0.041″ | 2.25 | 9716K95 | 8.74 |
| ⅝″ | 5/16″ | 0.327″ | 0.612″ | 0.0130″ | 0.077″ | 0.042″ | 9.00 | 9715K62 | 9.11 | 0.042″ | 9.00 | 9716K48 | 8.74 |
| ⅝″ | ⅜″ | 0.400″ | 0.612″ | 0.0090″ | 0.098″ | 0.036″ | 2.41 | 9715K29 | 9.83 | 0.056″ | 3.00 | 9716K51 | 9.00 |
| ⅝″ | ⅜″ | 0.400″ | 0.612″ | 0.0130″ | 0.074″ | 0.043″ | 6.00 | 9715K68 | 9.67 | 0.024″ | 4.65 | 9716K82 | 10.05 |
| 11/16″ | ⅜″ | 0.400″ | 0.672″ | 0.0100″ | 0.115″ | 0.042″ | 3.52 | 9715K49 | 10.17 | 0.059″ | 4.50 | 9716K79 | 9.50 |
| ¾″ | ⅜″ | 0.395″ | 0.735″ | 0.0110″ | 0.129″ | 0.073″ | 6.00 | 9715K72 | 10.30 | 0.073″ | 6.00 | 9716K52 | 9.50 |
| ¾″ | ⅜″ | 0.395″ | 0.735″ | 0.0160″ | 0.086″ | 0.050″ | 12.00 | 9715K73 | 10.30 | 0.050″ | 12.00 | 9716K53 | 9.53 |
| 13/16″ | ½″ | 0.531″ | 0.795″ | 0.0113″ | 0.129″ | 0.069″ | 5.00 | 9715K79 | 10.40 | 0.047″ | 3.43 | 9716K84 | 10.04 |
| 13/16″ | ½″ | 0.531″ | 0.795″ | 0.0170″ | 0.098″ | 0.054″ | 10.00 | 9715K81 | 10.42 | 0.032″ | 8.05 | 9716K85 | 10.00 |
| 1″ | ½″ | 0.525″ | 0.980″ | 0.0140″ | 0.164″ | 0.083″ | 10.00 | 9715K82 | 10.42 | 0.060″ | 6.91 | 9716K86 | 10.51 |
| 1″ | ½″ | 0.525″ | 0.980″ | 0.0180″ | 0.131″ | 0.073″ | 15.00 | 9715K83 | 10.42 | 0.045″ | 11.06 | 9716K87 | 10.48 |
| 1″ | ½″ | 0.525″ | 0.980″ | 0.0210″ | 0.110″ | 0.063″ | 20.00 | 9715K84 | 10.64 | 0.063″ | 20.00 | 9716K88★ | 7.96 |
| 1¼″ | ½″ | 0.525″ | 1.225″ | 0.0210″ | 0.151″ | 0.085″ | 25.00 | 9715K85 | 10.64 | 0.052″ | 18.05 | 9716K89★ | 8.38 |
| 1″ | ⅝″ | 0.663″ | 0.980″ | 0.0140″ | 0.169″ | 0.092″ | 7.00 | 9715K88 | 10.64 | 0.062″ | 5.62 | 9716K92★ | 8.45 |
| 1″ | ⅝″ | 0.663″ | 0.980″ | 0.0210″ | 0.118″ | 0.067″ | 14.00 | 9715K89 | 10.67 | 0.039″ | 11.87 | 9716K93★ | 8.78 |
| 1⅛″ | ¾″ | 0.800″ | 1.103″ | 0.0160″ | 0.185″ | 0.098″ | 8.00 | 9715K91 | 10.64 | 0.068″ | 7.00 | 9716K94★ | 8.90 |
| 1⅛″ | ¾″ | 0.800″ | 1.103″ | 0.0210″ | 0.138″ | 0.069″ | 12.00 | 9715K92 | 10.64 | 0.069″ | 12.00 | 9716K96★ | 9.14 |

★ Package quantity is 5.

## High-Carbon Steel Finger Disc Springs CAD

Finger springs combine the flexibility of disc springs and the axial-load strength of wave springs. They're designed to absorb vibration and reduce noise, end play, and skidding wear on parts rotating at high speed. Made from Grade 1074 high-carbon steel. All have six 0.125″ high "fingers", unless noted. Package quantity is 10.





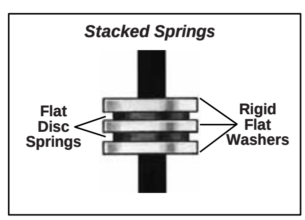

| For Bearing Trade No. | Bearing OD | Min. ID | Max. OD | Thickness | Defl. @ Load | Load, lbs. | | Per Pkg. |
|---|---|---|---|---|---|---|---|---|
| R4, 625, 634 | 0.630″ | 0.312″ | 0.595″ | 0.010″ | 0.062″ | 1 | 9717K51■ | $12.44 |
| 626, 635, R4A | 0.748″ | 0.344″ | 0.728″ | 0.006″ | 0.062″ | 8 | 9717K52 | 12.60 |
| 608, 627, 636 | 0.866″ | 0.453″ | 0.846″ | 0.006″ | 0.062″ | 7 | 9717K53 | 10.42 |
| 608, 627, 636 | 0.866″ | 0.453″ | 0.846″ | 0.008″ | 0.062″ | 14 | 9717K54 | 9.97 |
| 629, 6000 | 1.024″ | 0.516″ | 1.004″ | 0.006″ | 0.062″ | 10 | 9717K57 | 10.36 |
| 629, 6000 | 1.024″ | 0.516″ | 1.004″ | 0.007″ | 0.062″ | 13 | 9717K58 | 10.72 |
| 2000, 6903 | 1.181″ | 0.688″ | 1.164″ | 0.009″ | 0.062″ | 14 | 9717K59 | 9.64 |
| 2000, 6903 | 1.181″ | 0.688″ | 1.164″ | 0.018″ | 0.062″ | 81 | 9717K62 | 10.36 |
| 6002, 6201 | 1.260″ | 0.688″ | 1.240″ | 0.008″ | 0.062″ | 15 | 9717K63 | 10.06 |
| 6002, 6201 | 1.260″ | 0.688″ | 1.240″ | 0.010″ | 0.062″ | 23 | 9717K65 | 10.36 |
| 6202, 6300, 6003 | 1.378″ | 0.814″ | 1.360″ | 0.011″ | 0.062″ | 17 | 9717K66 | 9.20 |
| 6202, 6300, 6003 | 1.378″ | 0.814″ | 1.360″ | 0.014″ | 0.062″ | 26 | 9717K67 | 10.72 |
| 6203 | 1.575″ | 0.971″ | 1.555″ | 0.014″ | 0.062″ | 23 | 9717K68 | 12.44 |
| 6203 | 1.575″ | 1.000″ | 1.555″ | 0.018″ | 0.062″ | 42 | 9717K69 | 12.44 |
| 6005, 6204, 6303 | 1.850″ | 1.189″ | 1.830″ | 0.016″ | 0.062″ | 26 | 9717K71 | 14.59 |
| 6205, 6304 | 2.047″ | 1.359″ | 2.022″ | 0.019″ | 0.062″ | 27 | 9717K72 | 14.54 |

■ Has three 0.0937″ high fingers.

## Polyurethane Flat Disc Springs CAD

Flat disc springs hold high loads in small spaces, similar to Belleville springs. They are made from polyurethane with a durometer of 95A; tolerance is +3. They're nonmagnetic and resist oxidation, oil, abrasion, and deterioration from exposure to ozone. Load tolerance is ±25%. Deflection range is 0-10% for static applications (not to exceed 10%); 0-20% for dynamic (not to exceed 20%).

When stacked, polyurethane springs must be separated by rigid flat washers (see illustration). The washers must be large enough to cover the entire surface of the disc springs. For washers, see 98017A on page 3180.




| Fits Rod Size | OD | Thickness | Defl. @ Load | Load, lbs. | Pkg. Qty. | | Per Pkg. |
|---|---|---|---|---|---|---|---|
| 3/16″ | ½″ | 0.125″ | 0.013″ | 148 | 6 | 94045K116 | $6.44 |
| ¼″ | ½″ | 0.250″ | 0.025″ | 106 | 6 | 94045K122 | 7.70 |
| 5/16″ | ¾″ | 0.125″ | 0.013″ | 261 | 6 | 94045K142 | 7.31 |
| ⅜″ | ⅝″ | 0.250″ | 0.025″ | 140 | 6 | 94045K161 | 8.39 |
| ½″ | ⅞″ | 0.250″ | 0.025″ | 333 | 6 | 94045K212 | 11.84 |
| ½″ | 1 1/16″ | 0.125″ | 0.013″ | 732 | 6 | 94045K216 | 14.56 |
| ½″ | 1⅜″ | 0.125″ | 0.013″ | 1604 | 3 | 94045K226 | 11.04 |
| ⅝″ | 1 3/16″ | 0.250″ | 0.025″ | 666 | 3 | 94045K511 | 9.66 |
| | | | | | | | Each |
| ¾″ | 1 5/16″ | 0.250″ | 0.025″ | 757 | — | 94045K331 | $4.22 |
| ¾″ | 1⅝″ | 0.125″ | 0.013″ | 1143 | — | 94045K335 | 5.15 |
| 1″ | 2″ | 0.250″ | 0.025″ | 1717 | — | 94045K371 | 7.45 |

```
clc;clear;
result_file='displacement_y.csv'; maxTerm=100;

fid=fopen(result_file);
flag=0;
while (flag==0)
uz=textscan(fid, '%*n %n %n %n %n','delimiter', ',');
flag=fseek(fid,1,'cof');
end
fclose('all');

SurfaceData=[uz{2},uz{4},uz{1}];
%SurfaceData=unique(SurfaceData,'rows');
X=SurfaceData(:,1); Y=SurfaceData(:,2);
[Theta,Rho] = cart2pol(X,Y);
NomalizedRHO = Rho/max(Rho);
[zMatrix,nVec,mVec,jVec] = zStd(NomalizedRHO,Theta,maxTerm);
Weight=EvaluateWeight([X,Y],1);
WeightedZernikeCoefficient=lscov(zMatrix,SurfaceData(:,3),Weight);

Data_removed_piston_tip_tilt=SurfaceData(:,3)-zMatrix(:,1:3)*WeightedZernikeCoefficient(1:
3);
RMS_surface=rms(Data_removed_piston_tip_tilt);
Residual=SurfaceData(:,3)-zMatrix*WeightedZernikeCoefficient;

%% Zernike functions with GRID dataset for slope error
sampling_width=0.04;
grid_xy=zeros(2/sampling_width+1,2);
g_r=zeros(2/sampling_width+1,1);
g_theta=zeros(2/sampling_width+1,1);
k=1;
for i=-1:sampling_width:1
    for j=-1:sampling_width:1
    grid_xy(k,1)=i; grid_xy(k,2)=j;
        if (norm([i j]) > 1)
          g_r(k)=nan;g_theta(k)=nan;
        else
          [g_theta(k),g_r(k)]= cart2pol(j,i);
        end
    k=k+1;
    end
end

[g_zMatrix_temp,g_nVec,g_mVec,g_jVec] = zStd(g_r,g_theta,maxTerm);

k=1;
g_zMatrix_dimension=sqrt(length(g_zMatrix_temp));
g_zMatrix=zeros(g_zMatrix_dimension,g_zMatrix_dimension,maxTerm);
g_wzf=zeros(g_zMatrix_dimension);
% zernike fitting grid results

% % weighted zernike fitting
%WeightedZernikeCoefficient(1:3,1)=0;
% WeightedZernikeCoefficient(:,2)=nan;WeightedZernikeCoefficient(:,3)=nan;
```

```
wzf=g_zMatrix_temp*WeightedZernikeCoefficient;

%Rearrange row data to grid data
for t=1:maxTerm
    for i=1:g_zMatrix_dimension
        for j=1:g_zMatrix_dimension
            g_zMatrix(i,j,t)=g_zMatrix_temp(k,t);
            g_wzf(i,j)=wzf(k);
            k=k+1;
        end
    end
    k=1;
end
%% Get slope error
[w_slope_x,w_slope_y]=gradient(g_wzf,sampling_width,sampling_width);
w_slope_2d=sqrt(w_slope_x.^2+w_slope_y.^2);
% %% Get slope map
% %[slope_x,slope_y]=ZernGradient(ZernikeCoefficient,X,Y);
% [w_slope_x,w_slope_y]=ZernGradient(WeightedZernikeCoefficient,X,Y);
% %slope_2d=sqrt(slope_x.^2+slope_y.^2);
% w_slope_2d=sqrt(w_slope_x.^2+w_slope_y.^2);
% %Slope_PV = abs(min(min(slope_2d))-max((slope_2d)));
Slope_PV = abs(min(min(w_slope_2d))-max(max(w_slope_2d)));
Slope_RMS = rms(w_slope_2d);

%% Plots
tri=delaunay(X,Y);
xi=-1:sampling_width:1;
[X_n,Y_n]=pol2cart(Theta,NomalizedRHO);

figure;
        subplot(2,3,1)
        trisurf(tri,X,Y,SurfaceData(:,3),...
            'facecolor','interp',...
            'edgecolor','interp')
        title('Original surface from Cosmosworks')
        view(0,90)

        subplot(2,3,2)
        trisurf(tri,X_n,Y_n,zMatrix*WeightedZernikeCoefficient,...
            'facecolor','interp',...
            'edgecolor','interp')
        title('Fitted surface by Zernike polynomial')
        view(0,90)

        subplot(2,3,3)
        trisurf(tri,X_n,Y_n,Residual,...
            'facecolor','interp',...
            'edgecolor','interp')
        title('Residual')
        view(0,90)

        subplot(2,3,4)
        quiver(xi,xi,w_slope_x,w_slope_y)
```

```
xlim ([-1 1])
ylim ([-1 1])
title('Slope vector map')

subplot(2,3,5)
pcolor(xi,xi,w_slope_x)
title('X direction slope')
shading interp;
view(0,90)

subplot(2,3,6)
pcolor(xi,xi,w_slope_y)
title('Y direction slope')
shading interp;
```