Engineering Mechanics and Design of the Monterey Bay Aquarium AMP Exhibit

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1. ABSTRACT

This paper details the engineering mechanics and engineering design behind the MBARI/MBA AMP exhibit. The exhibit provides a fly-on-the-wall perspective for observers of how research dives are conducted using remotely operated vehicles (ROVs) like the Doc Ricketts ROV. The exhibit features a model ROV suspended overhead in the center of a room with a 360 degree view of a marine landscape. The model ROV simulates a mission while educating the observer about the various marine life highlighted in the marine landscape, one section at a time. This paper explains the design process behind safely suspending the ROV overhead, while allowing for full rotational movement as well as tilt/lifting capabilities in an effort to accurately simulate ROV movements on a typical scientific dive in the ocean. The exhibit is on display for eight years (2014-2022) and must be designed to safely operate for that entire duration of time. All engineering drawings and calculations are included in the appendixes.

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LIST OF SYMBOLS

σ	Stress
W	Weight
a	Height
b	Width
Z	Section Modulus
l	Length
y	Distance to Neutral Axis
I	Moment of Inertia
$\tau_{\perp}$	Shear Stress (Perpendicular)
F	Force
t	Thickness
M_{rb}	Moment (Radial at Point b)
μ	Coefficient of Friction
ϵ	Strain
h	Height of Flange
E	Elastic Modulus
Q	Deflection Magnification Factor (Corresponding to Aspect Ratio length/thickness)

2. Project Overview

The MBARI/MBA AMP exhibit has the goal of providing a first-hand experience to museum-goers of how remotely operated vehicles (ROVs), like the Doc Ricketts, are used to conduct scientific research. The exhibit is set in a circular room, with all 360 degrees of wall space covered by a mural of aquatic landscape, to give the observer the impression of being fully submerged in the ocean. A scale model of the Dock Ricketts ROV is suspended from the center of the ceiling using 4 small black cables and has the ability of full 360 degree rotation as well as raising, lowering, and tilting capabilities. This is to give the illusion that the model ROV is suspended in water and moving through the ocean just as a real ROV would be on a mission. Hidden projectors from various positions in the room project an image of marine life onto the aquatic background mural in various locations, highlighting marine life that was before unseen. These projections correlate to the position of the model ROV, which points a dim floodlight in the direction it faces, and gives the impression that the ROV is illuminating different parts of the marine landscape. As one section is highlighted, information about the different sea life in that section is stated to the observer, providing them with an educational, fly-on-the-wall perspective of a typical ROV dive. An artistic rendering of the exhibit in action is shown below in *Figure 1*.

Figure 1-Artistic Rendering of the AMP Exhibit [4]

From an engineering perspective, there are many tasks that must be completed in order to make this exhibit both functional, and safe for the observer. Those of which MBARI was tasked with producing include: *suspension framework* to safely suspend the ROV, *rotation framework* and a *drive mechanism* to allow for 360 degree rotation, a *tilt/lifting mechanism* with a separate *drive mechanism* to tilt and move the ROV up and down, and *construction of the model ROV* itself. This paper will focus on the design of the *suspension framework* and the *rotation framework* of the exhibit. All welding in the assembly was aluminum TIG welding. This type of welding was chosen to maximize weld strength and to produce a much more aesthetically pleasing final product than possible with other types of welding. For all engineering drawings of the assembly refer to Appendix A. For full calculations refer to Appendix B.

3. Suspension Framework

The model ROV was to be suspended from the center of the circular room. In order to accomplish this, the wooden rafters already present in the exhibit room were utilized. Two wooden beams, both 7 1/4 inches wide spaced 115 5/8 inches apart from centerline-to-centerline, were used as mounts to securely attach the suspension framework to the building. A floor plan for the room is shown below in *Figure 2*; the walls represented by the green circle and the wooden rafters represented by the red horizontal lines.

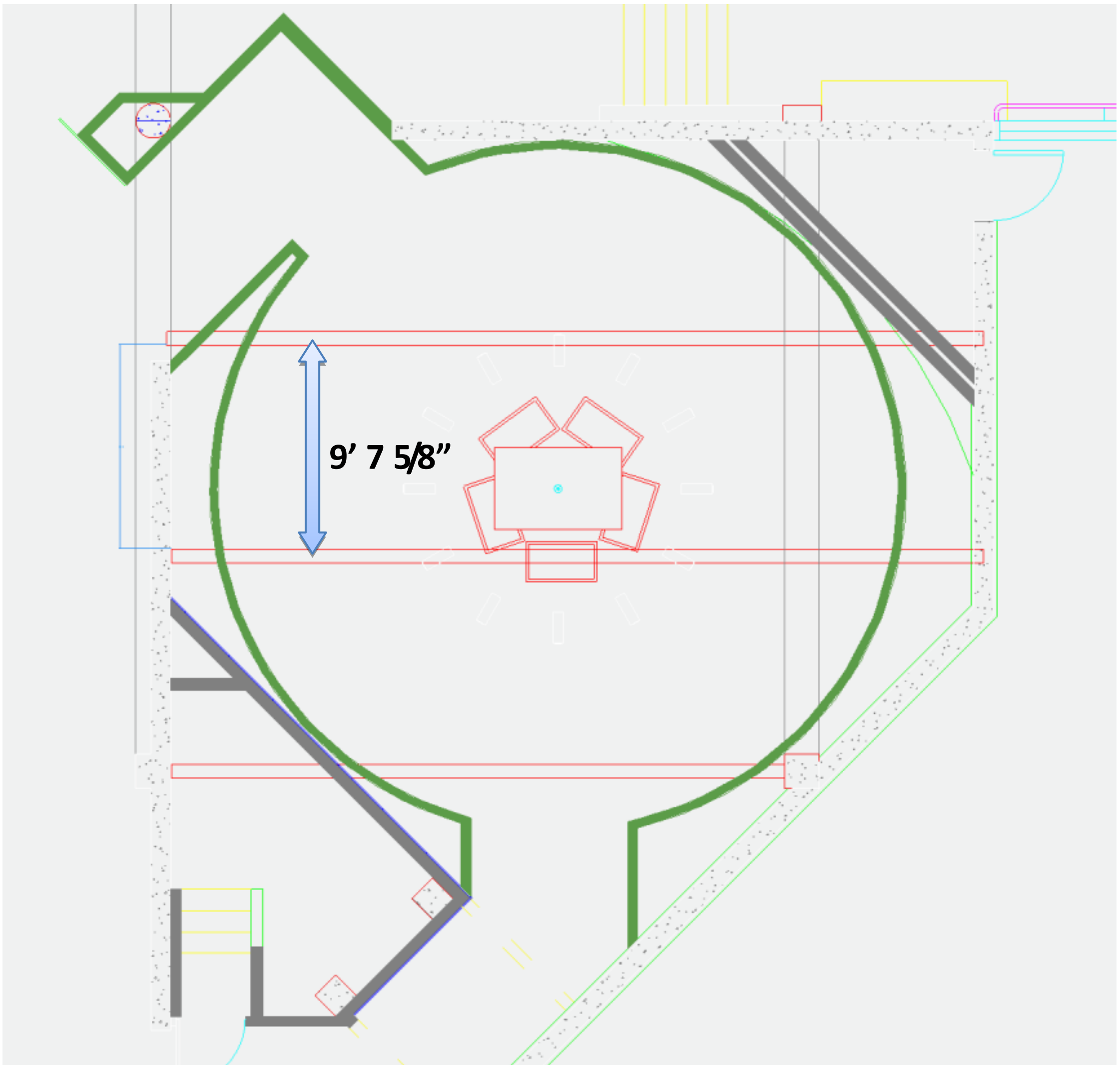


Figure 2-Exhibit Floorplan [4]

The framework was constructed to span the width of the rafters, attach to them securely, and provide a stable base to attach to the rest of the assembly. All components of the suspension framework were manufactured out of Aluminum 6061-T6 because of its easy machinablility/weldability, high strength-to-weight ratio, and relatively low material cost. An overview of the entire framework assembly can be seen below in *Figure 3 and Figure 4* spanning the wooden rafters, and the position of the suspended model ROV can be seen in *Figure 5*.

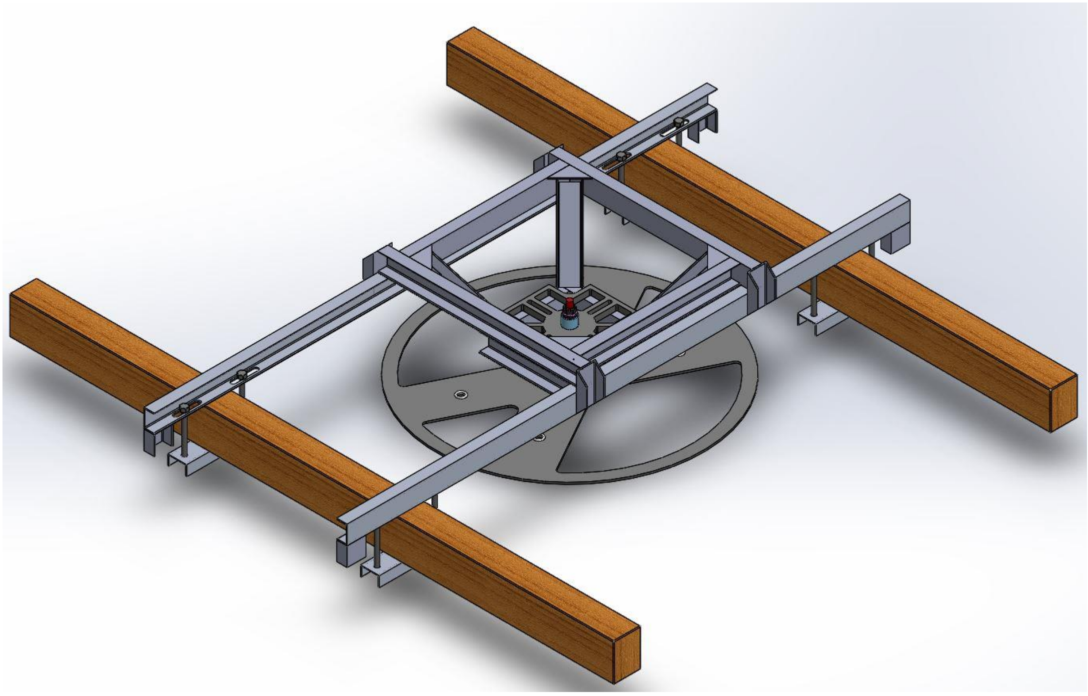


Figure3-3D CAD model of the Suspension and Rotation Framework Assembly(ISO View)

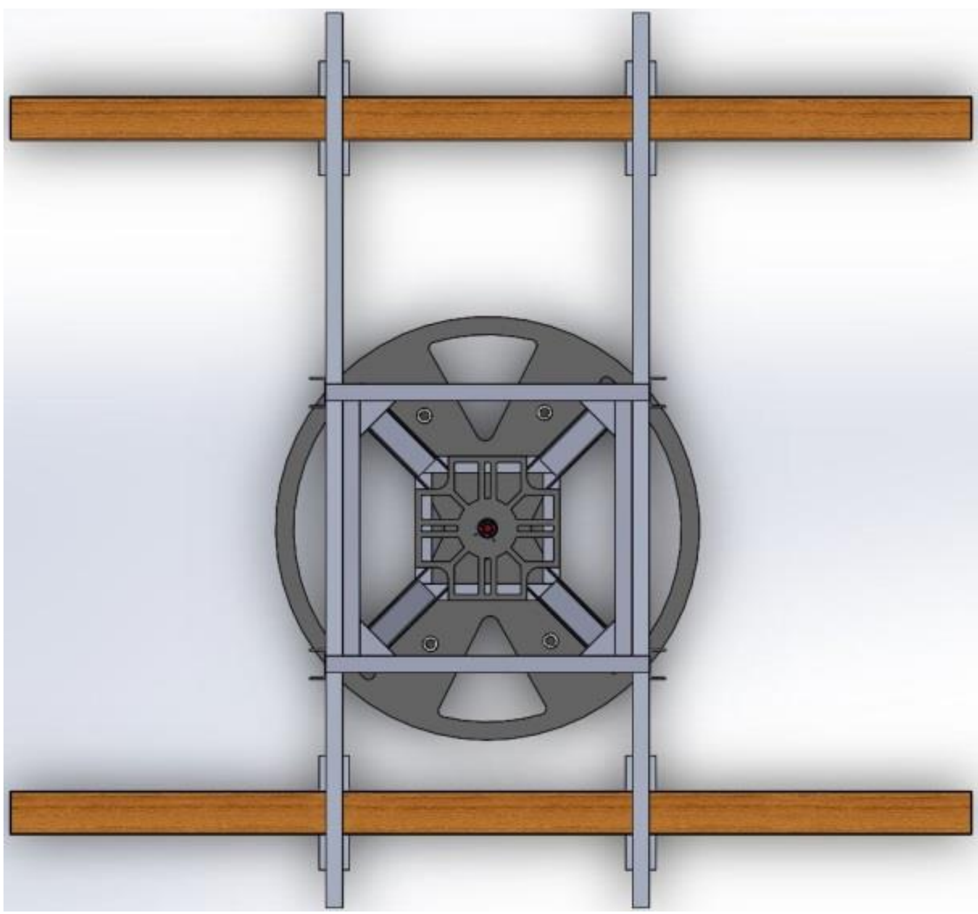


Figure4-3D CAD model of the Suspension and Rotation Framework Assembly(Top View)

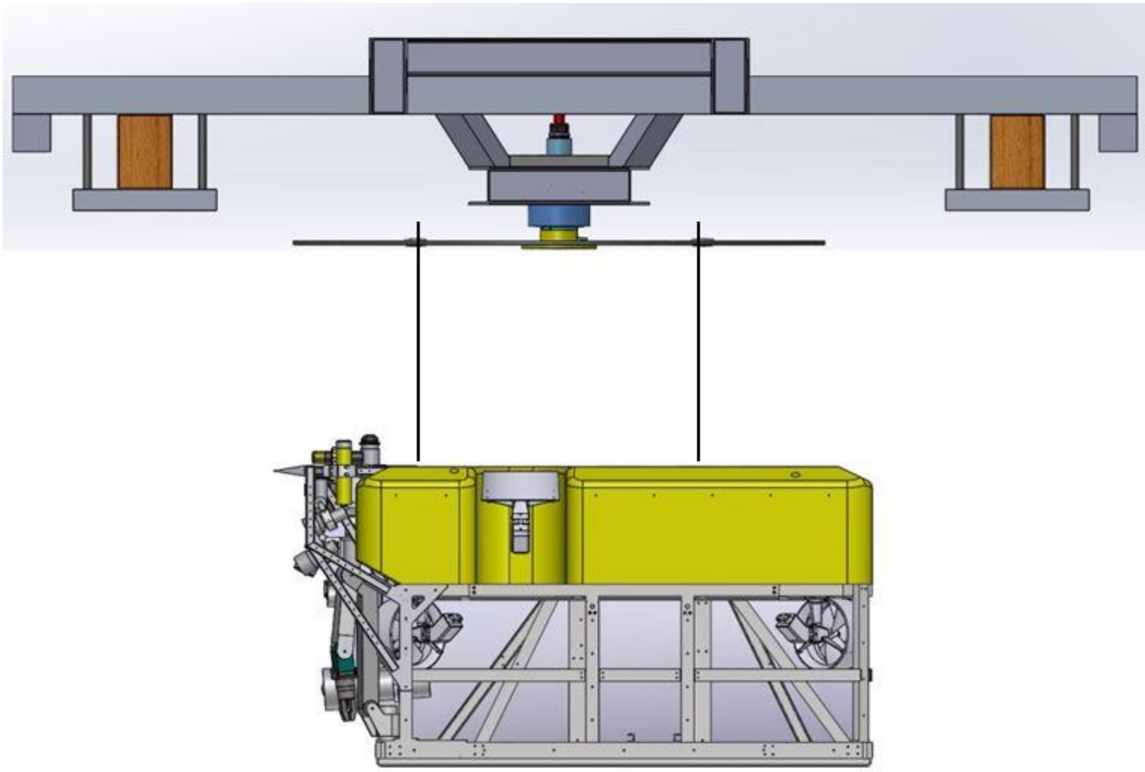


Figure 5-3D CAD Model of Suspended Model ROV

3.1 SUPPORT BEAMS

The support beams are constructed out of Aluminum 6061-T6 U-Channel and span the length of the wooden rafters. They are positioned with the spine in the vertical position, to maximize the strength of the geometry of the cross-section. Each of the two beams sees two downward forces, one force from each of the connecting points to the frame. Because each end of the support beam is simply supported, the stress seen by the support beam can be calculated using the following formulas [5]:

$$\sigma_{max} = \frac{Wab^2}{Zl^2} \quad (1)$$

Where,

$$Z = \frac{I}{y} \tag{2}$$

And

$$I = \frac{bd^2 - h^3(b-t)}{12} \tag{3}$$

From these equations, it was found that the maximum stress seen by each support beam was 2,126.05 psi, when considering the weight of the entire assembly acting as each individual force on the beams (for added safety). It should be noted that the yield strength of Aluminum 6061-T6 is 40,000 psi, and when compared to the maximum stress seen the support beam will not fail:

$$Aluminum\ \sigma_{Yield} = 40{,}000\ psi > 2{,}126.05\ psi = \sigma_{max}$$

The support beams are held in place by two 1 inch diameter hex bolts on each end, which straddle the wooden rafters and attach to the underside beam (U-Channel) beneath the rafters. There are two 6 inch slots, 9.25 inches apart, on the end of each support beam through which the hex bolts are fastened. This design allows for the support beams to be adjusted 3 inches from center on either side, which enables the assembly to be installed in the precise location desired, and allows for looser machining tolerances in the assembly. This adjustability can be seen below in *Figure 6*.

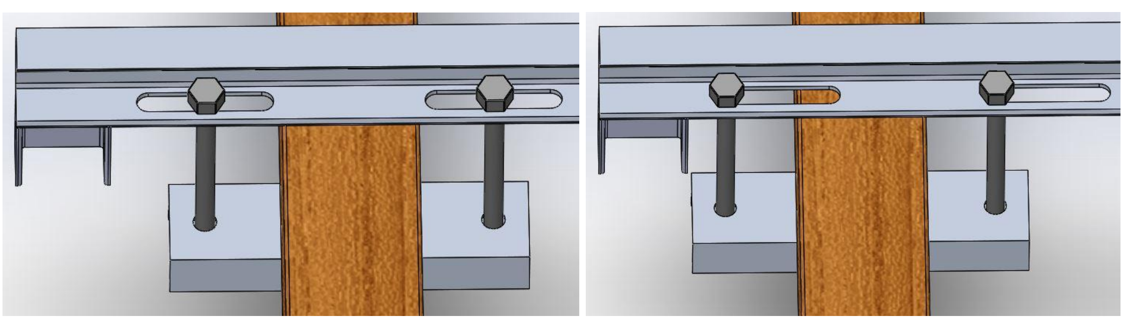


Figure 6- Adjustable Positioning of the Support Beams (3D CAD Model)

3.2 Frame

The frame is backbone of the entire assembly, and provides a structure for all other components to be mounted. The frame must withstand the load of the assembly as well as the torsional forces applied by the motor in order to rotate the model ROV. It was crucial that the frame stay rigid, without any flexure resulting from the applied forces. This rigidity was accomplished by implementing an angular design, as shown below in *Figure 7*. The frame was secured to the support beams using 4 bolts, one through each of the 4 side beams. The side beam components of the frame and the support beams were match drilled to ensure perfect alignment between the two.

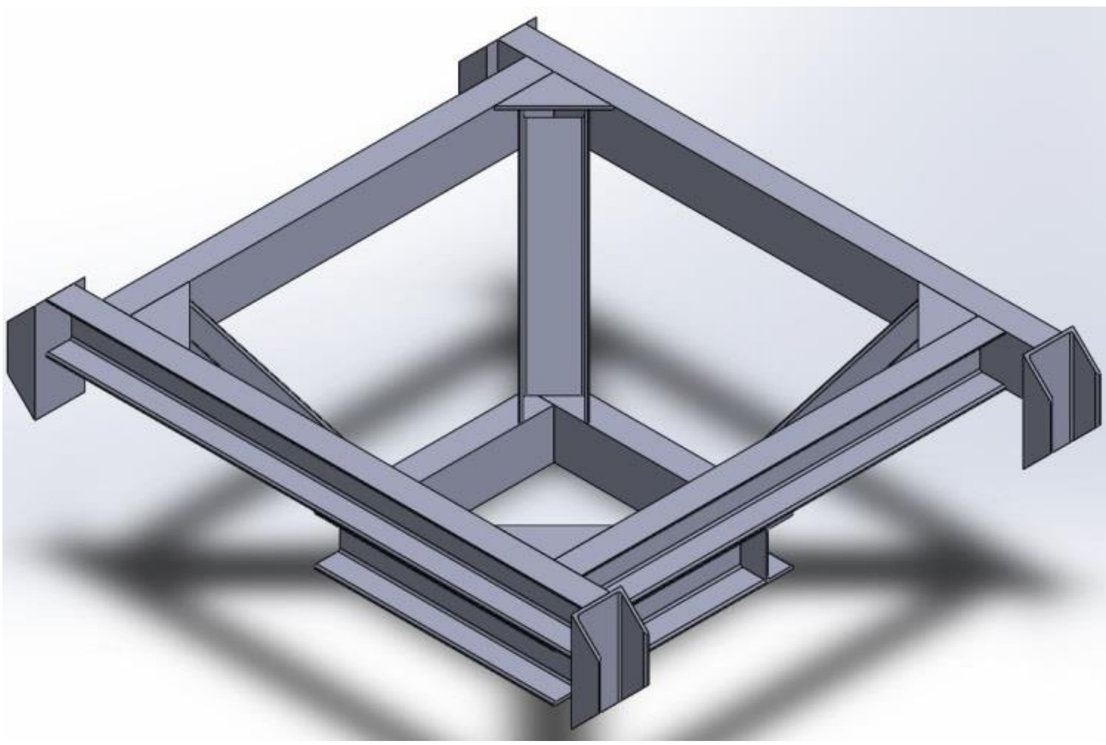


Figure 7- Frame Component (3D CAD Model)

The points considered most likely to fail on the frame were located at the two weldment points of the diagonal beam, connecting the top and bottom sub-assemblies of the frame together. These joints can be seen below in *Figures 8* and *9*.

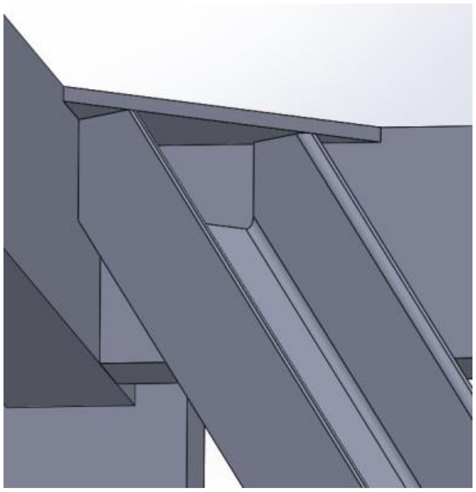


Figure 8- Upper Weld Joint (3D CAD Model)

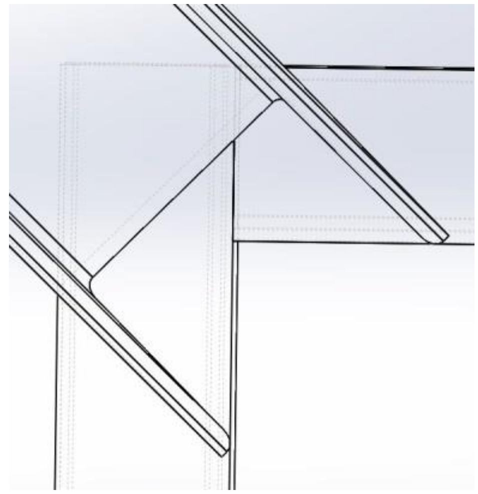


Figure 9- Lower Weld Joint (3D CAD Model)

The stresses at these crucial points were evaluated to ensure that the frame would not fail, given the yield strength of 8,000 psi for annealed aluminum 6061-0. The full weight of the assembly was applied to the weldment joints and the stresses were calculated using the following equations [3]:

Weld Shear Strength:

$$\tau_{\perp} = \frac{F}{2 \times W \times a} \tag{4}$$

$$Al\ annealed\ \sigma_{Yield} = 8{,}000\ psi > 81.46\ psi = \tau_{max}$$

Weld Tensile Strength (Normal To):

$$\sigma_N = 0.7\sqrt{\left(\frac{F}{2\times W\times a(\sqrt{2})}\right)^2 + 3\left(\frac{F}{2\times W\times a(\sqrt{2})}\right)^2} \tag{5}$$

$$Al\ annealed\ \sigma_{Yield} = 8{,}000\ psi > 30.675\ psi = \sigma_{max}$$

The shear stress was seen by the vertical wall in the upper weld joint and the tensile stress was seen in the lower weld joint. When evaluating the upper weld for failure, only the vertical weld was considered in the calculation. The added strength of the horizontal weld to the gusset was not considered. Thus, the shear calculation is an overestimate of the actual stress seen, as the horizontal weld shares the load with the vertical weld in the upper weld joint. When compared to the yield strength of the material, the stresses shown by the calculations ensure that the frame will not fail from regular use.

4. Rotation Framework

The rotation framework supports the model ROV while still allowing full 360 degree rotation. The drive shaft sub-assembly features a main drive shaft coupled to the motor, which drives the rotation of the model ROV. A concentric outer tube (bearing tube) covers the main drive shaft and rides on bearings to allow independent rotation from the main drive shaft. The bearing tube was welded to the frame sub-assembly, thereby mounting the drive shaft sub-assembly to the frame sub-assembly. The bearing tube maintains a fixed position while the main drive shaft rotates along with the model ROV. An exploded view and section view of the drive shaft sub-assembly are shown below in *Figure 10*.

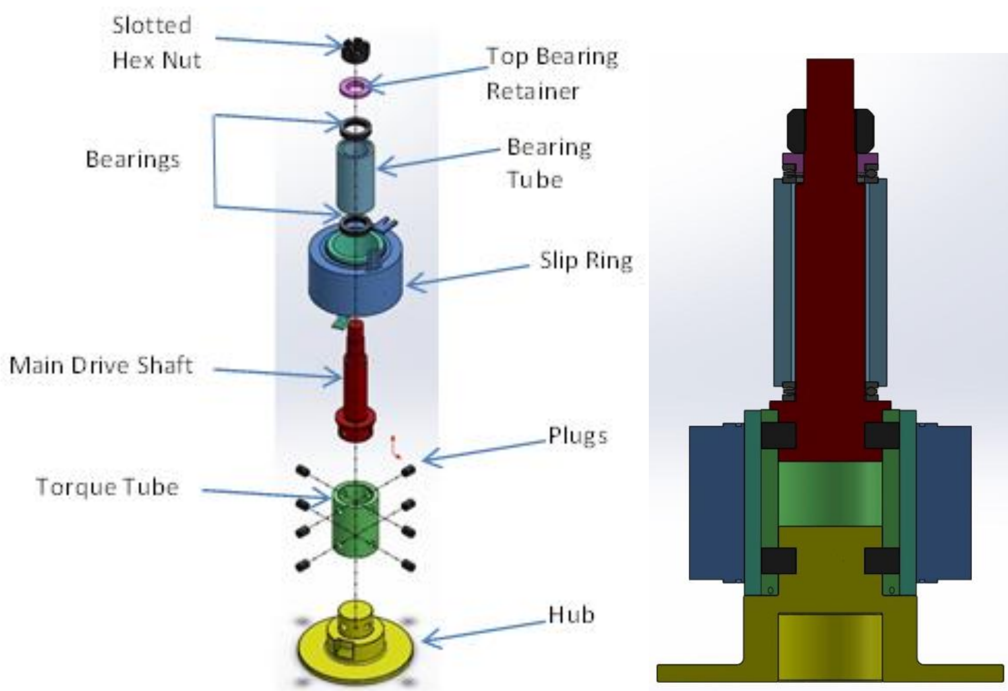


Figure 10-Drive Shaft Sub-Assembly Exploded and Section Views (3D CAD Model)

Electrical contact must be maintained throughout the full 360 degree rotation of drive shaft sub-assembly in order to power the tilt/lifting mechanism which rotate along with the model ROV. This was accomplished with the addition of a MOOG AC6098 slip ring. The slip ring has an inner and an outer portion which rotate independently while still maintaining electrical contact between the two portions. This allows for the transfer of electrical power from a rotating to a non-rotating surface without the entanglement of electrical wires. As shown in the above sub-assembly, the inner portion of the slip ring rotates with the main drive shaft while the outer portion stays stationary. Thus, allowing the transfer of electrical power onto the rotating portion of the suspension framework.

4.1 Hub

The hub component supports the suspension tray, from which the model ROV was suspended via 4 cables attached to the tilt/lifting mechanism. Therefore, the bottom surface of the hub sees a uniformly distributed load equivalent to the weight of the model ROV and suspension tray along with the tilt/lifting mechanism. The hub was loaded as seen in *Figure 11* and was designed to withstand this load with very little deflection. The green arrows represent the fixed points and the orange arrows represent the load. A miniscule deflection was important in providing a stable platform to suspend the model ROV from. The deflection is exaggerated in the figure for illustration purposes.

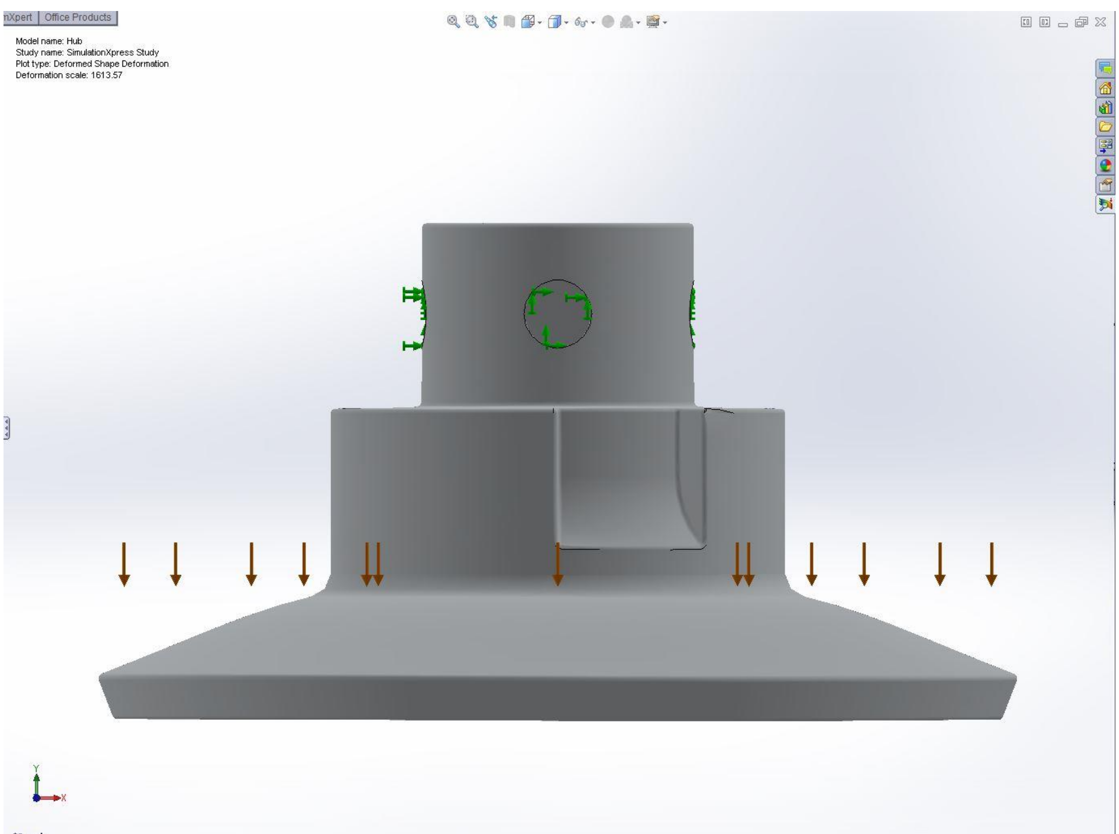


Figure 11- Hub Under Previously Describe Loading (3D CAD Model)

This loading fits the mathematical model of a distributed load applied to a circular plate of constant thickness, with the outer edge free and the inner edge fixed. From this mathematical model, the unit moment at the inner edge was calculated to be M_{rb}= 146.623 in*lb. /in. The maximum stress occurred at the inner edge and was calculated by the formula [6]:

$$\sigma_{max} = \frac{6 \times M_{rb}}{t^2} \quad (6)$$

$$Al\ annealed\ \sigma_{Yield} = 8{,}000\ psi > 3{,}518.946\ psi = \sigma_{max}$$

The maximum stress seen by the hub is well under the yield strength of 6061-0 annealed aluminum. The assumption that the aluminum was fully annealed at the inner edge was conservative. In reality, the aluminum at the inner edge was unlikely fully annealed, resulting in the yield strength being much higher than 8,000 psi. The maximum deflection of the outer edge of the hub was calculated to be 0.00618 in, proving that the hub will be very stable under the applied loading.

4.2 Suspension Tray

The suspension tray provides a surface for the tilt/lifting mechanism to be mounted to, while rotating along with the model ROV. The suspension tray was welded to the hub, with the underside surface coincident to the bottom surface of the hub, thus applying the before mentioned distributed load. There were 4 holes made in the suspension tray in order to run the connecting cables from the tilt/lifting mechanism down to the attachment points on the model ROV. The suspension tray is shown in *Figure 12*.

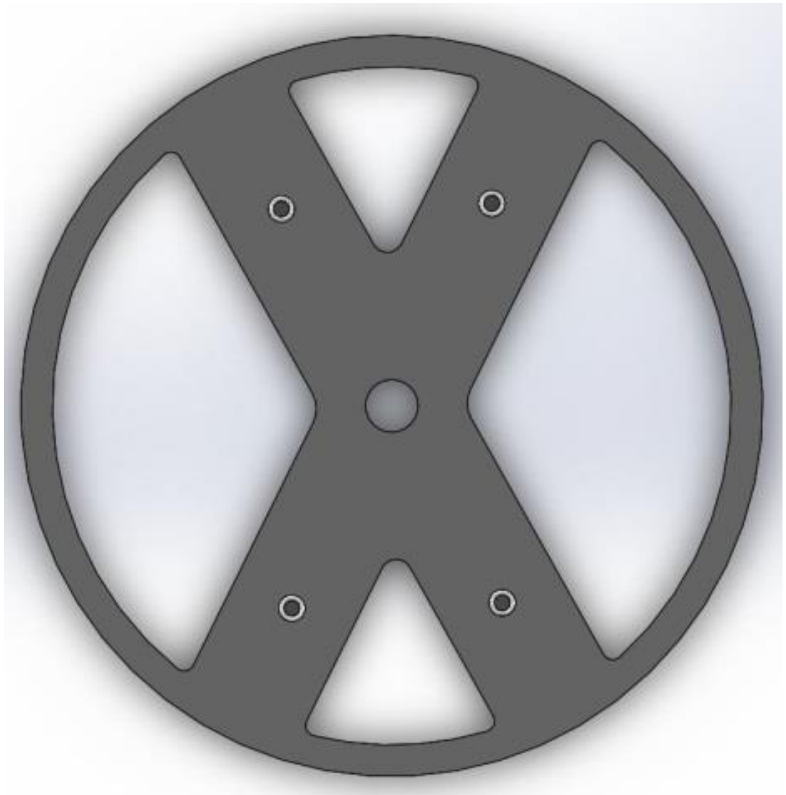


Figure 12- Suspension Tray (3D CAD Model)

4.3 Live-Hinge Snap-Fittings

The cables used to suspend the model ROV needed to be protected from any possible contact with the suspension tray. To accomplish this, Delrin inserts were created to provide a smooth surface for the holes in the suspension tray and protect the cables from wear caused by rubbing on the edges of the openings. Delrin was chosen because of its remarkable wear resistance and low coefficient of friction. These inserts were designed as live-hinge snap fittings, held in place by their own geometry. These snap fittings are shown below in *Figure 13* and can be seen as installed onto the suspension tray above in *Figure 12*.

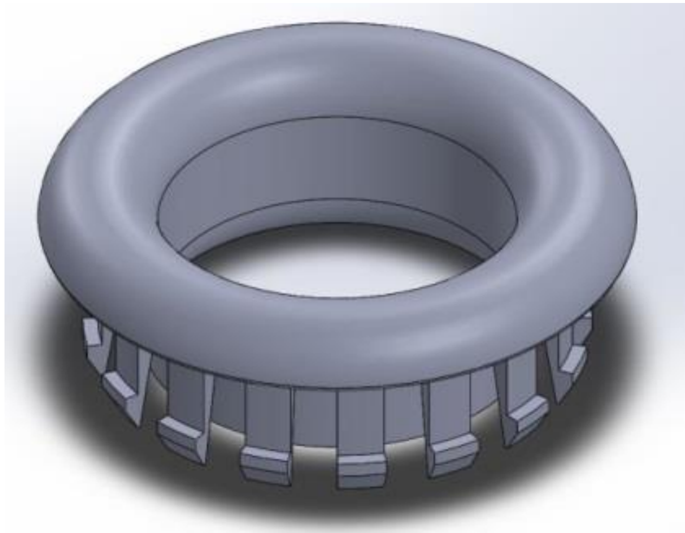


Figure 13- Snap Fitting (3D CAD Model)

Careful consideration had to be made in the design process to allow the snap fittings to be installed with a reasonable amount of force, while still protecting any of the snaps from failure during installation. To accomplish this, the geometry of the snaps was based off of accepted theory, as depicted below in *Figure 14*. However, the dimension of 3/4 *t* was reduced further to 1/2 *t*.

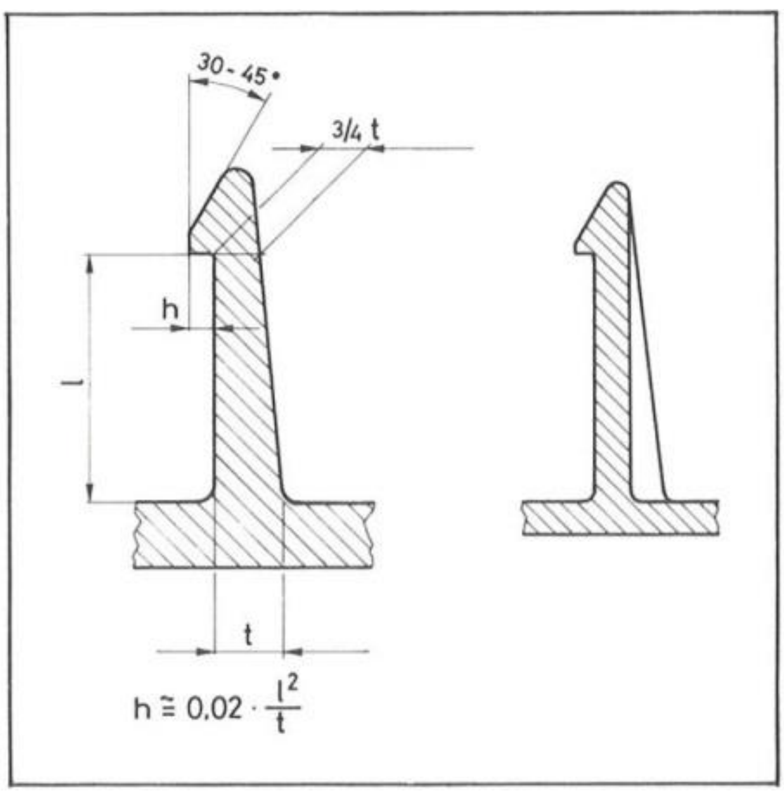


Figure 14-Cantilever Snap Fit Lug Design [2]

Calculations were performed using the chosen geometry to ensure that the snaps would not fail. Multiple iterations were done to determine width of the snaps that would prevent failure, while allowing for a reasonable force required to install the snap fittings. A depiction of these forces on the snap fittings' geometry is shown in *Figure 15*.

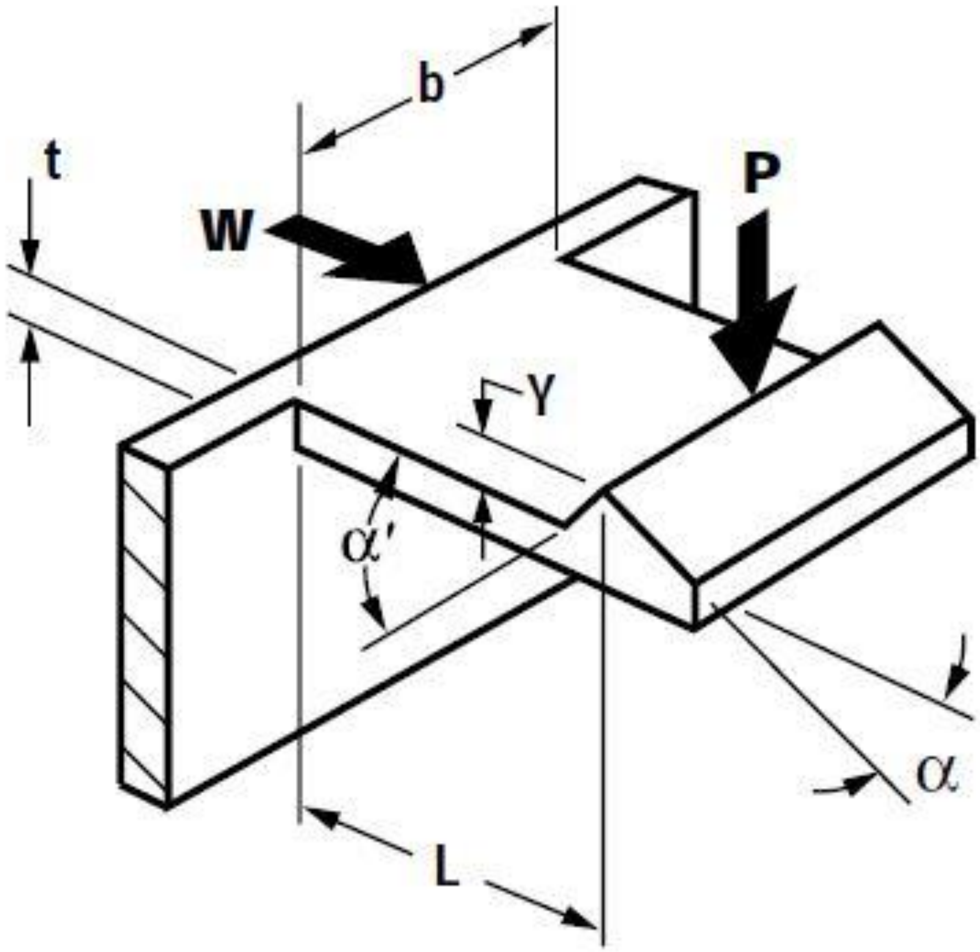


Figure 15- Cantilever Snap Fit Lug Forces [1]

The force *P* represents the force seen by the snap fitting during installation and the force *W* represents the force applied by user to perform the installation. These forces were calculated using the following equations [1]:

$$P = \frac{bt^2 E \in_{max}}{6l} \tag{7}$$

$$W = \frac{\mu + \tan(\alpha)}{1 + \mu \times \tan(\alpha)} \tag{8}$$

Where:

$$\in_{max} = \frac{t \times h}{l^2 \times Q} \tag{9}$$

The maximum strain was seen at the base of the cantilever snap fitting lug and therefore the maximum stress was located there as well. Assuming the stress seen by the material was in the elastic regime, the maximum stress at the base of the cantilever is given by [1]:

$$\sigma_{max} = E \times \in_{max} \tag{10}$$

$$Delrin\ \sigma_{yield} = 9{,}137\ psi > 7{,}210.44 = \sigma_{max}$$

With the yield strength of Delrin being 9,137 psi, the calculations reveal that the snaps do not fail during installation. From the calculations in Equations 7 and 8, P = 3.076 lbs. per snap, applied to 16 snaps, resulting in a P_{total} = 49.215 lbs. Therefore, W = 43.252 lbs. required by the user for installation. This satisfied the requirement of a *reasonable* amount of force required by the user for installation, while not causing any of the cantilevered snaps to fail.

5 Appendixes

A. APPENDIX A: CALCULATIONS

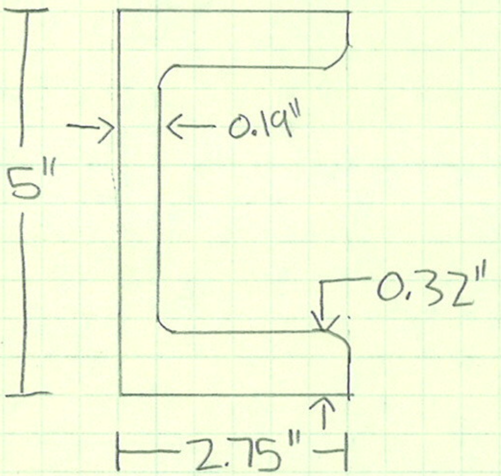
IN ORDER OF APPEARANCE IN PAPER

Support Beam Stress Calculation | AMP Project | nreed

(Pg. 1 of 2)

Material: 6061-T6 Aluminum

U-Channel



Section Modulus $\Rightarrow Z = \frac{I}{Y}$

$$I = \frac{bd^3 - h^3(b-t)}{12}$$

$b = 2.75$

$d = 5.00$ $\quad$ $Y = 2.5$

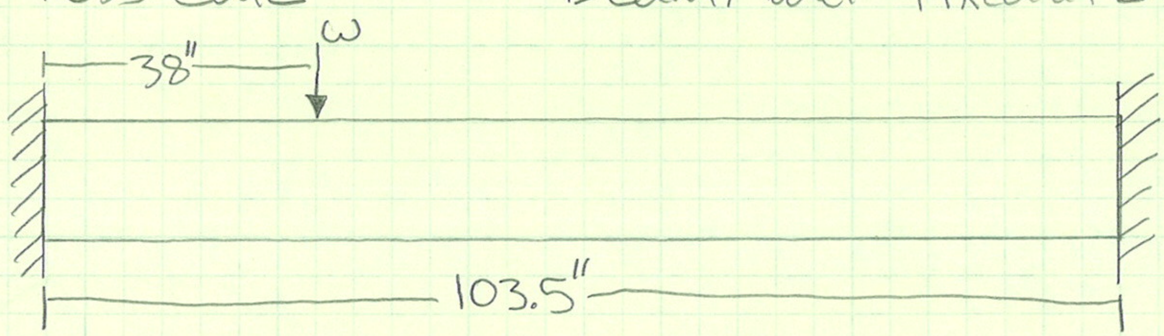
$h = 4.36$

$t = 0.19$

$$I = \frac{(2.75)(5)^3 - (4.36)^3(2.75-0.19)}{12} = 10.96$$

$$Z = \frac{10.96}{2.5} = 4.39$$

Stress Calc $\quad$ Beam Model - Fixed at Ends



$\omega = 600 lbs$

$$\sigma_{max} = \frac{Wab^2}{Z\ell^2}$$

$$\sigma_{max} = \frac{(600)(38)(67.50)^2}{4.39(105.5)^2} = 2126.05$$

Aluminum 6061-T6 $\sigma_{yield} = 40,000 psi > 2,126.05 psi$

Max Deflection => δ_{max}

$$\delta_{max} = \frac{2Wa^2b^3}{3EI(l+2b)^3}$$

W = 600 lbs

I = 10.96 in^4

E = 10×10^6 psi (Youngs Modulus Al 6061)

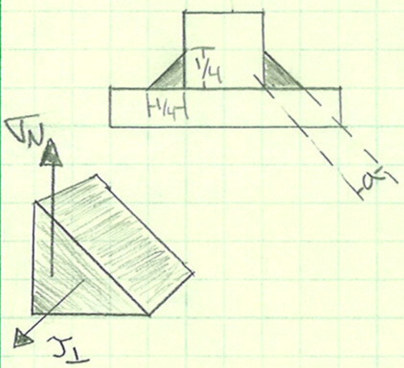
$$\delta_{max} = \frac{2(600)(38)^2(67.50)^3}{3(10.96)(10\times10^6)(105.5+(2)(38))^3}$$

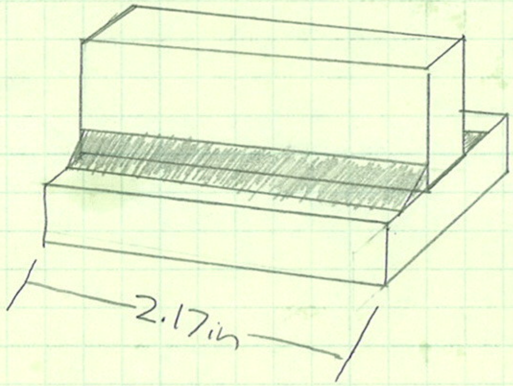
δ_{max} = 0.0003 in

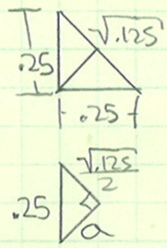
Frame Weld Shear Strength Calculation	AMP Project	nreed 7-18-14

Aluminum Weld Filler Material: 5356 Al

5356 Al Min Shear Strength: 117 MPa = 16,969 psi







$a = 0.176777\text{in}$

Weight of Assembly ≈ 500 lbs / 8 joints = 62.5 lbs/joint

$$\tau_\perp = \frac{F}{2 \cdot W \cdot a} = \frac{62.5\text{ lbs}}{(2)(2.17\text{in})(0.176777\text{in})}$$

$\tau_\perp = 81.464$ psi per joint

81.464 psi < 8,000 psi   Al 6061-0 $\sigma_{yield} = 8,000$ psi

* only 81.464 psi seen by each fillet weld

Frame Weld Tensile Strength calculation	AMP Project	nreed 7/21/14

Aluminum Weld Filler Material: 5356Al

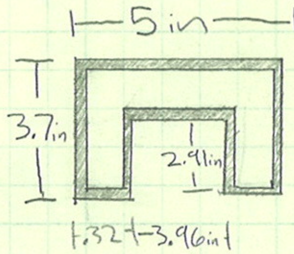
5356 Al All-Weld-Metal Ultimate Tensile Strength

= 262MPa = 38,000 psi

Allowable Tensile Stress $= \beta \sqrt{\left(\frac{F}{2 \cdot W \cdot a \cdot \sqrt{2}}\right)^2 + 3\left(\frac{F}{2 \cdot W \cdot a \cdot \sqrt{2}}\right)^2}$

β = property of Material
↳ worst case = 0.7

a = 0.176777in For 1/4in fillet weld



Total Weld length

L = 22.82in

Allowable Tensile Stress $\geq \beta \sqrt{\left(\frac{F}{L \cdot a \sqrt{2}}\right)^2 + 3\left(\frac{F}{L \cdot a \sqrt{2}}\right)^2}$

Weight of Assembly = 500lbs / 4 beams = 125lbs

$$\sigma_N = 0.7 \sqrt{\left(\frac{(125\,lbs)}{(22.82\,in)(0.176777\,in) \cdot \sqrt{2}}\right)^2 + 3\left(\frac{125\,lbs}{(22.82\,in)(0.176777\,in) \cdot \sqrt{2}}\right)^2}$$

σ_N = 30.675 psi

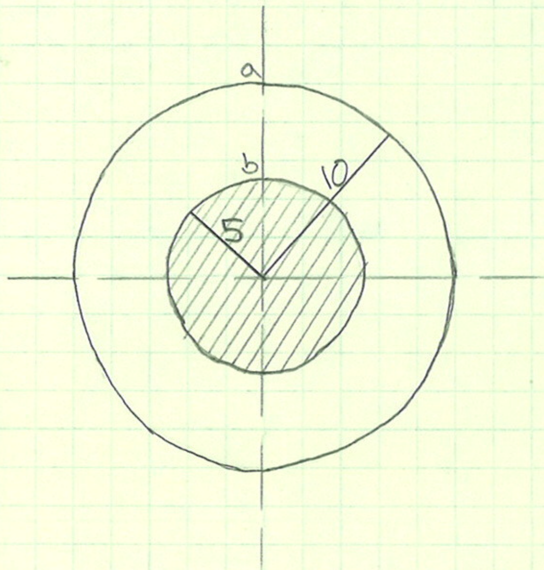
8,000 psi >> 30.675 psi

Al 6061-0
σ_{yield} = 8,000 psi

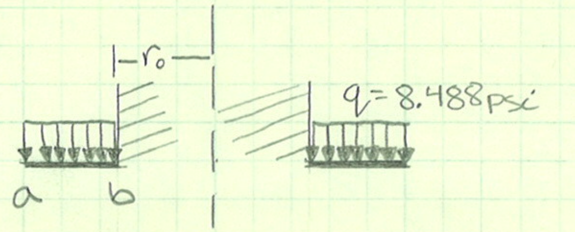
* Only 30.675 psi seen by fillet weld

Hub Stress and Deflection Calcs | AMP Project | nreed 21Jul2014

Material: 6061-O Aluminum ⇒ $E = 10\times10^6$ psi
$\nu = 0.33$



$r_o = b$ uniform load over entire plate



Outer edge free, inner edge fixed

thickness: $t = 1/2$ in

Area $= \pi(5^2 - 2.5^2) = 58.905\ in^2$
Load $= 500$ lbs
Distributed Load $q = 500/58.905 = 8.488\ lb/in^2$

Moment Calculation

Maximum radial bending moment occurs at point b

$$M_{rb} = \frac{-qa^2}{C_8}\left[\frac{C_9}{2ab}(a^2 - r_o^2) - L_{17}\right]$$

$$C_8 = \frac{1}{2}\left[1 + \nu + (1-\nu)\left(\frac{b}{a}\right)^2\right]$$

$$= \frac{1}{2}\left[1 + 0.33 + (1-0.33)\left(\frac{5}{10}\right)^2\right]$$

$$= 0.74875$$

$$C_9 = \frac{b}{a}\left\{\frac{1+\nu}{2}\ln\left(\frac{a}{b}\right) + \frac{1-\nu}{4}\left[1 - \left(\frac{b}{a}\right)^2\right]\right\}$$

$$= \frac{5}{10}\left\{\frac{1+0.33}{2}\ln\left(\frac{10}{5}\right) + \frac{1-0.33}{4}\left[1 - \left(\frac{5}{10}\right)^2\right]\right\}$$

$$= 0.29328$$

$$L_{17} = \frac{1}{4}\left\{1 - \frac{1-\nu}{4}\left[1-\left(\frac{r_0}{a}\right)^4\right] - \left(\frac{r_0}{a}\right)^2\left[1+(1+\nu)\ln\frac{a}{r_0}\right]\right\}$$

$$= \frac{1}{4}\left\{1 - \frac{1-0.33}{4}\left[1-\left(\frac{5}{10}\right)^4\right] - \left(\frac{5}{10}\right)^2\left[1+(1+0.33)\ln\left(\frac{10}{5}\right)\right]\right\}$$

$$= 0.09062$$

$$M_{rb} = \frac{-(8.488)(10^2)}{0.74875}\left[\frac{0.29328}{(2)(10)(5)}(10^2-5^2) - 0.09062\right]$$

* $= -146.62276$ in·lb/in

Stress Calculation

Maximum Stress occurs at point b

$$\sigma_{max} = \frac{(6)|M_{rb}|}{t^2} = \frac{(6)(146.62276)}{0.5^2}$$

* $= 3{,}518.94625$ lb/in² (psi)

Shear Calculation

Maximum shear occurs at point b

$$Q_b = \frac{q}{2b}(a^2 - r_0^2) = \frac{8.488}{(2)(5)}(10^2 - 5^2)$$

* $= 63.66$ lb/in

Deflection Calculation

Maximum deflection occurs at point a

$$y_a = M_{rb}\frac{a^2}{D}C_2 + Q_b\frac{a^3}{D}C_3 - \frac{qa^4}{D}L_{11}$$

$$D = \frac{Et^3}{12(1-\nu^2)} = \frac{(10\times10^6)(0.5)^3}{12(1-0.33^2)}$$

$$= 116{,}896.71940$$

$$C_2 = \frac{1}{4}\left[1-\left(\frac{b}{a}\right)^2\left(1+2\ln\frac{a}{b}\right)\right] = \frac{1}{4}\left[1-\left(\frac{5}{10}\right)^2\left(1+2\ln\left(\frac{10}{5}\right)\right)\right]$$

$$= 0.10086$$

$$C_3 = \frac{b}{4a}\left\{\left[\left(\frac{b}{a}\right)^2+1\right]\ln\left(\frac{a}{b}\right)+\left(\frac{b}{a}\right)^2-1\right\}$$

$$= \frac{5}{(4)(10)}\left\{\left[\left(\frac{5}{10}\right)^2+1\right]\ln\left(\frac{10}{5}\right)+\left(\frac{5}{10}\right)^2-1\right\}$$

$$= 0.01455$$

$$L_{11} = \frac{1}{64}\left\{1+4\left(\frac{r_o}{a}\right)^2-5\left(\frac{r_o}{a}\right)^4-4\left(\frac{r_o}{a}\right)^2\left[2+\left(\frac{r_o}{a}\right)^2\right]\ln\left(\frac{a}{r_o}\right)\right\}$$

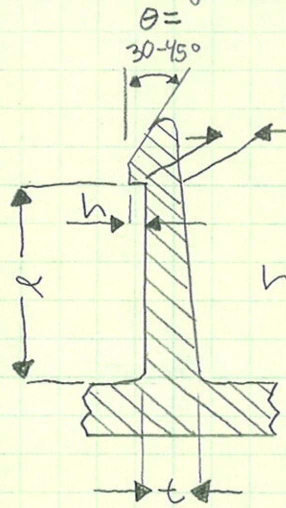
$$= \frac{1}{64}\left\{1+4\left(\frac{5}{10}\right)^2-5\left(\frac{5}{10}\right)^4-4\left(\frac{5}{10}\right)^2\left[2+\left(\frac{5}{10}\right)^2\right]\ln\left(\frac{10}{5}\right)\right\}$$

$$= 0.001999$$

$$y_a = (-146.62276)\frac{10^2}{116{,}896.71940}(0.10086) + (63.66)\frac{10^3}{116{,}896.71940}$$

$$\cdot(0.01455) - \frac{(8.488)(10^4)}{116{,}896.71940}(0.001999)$$

* $= -0.00618$ in (downward)



$l = 0.5$ in
$h = 0.0625$ in
$\theta = 30°$

$h = 0.02 \cdot \frac{l^2}{t}$

Find t:

$$0.0625 = 0.02 \cdot \frac{0.5^2}{t}$$

$t = 0.08$ in $\rightarrow \frac{1}{2}t = 0.04$ in

Material: Delrin

Young's Modulus $E = 420{,}609$ psi

Yield Strength $\sigma_Y = 9{,}137$ psi

Max Strain (at base)

$$\varepsilon_{max} = 1.5 \frac{t h}{l^2 Q} = \frac{(1.5)(0.08)(0.0625)}{(0.5)(1.75)}$$

$\varepsilon_{max} = 0.01714 = 0.1714\%$

Correction Factor Q

$Q \Rightarrow \frac{l}{t} = \frac{0.5}{0.08} = 6.25$

From Graph

$6.25 \rightarrow Q = 1.75$

Max Stress (at base)

$$\sigma_{max} = E\varepsilon_{max} = (420{,}609 \text{ psi})(0.01714) = 7{,}210.44 \text{ psi}$$

$\rightarrow 7{,}210.44 < 9{,}137$ psi

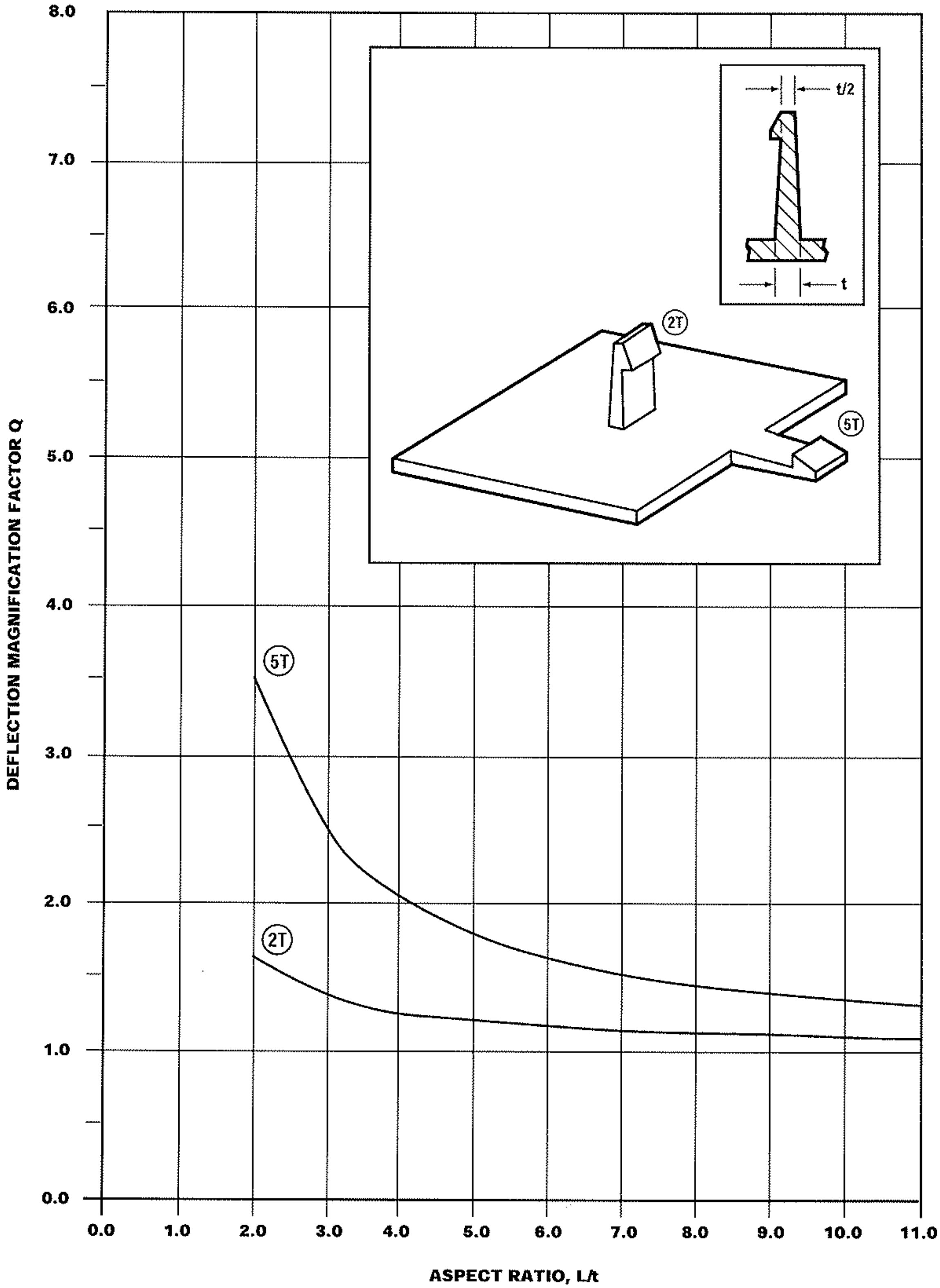
Mating Force

$$P = \frac{b t^2 E \varepsilon_{max}}{6l} = \frac{(0.2)(0.08)^2(420{,}609)(0.01714)}{(6)(0.5)}$$

$P = 3.076$ lbs per snap

$P(\times 16 \text{ snaps}) = P_{total}$

$P_{total} = 49.215$ lbs



Tapered Beam, Q Factor
Figure IV-2

Installation Force

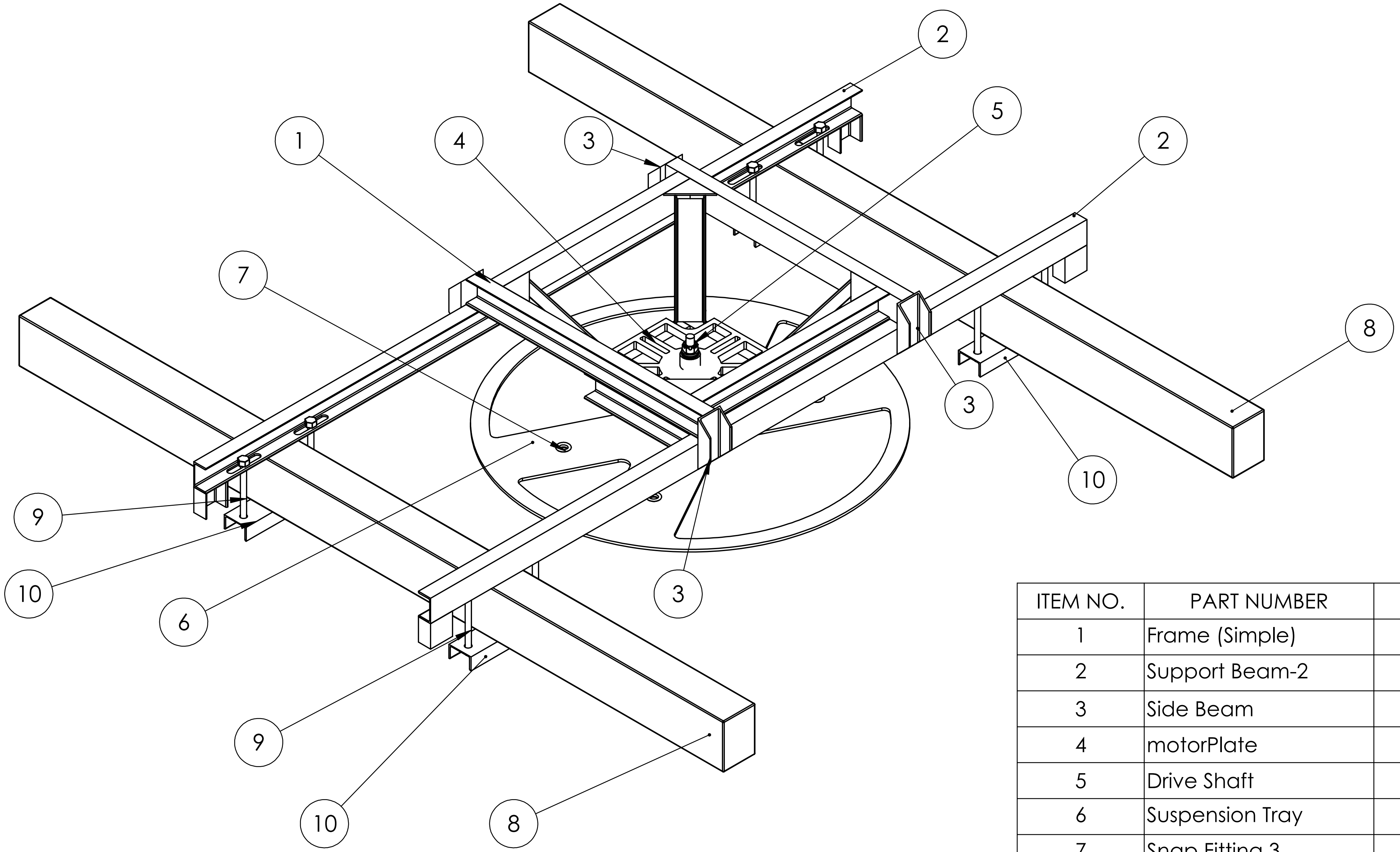
Delrin Coefficient of Dynamic Friction: $\mu = 0.20$

$$W = P \frac{\mu + \tan\theta}{1 - \mu\tan\theta} = (49.215)\frac{0.2 + \tan 30°}{1 - 0.2\tan 30°}$$

→ $W = 43.252$ lbs *Applied by user to install

B. APPENDIX B: ENGINEERING DRAWINGS

IN ORDER OF APPEARANCE IN PAPER



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Frame (Simple)		1
2	Support Beam-2		2
3	Side Beam		4
4	motorPlate		1
5	Drive Shaft		1
6	Suspension Tray		1
7	Snap Fitting 3		4
8	Wooden Rafters		2
9	Hex Bolt		8
10	Underside Beam-2		4

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION N/C

	NAME	SIGNATURE	DATE
DRAWN	NATHAN REED		8/11/14
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL:

WEIGHT:

TITLE:

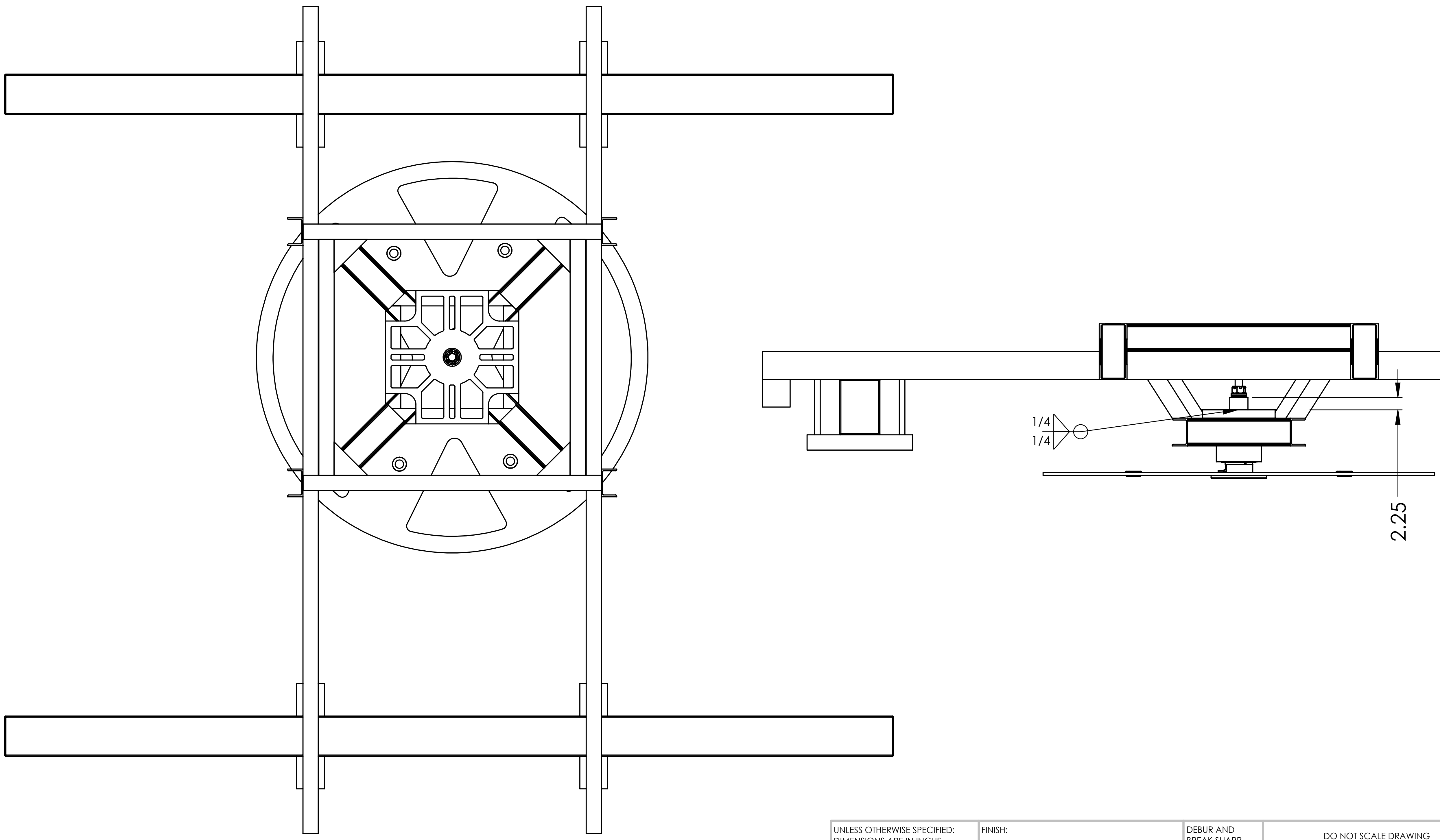
Full Assembly

DWG NO.

A3

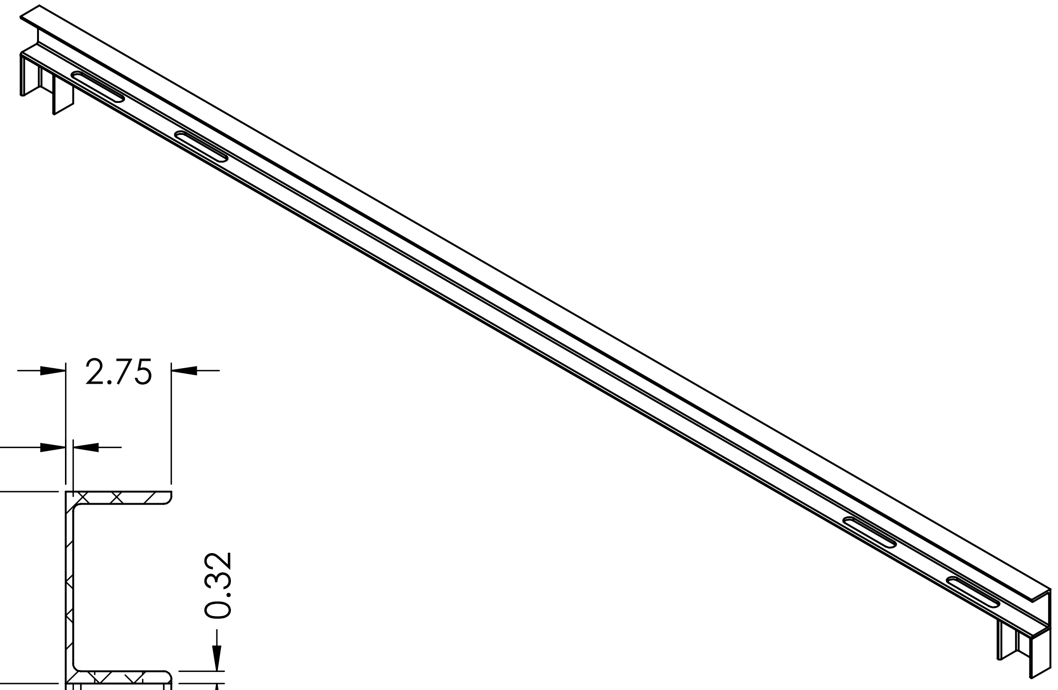
SCALE:1:50

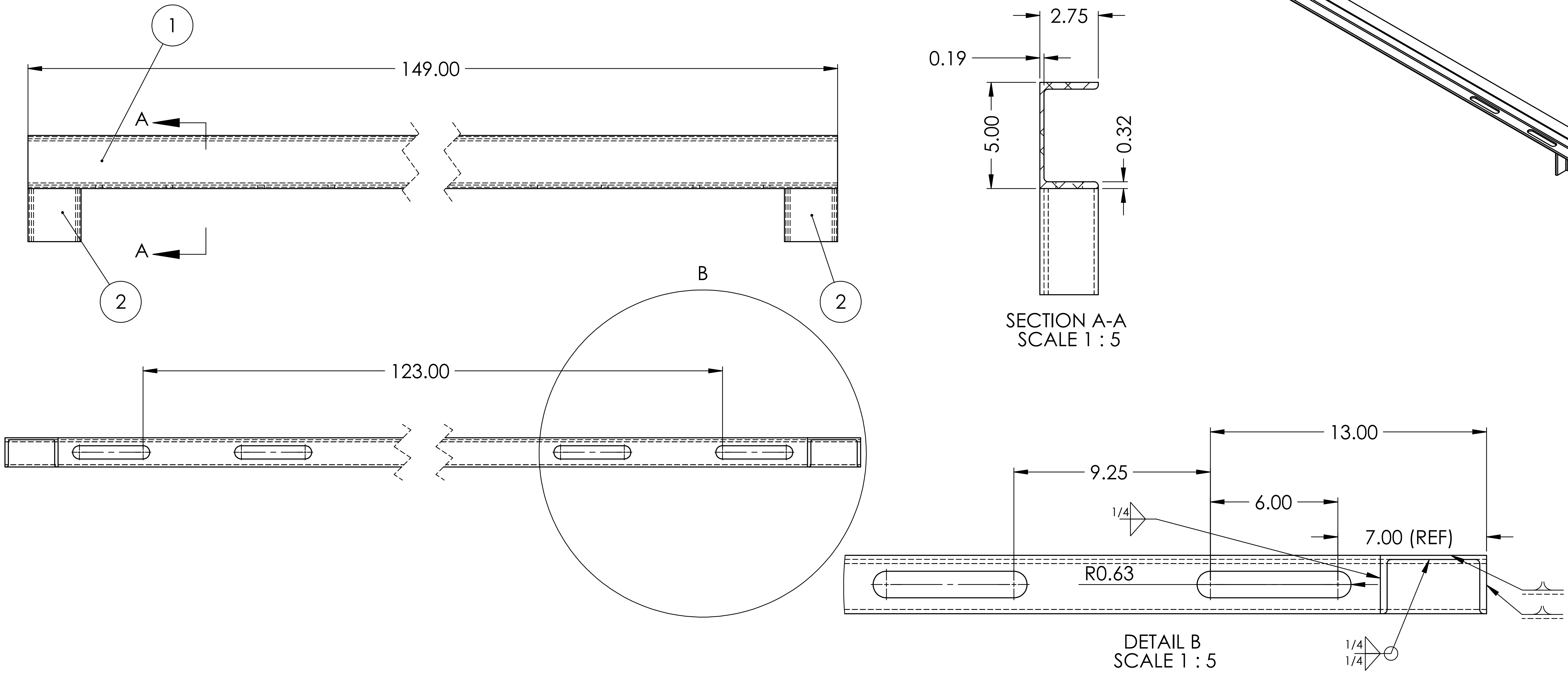
SHEET 1 OF 2



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:		FINISH:			DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION N/C
	NAME	SIGNATURE	DATE			TITLE:	
DRAWN	NATHAN REED		8/11/14			Full Assembly	
CHK'D							
APPV'D							
MFG							
Q.A				MATERIAL:		DWG NO.	A3
				WEIGHT:		SCALE:1:50	SHEET 2 OF 2

REVISIONS	DATE
A	6-16-14
B	6-18-14





1	SUPPORT BEAM	2x
2	STOPPER	4x

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION B

	NAME	SIGNATURE	DATE
DRAWN	NATHAN REED		6/18/14
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL:
6061 ALUMINUM

WEIGHT:

TITLE:
Support Beam-2

DWG NO.

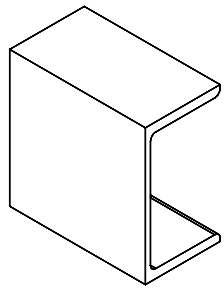
A3

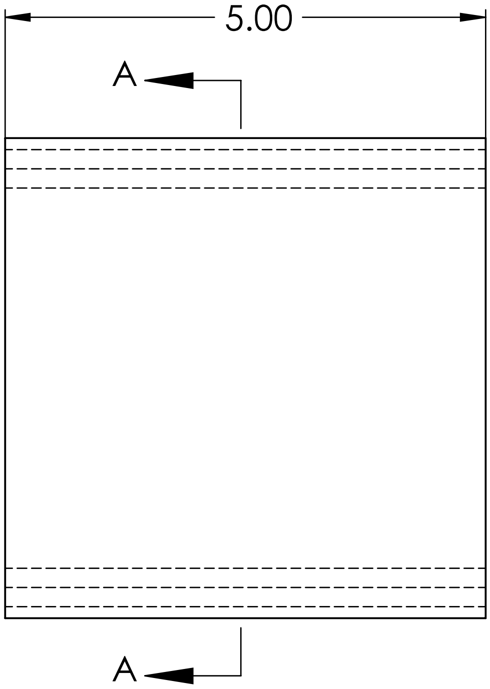
SCALE:1:20

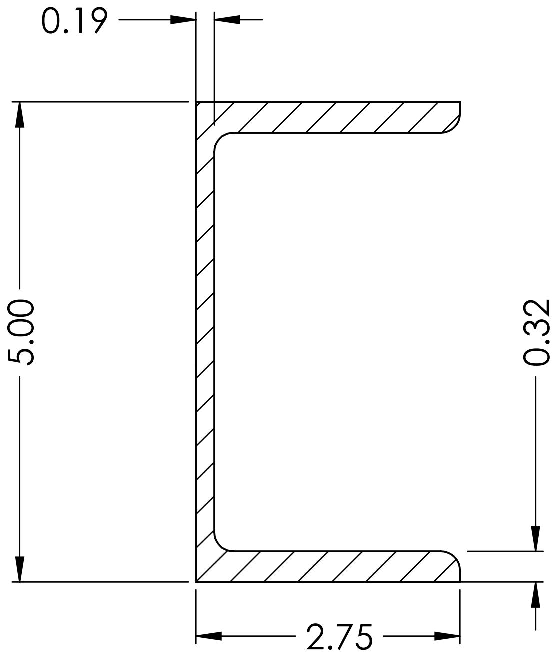
SHEET 1 OF 1

NOTES:
1) 2 PARTS NEEDED
2) MATERIAL: MULTIPURPOSE 6061 ALUMINUM
3) STOPPERS 2x WELDED TO BOTTOM OF EACH SUPPORT BEAM
4) FOR STOPPER DIMENSIONS REFER TO STOPPER DRAWING

REVISION	DATE
A	6-16-14
B	6-18-14





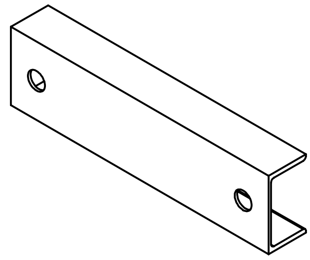


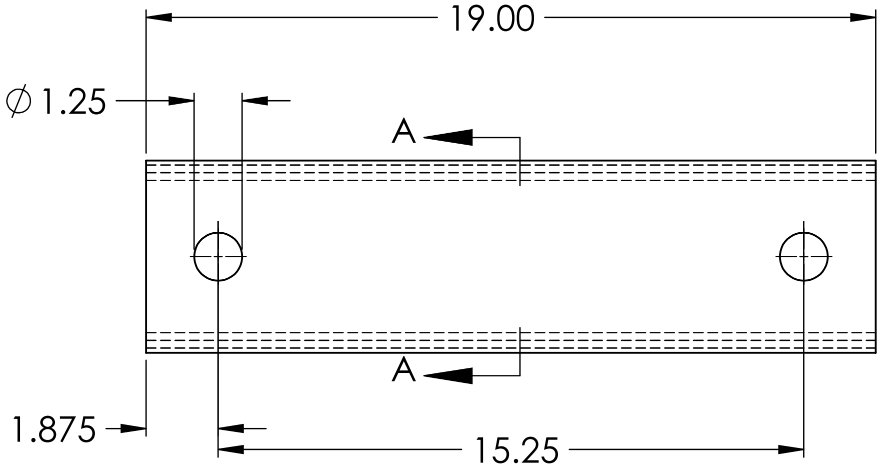
SECTION A-A

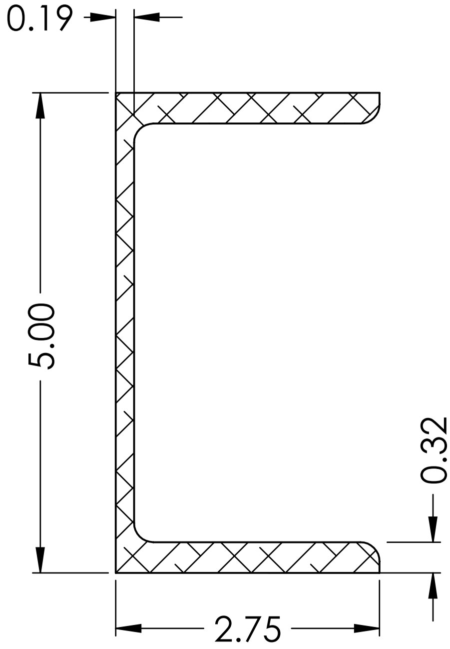
NOTES:
1) 4 PARTS NEEDED
2) STOPPERS 2x WELDED TO BOTTOM OF EACH SUPPORT BEAM
3) MATERIAL: MULTIPURPOSE 6061 ALUMINUM

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:			FINISH:			DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION B
	NAME	SIGNATURE	DATE				TITLE:	
DRAWN	NATHAN REED		6/18/14				Stoppers-2	
CHK'D								
APPV'D								
MFG								
Q.A				MATERIAL: 6061 ALUMINUM			DWG NO.	A4
							SCALE:1:2	SHEET 1 OF 1
				WEIGHT:				

REVISIONS	DATE
A	6-16-14
B	6-18-14





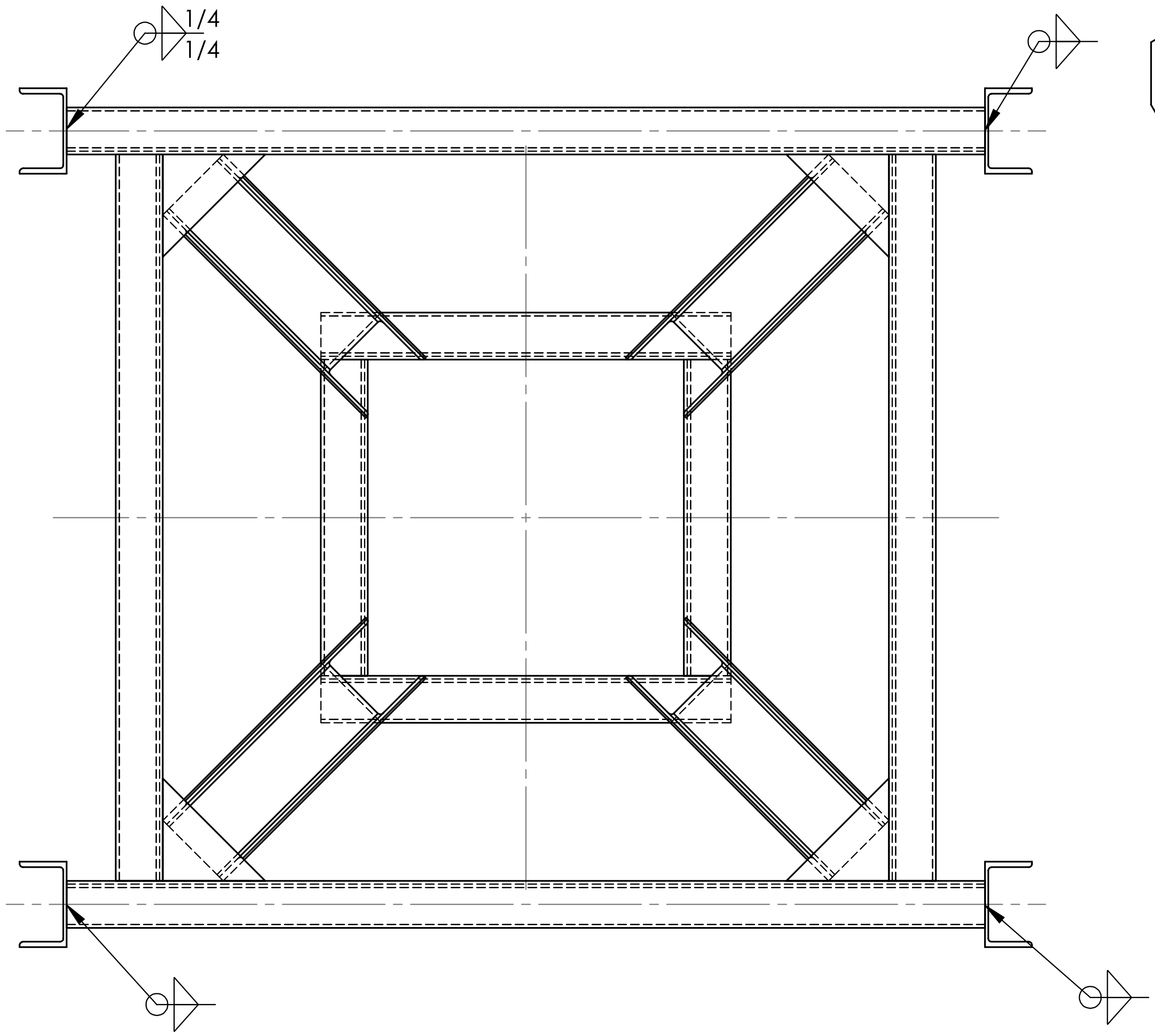


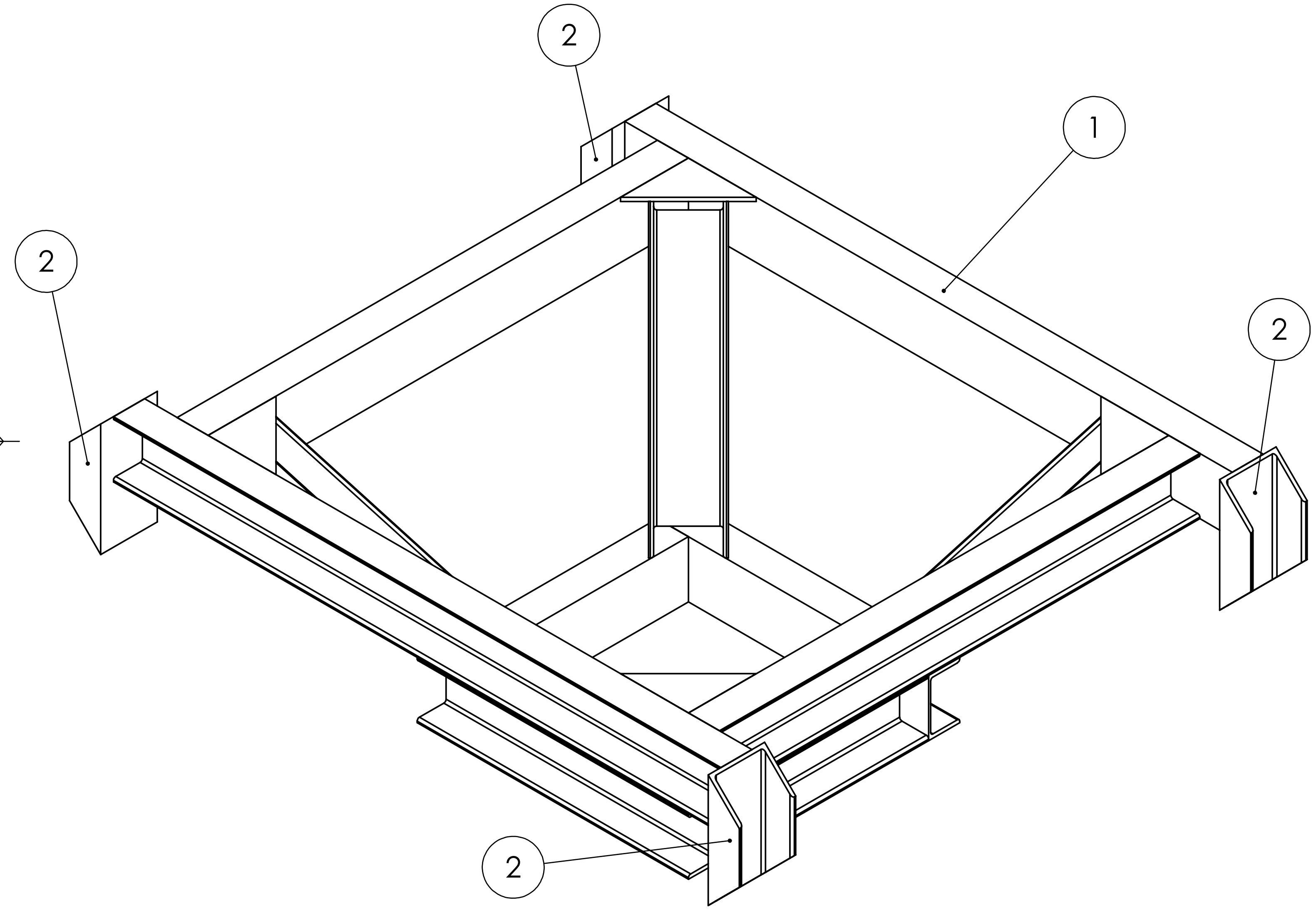
SECTION A-A
SCALE 1 : 2

NOTES:
1) 4 PARTS NEEDED
2) MATERIAL: MULTIPURPOSE 6061 ALUMINUM
3) WILL BE BOLTED TO SECURE SUPPORT BEAMS TO THE RAFTERS

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION B	
	NAME	SIGNATURE	DATE		
DRAWN	NATHAN REED		6/18/14	TITLE:	
CHK'D				Underside Beam-2	
APPV'D					
MFG					
Q.A				DWG NO.	A4
MATERIAL:	6061 ALUMINUM			SCALE:1:10	SHEET 1 OF 1
WEIGHT:					

NOTES:
1) ASSEMBLY OF FRAME (SIMPLE)WITH SIDE BEAM
2) FOR PART DIMENSIONS REFER INDIVIDUAL PART DRAWINGS
3) 1/4 INCH CONTINUOUS FILLET WELD CONNECTING SIDE BEAM AND FRAME
4) MATERIAL: 6061 ALUMINUM
5) SHEET 1 OF 2





ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Frame (Simple)		1
2	Side Beam		4

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION N/C

	NAME	SIGNATURE	DATE
DRAWN	NATHAN REED		7/1/14
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

FRAME W/SIDE BEAM

MATERIAL:
6061 ALUMINUM

DWG NO.

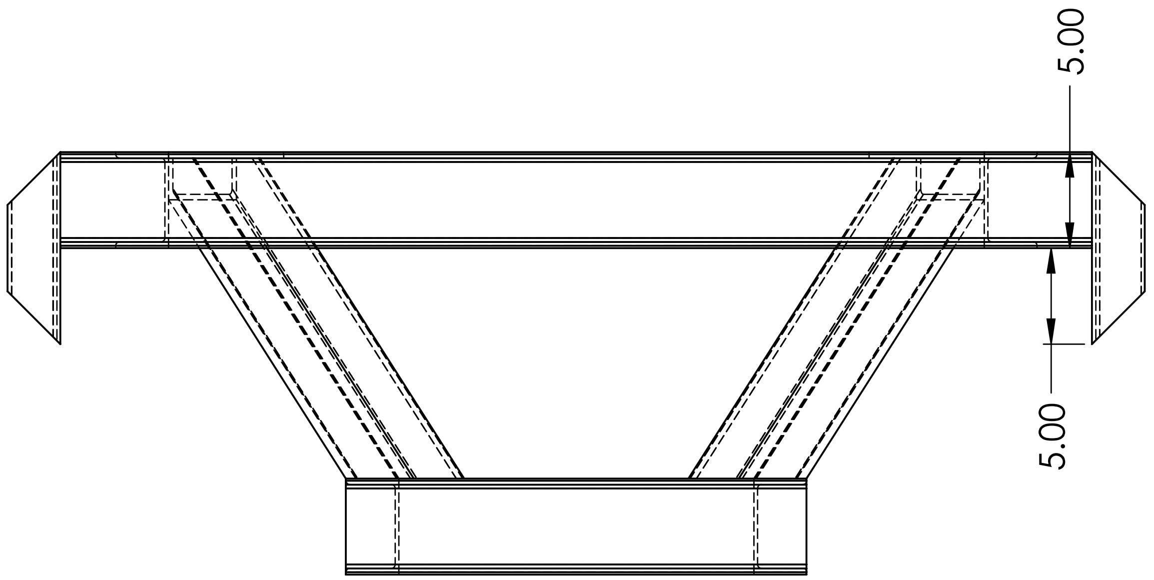
A3

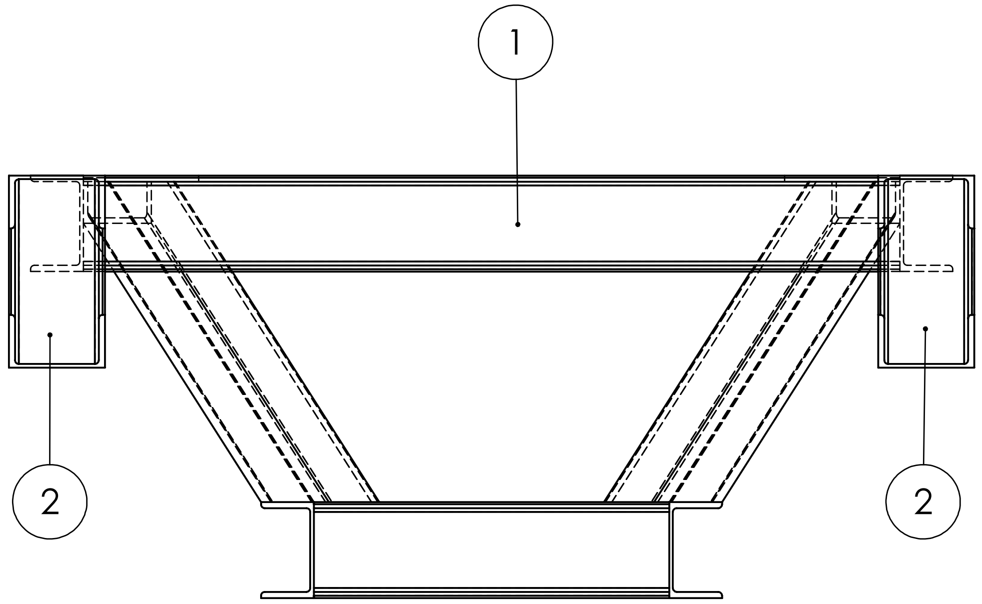
WEIGHT:

SCALE:1:10

SHEET 1 OF 2

NOTES:
1) MATERIAL: 6061 ALUMINUM
2) SHEET 2 OF 2





ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Frame (Simple)		1
2	Side Beam		4

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION N/C

	NAME	SIGNATURE	DATE
DRAWN	NATHAN REED		7/1/14
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:
FRAME W/SIDE BEAM

MATERIAL:
6061 ALUMINUM

WEIGHT:

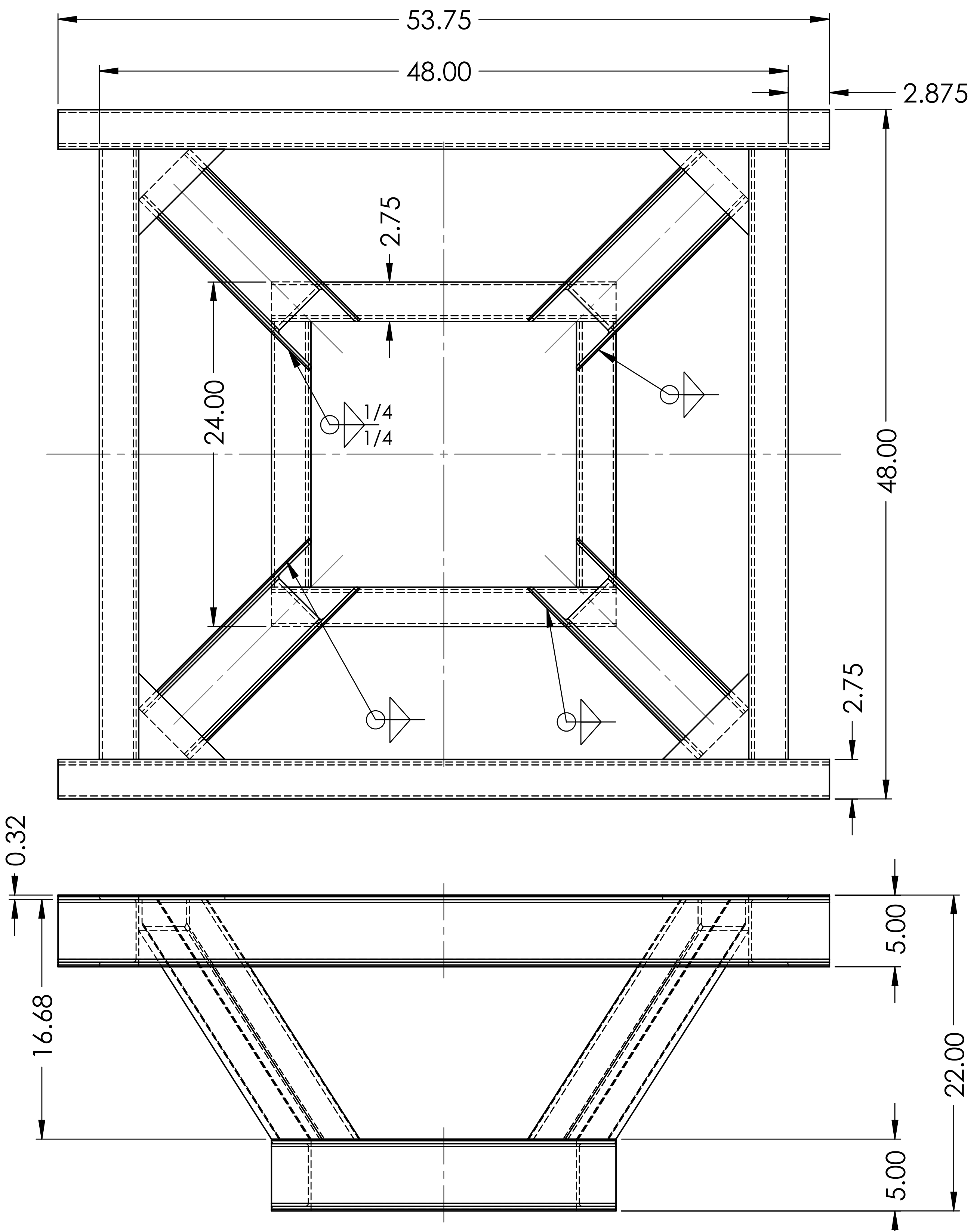
DWG NO.

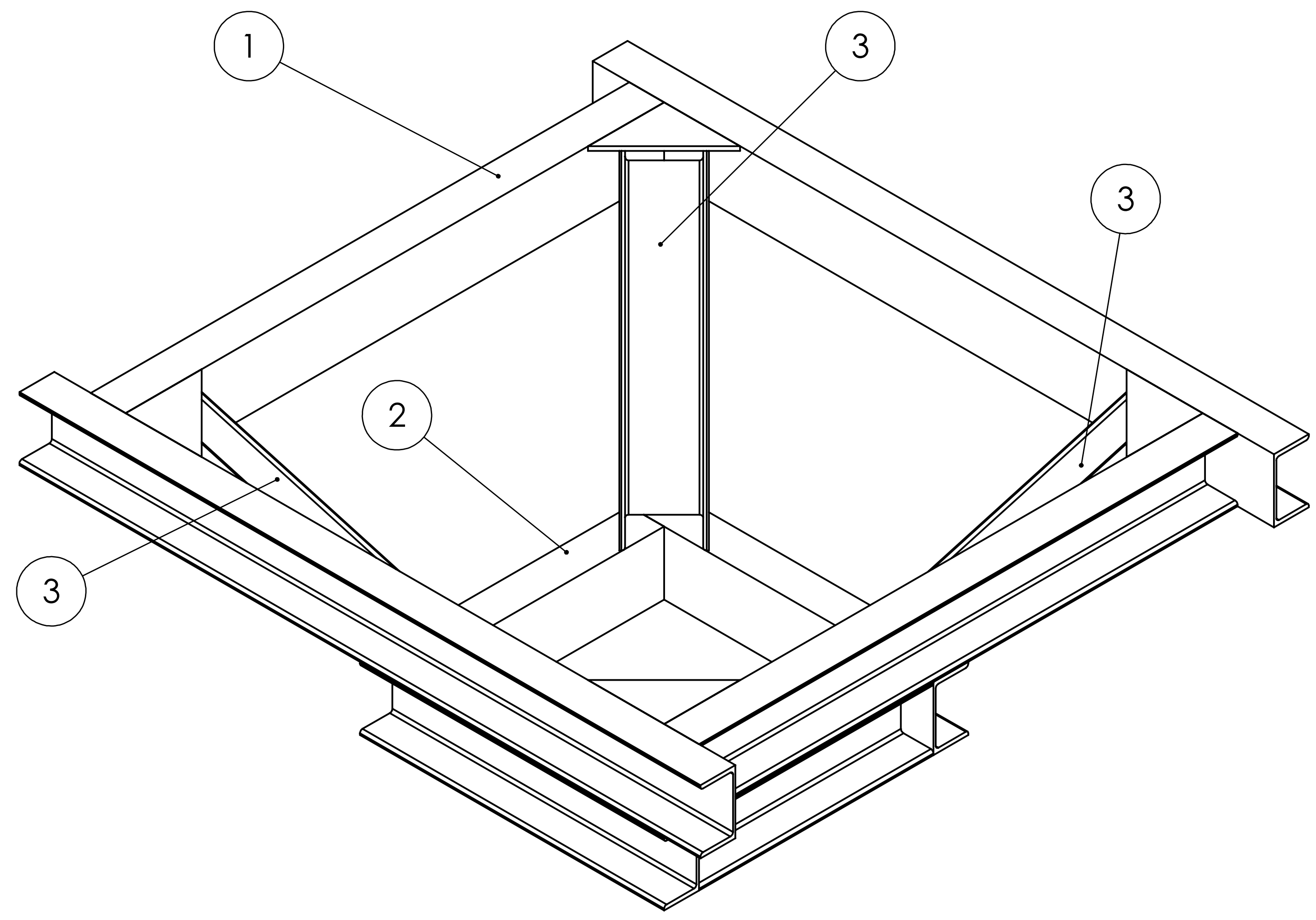
A3

SCALE:1:10

SHEET 2 OF 2

NOTES:
1) ASSEMBLY OF FRAME (SIMPLE)
2) FOR PART DIMENSIONS REFER INDIVIDUAL PART DRAWINGS
3) 1/4 INCH CONTINUOUS FILLET WELD CONNECTING DIAGONAL BEAM TO FRAME (TOP), FRAME (BOTTOM), AND GUSSET(TOP)
4) MATERIAL: 6061 ALUMINUM
5) SHEET 1 OF 2





ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Frame (Top)		1
2	Frame (Bottom)		1
3	Diagonal Beam (Simple Cut)		4

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION N/C

	NAME	SIGNATURE	DATE
DRAWN	NATHAN REED		6/22/14
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

Frame (Simple)

MATERIAL:
6061 ALUMINUM

WEIGHT:

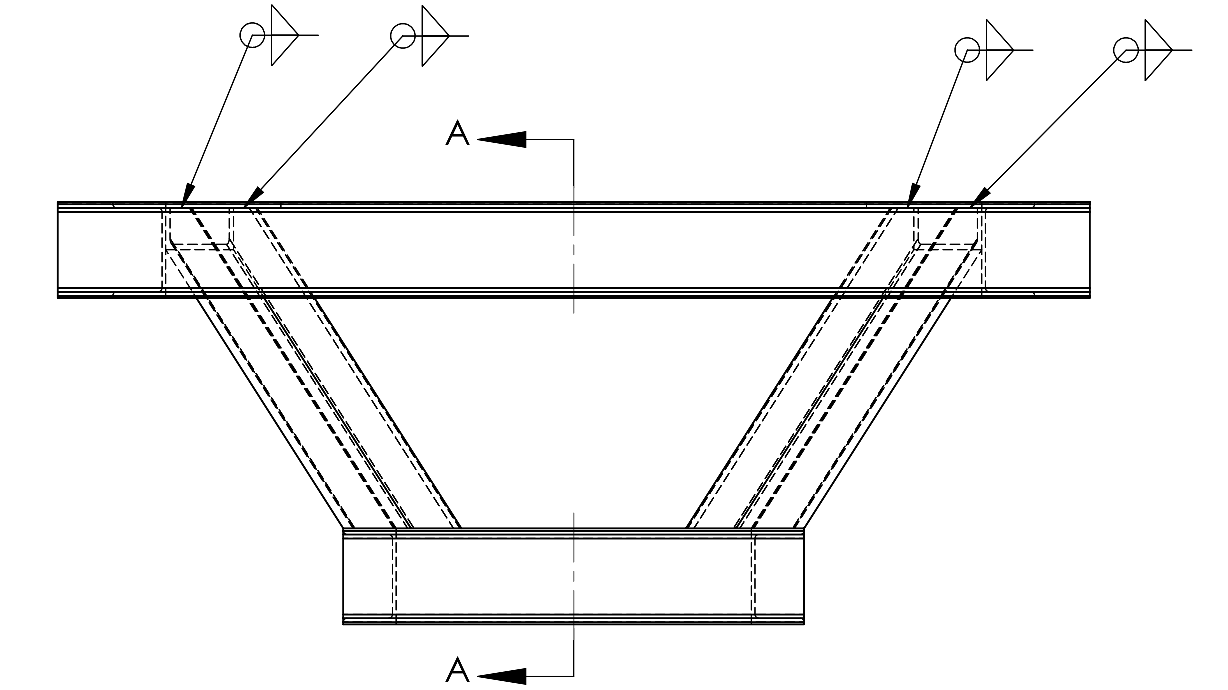
DWG NO.

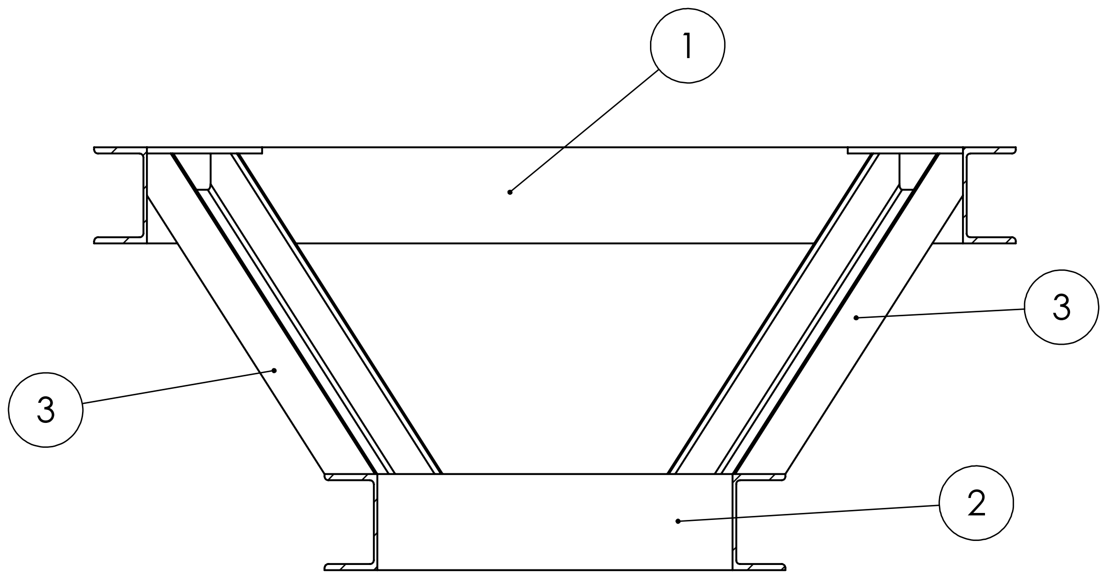
A3

SCALE:1:10

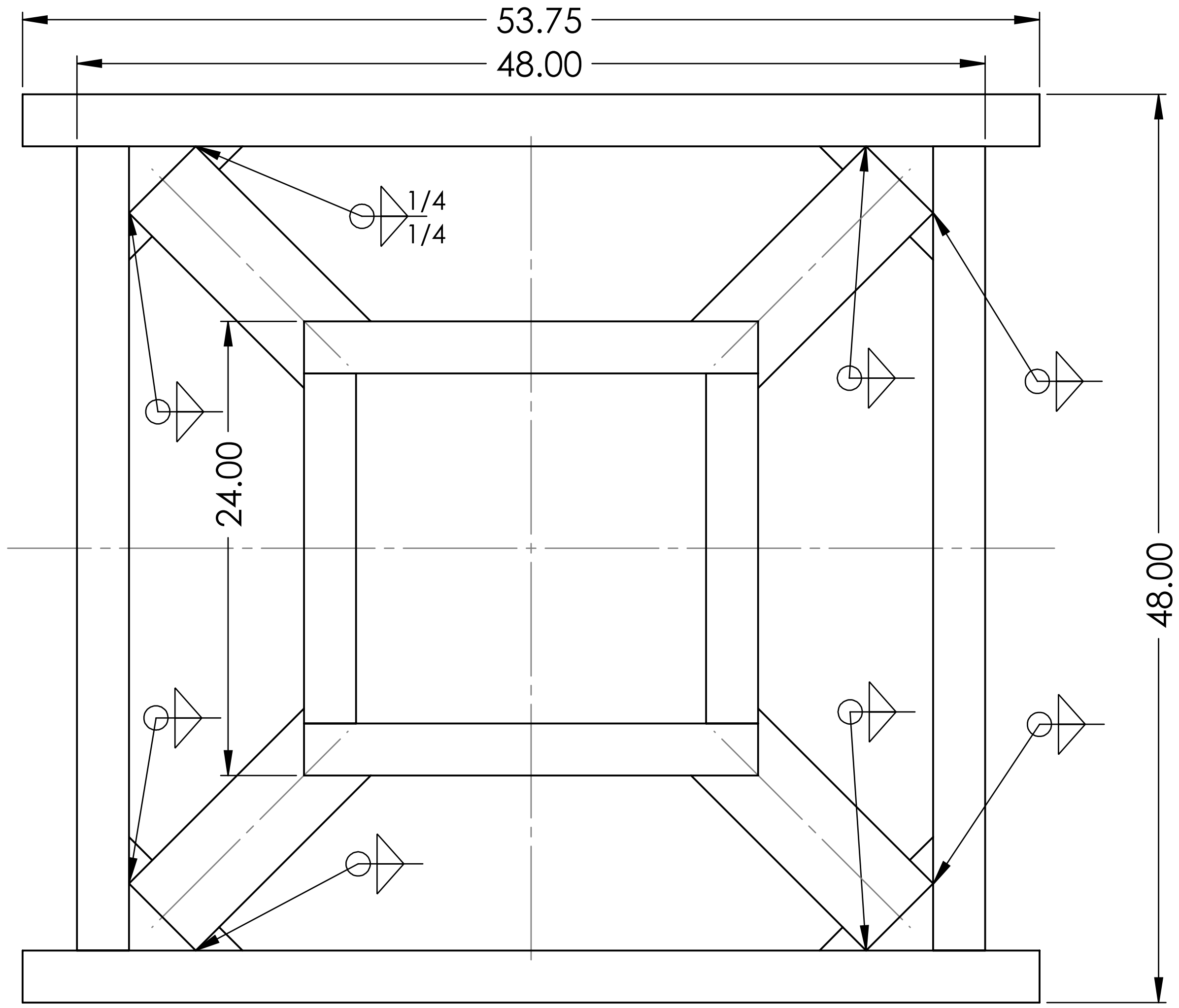
SHEET 1 OF 2

NOTES:
1) 1/4 INCH CONTINUOUS FILLET WELD CONNECTING DIAGONAL BEAM TO FRAME (TOP), FRAME (BOTTOM), AND GUSSET(TOP)
2) SHEET 2 OF 2





SECTION A-A
SCALE 1 : 10



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Frame (Top)		1
2	Frame (Bottom)		1
3	Diagonal Beam (Simple Cut)		4

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION N/C

	NAME	SIGNATURE	DATE
DRAWN	NATHAN REED		6/22/14
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL:
6061 ALUMINUM

WEIGHT:

TITLE:
Frame (Simple)

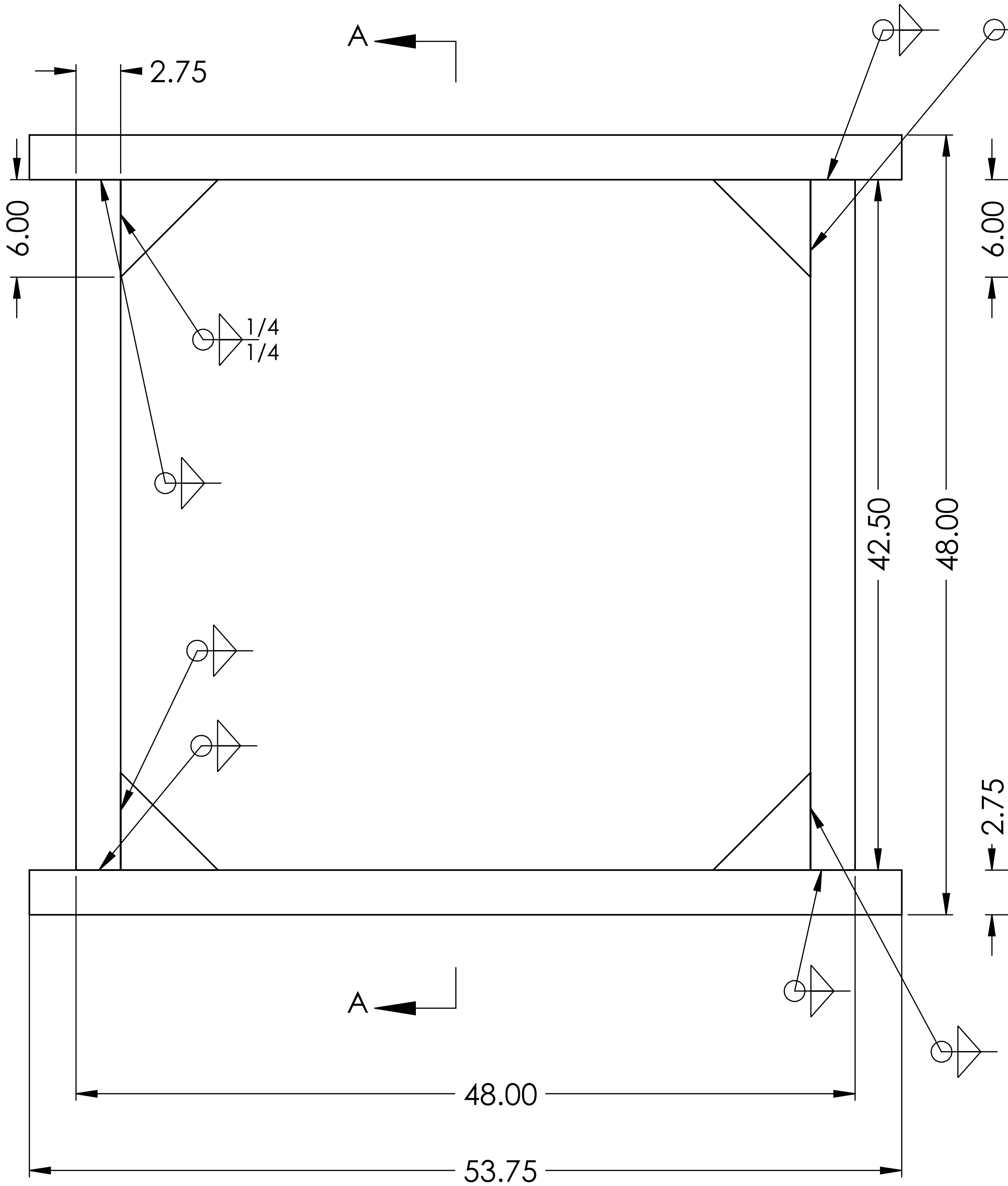
DWG NO.

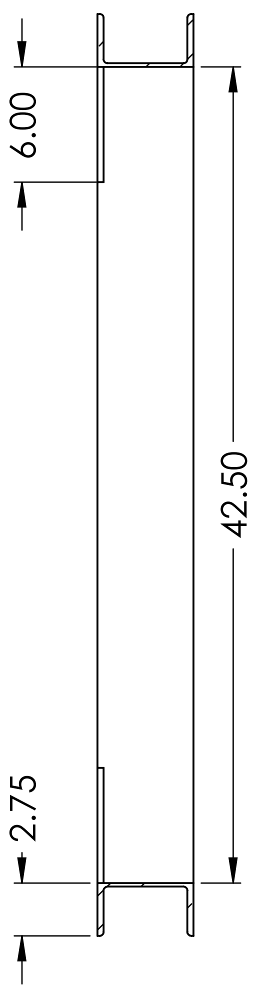
A3

SCALE:1:10

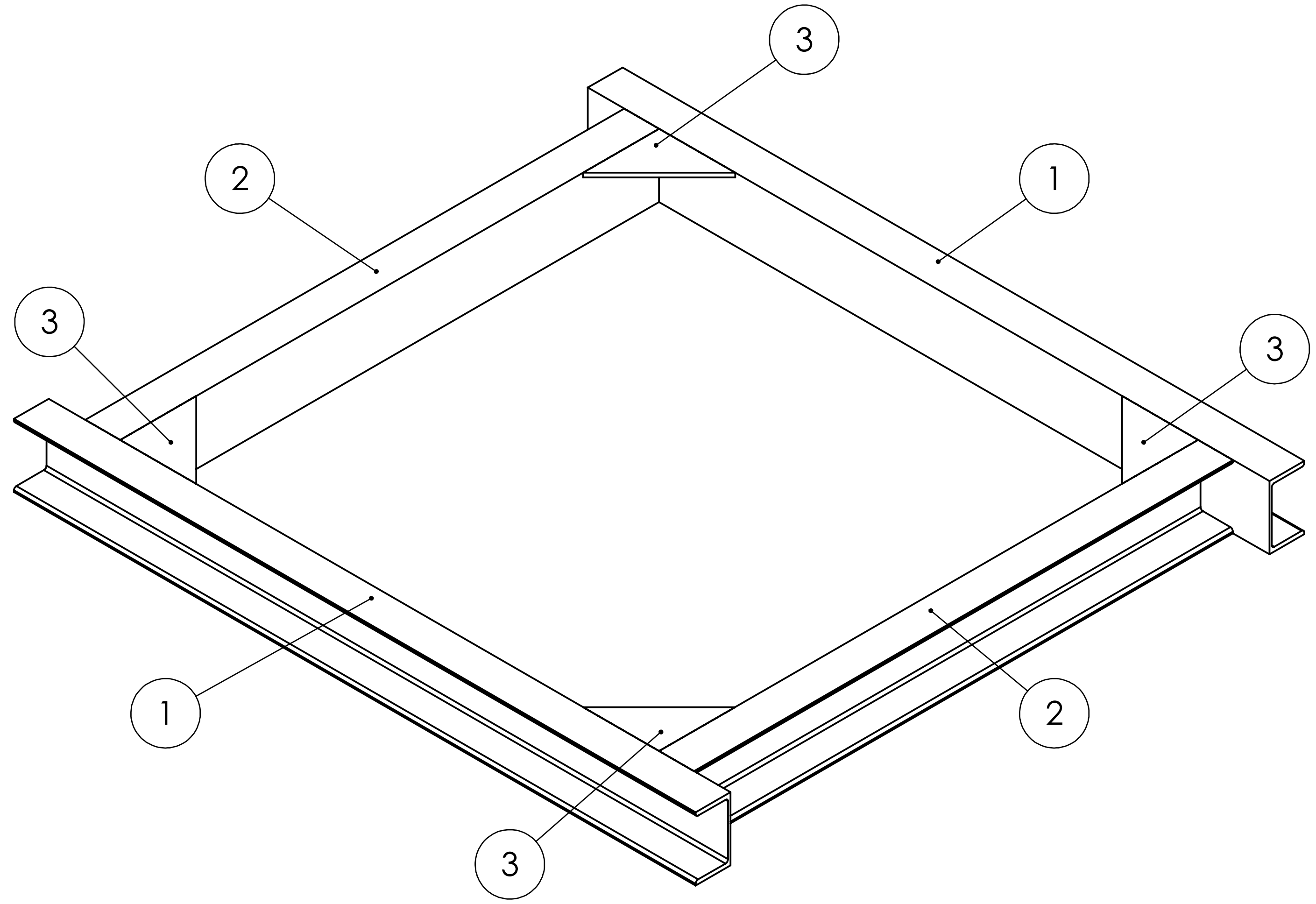
SHEET 2 OF 2

NOTES:
1) SUB-ASSEMBLY OF FRAME (TOP)
2) FOR PART DIMENSIONS REFER TO HANGERS (TOP), INNER CROSSBAR (TOP), AND GUSSET (TOP) PART DRAWINGS
3) 1/4 INCH CONTINUOUS FILLET WELD CONNECTING HANGERS (TOP), INNER CROSSBAR (TOP), AND GUSSET (TOP)
4) MATERIAL: 6061 ALUMINUM





SECTION A-A
SCALE 1 : 10



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Hangers (Top)		2
2	Inner Crossbar (Top)		2
3	Gusset (Top)		4

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION N/C

	NAME	SIGNATURE	DATE
DRAWN	NATHAN REED		6/22/14
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

Frame (Top)

MATERIAL: 6061 ALUMINUM

WEIGHT:

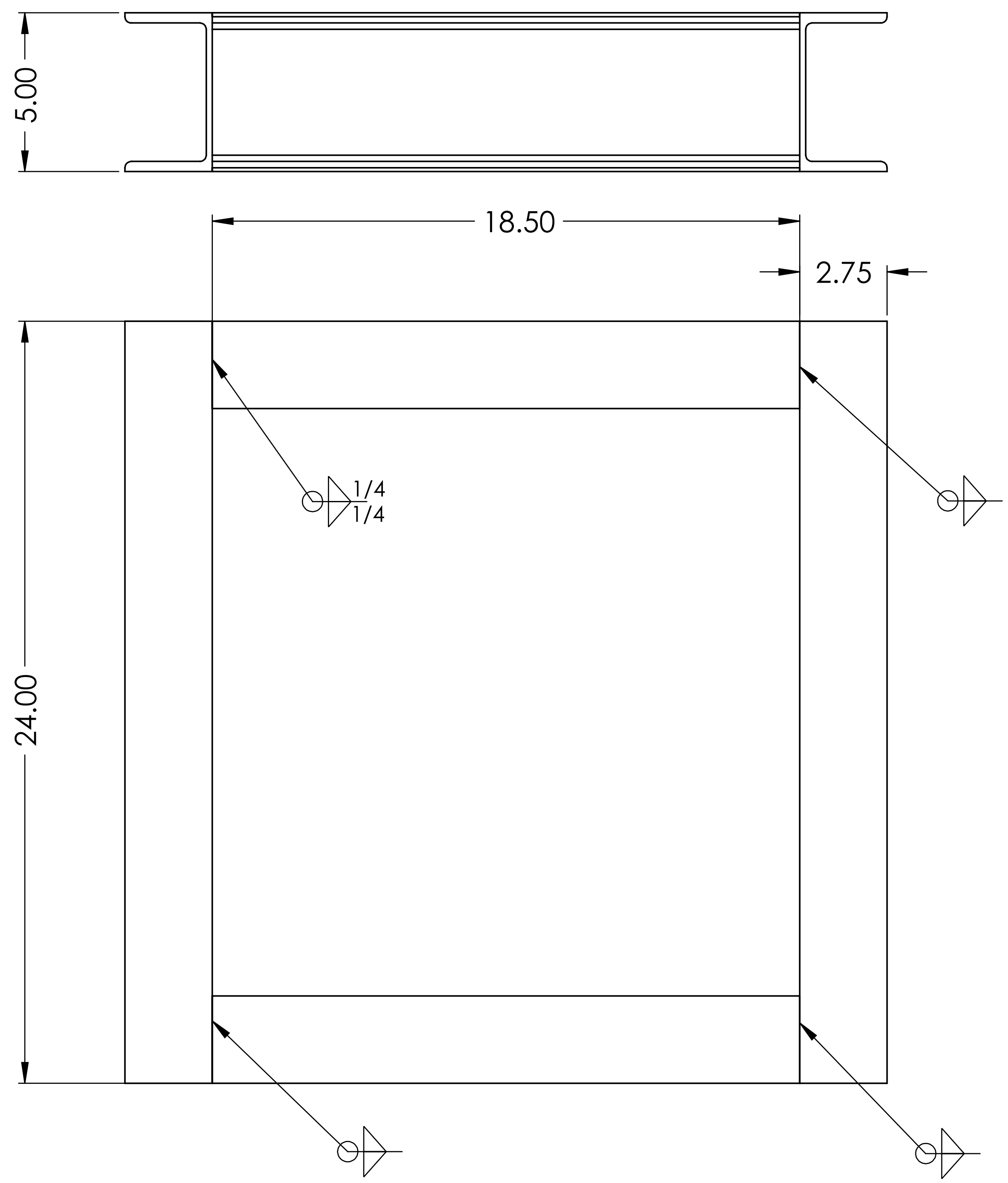
DWG NO.

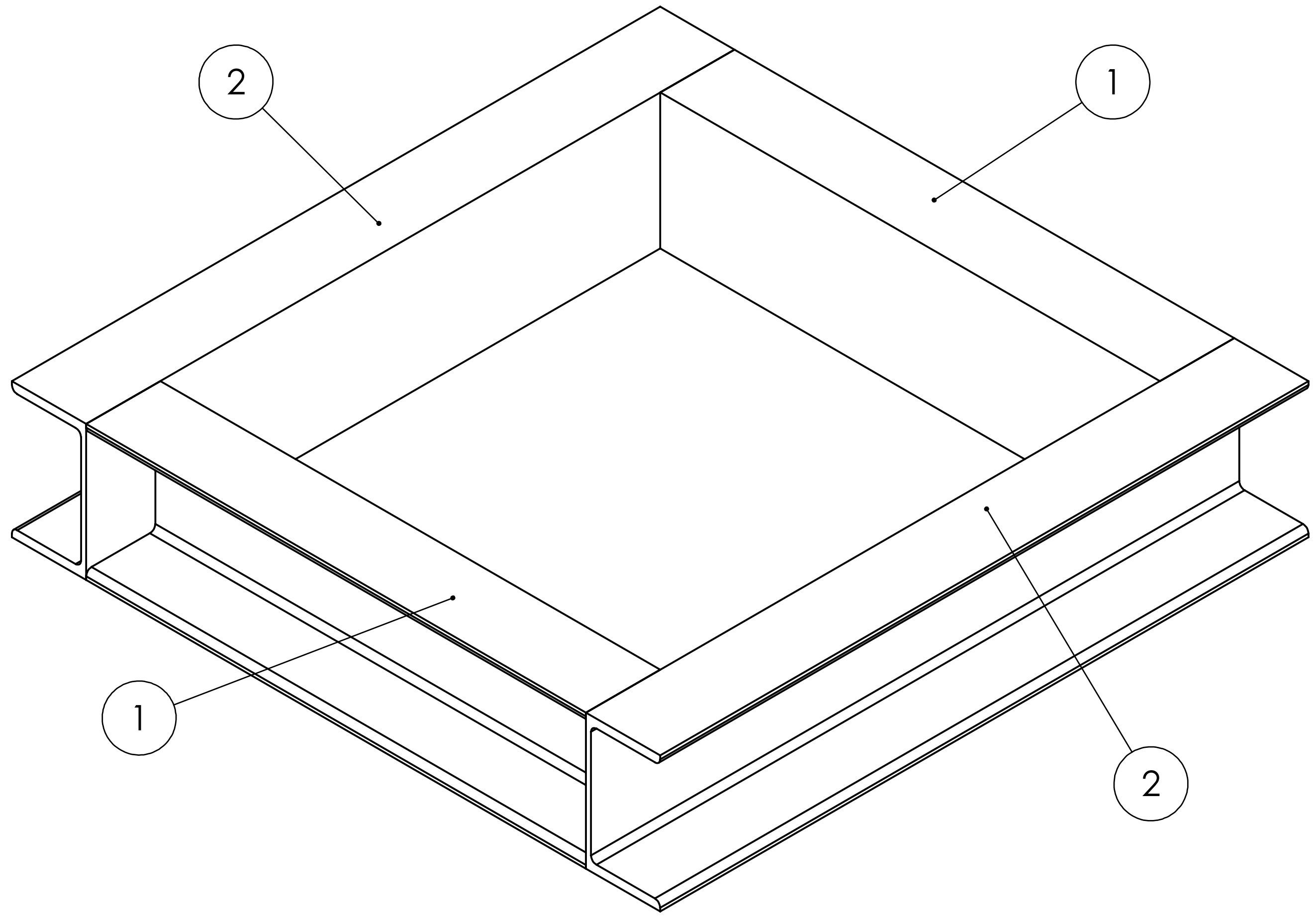
A3

SCALE:1:10

SHEET 1 OF 1

NOTES:
1) SUB-ASSEMBLY OF FRAME (BOTTOM)
2) FOR PART DIMENSIONS REFER TO INNER CROSSBAR (BOTTOM) AND OUTER CROSSBAR (BOTTOM) PART DRAWINGS
3) 1/4 INCH CONTINUOUS FILLET WELD CONNECTING INNER CROSSBAR (BOTTOM) AND OUTER CROSSBAR (BOTTOM)
4) MATERIAL: 6061 ALUMINUM





ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Inner Crossbar (Bottom)		2
2	Outer Crossbar (Bottom)		2

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION N/C

	NAME	SIGNATURE	DATE
DRAWN	NATHAN REED		6/22/14
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:
Frame (Bottom)

MATERIAL:
6061 ALUMINUM

WEIGHT:

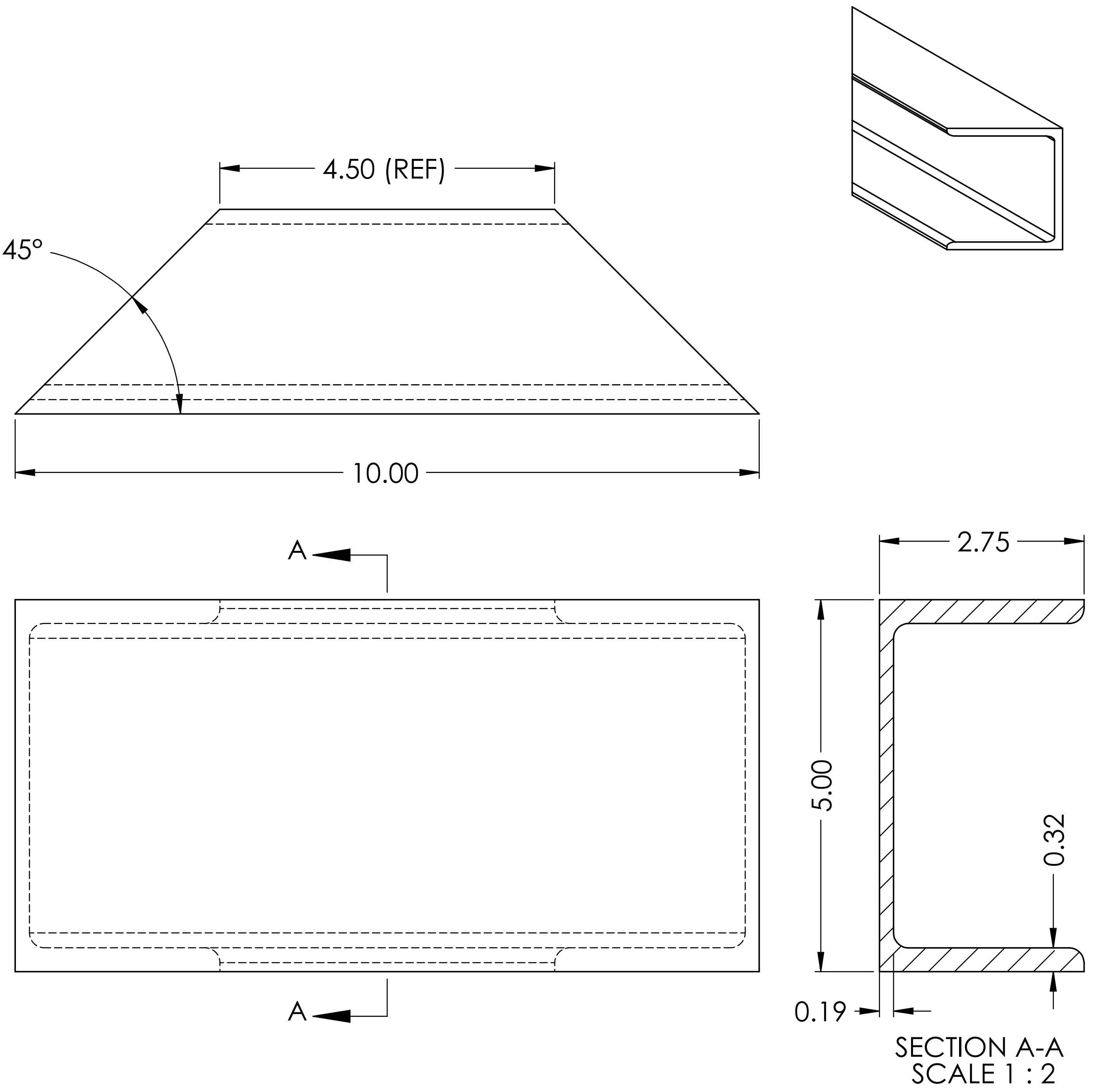
DWG NO.

A3

SCALE:1:5

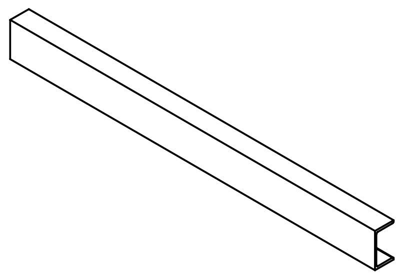
SHEET 1 OF 1

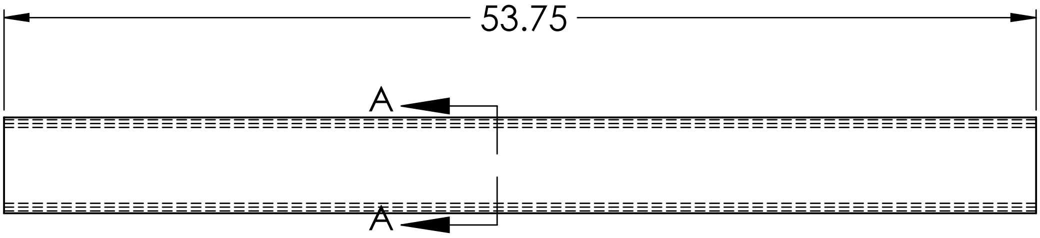
NOTES:
1) 4 PARTS NEEDED
2) WILL BE WELDED TO ENDS OF
HANGERS IN FRAME ASSEMBLY
3) MATERIAL: 6061 ALUMINUM

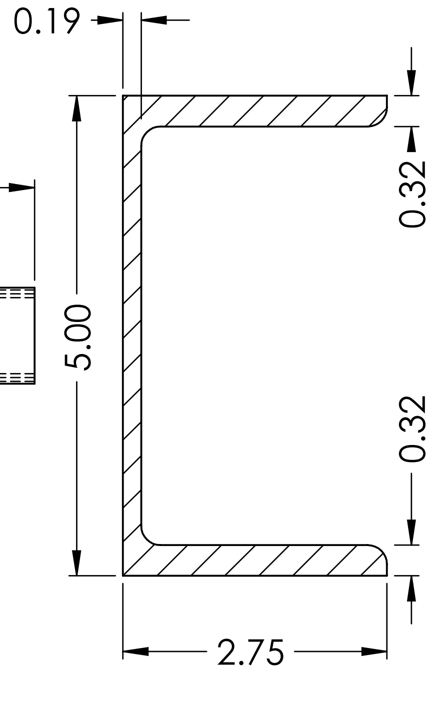


UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:		FINISH:		DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION N/C	
	NAME	SIGNATURE	DATE		TITLE:		
DRAWN	NATHAN REED		7/1/14		Side Beam		
CHK'D							
APPV'D							
MFG							
Q.A				MATERIAL: 6061 ALUMINUM	DWG NO.		A4
				WEIGHT:	SCALE:1:2	SHEET 1 OF 1	

NOTES:
1) 2 PARTS NEEDED
2) WILL BE WELDED IN
FRAME (TOP) ASSEMBLY
3) MATERIAL: 6061 ALUMINUM







SECTION A-A
SCALE 1 : 2

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION N/C

	NAME	SIGNATURE	DATE
DRAWN	NATHAN REED		6/22/14
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

Hangers (Top)

MATERIAL:
6061 ALUMINUM

WEIGHT:

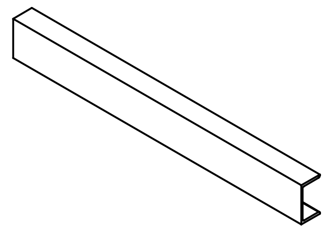
DWG NO.

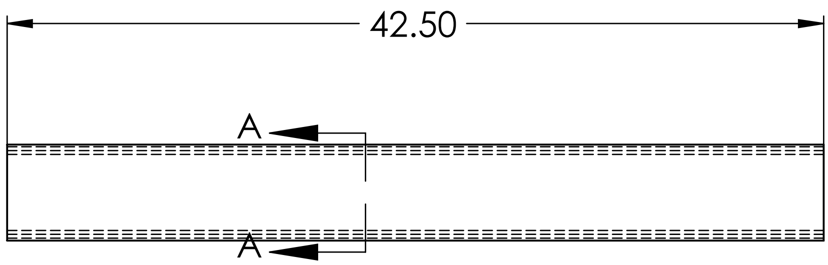
A4

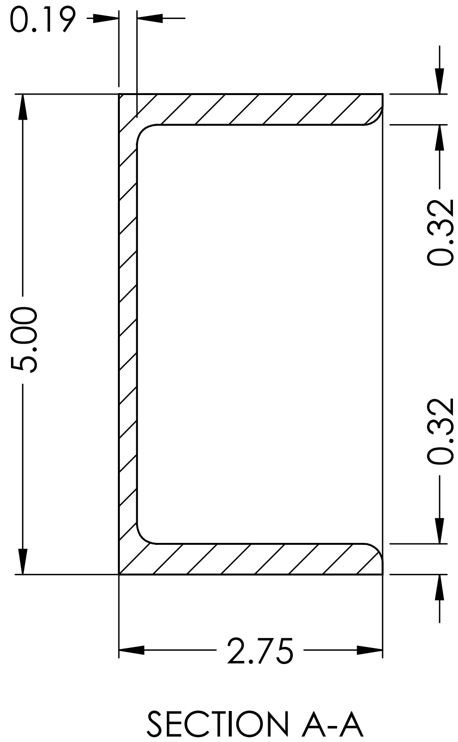
SCALE:1:5

SHEET 1 OF 1

NOTES:
1) 2 PARTS NEEDED
2) WILL BE WELDED IN
FRAME (TOP) ASSEMBLY
3) MATERIAL: 6061 ALUMINUM







SECTION A-A
SCALE 1 : 2

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION N/C

	NAME	SIGNATURE	DATE
DRAWN	NATHAN REED		6/22/14
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

Inner Crossbar (Top)

MATERIAL:
6061 ALUMINUM

WEIGHT:

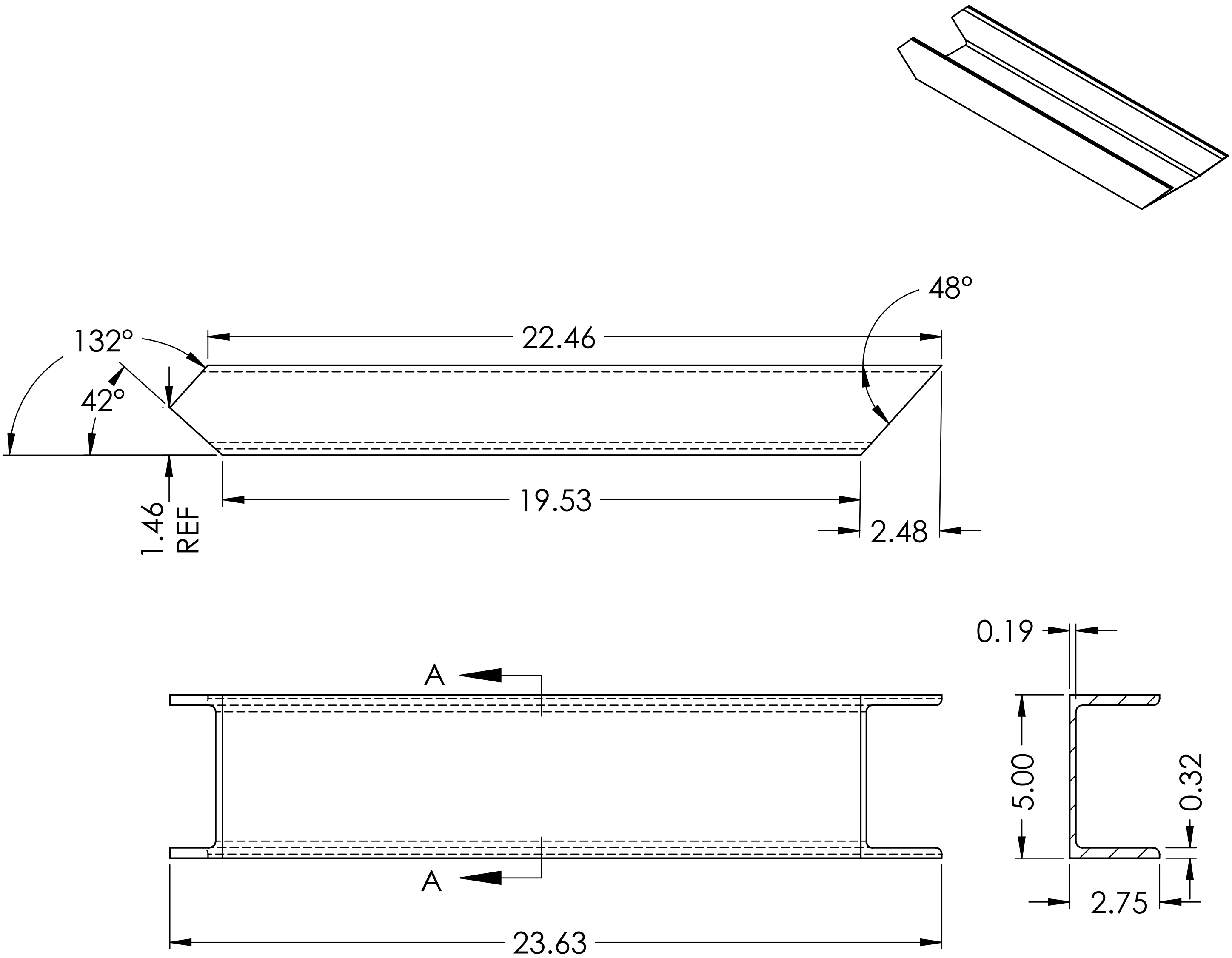
DWG NO.

A4

SCALE:1:10

SHEET 1 OF 1

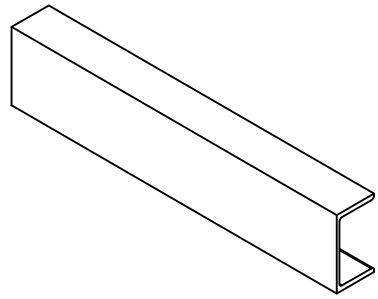
NOTES:
1) 4 PARTS NEEDED
2) WILL BE WELDED TO CONNECT FRAME (TOP) AND FRAME (BOTTOM) ASSEMBLIES
3) MATERIAL: 6061 ALUMINUM

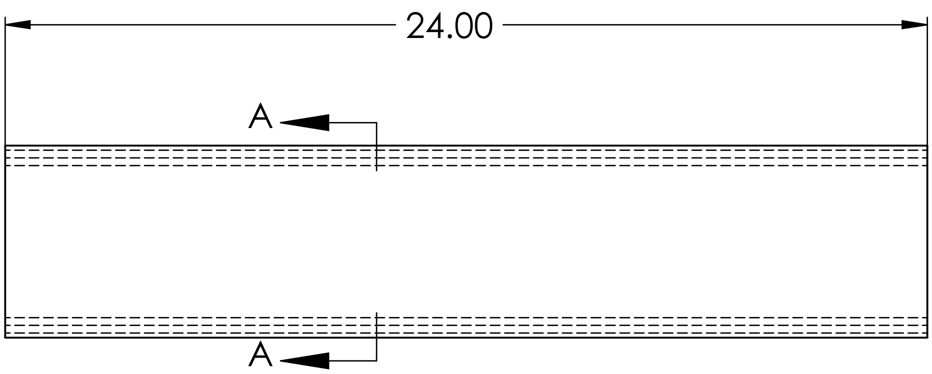


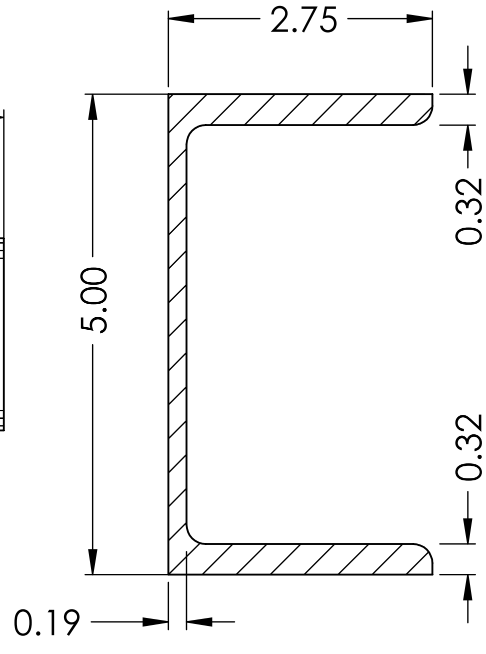
SECTION A-A
SCALE 1 : 5

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:		FINISH:			DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION N/C
	NAME	SIGNATURE	DATE			TITLE:	
DRAWN	NATHAN REED		6/22/14			Diagonal Beam (Simple Cut)	
CHK'D							
APPV'D							
MFG							
Q.A				MATERIAL: 6061 ALUMINUM		DWG NO.	A4
						SCALE:1:5	SHEET 1 OF 1
				WEIGHT:			

NOTES:
1) 2 PARTS NEEDED
2) WILL BE WELDED IN
FRAME (BOTTOM) ASSEMBLY
3) MATERIAL: 6061 ALUMINUM



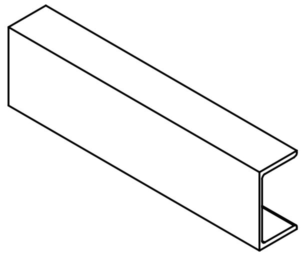


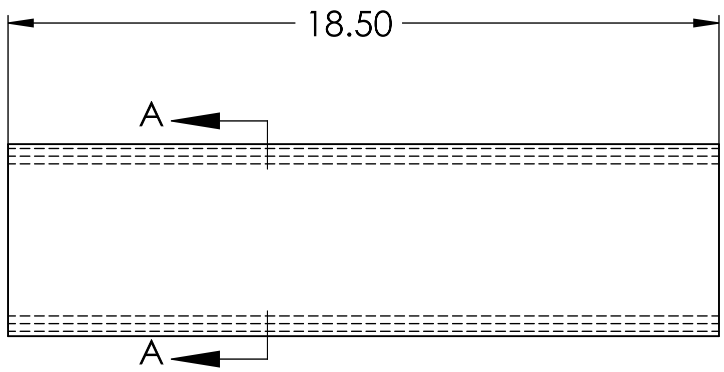


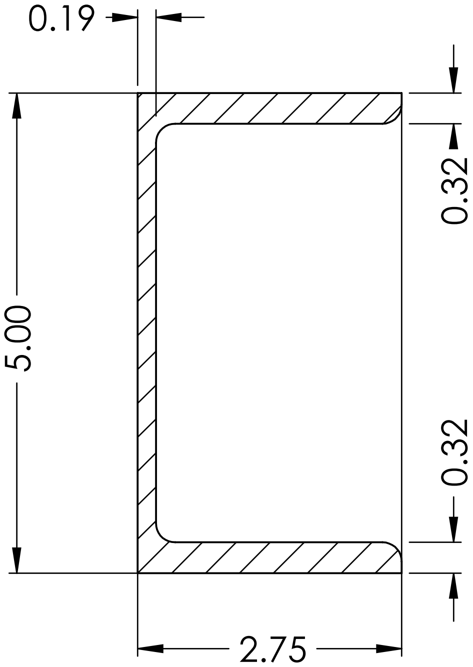
SECTION A-A
SCALE 1 : 2

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:		DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION N/C	
	NAME	SIGNATURE	DATE	TITLE:		
DRAWN	NATHAN REED		6/22/14	Outer Crossbar (Bottom)		
CHK'D						
APPV'D						
MFG						
Q.A			MATERIAL: 6061 ALUMINUM	DWG NO.		A4
			WEIGHT:	SCALE:1:5	SHEET 1 OF 1	

NOTES:
1) 2 PARTS NEEDED
2) WILL BE WELDED IN
FRAME (BOTTOM) ASSEMBLY
3) MATERIAL: 6061 ALUMINUM



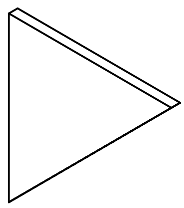


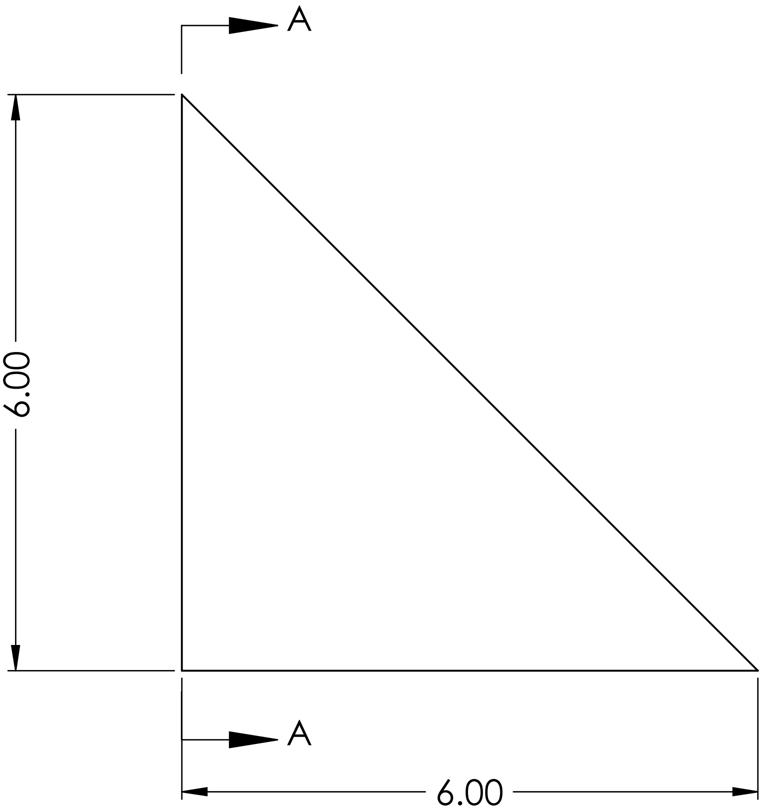


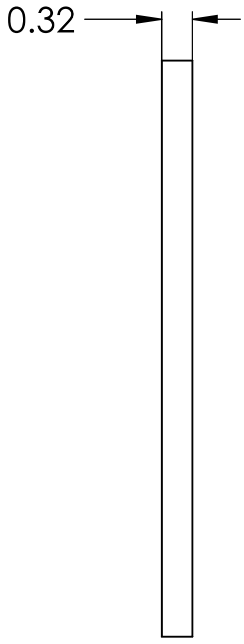
SECTION A-A
SCALE 1 : 2

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:		DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION N/C	
	NAME	SIGNATURE	DATE	TITLE:		
DRAWN	NATHAN REED		6/22/14	Inner Crossbar (Bottom)		
CHK'D						
APPV'D						
MFG						
Q.A			MATERIAL: 6061 ALUMINUM	DWG NO.		A4
				SCALE:1:5	SHEET 1 OF 1	
			WEIGHT:			

NOTES:
1) 4 PARTS NEEDED
2) WILL BE WELDED IN
FRAME (TOP) ASSEMBLY
3) MATERIAL: 6061 ALUMINUM

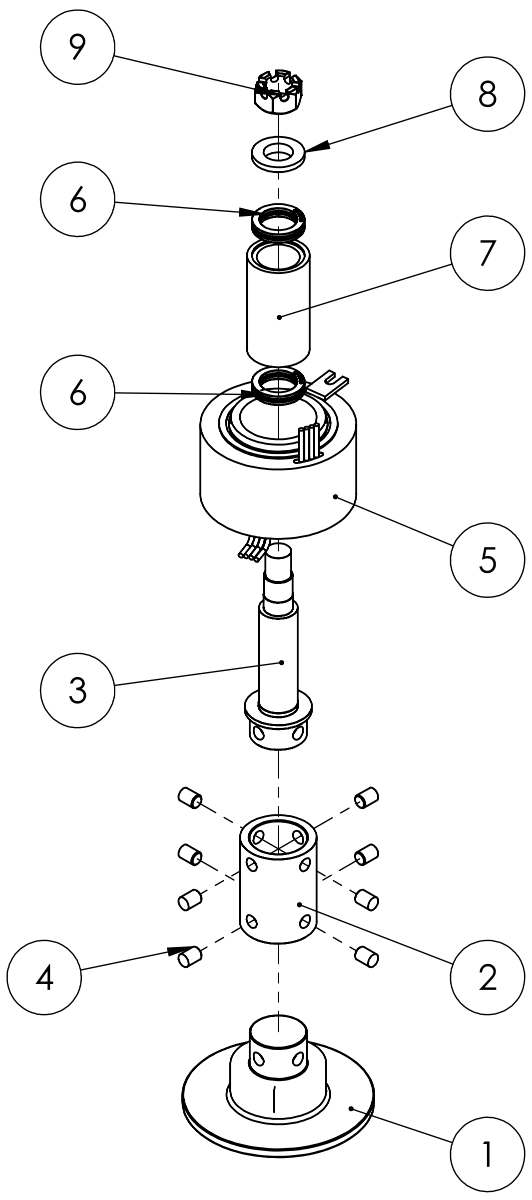


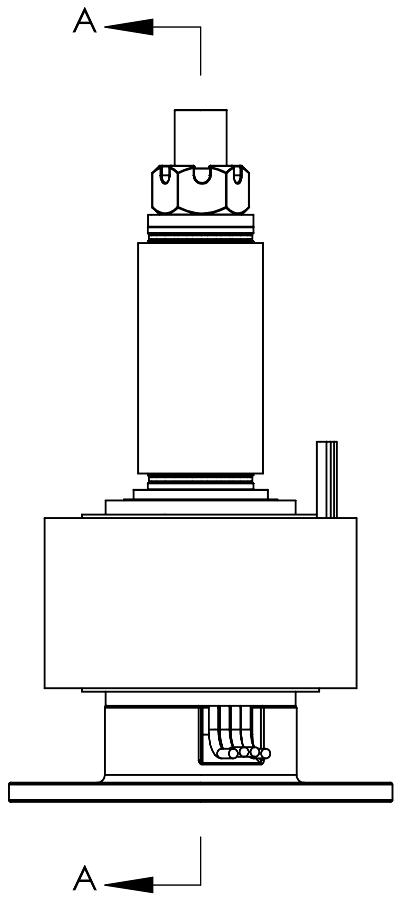


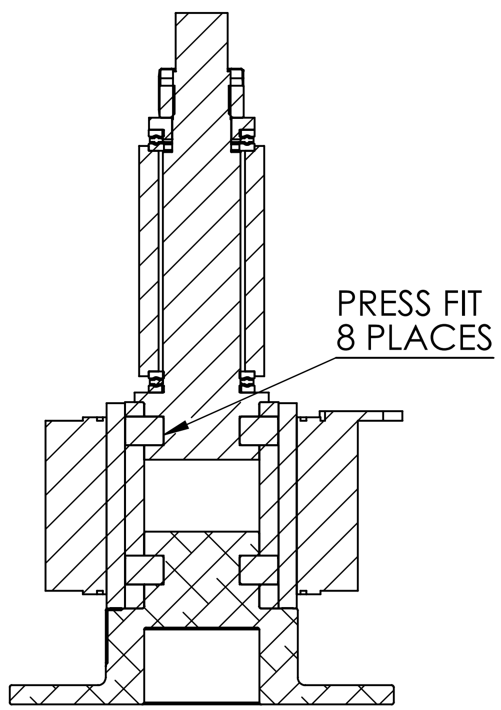


SECTION A-A
SCALE 1 : 2

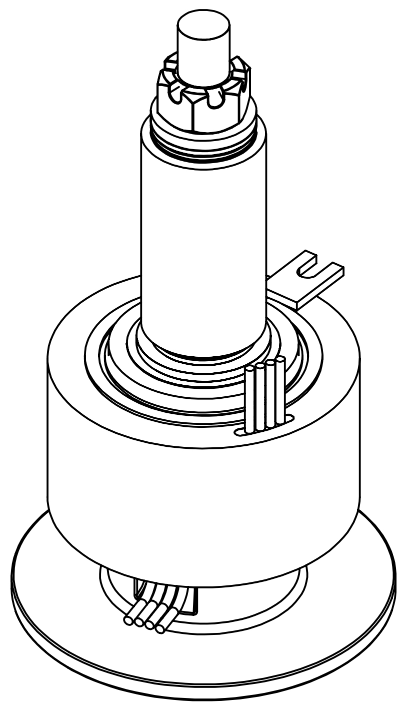
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:		DEBUR AND BREAK SHARP EDGES		DO NOT SCALE DRAWING	REVISION N/C
	NAME	SIGNATURE	DATE		TITLE:	
DRAWN	NATHAN REED		6/22/14		Gusset (Top)	
CHK'D						
APPV'D						
MFG						
Q.A				MATERIAL: 6061 ALUMINUM	DWG NO.	A4
					SCALE:1:2	SHEET 1 OF 1
				WEIGHT:		







SECTION A-A



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Hub		1
2	4in.TorqueTube		1
3	Main Drive Shaft		1
4	Plug		8
5	Slip Ring		1
6	AST_Bearings_51110dwg		2
7	bearing tube		1
8	topBearingRetainer		1
9	Slotted Hex Nut		1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION N/C

	NAME	SIGNATURE	DATE
DRAWN	NATHAN REED		8/11/14
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

MATERIAL:

WEIGHT:

DWG NO. Drive Shaft

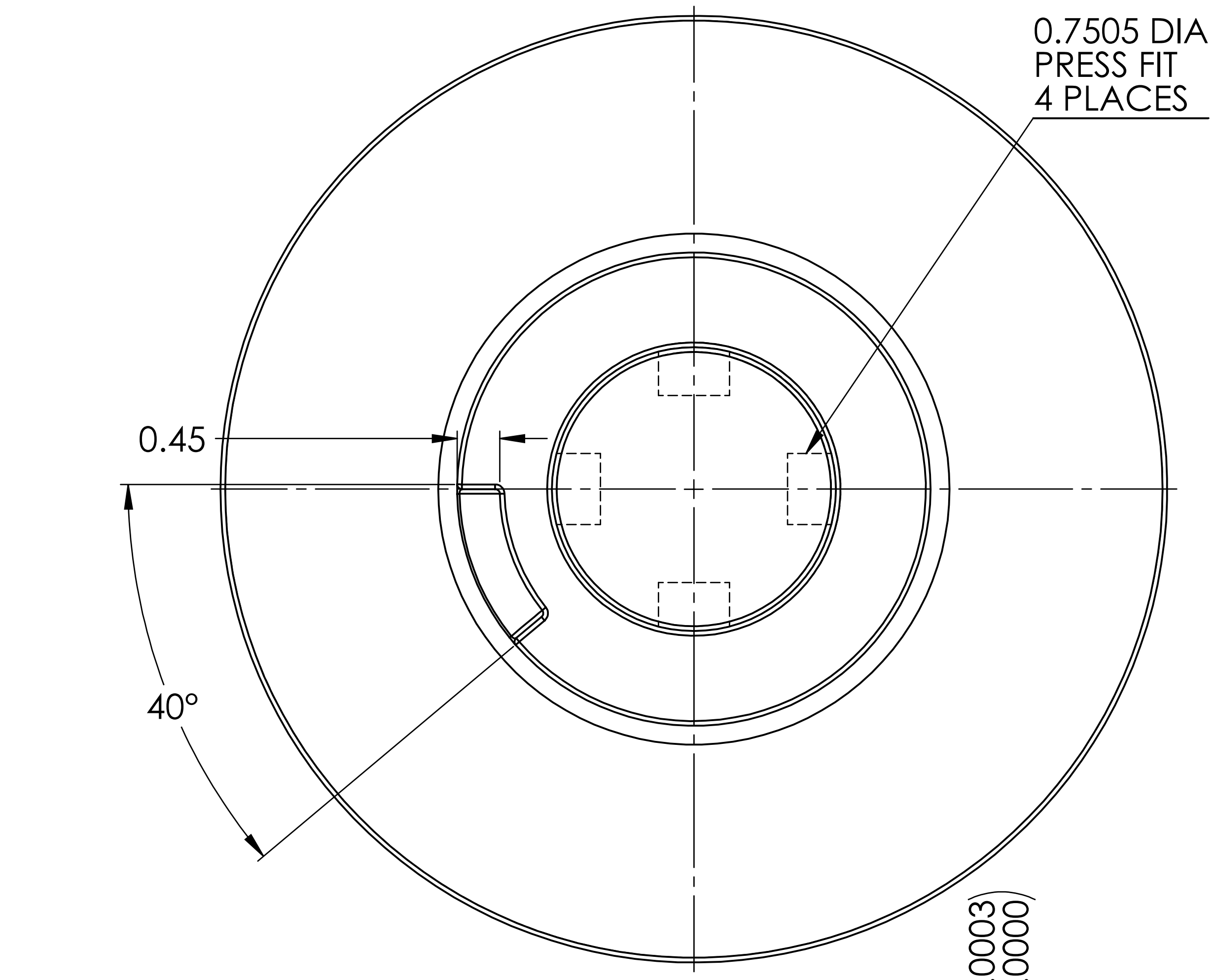
A3

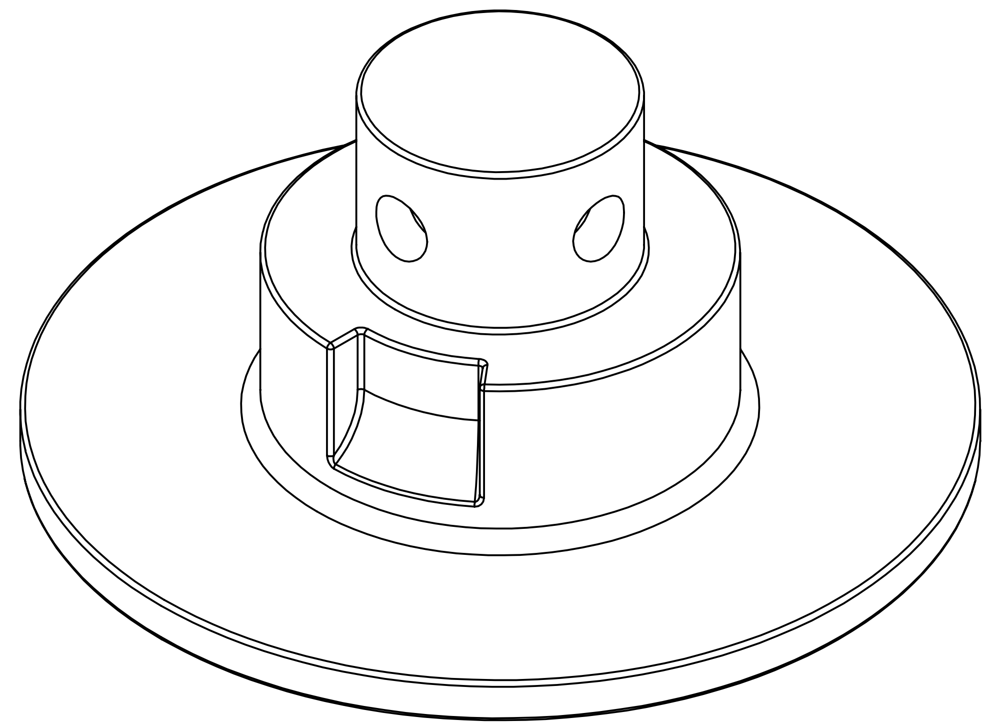
SCALE:1:5

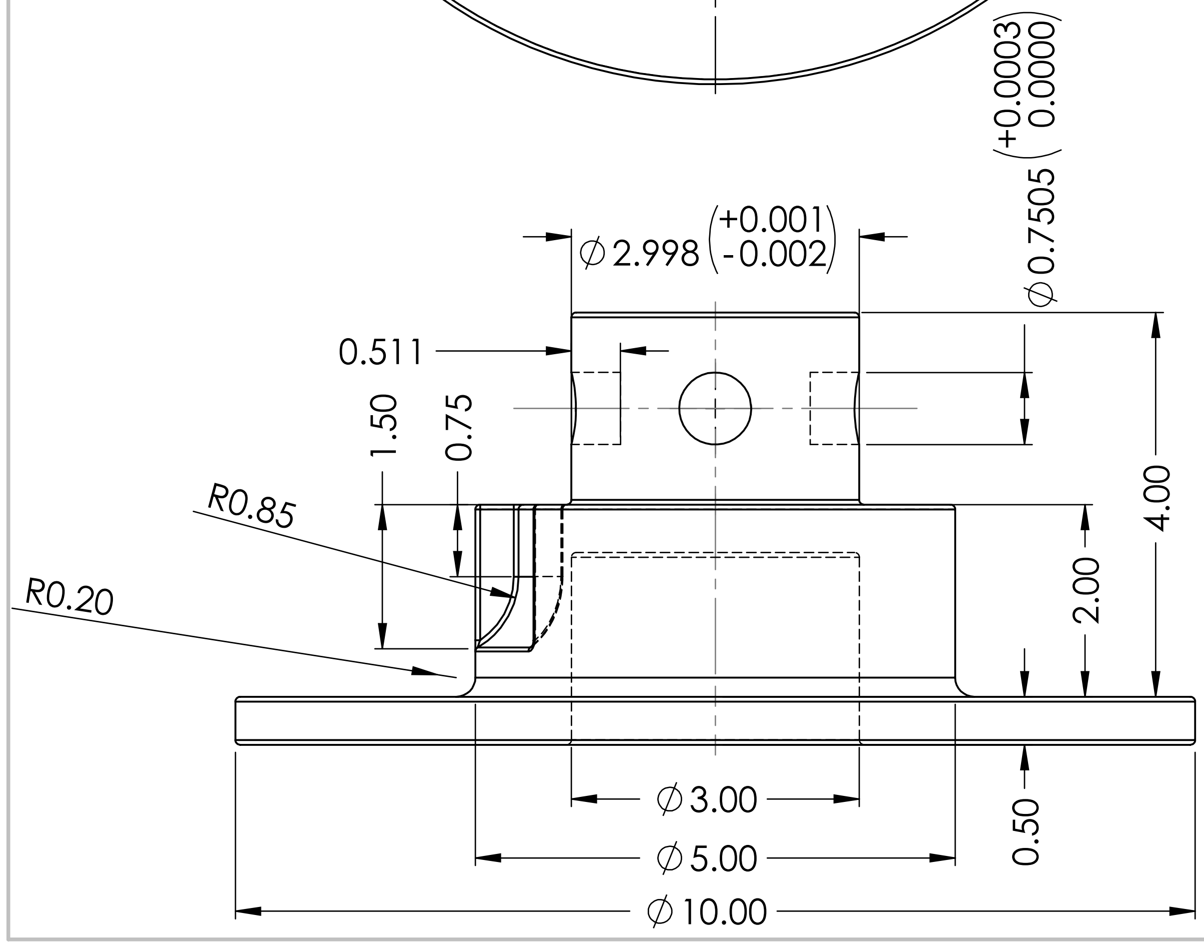
SHEET 1 OF 1

NOTES:
1) 1 PART NEEDED
2) 0.05 RADUIS ON ALL EDGES
UNLESS OTHERWISE SPECIFIED
3) MATERIAL: 6061 ALUMINUM

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED
	N/C	INITIAL DRAFT	7/02/14	
	A		7/28/14	

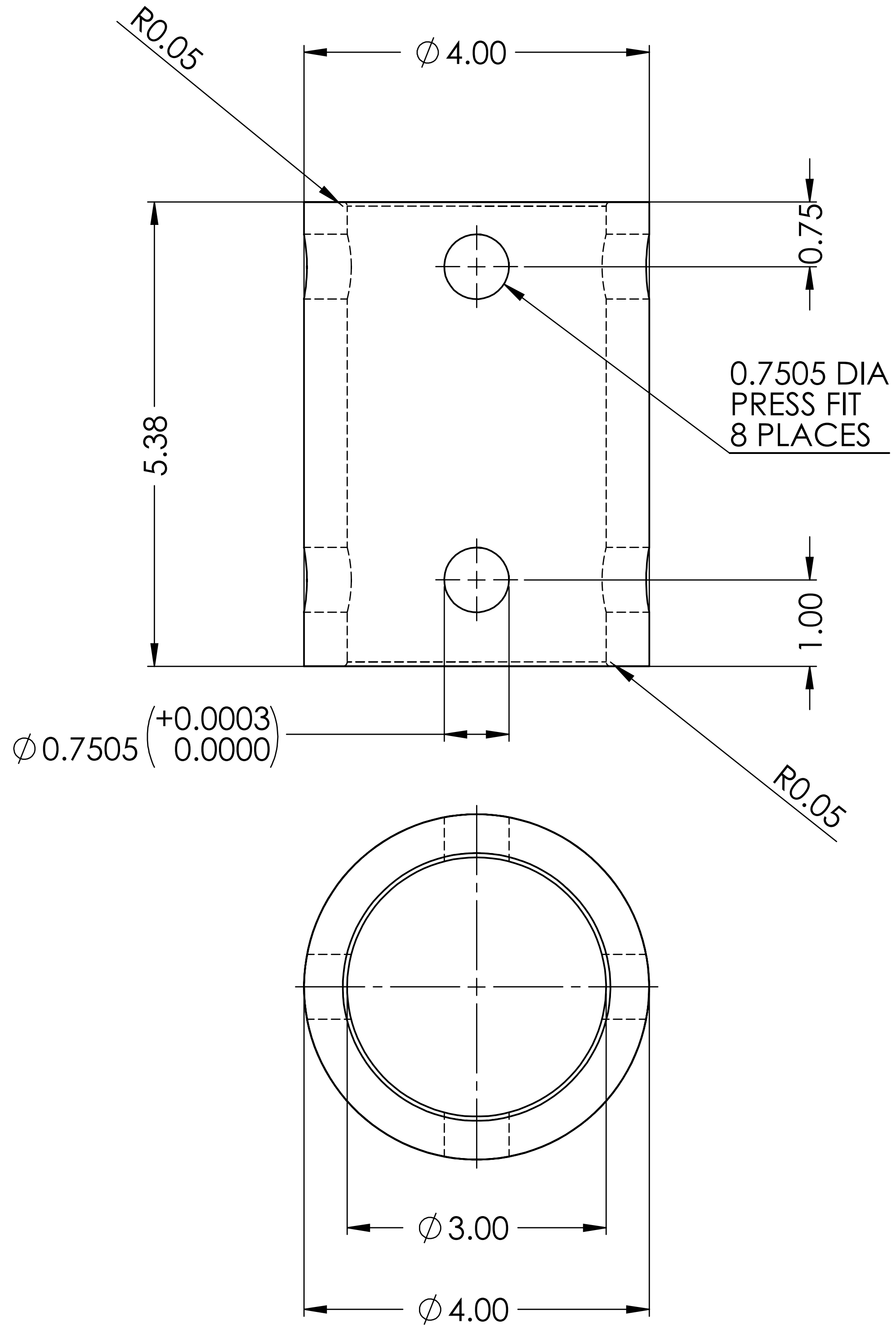


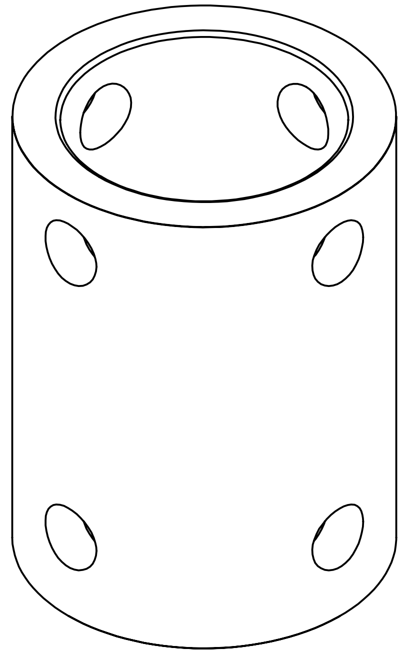




UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION A
	NAME	SIGNATURE	DATE	TITLE: Hub
DRAWN	NATHAN REED		7/28/14	
CHK'D				
APPV'D				
MFG				
Q.A			MATERIAL: 6061 ALUMINUM	DWG NO. A3
			WEIGHT:	SCALE:1:2 SHEET 1 OF 1

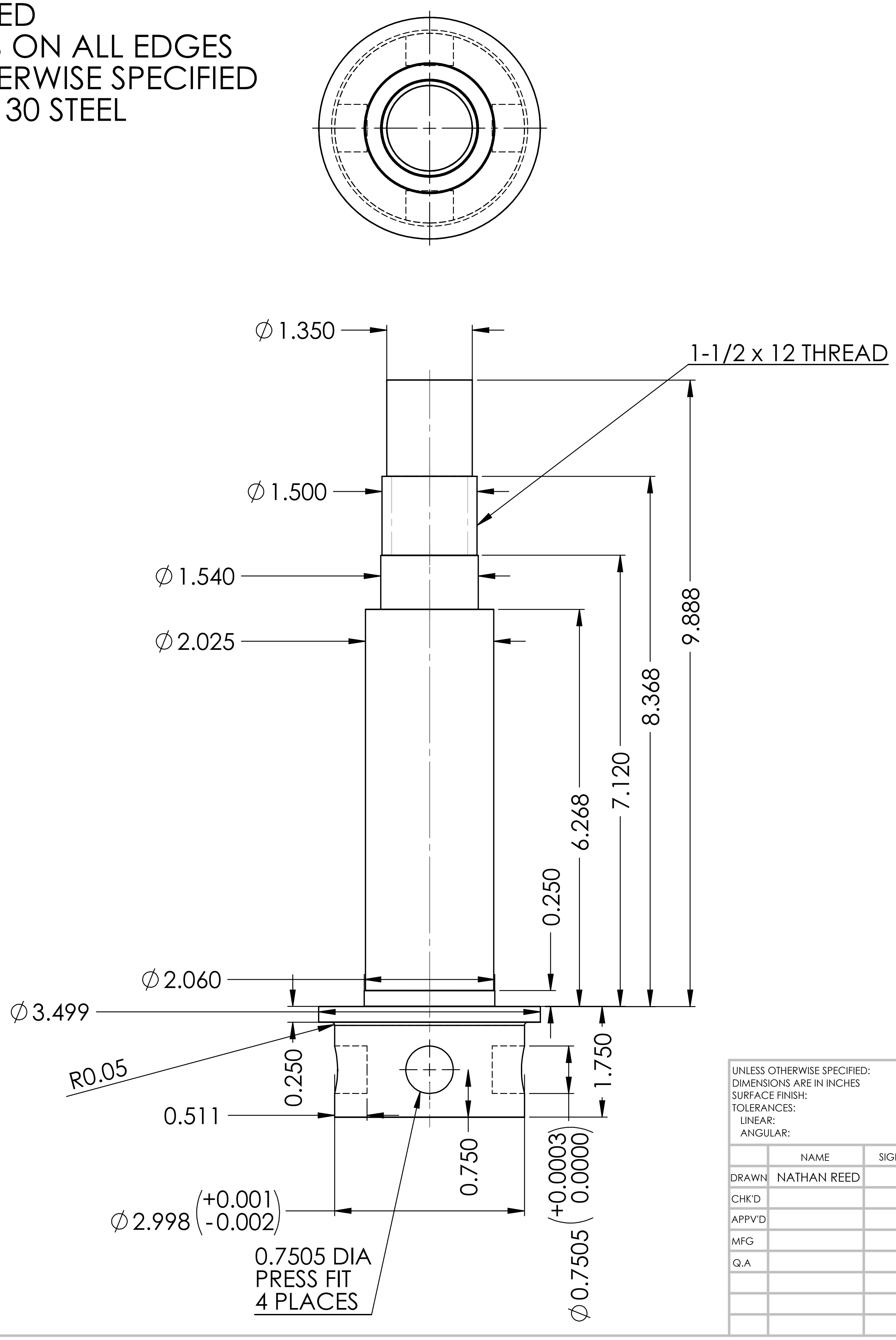
NOTES:
1) 1 PART NEEDED
2) 0.002 RADUIS ON ALL EDGES
UNLESS OTHERWISE SPECIFIED
3) MATERIAL: 6061 ALUMINUM

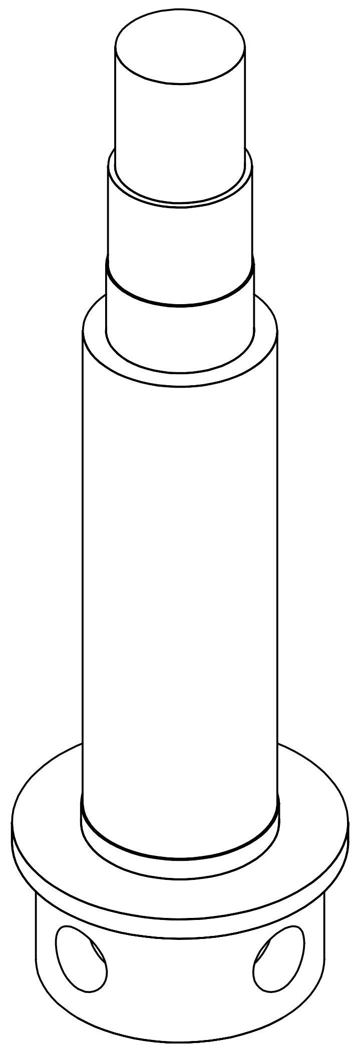




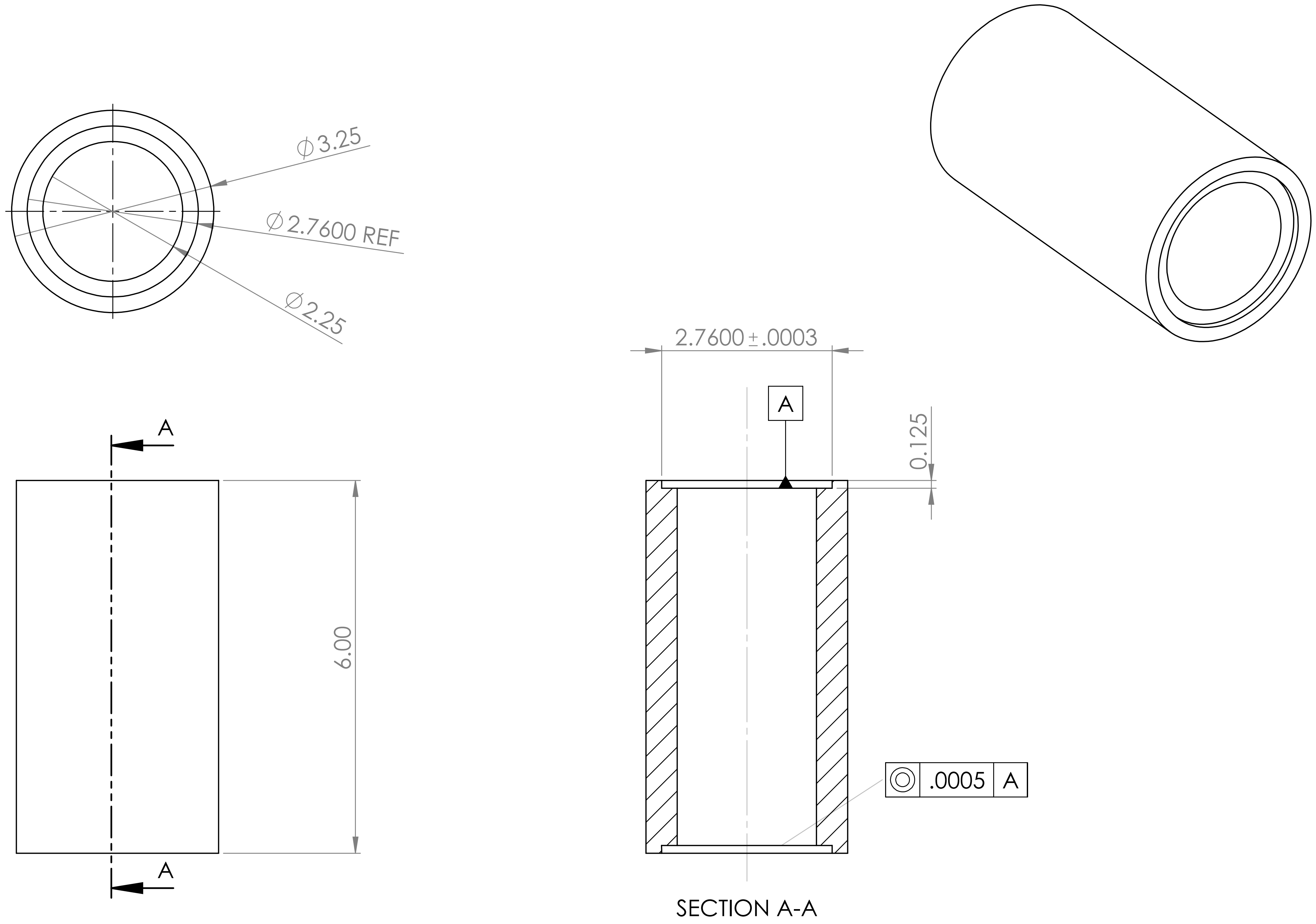
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:		FINISH:			DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION N/C
	NAME	SIGNATURE	DATE			TITLE:	
DRAWN	NATHAN REED		7/30/14			4in.TorqueTube	
CHK'D							
APPV'D							
MFG							
Q.A				MATERIAL: 6061 ALUMINUM		DWG NO.	A3
				WEIGHT:		SCALE:1:2	SHEET 1 OF 1

NOTES:
1) 1 PART NEEDED
2) 0.002 RADUIS ON ALL EDGES
UNLESS OTHERWISE SPECIFIED
3) MATERIAL: 4130 STEEL

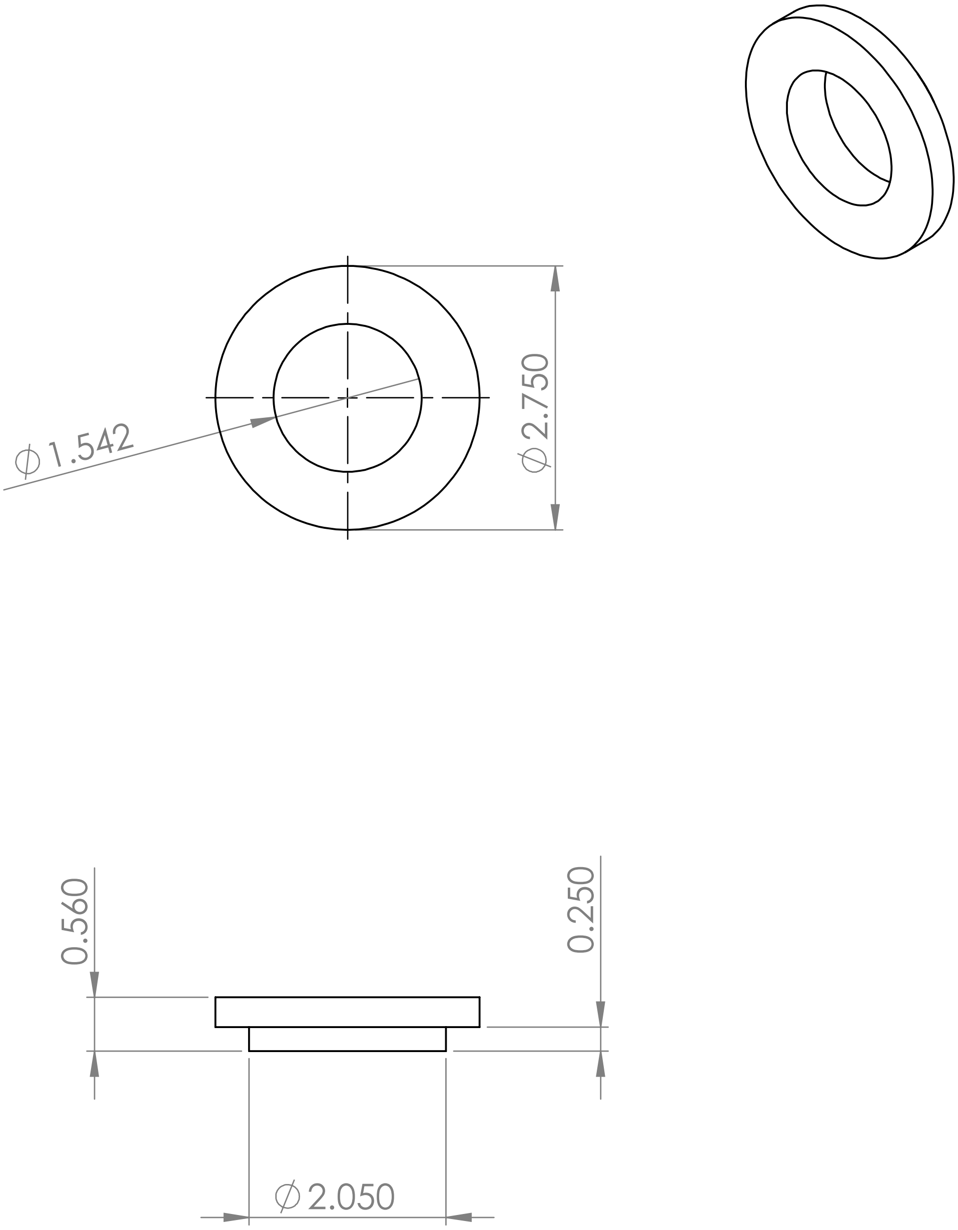




UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:		DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION N/C	
	NAME	SIGNATURE	DATE	TITLE:		
DRAWN	NATHAN REED		7/28/14	Main Drive Shaft		
CHK'D						
APPV'D						
MFG						
Q.A			MATERIAL: 4130 STEEL	DWG NO.		A3
			WEIGHT:	SCALE:1:5	SHEET 1 OF 1	



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:		FINISH:			DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
	NAME	SIGNATURE	DATE			TITLE:	
DRAWN							
CHK'D							
APPV'D							
MFG							
Q.A				MATERIAL: 6061-T6		DWG NO. bearing tube	A3
				WEIGHT:		SCALE:1:2	SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL:
4130

WEIGHT:

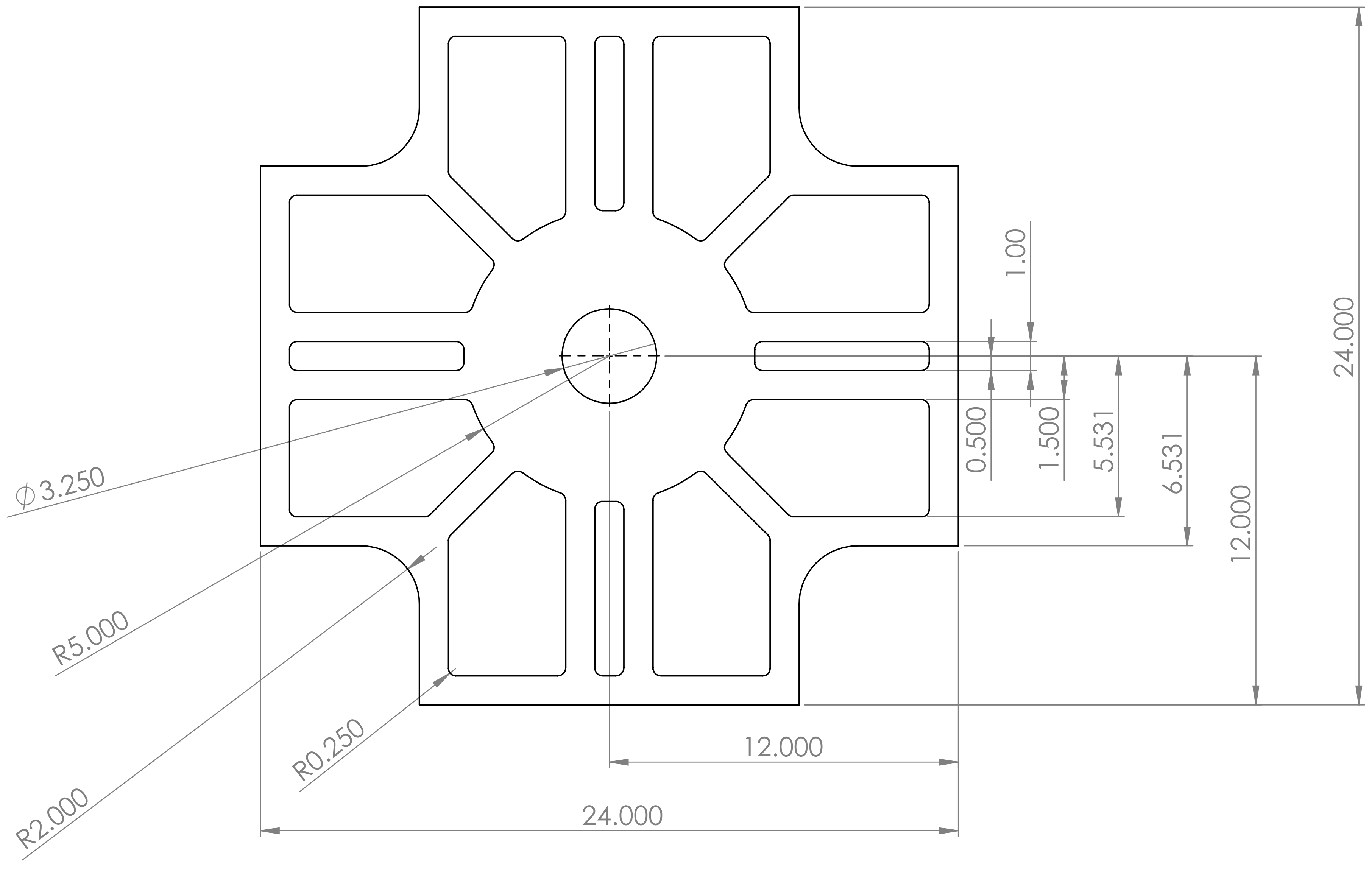
TITLE:

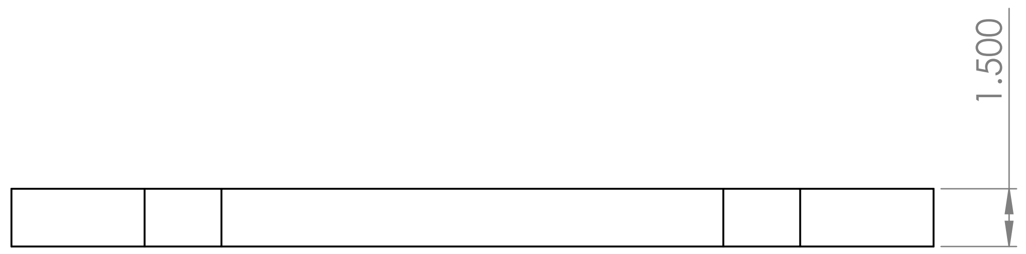
DWG NO. topBearingRetainer

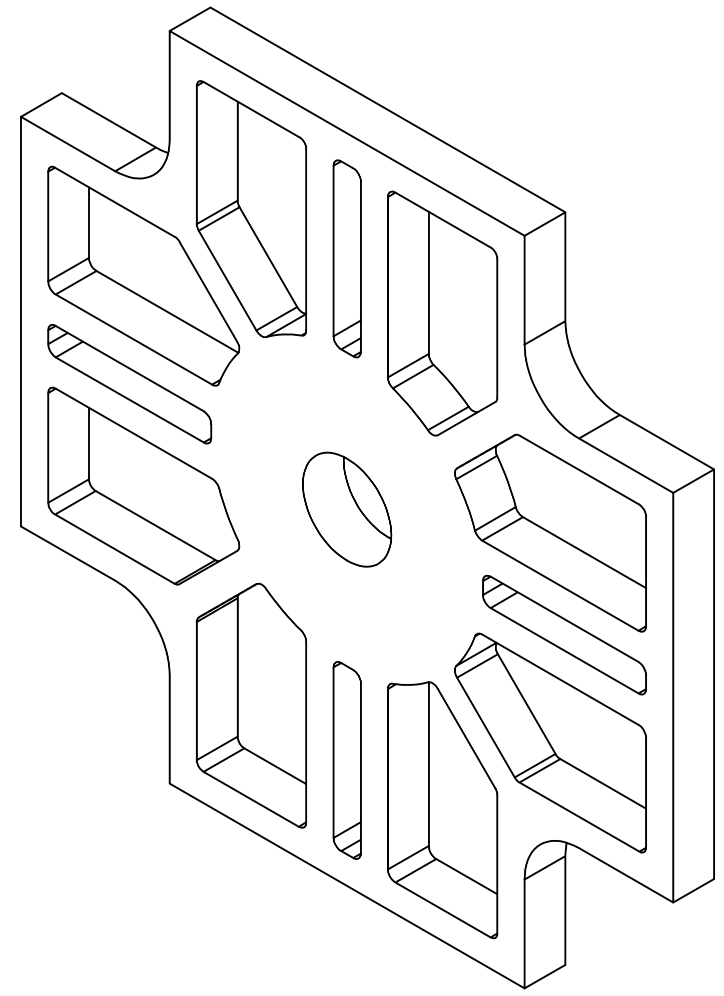
A4

SCALE:1:2

SHEET 1 OF 1

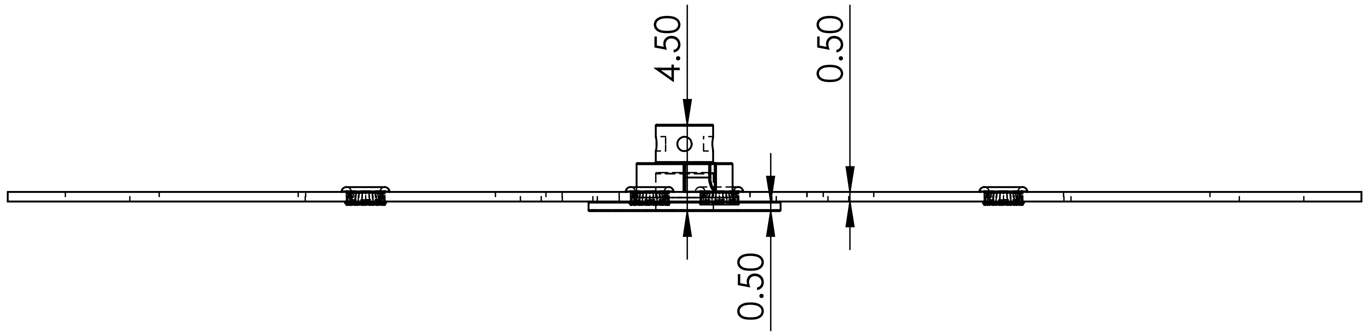


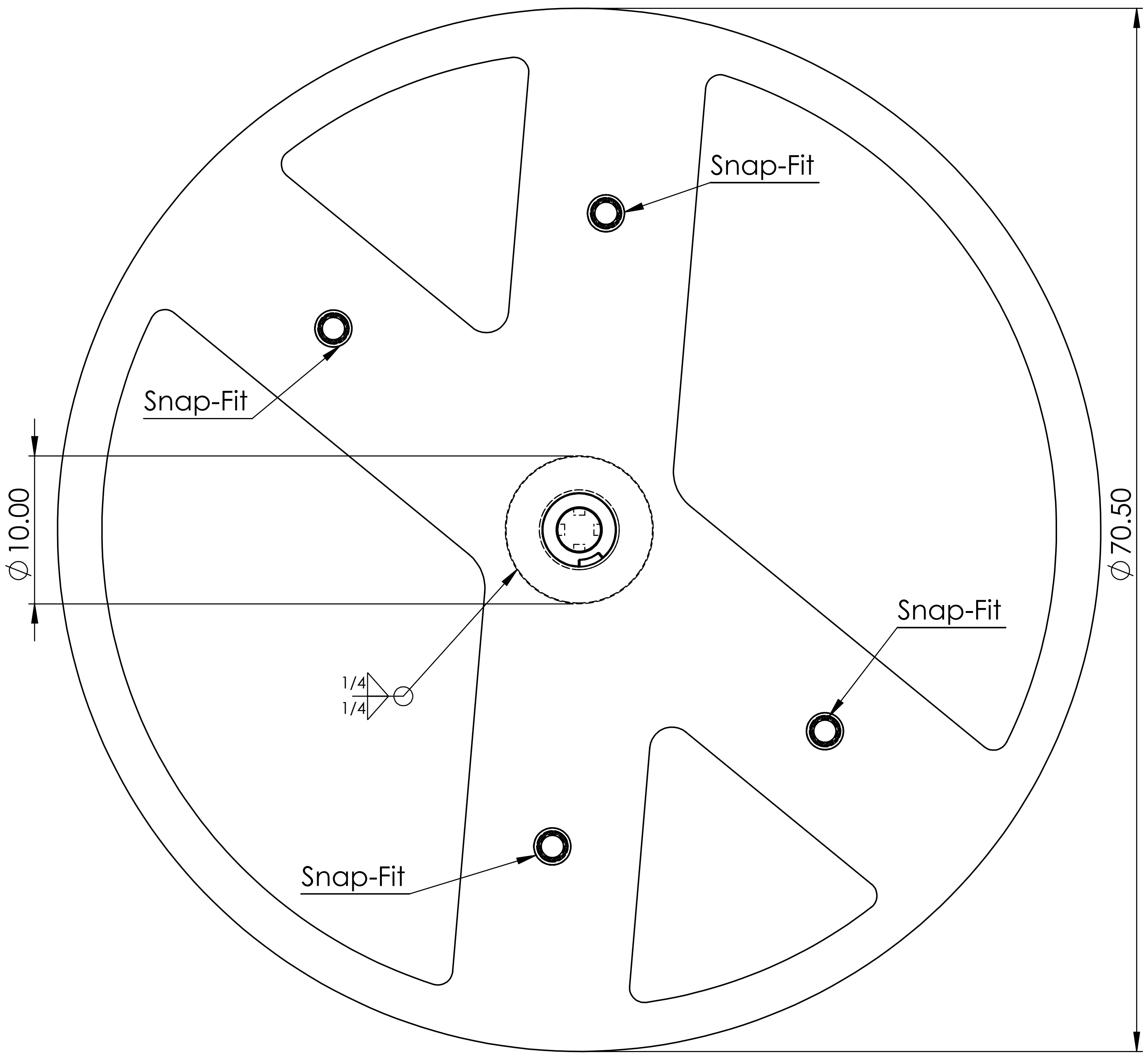


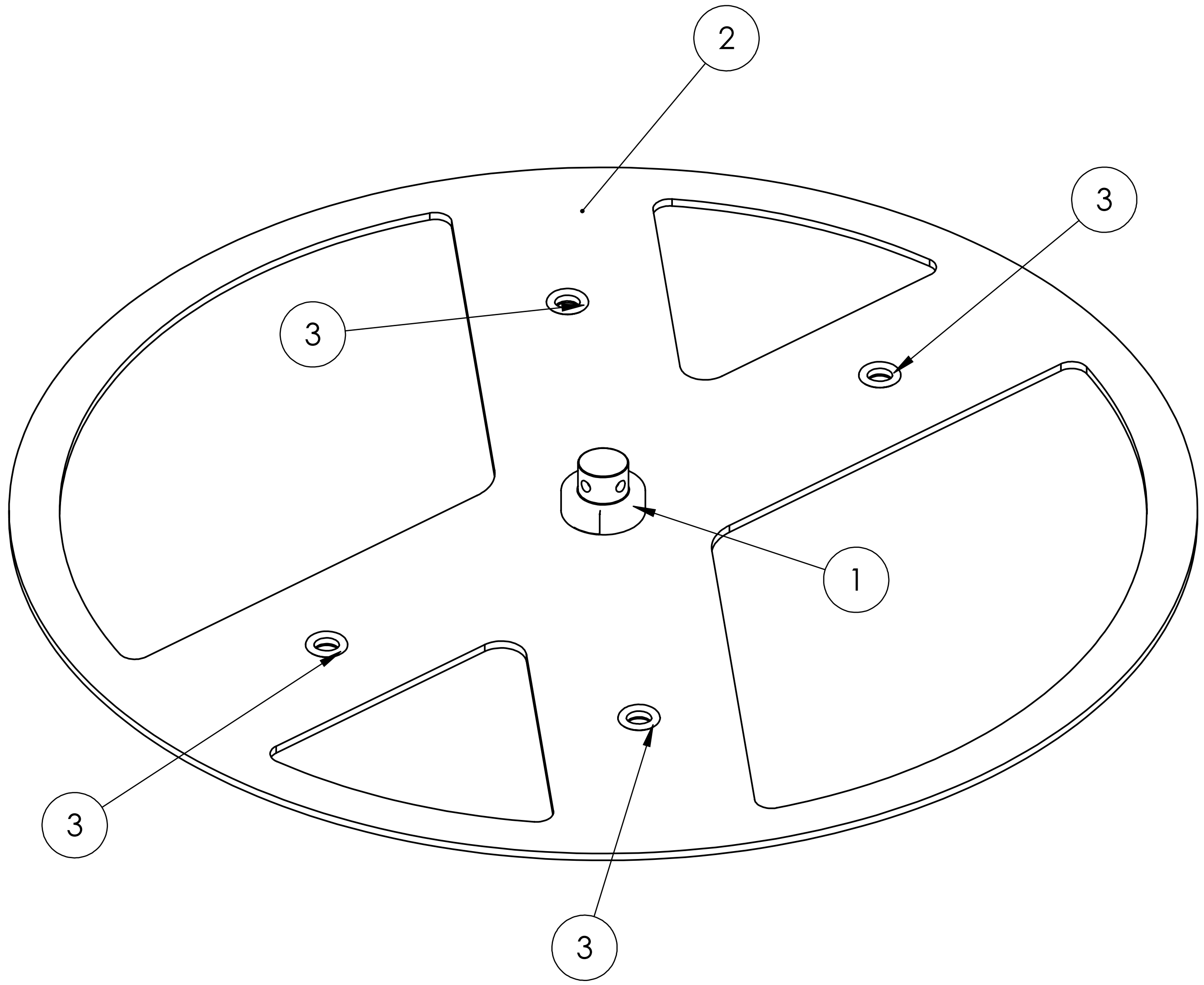


UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:			FINISH:		DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
	NAME	SIGNATURE	DATE			TITLE:	
DRAWN							
CHK'D							
APPV'D							
MFG							
Q.A				MATERIAL:		DWG NO. motorPlate	A2
				WEIGHT:		SCALE:1:5	SHEET 1 OF 1

NOTES:
1) ASSEMBLY OF SUSPENSION TRAY WITH HUB
2) FOR PART DIMENSIONS REFER INDIVIDUAL PART DRAWINGS
3) 1/4 INCH CONTINUOUS FILLET WELD CONNECTING SUSPENSION TRAY AND HUB
4) SNAP FITTINGS PRESSED INTO PLACE







ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Hub		1
2	Suspension Tray		1
3	Snap Fitting 3		4

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION N/C

	NAME	SIGNATURE	DATE
DRAWN	NATHAN REED		8/11/14
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

Suspension Tray-Hub-Snap Fittings

MATERIAL:

DWG NO.

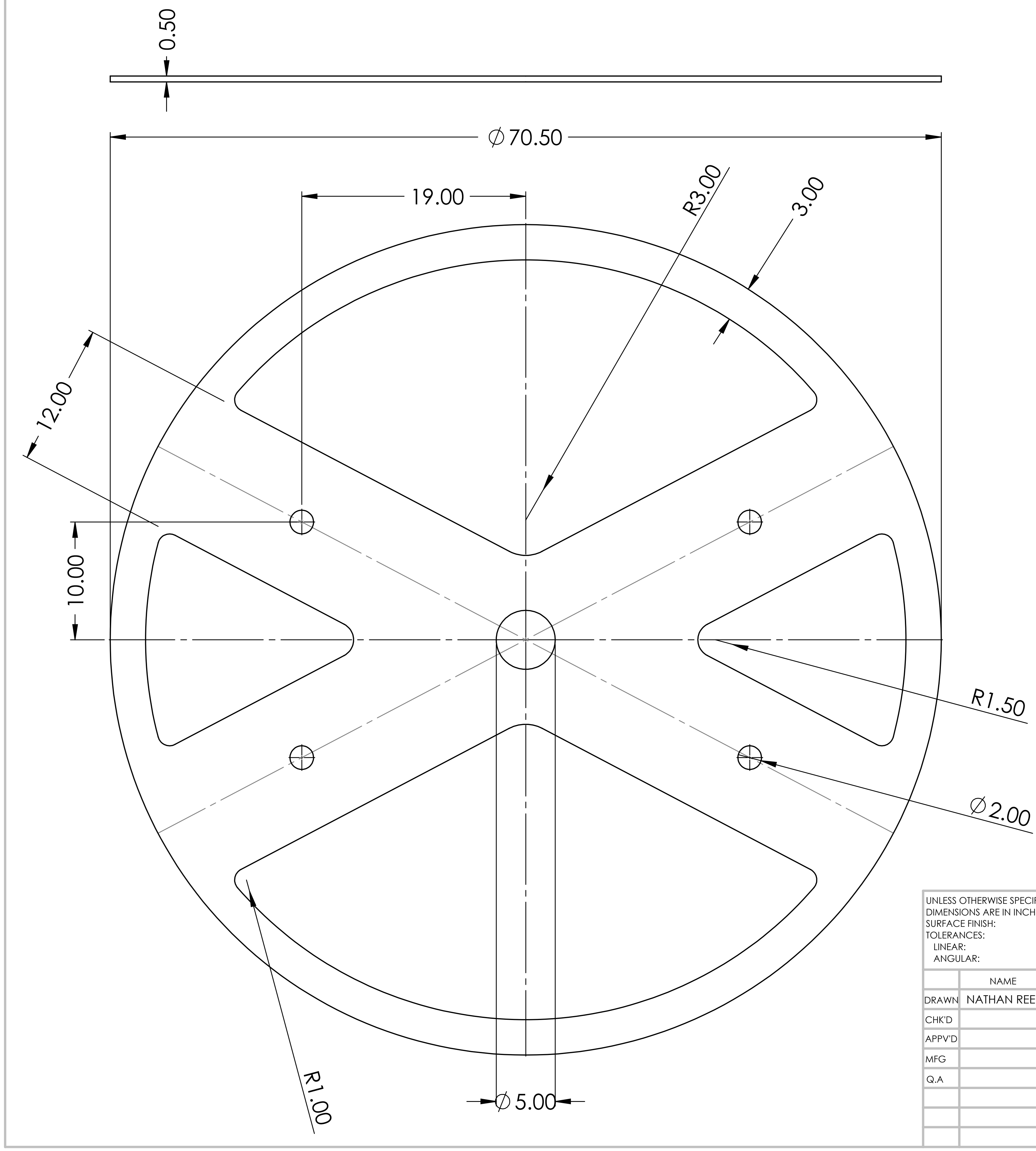
A3

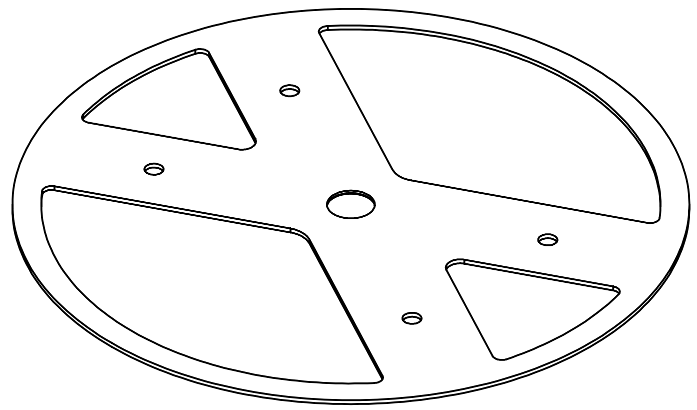
WEIGHT:

SCALE:1:50

SHEET 1 OF 1

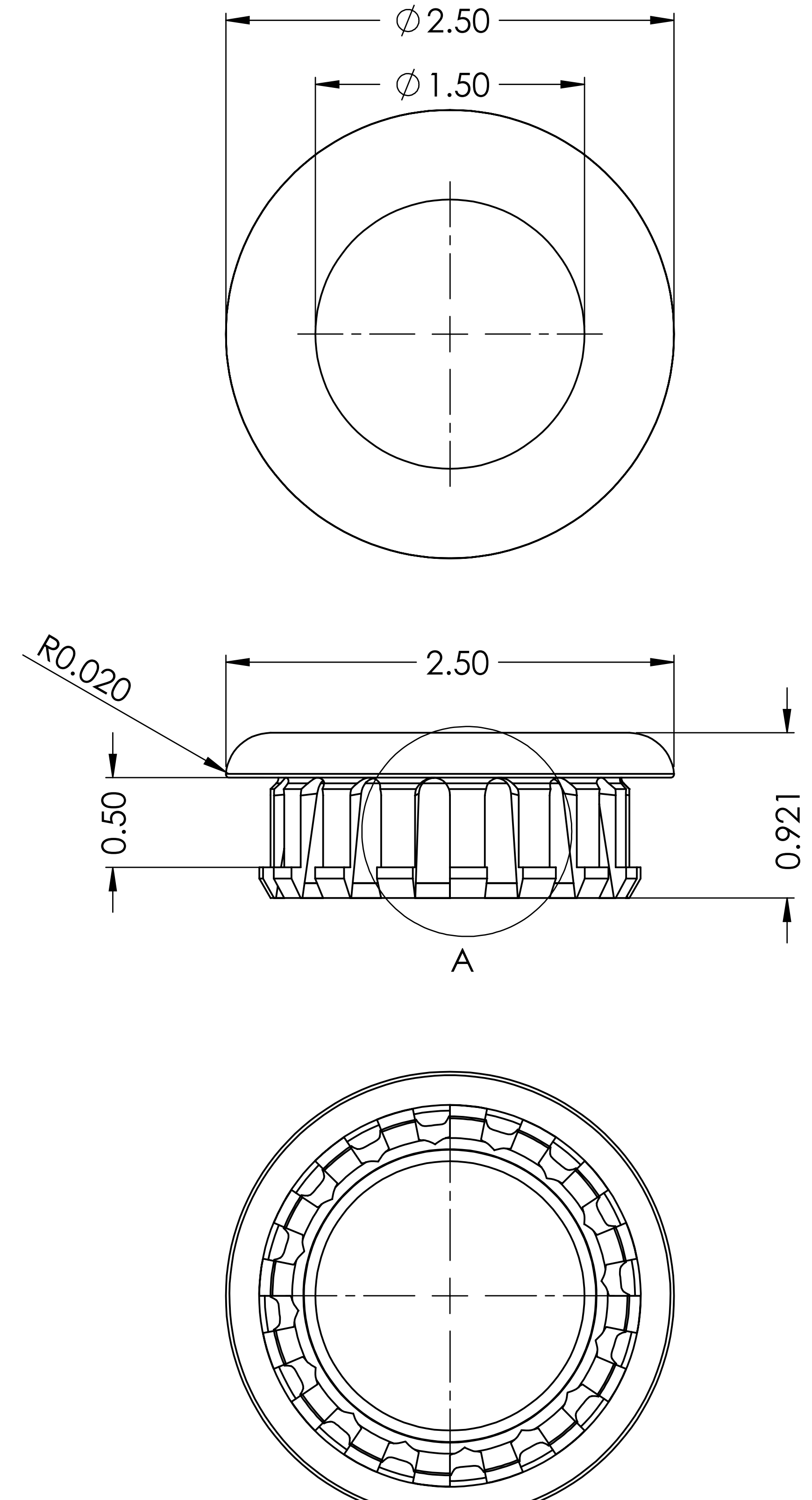
NOTES:
1) 1 PART NEEDED
2) MATERIAL: 6061 ALUMINUM

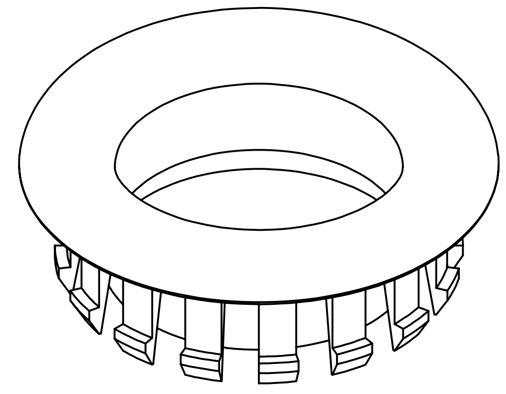


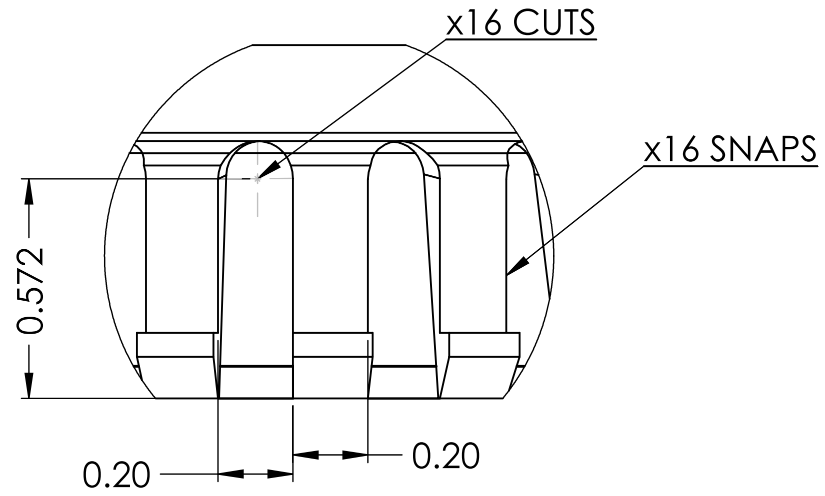


UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:			DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION N/C
	NAME	SIGNATURE	DATE		TITLE:	
DRAWN	NATHAN REED		7/07/14		Suspension Tray	
CHK'D						
APPV'D						
MFG						
Q.A				MATERIAL: 6061 ALUMINUM	DWG NO.	A3
				WEIGHT:	SCALE:1:10	SHEET 1 OF 1

NOTES:
1) 4 PART NEEDED
2) SNAP-TO-FIT PIECES
3) MATERIAL: DELRIN
4) SHEET: 1 OF 2



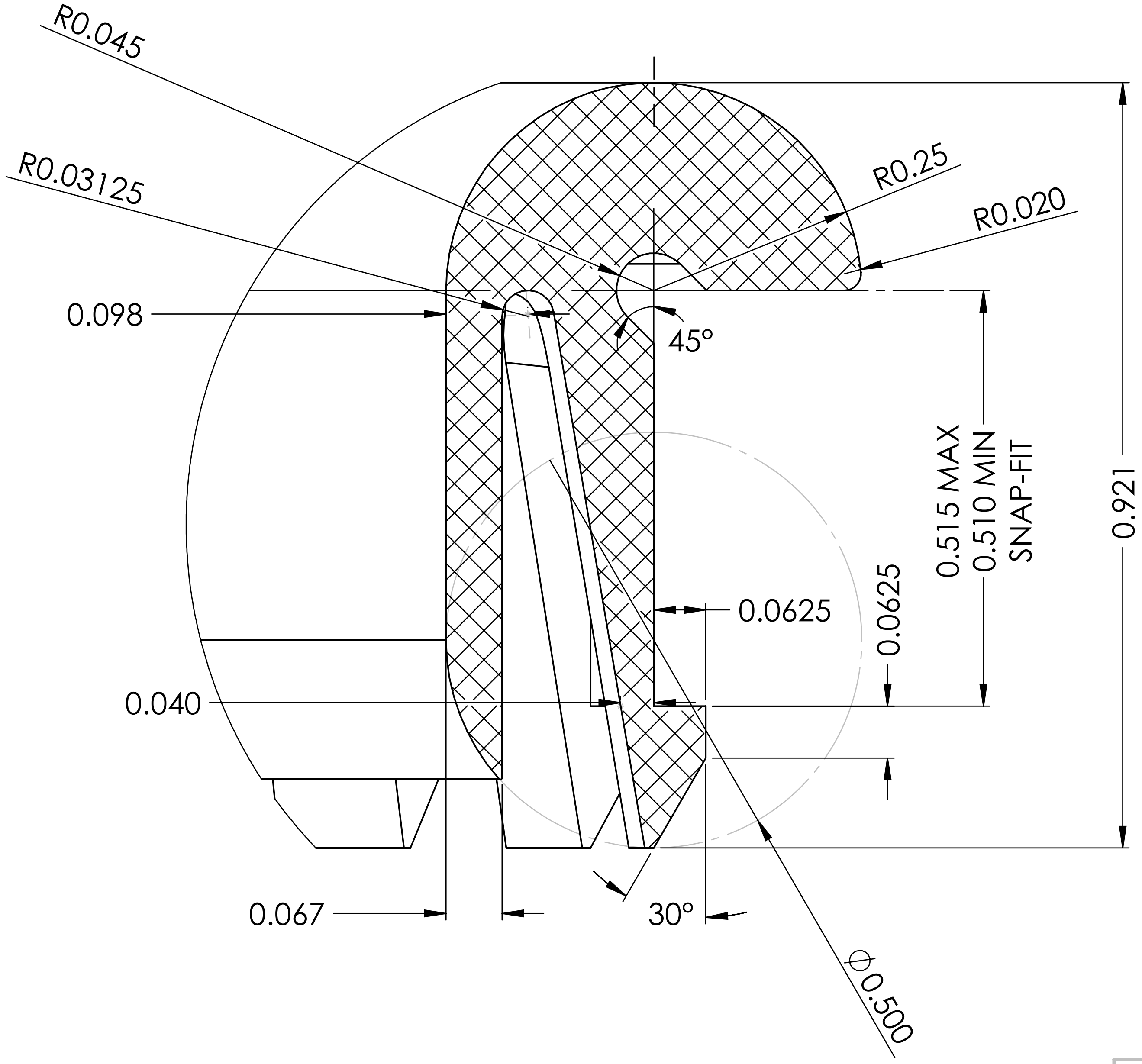




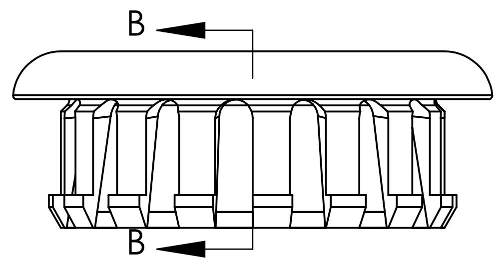
DETAIL A
SCALE 2 : 1

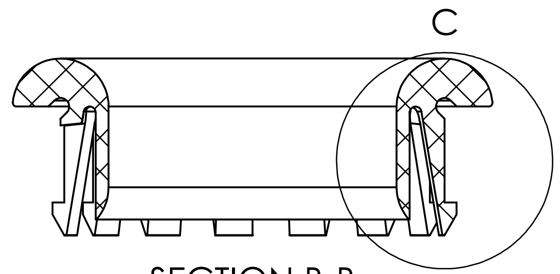
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:		FINISH:			DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING — REVISION N/C
	NAME	SIGNATURE	DATE			TITLE:
DRAWN	NATHAN REED		8/1/14			Snap Fitting 3
CHK'D						
APPV'D						
MFG						
Q.A				MATERIAL: DELRIN		DWG NO. — A3
				WEIGHT:		SCALE:1:1 — SHEET 1 OF 2

NOTES:
1)SHEET: 2 OF 2



DETAIL C
SCALE 5 : 1





SECTION B-B

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:		FINISH:		DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION N/C
	NAME	SIGNATURE	DATE		TITLE:	
DRAWN	NATHAN REED		8/1/14		Snap Fitting 3	
CHK'D						
APPV'D						
MFG						
Q.A				MATERIAL: DELRIN	DWG NO.	A3
				WEIGHT:	SCALE:1:1	SHEET 2 OF 2

6 Acknowledgements

I would like to thank the David and Lucile Packard Foundation, as well as, the Monterey Bay Aquarium Research Institute for making the 2014 Summer Internship program possible. This internship has truly been an amazing experience and has given me invaluable experience in continuing my engineering career. I would like to thank Dr. George Matsumoto and Linda Kuntz for organizing this internship program. They both have created a program that is extremely unique and a privilege to be a part of. I would like to thank Bill Kirkwood for his mentorship and allowing me to be a part of this project. Mr. Kirkwood has helped me to grow as an engineer and has provided me with incredibly valuable knowledge and experience applicable to all aspects of my career. I would also like to thank Frank Flores, Mike Parker, and Farley Shane for their guidance and expertise. Without any of whom, this paper would not have been possible.

7 References

[1] BASF Corporation. *Snap-Fit Design Manual*. July 2014. *http://www2.basf.us/PLASTICSWEB/displayanyfile?id=0901a5e1801499d5*

[2] DuPont USA. *DuPont Delrin Design Handbook*. (1981). Wilmington, Deleware.

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