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Variable Spaced Grating (VSG) Snout, Rotator and Rails for use at LLE

S. K. Mukherjee, J. A. Emig, L. V. Griffith, R. F. Heeter, F. A. House, D. L. James, M. B. Schneider, C. M. Sorce

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Disclaimer

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Mechanical Engineering Safety Note

Variable Spaced Grating (VSG) Snout, Rotator, and Rails for use at LLE

EDSN09-500023-AA

Prepared by: ______________________ Date: __________

Sam Mukherjee
Mechanical Engineer
Laser Systems Engineering and Operations (LSEO)

Reviewed by: ______________________ Date: 1/20/10

Bob Murray
Civil Engineer
Laser Systems Engineering and Operations (LSEO)

Reviewed by: ______________________ Date: 1-21-10

Allen House
Responsible Individual
National Security Engineering Division (NSED)

Approved by: ______________________ Date: 1/20/10

Joel Bowers
Division Leader
Technology Resources Engineering Division (TRED)

Distribution:

Bob Heeter	(L-472)	Jim Emig	(L-251)
Allen House	(L-168)	Charles Sorce	(L-735)
Joel Bowers	(L-113)	Lee Griffith	(L-125)
LSEO Office	(L-447)		

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Section A – Scope and Equipment (or System) Description

The Variable Spaced Grating (VSG) is a spectrometer snout mounted to an X-Ray Framing Camera (XRFC) through the Unimount flange. This equipment already exists and is used at the University of Rochester, Laboratory for Laser Energetics (LLE) facility. The XRFC and the Unimount flange are designed by LLE. The Tilt Rotator fixture that mounts next to the XRFC and the cart rails are designed by LLNL, and are included in this safety note. The other related components, such as the TIM rails and the Unimount flange, are addressed in a separate safety note, EDSN09-500005-AA.

The Multipurpose Spectrometer (MSPEC) and VSG are mounted on the TIM Boat through the cart rails that are very similar in design. The tilt rotator combination with the Unimount flange is also a standard mounting procedure. The later mounting system has been included in this safety note.

Figure-1 shows the interface components and the VSG snout. Figure-2 shows the VSG assembly mounted on the Unimount flange. The calibration pointer attachment is shown in place of the snout. There are two types of VSG, one made of 6061-T6 aluminum, weighing approximately 3 pounds, and the other made of 304 stainless steel, weighing approximately 5.5 pounds. This safety note examines the VSG steel design.

Specific experiments may require orienting the VSG snout in 90 degrees increment with respect to the Unimount flange. This is done by changing the bolts position on the VSG-main body adapter flange to the Unimount adapter plate. There is no hazard involved in handling the VSG during this procedure as it is done outside the target chamber on the cart rail before installing on the TIM. This safety note addresses the mechanical integrity of the VSG structure, the tilt rotating fixture, the cart rails with handle and their connections. Safety Factors are also calculated for the MSPEC in place of the VSG.

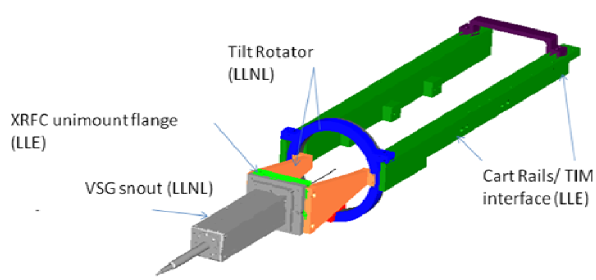


Figure-1 The VSG snout attached to the Unimount flange and Tilt Rotator attached to the cart rails

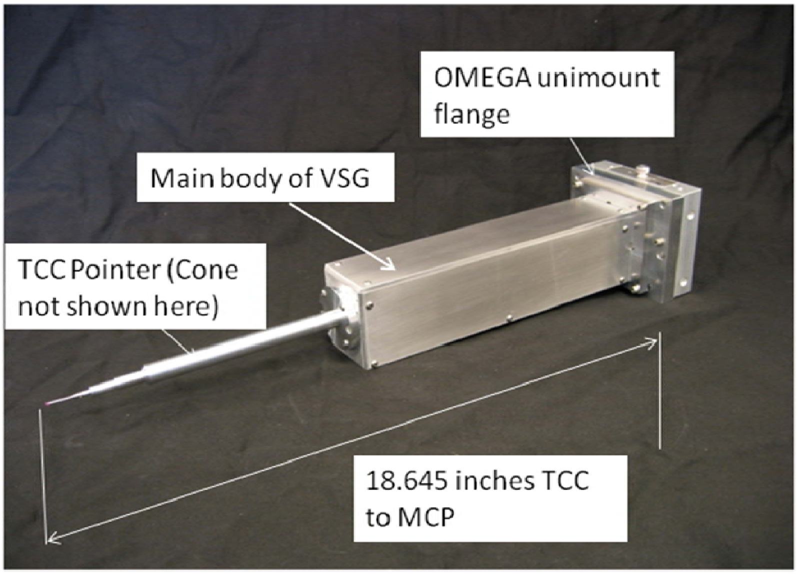


Figure-2 Photo of the VSG assembly with TCC Pointer attached connected to the LLE unimount flange (TCC =Target Chamber Center, MCP= Micro Channel Plate)

The VSG is attached to a Rotator through support arms, the Rotator is supported by cart rails as shown in Figure-3. This type of rotator design is capable of supporting other snout assemblies heavier than the VSG. The arms are connected to the stainless steel ring that can rotate inside the outer aluminum ring. The two rings are clamped together. The camera and the cables weigh approximately 4 lbs. and are positioned between the two arms.

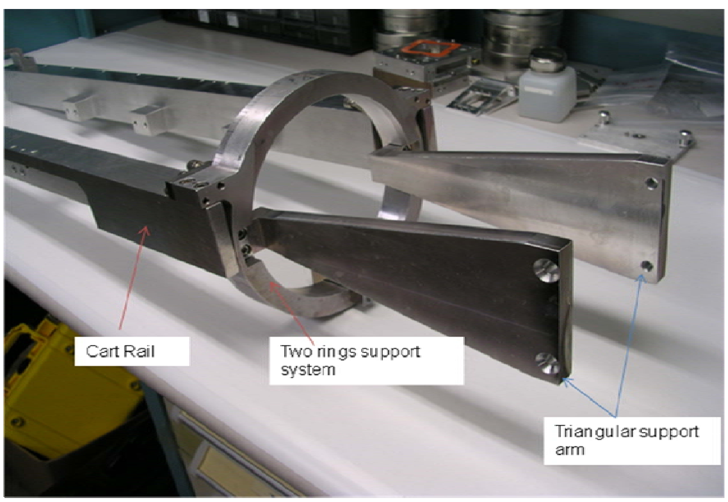


Figure-3 Photo of the rotator and cart rails hardware

The weight of the spectrometer is very small and the maximum forces on the fasteners are determined by the preload torque applied to the fasteners, rather than by operational forces applied to the VSG.

The location of center of gravity of the VSG assembly is shown in Figure-4. The worst case loading will be when the grating support is positioned as shown in Figures-4 and -5.

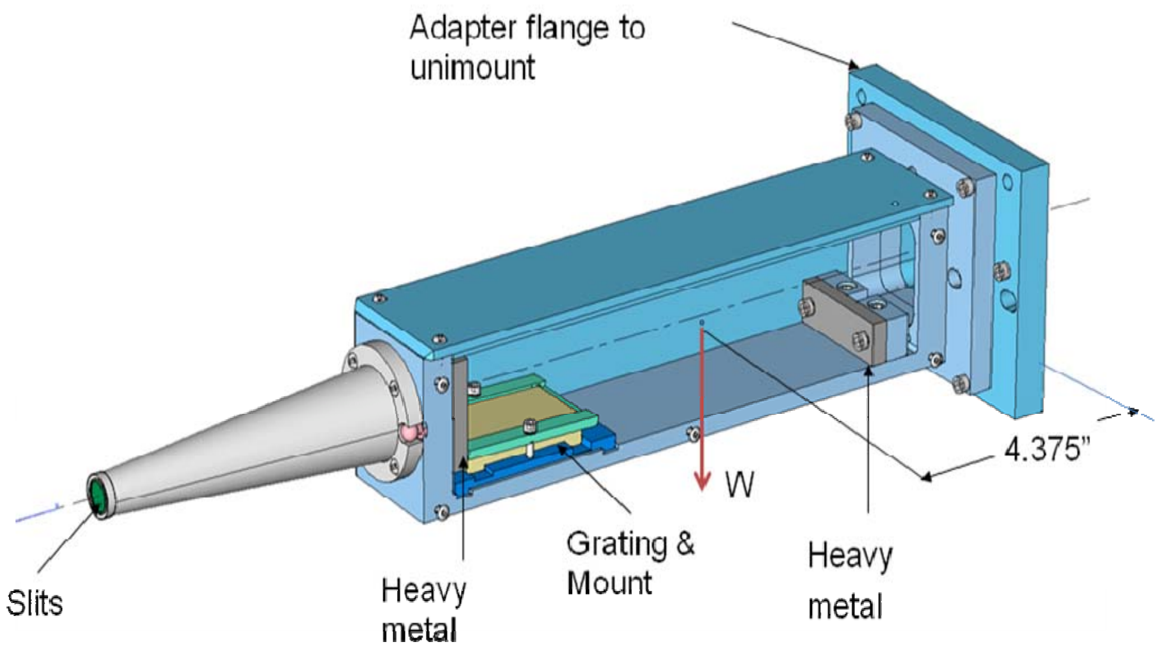


Figure-4 Location of the center of gravity of the VSG snout

Section B – Operational Hazards

Mechanical failure of the VSG device or its mechanical support components could cause injury to personnel, damage to equipment, and may have significant impact on programmatic schedule and cost.

There are no electrical hazards in the VSG device.

Section C – Operational Procedure

Use of the VSG is governed by a separate LLE procedure.

Section D – Design Calculations

The VSG components can be divided into the following subsystems (See Figure-5):

VSG Snout and Main Body Assembly

1. OMEGA Adapter Flange connection to the Unimount Flange (2x 8-32 screws)
2. Main body Adapter Flange connection to the OMEGA Adapter flange (4x 6-32 screws)
3. Main body connection to VSG Adapter Flange (4x 6-32 screws)
4. The main body and side cover fasteners (14x 4-40 screws)
5. The Cone mounts to the main body (2x 4-40 screws)

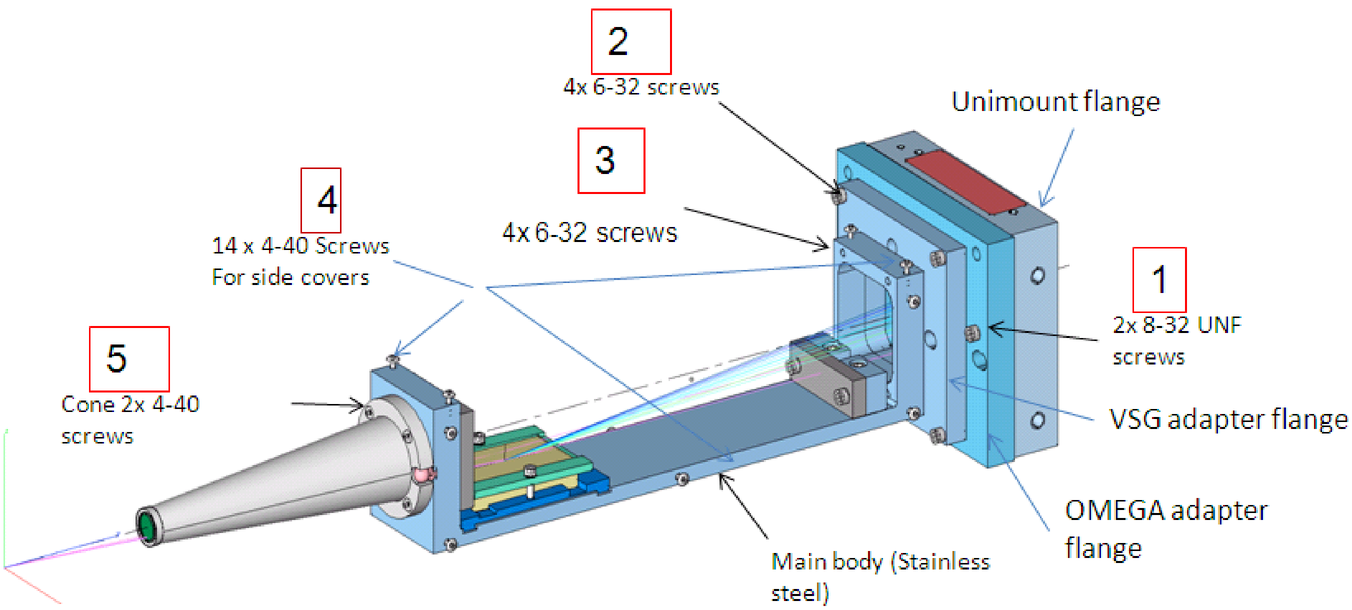


Figure-5 Mounting fasteners of the VSG assembly

Tilt rotator assembly (See Figure-6)

- The Rotating Rings subassembly support on the Cart Rails (8 x 10-32 screws each side)
- Rotator side arm connection to the steel ring (4 x 10-32 screws)
- Rotator side arm connection to the Unimount Flange (2 x ¼ - 20 screws each arm see Figure-7)

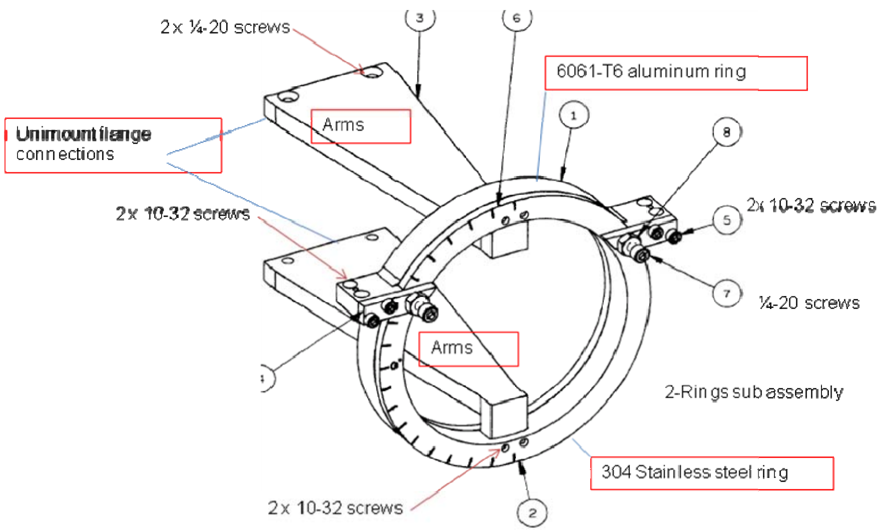


Figure-6 Tilt Rotator subsystem fasteners

The rotator design shown here is analyzed for the VSG loads only. However the rotator support with the cart rails has been improved and it can support heavier load. The cart rails for the rotator support are shown in drawings AAA09-503322-AA and AAA09-503317-AA.

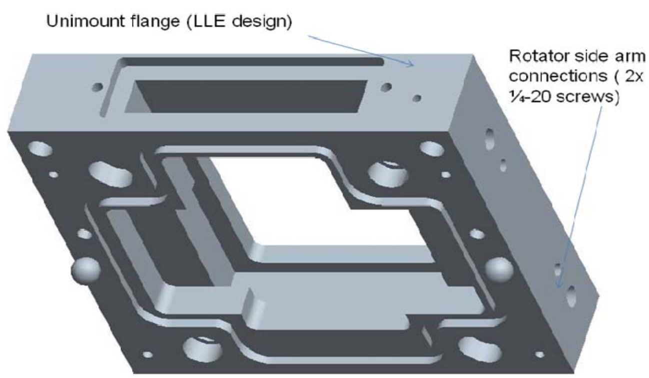


Figure-7 Unmount Flange ¼-20 screws connections with Rotator Side Arm

The following load paths were analyzed:

- Snout to VSG Box connection
- Snout and VSG Box connection to the VSG Adapter Flange
- Snout, VSG Box, VSG Adapter Flange connection to OMEGA Adapter Flange
- Snout, VSG Box, VSG Adapter Flange, OMEGA Adapter Flange connection to Unimount Flange
- VSG Assembly connection to Support Arms at Unimount
- Support Arms connection to Rotator
- Rotator connection to TIM Rails
- TIM Rail connection to TIM

Dimensions were confirmed by measurements on the VSG components. Dead Weight and Seismic loads, as shown in Appendix B, were applied to each load path to determine the fastener forces. Fastener stresses were then computed and a Safety Factor determined. Screw Specifications and Drawings are shown in Appendix C.

Distance of the VSG center of gravity from the TIM tooling ball is derived as follows (See Figure-8):

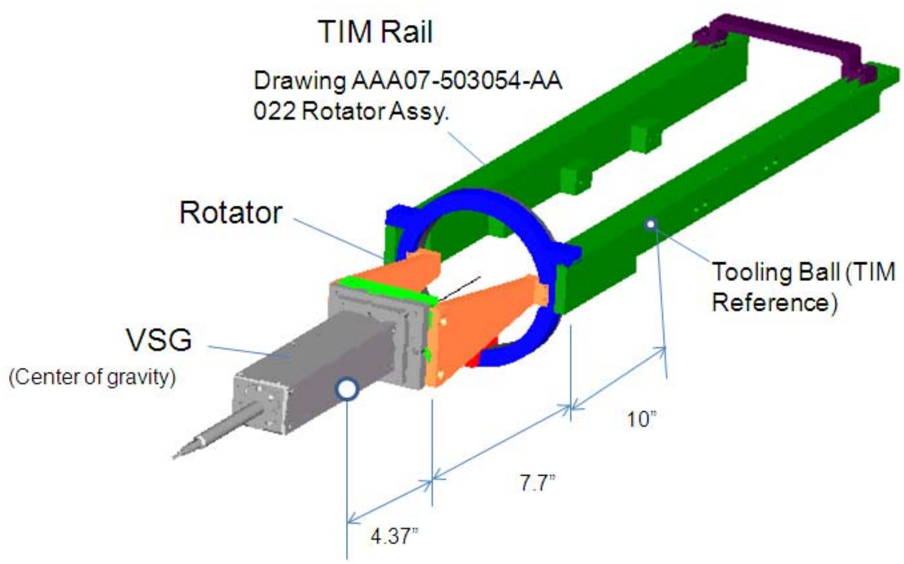


Figure-8 VSG ceneter of gravity distance from the TIM tooling ball

Tooling Ball to Rotator	= 10 in (Reference drawing AAA07-503054-AA)
Rotator Arm length	= 7.7 in (Reference drawing AAA07-503051-AA)
VSG cg from Unimount	= 4.37 in (steel design)
Total Moment Arm	= 22.07 in

VSG weight	= 5.5 lb (steel design)
Camera weight	= 4.0 lb
Total weight at Unimount	= 9.5 lb

LLE drawing D-EA-C-94, Rev. C, has the following specifications which are to be satisfied by any assembly mounted to a TIM:

The total dead load should not exceed 100 lb

- Weight Complete Assemble = 25.85 lb < 100 lb

The maximum moment at the tooling ball location should not exceed 700 in-lb

- Overall cg = 0.773 in (behind Rotator, from Appendix A)
- Moment Arm = 10.0 in – 0.773 in = 9.227 in
- Calculated moment is 25.85 lb x 9.227 in = 238.52 in-lb < 700 in-lb

A summary of the Stresses and Safety Factors calculated is shown in Table-1.

Table-1: Calculated Stresses and Safety Factors for Connections and Components

Component	von Mises Stress (psi)	Yield Stress (ksi)	Safety Factor (on Yield)
Snout to VSG Box Connection Two 4-40 screws	35.1	30	855.9
Snout, VSG Box to VSG Adapter Flange Connection Four 6-32 screws	2105.7	30	14.2
Snout, VSG Box, Adapter Flange to Omega Flange Connection Four 6-32 screws	1420.3	30	21.1
Snout, VSG Box, Flanges to Unimount Flange Connection Two 8-32 screws	999.9	30	30.0
VSG Assembly to Support Arms Connection Four 0.25-29 screws	767.4	30	39.1
Support Arms to Rotator Connection Four 10-32 screws	3857.0	30	7.8
Rotator to TIM Rail Connection Eight 10-32 screws	5498.0	30	5.5
TIM Rails to TIM Connection Four 10-32 screws	5225.7	30	5.7
Support Arms 6061-T6 Aluminum	440	35	79.5
Rotator Ring 6061-T6 Aluminum	380	35	92.1
TIM Rails 6061-T6 Aluminum	342	35	102.3

All Safety Factors > 1.0, VSG design meets LLNL Engineering Design Safety Standards Manual criteria.

Table 2 shows the Installation Torques, Preload, Engagement Length, and Safety Factors for the screws.

Connection	Screw	Installation Torque (in-lbs)	Preload (lbs)	Safety Factor (Tension)	Engagement Length (in)	Safety Factor (Thread Shear)
Snout	**(2) 4-40**	**2.4**	**108.6**	**1.67**	**0.224***	**4.9**
VSG Box	**(4) 6-32**	**4.5**	**163.5**	**1.67**	**0.276***	**4.9**
Adapter	**(4) 6-32**	**4.5**	**163.5**	**1.67**	**0.276***	**4.9**
OMEGA	**(2) 8-32**	**8.3**	**252.2**	**1.67**	**0.38**	**5.5**
Arms	**(4) 0.25-20**	**28.6**	**572.8**	**1.67**	**0.38**	**3.6**
Rotator	**(4) 10-32**	**13.7**	**359.9**	**1.67**	**0.380***	**4.6**
TIM Rails	**(8) 10-32**	**13.7**	**359.9**	**1.67**	**0.41**	**4.9**
TIM	**(4) 10-32**	**13.7**	**359.9**	**1.67**	**0.380***	**4.6**

*L_e = two diameter Engagement Length to be used on new assemblies.
This produces Safety Factor >3.

Multipurpose Spectrometer

The analysis for the VSG was extended to cover the MSPEC. The MSPEC weighs 11.0 pounds while the VSG steel design weighs 5.5 pounds.

The lowest Safety Factors on yield for the VSG design are:

Support Arms to Rotator	(4) 10-32	7.8
Rotator to TIM Rails	(4) 10-32	5.5
TIM Rails to TIM	(8) 10-32	5.7

The Support Arm to Rotator and the Rotator to TIM Rail connections were redesigned as follows:

The narrow end of the Support Arms was increased in length from 0.937 in to 2 in to space the screws further apart

Two tabs were added to the Rotator Ring to connect to the bottom of the TIM Rails. The bottom tab was cut into the TIM Rail to avoid any interference. Four additional 10-32 screws were added

The weight of the VSG Box was doubled to represent the MSPEC. All other flanges and arms were kept the same. The results, documented in Appendix A, are shown below:

	VSG	MSPEC
Support Arms to Rotator	7.8	7.0
Rotator to TIM Rails	5.5	3.5
TIM Rails to TIM	5.7	4.0

The Safety factors on the MSPEC are > 3.0, therefore a Dead Load analysis alone is not needed.

The Safety Factors for the Support Arms to Rotator and Rotator to TIM Rail connections are conservative since only half of the screws were used in the calculations. Only four of the possible 14 screws were used in the TIM Rail to TIM connection calculation.

The MSPEC can be used in place of the VSG Box for this arrangement.

Section E – Testing Requirements

The VSG is a legacy diagnostic that has been used in many experiments over the past several years. There are no load paths through weak materials, such as lead, thus there are no testing requirements from a safety perspective.

Section F – Labeling Requirements

The equipment needs to be labeled per the requirement in Appendix-B – LLE Seismic Requirements Memo.

The Engineering Directorate Safety Note (EDSN) Number, documenting the design, should be indicated on the equipment or component.

Since the LLE Seismic Criteria shown in Appendix B was used in the analysis of the equipment or component, label the equipment or component with the following:

"For Use at LLE Only"

Section G – Associated Procedures

Since the VSG assembly uses different diameter small screws with the same threads per inch, 6-32 (diameter = 0.138in), 8-32 (diameter = 0.164in), and 10-32 (diameter = 0.190in), there is the possibility of using the wrong screw. Special care should be given to using the correct screw for each connection.

Section H – References

1. Engineering Design Safety Standards Manual, M-102, Lawrence Livermore National Laboratory, 2009.

2. OMEGA Conceptual Design Review, May 15, 2006.

3. Compton Radiography Snout Diagnostic for use at LLE, Shannon Ayers, Lawrence Livermore National Laboratory, EDSN09-500005-AA, 2009.

4. Multipurpose Spectrometer for use at LLE, EDSN09-500012-AA, 2009.

Appendix-A
Mechanical Safety Factor Calculations

The TIM and VSG are elevated equipment as described in "*Recommended Seismic Criteria for LLNL Equipment Located at LLE"* (See Appendix -B).

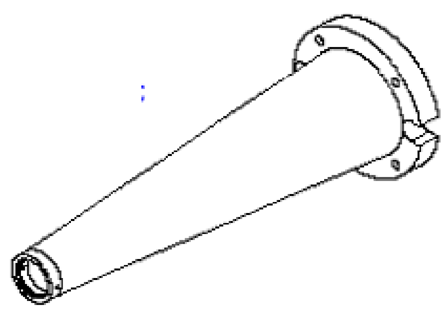
The seismic loads are applied in all three directions. The seismic forces are combined with the total dead load to obtain the maximum forces at the screws. Stresses and Safety Factors are then determined.

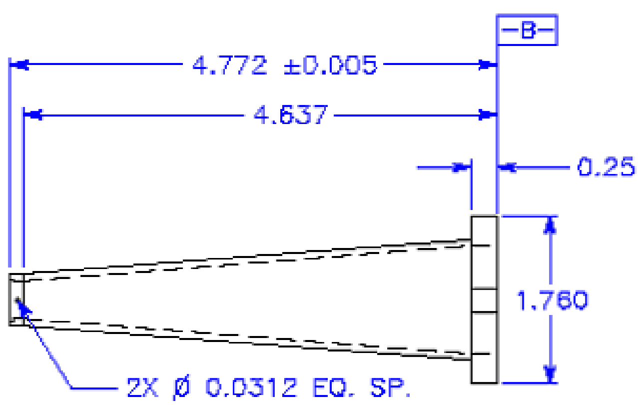
All connections are made with 18-8 Grade Stainless Steel Screws

$\sigma_y := 30\text{ksi}$ Yield strength of 18-8 stainless steel screw material

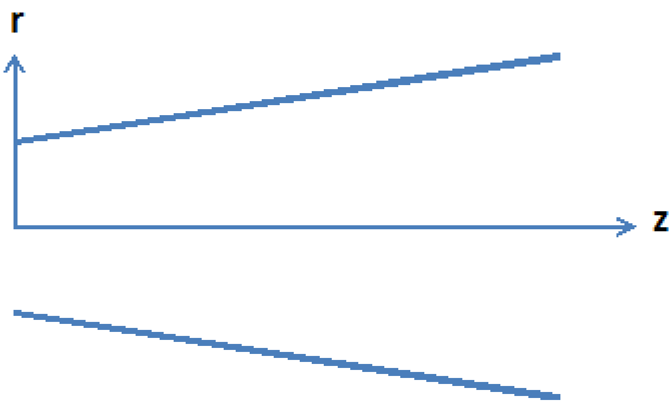
1. Snout to VSG Connection

The Snout is connected to the VSG Main Body with 4 x 4-40 screws on a 1.5in bolt circle





Determine Weight and Location of Center of Gravity



Volume

$h := 4.775\,in$

$t := 0.075\,in$

$r_i(z) := 0.2\,in + \frac{0.3625}{4.772} \cdot z \qquad \frac{.3625}{4.772} = 0.0759640$

$r_o(z) := r_i(z) + t$

$r_i(0in) = 0.2 \cdot in \qquad r_o(0in) = 0.275\,in$

$r_i(4.772\,in) = 0.5625\,in \qquad r_o(4.772\,in) = 0.6375\,in$

$$Vol := \int_0^h \pi \cdot \left[(0.2\,in + t + 0.075964 \cdot z)^2 - (0.2\,in + 0.075964 \cdot z)^2 \right] dz = 0.943\,in^3$$

Weight

$\gamma := 0.098 \frac{lbf}{in^3}$ Weight density of Aluminum

$W := \gamma \cdot Vol = 0.092 lbf$ Weight of Cone (use calculated weight)

$W_{measure} := 1.6 oz = 0.1 lb$ Measured weight of anodized aluminum cone

Centroid

$$z_{bar} := \frac{\int_0^h z\pi \cdot \left[(0.2in + t + 0.075964 0z)^2 - (0.2in + 0.075964 0z)^2\right] dz}{Vol}$$

$z_{bar} = 2.732 \cdot in$

$L := h - z_{bar} = 2.043 \cdot in$

$r_{bc} := \frac{1.5in}{2} = 0.75 \cdot in$

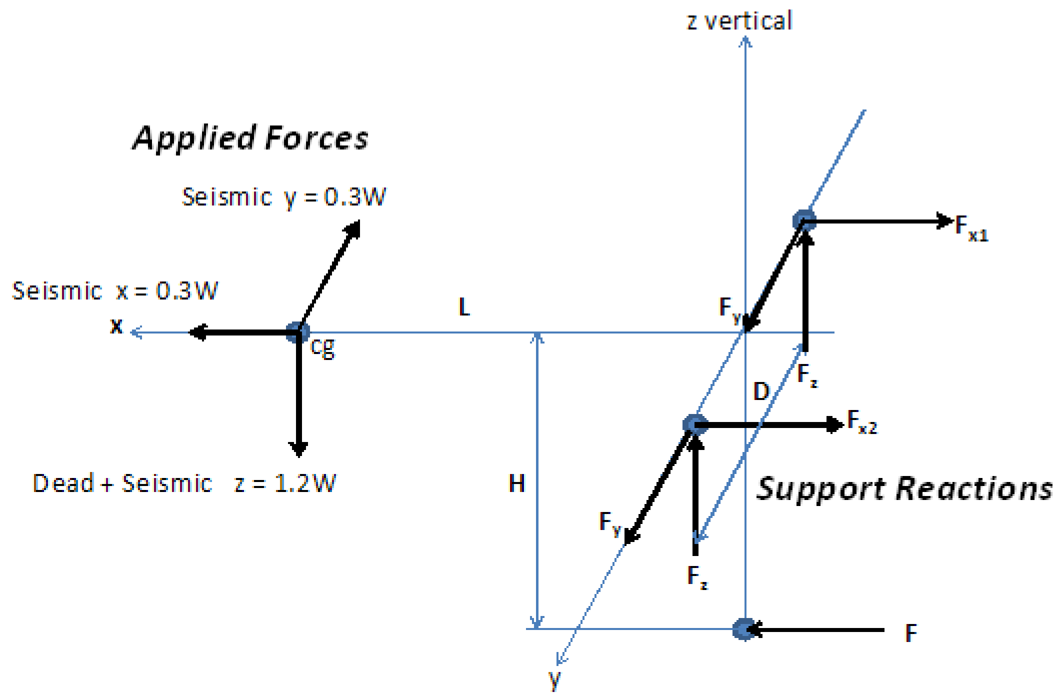
$H := 2 \cdot r_{bc} \cdot \sin(45deg) = 1.061 \cdot in$

$D := H = 1.061 \cdot in$

$W = 0.092 lbf$

$0.2W = 0.018 lbf$

$0.3W = 0.028 lbf$



Seismic plus Dead Weight Loading

Only two screws carry the load

$$F_y := \frac{0.3W}{2} = 0.014\text{lbf}$$

$$F_z := \frac{1.2W}{2} = 0.055\text{lbf}$$

Guess Values

$$F_{x1} := 1\text{lbf}$$

$$F_{x2} := 1\text{lbf}$$

$F := 1\text{lbf}$ Force at Bottom of Plate

Given

$$-F + F_{x1} + F_{x2} = 0.3W \qquad \Sigma Fx = 0$$

$$\left(F_{x1} + F_{x2}\right) \cdot H = 1.2W \cdot L + 0.3W \cdot H \qquad \Sigma My = 0$$

$$-F_{x1} \cdot \frac{D}{2} + F_{x2} \cdot \frac{D}{2} = 0.3W \cdot L \qquad \Sigma Mz = 0$$

$$\begin{pmatrix} F_{x1} \\ F_{x2} \\ F \end{pmatrix} := \mathrm{Find}\left(F_{x1}, F_{x2}, F\right) = \begin{pmatrix} 0.067 \\ 0.174 \\ 0.213 \end{pmatrix} \mathrm{lbf}$$

$$F_x := F_{x2} = 0.174\mathrm{lbf}$$

4-40 Screws

$$A_t := 0.00603\mathrm{in}^2$$ Tensile Stress Area

$$A_r := 0.00497\mathrm{in}^2$$ Root Area

$$\sigma := \frac{F_x}{A_t} = 28.9\mathrm{psi}$$ Normal Stress

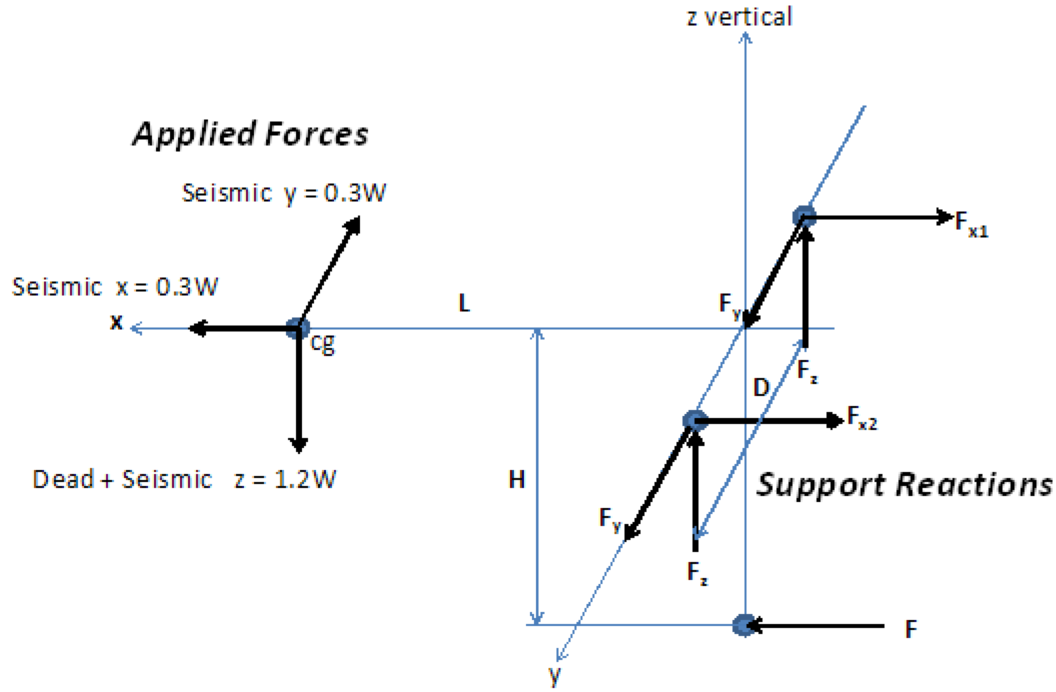
$$\tau := \frac{\sqrt{F_y^2 + F_z^2}}{A_r} = 11.5\mathrm{psi}$$ Shear Stress

$$\sigma_{vm} := \sqrt{\sigma^2 + 3\tau^2} = 35.1\mathrm{psi}$$ von Mises Stress

$$SF := \frac{30\mathrm{ksi}}{\sigma_{vm}} = 855.9$$ >1 Adequate

Since >3 Dead Load analysis alone is not needed.

2. VSG to VSG Adapter Flange



$W := (0.092 + 0.37 + 5.5)\text{lbf} = 5.962\text{lbf}$ $\quad 0.2W = 1.192\text{lbf}$ $\quad 0.3W = 1.789\text{lbf}$

$D := 1.25\text{in}$ $\quad H := 1.75\text{in}$

$$L := \frac{0.092\text{lbf}\cdot 11.146\text{in} + 0.37\text{lbf}\cdot 9.115\text{in} + 5.5\text{lbf}\cdot 4.375\text{in}}{W} = 4.774\,\text{in}$$

Seismic plus Dead Weight Loading

Only two screws carry the load

$$F_y := \frac{0.3W}{2} = 0.894\text{lbf}$$

$$F_z := \frac{1.2W}{2} = 3.577\text{lbf}$$

Guess Values

$F_{x1} := 1\text{lbf}$

$F_{x2} := 1\text{lbf}$

$F := 1\text{lbf}$ Force at Bottom of Plate

Given

$-F + F_{x1} + F_{x2} = 0.3W$ ΣFx = 0

$(F_{x1} + F_{x2}) \cdot H = 1.2W \cdot L + 0.3W \cdot H$ ΣMy = 0

$-F_{x1} \cdot \frac{D}{2} + F_{x2} \cdot \frac{D}{2} = 0.3W \cdot L$ ΣMz = 0

$$\begin{pmatrix} F_{x1} \\ F_{x2} \\ F \end{pmatrix} := \text{Find}(F_{x1}, F_{x2}, F) = \begin{pmatrix} 3.822 \\ 17.483 \\ 19.516 \end{pmatrix} \text{lbf}$$

$F_x := F_{x2} = 17.483\,\text{lbf}$

6-32 Screws

$A_t := 0.00909\,\text{in}^2$ Tensile Stress Area

$A_r := 0.00745\,\text{in}^2$ Root Area

$$\sigma := \frac{F_x}{A_t} = 1923.3\,\text{psi}$$

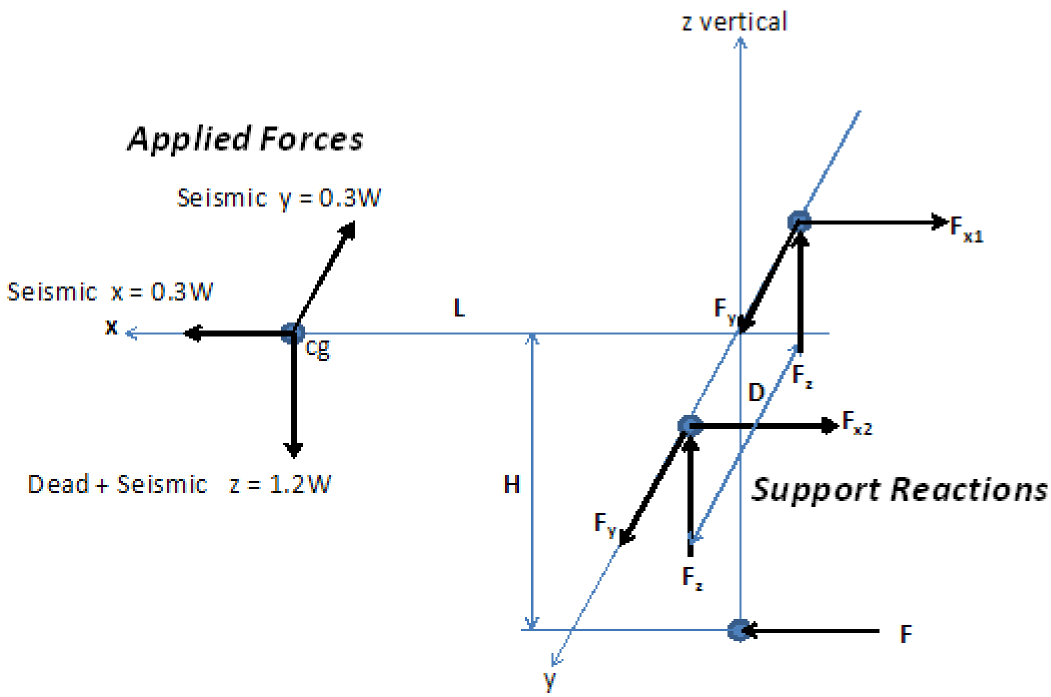
$$\tau := \frac{\sqrt{F_y^{\,2} + F_z^{\,2}}}{A_r} = 494.9\,\text{psi}$$

$$\sigma_{vm} := \sqrt{\sigma^2 + 3\tau^2} = 2105.7\,\text{psi}$$

$$SF := \frac{30\text{ksi}}{\sigma_{vm}} = 14.2$$ >1 Adequate

Since >3 Dead Load analysis alone is not needed.

3. VSG Assembly Connection to Omega Adapter Flange



$W := (0.092 + 0.37 + 5.5)\text{lbf} = 5.962\text{lbf}$ $\quad 0.2W = 1.192\text{lbf}$ $\quad 0.3W = 1.789\text{lbf}$

$D := 2.725\text{in}$ $\quad H := 2.725\text{in}$

$$L := \frac{0.092\text{lbf}\cdot 11.146\text{in} + 0.37\text{lbf}\cdot 9.115\text{in} + 5.5\text{lbf}\cdot 4.375\text{in}}{W} = 4.774\,\text{in}$$

Seismic plus Dead Weight Loading

Assume only top two screws carry the load

$$F_y := \frac{0.3W}{2} = 0.894\text{lbf}$$

$$F_z := \frac{1.2W}{2} = 3.577\text{lbf}$$

Guess Values

$F_{x1} := 1\text{lbf}$

$F_{x2} := 1\text{lbf}$

$F := 1\text{lbf}$ Force at Bottom of Plate

Given

$-F + F_{x1} + F_{x2} = 0.3W$ ΣFx = 0

$(F_{x1} + F_{x2}) \cdot H = 1.2W \cdot L + 0.3W \cdot H$ ΣMy = 0

$-F_{x1} \cdot \frac{D}{2} + F_{x2} \cdot \frac{D}{2} = 0.3W \cdot L$ ΣMz = 0

$$\begin{pmatrix} F_{x1} \\ F_{x2} \\ F \end{pmatrix} := \text{Find}(F_{x1}, F_{x2}, F) = \begin{pmatrix} 4.028 \\ 10.294 \\ 12.533 \end{pmatrix} \text{lbf}$$

$F_x := F_{x2} = 10.294\,\text{lbf}$

6-32 Screws

$A_t := 0.00909\,\text{in}^2$ Tensile Stress Area

$A_r := 0.00745\,\text{in}^2$ Root Area

$$\sigma := \frac{F_x}{A_t} = 1132.5\,\text{psi}$$

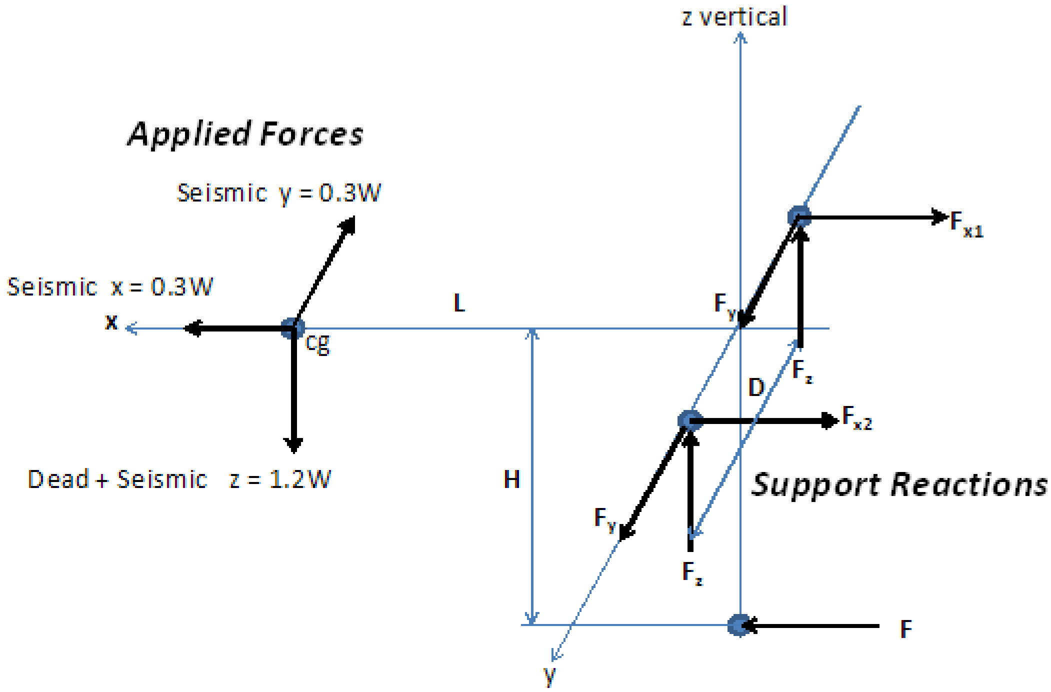
$$\tau := \frac{\sqrt{F_y^2 + F_z^2}}{A_r} = 494.9\,\text{psi}$$

$$\sigma_{vm} := \sqrt{\sigma^2 + 3\tau^2} = 1420.3\,\text{psi}$$

$SF := \frac{30\,\text{ksi}}{\sigma_{vm}} = 21.1$ >1 Adequate

Since >3 Dead Load analysis alone is not needed.

4. VSG Assembly Connection to Unimount Flange



$W := (0.092 + 0.37 + 5.5)\text{lbf} = 5.962\text{lbf}$

$0.2W = 1.192\text{lbf}$ $\qquad$ $0.3W = 1.789\text{lbf}$

$D := 3.54\text{in}$ $\qquad$ $H := 2.0\text{in}$

$$L := \frac{0.092\text{lbf}\cdot 11.146\text{in} + 0.37\text{lbf}\cdot 9.115\text{in} + 5.5\text{lbf}\cdot 4.375\text{in}}{W} = 4.774\,\text{in}$$

Seismic plus Dead Weight Loading

Only two screw carry all of the load

$$F_y := \frac{0.3W}{2} = 0.894\text{lbf}$$

$$F_z := \frac{1.2W}{2} = 3.577\text{lbf}$$

Guess Values

$F_{x1} := 1\text{lbf}$

$F_{x2} := 1\text{lbf}$

$F := 1\text{lbf}$ $\qquad$ Force at Bottom of Plate

Given

$$-F + F_{x1} + F_{x2} = 0.3W \qquad \Sigma Fx = 0$$

$$\left(F_{x1} + F_{x2}\right)\cdot H = 1.2W\cdot L + 0.3W\cdot H \qquad \Sigma My = 0$$

$$-F_{x1}\cdot\frac{D}{2} + F_{x2}\cdot\frac{D}{2} = 0.3W\cdot L \qquad \Sigma Mz = 0$$

$$\begin{pmatrix} F_{x1} \\ F_{x2} \\ F \end{pmatrix} := \mathrm{Find}\left(F_{x1}, F_{x2}, F\right) = \begin{pmatrix} 7.021 \\ 11.844 \\ 17.076 \end{pmatrix} lbf$$

$$F_x := F_{x2} = 11.844\,lbf$$

8-32 Screws

$A_t := 0.01401\,in^2$ Tensile Stress Area

$A_r := 0.01196\,in^2$ Root Area

$$\sigma := \frac{F_x}{A_t} = 845.4\,psi$$

$$\tau := \frac{\sqrt{F_y{}^2 + F_z{}^2}}{A_r} = 308.3\,psi$$

$$\sigma_{vm} := \sqrt{\sigma^2 + 3\tau^2} = 999.9\,psi$$

$SF := \frac{30ksi}{\sigma_{vm}} = 30$ >1 Adequate

Since >3 Dead Load analysis alone is not needed.

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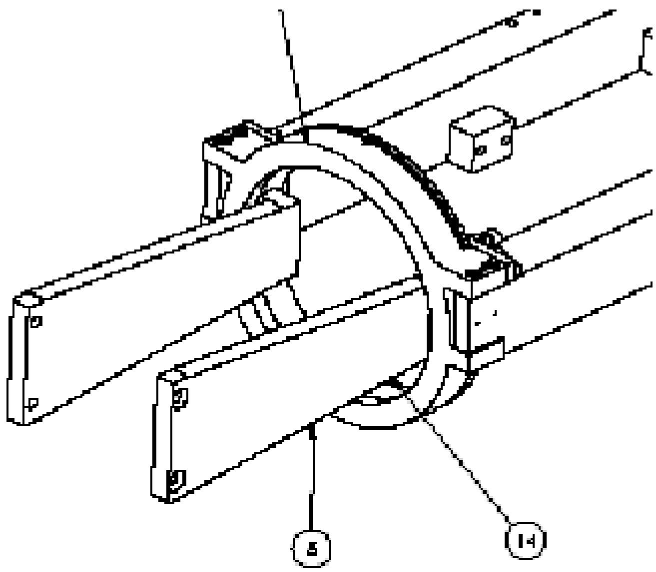
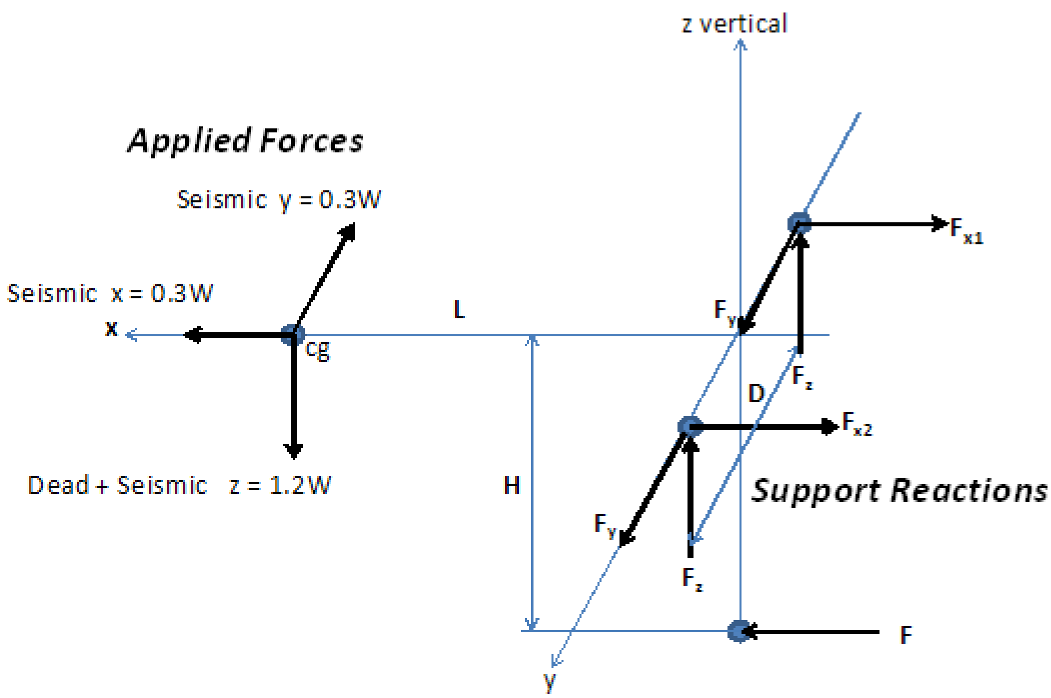
5. Unimount Flange Connection to Rotator Arm

This connection is made with four 4-40 screws on the side of the Unimount Flange to the Rotator Arms as shown below.

The same approach will be used, however the tensile forces will now be F_y and the shear forces will be F_x and F_z.





$W := (0.092 + 0.37 + 5.5 + 1.47) lbf = 7.432 lbf$

$0.2W = 1.486 lbf$ $\quad\quad$ $0.3W = 2.23 lbf$

$D := 4.0 in$ $\quad\quad$ $H := 2.25 in$

$$L := \frac{0.092 lbf \cdot 11.146 in + 0.37 lbf \cdot 9.115 in + 5.5 lbf \cdot 4.375 in + 1.47 lbf \cdot 0.4 in}{W} = 3.909 in$$

Seismic plus Dead Weight Loading

Assume only top two screws carry all of the load

$$F_y := \frac{0.3W}{2} = 1.115 lbf$$

$$F_z := \frac{1.2W}{2} = 4.459 lbf$$

Guess Values

$F_{x1} := 1 lbf$

$F_{x2} := 1 lbf$

$F := 1 lbf$ $\quad\quad$ Force at Bottom of Plate

Given

$-F + F_{x1} + F_{x2} = 0.3W$ $\quad\quad$ ΣFx = 0

$(F_{x1} + F_{x2}) \cdot H = 1.2W \cdot L + 0.3W \cdot H$ $\quad\quad$ ΣMy = 0

$-F_{x1} \cdot \frac{D}{2} + F_{x2} \cdot \frac{D}{2} = 0.3W \cdot L$ $\quad\quad$ ΣMz = 0

$$\begin{pmatrix} F_{x1} \\ F_{x2} \\ F \end{pmatrix} := Find(F_{x1}, F_{x2}, F) = \begin{pmatrix} 6.682 \\ 11.04 \\ 15.493 \end{pmatrix} lbf$$

$F_x := F_{x2} = 11.04 lbf$

0.25 - 20 Screws

$A_t := 0.0318\,in^2$ Tensile Stress Area

$A_r := 0.0269\,in^2$ Root Area

$$\sigma := \frac{F_y}{A_t} = 35.1psi$$

$$\tau := \frac{\sqrt{F_x^2 + F_z^2}}{A_r} = 442.6psi$$

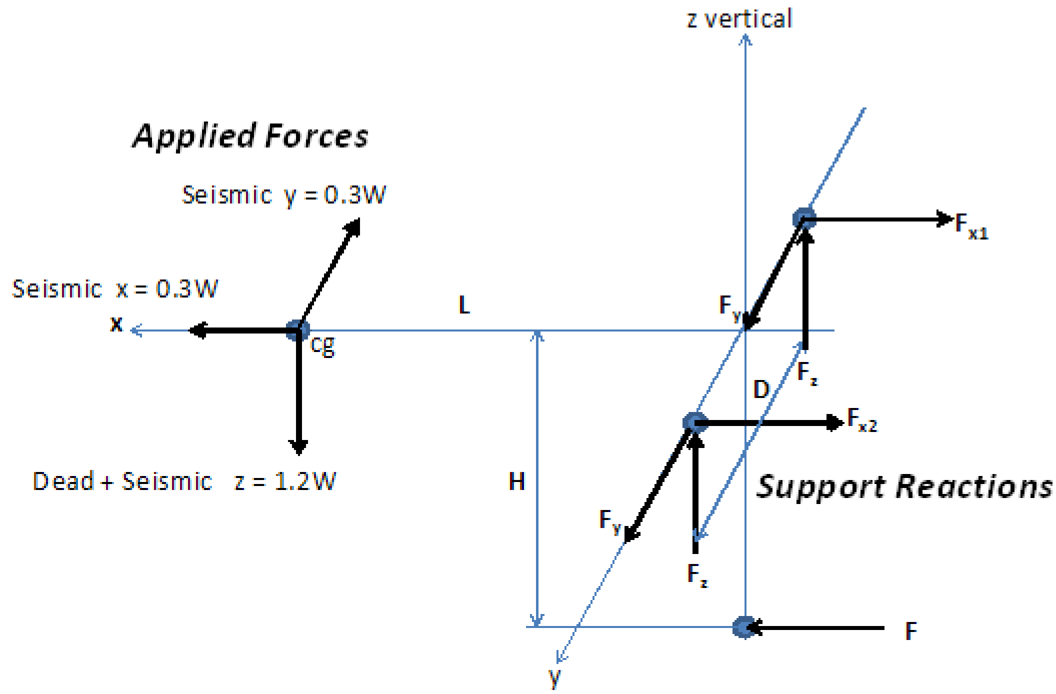
$$\sigma_{vm} := \sqrt{\sigma^2 + 3\tau^2} = 767.4psi$$

$$SF := \frac{30ksi}{\sigma_{vm}} = 39.1$$ >1 Adequate

Since >3 Dead Load analysis alone is not needed.

6. Support Arm Connection to Rotator Ring

In addition to the VSG Assembly there is a 4 pound Camera attached. Assume the weight of the Camera is distributed over the support Arms which weigh 2.26 pounds. The cg of the Support Arms is 4.41 in from the 2 in (smaller) end.



$$W := (0.092 + 0.37 + 5.5 + 1.47 + 4.0 + 2.26)\,lbf = 13.692\,lbf$$

$0.2W = 2.738\,lbf$ $\qquad$ $0.3W = 4.108\,lbf$

$D := 6.038\,in$ $\qquad$ $H := 1.0618\,in$

$$L := \frac{0.092\,lbf\cdot 19.626\,in + 0.37\,lbf\cdot 17.595\,in + 5.5\,lbf\cdot 12.855\,in + 1.47\,lbf\cdot 8.48\,in\ ... + 4.0\,lbf\cdot 4.41\,in + 2.26\,lbf\cdot 4.41\,in}{W} = 8.698\,in$$

Seismic plus Dead Weight Loading

Assume only top two screws carry all of the load

$$F_y := \frac{0.3W}{2} = 2.054\,lbf$$

$$F_z := \frac{1.2W}{2} = 8.215\,lbf$$

Guess Values

$F_{x1} := 1\,lbf$ $\quad F := 1\,lbf$ $\quad$ Force at Bottom of Plate

$F_{x2} := 1\,lbf$

Given

$-F + F_{x1} + F_{x2} = 0.3W$ $\quad$ ΣFx = 0

$(F_{x1} + F_{x2})\cdot H = 1.2W\cdot L + 0.3W\cdot H$ $\quad$ ΣMy = 0

$-F_{x1}\cdot\frac{D}{2} + F_{x2}\cdot\frac{D}{2} = 0.3W\cdot L$ $\quad$ ΣMz = 0

$$\begin{pmatrix} F_{x1} \\ F_{x2} \\ F \end{pmatrix} := \text{Find}(F_{x1}, F_{x2}, F) = \begin{pmatrix} 63.432 \\ 75.266 \\ 134.591 \end{pmatrix} lbf$$

$F_x := F_{x2} = 75.266\,lbf$

10-32 Screws

$A_t := 0.01999\,in^2$ $\quad$ Tensile Stress Area

$A_r := 0.01753\,in^2$ $\quad$ Root Area

$$\sigma := \frac{F_x}{A_t} = 3765.2\,psi$$

$$\tau := \frac{\sqrt{F_y^{\,2} + F_z^{\,2}}}{A_r} = 483.1\,psi$$

$$\sigma_{vm} := \sqrt{\sigma^2 + 3\tau^2} = 3857\text{psi}$$

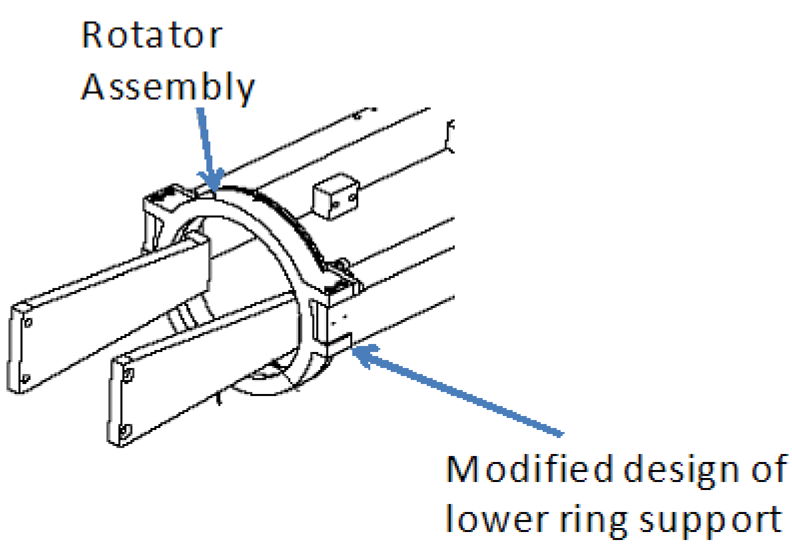
$$SF := \frac{30\text{ksi}}{\sigma_{vm}} = 7.778$$ >1 Adequate

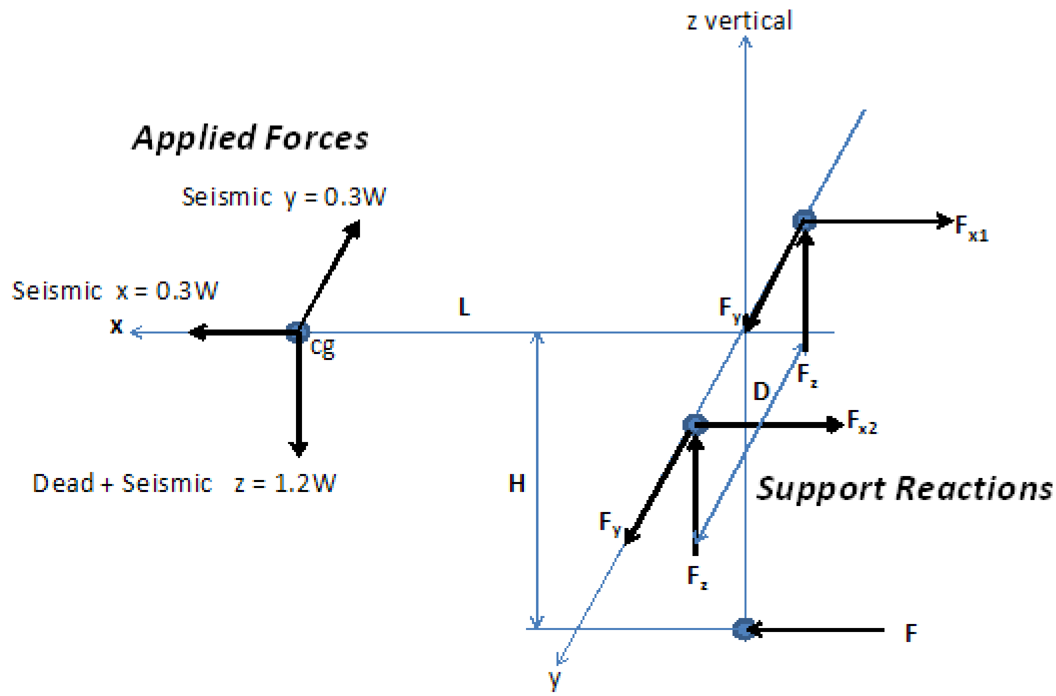
Since >3 Dead Load analysis alone is not needed.

7. VSG Rotator Connection to Cart Rails

The original rotator load path is the two 10-32 screws, one on each side of the cart rails. The VSG assembly attached to the rotator arms produces a cantilever load.

The Rotator attachment to the cart rails has been improved as shown below. A second set of tabs have been added at the bottom of the cart rails. These tabs were cut into the rails to avoid interferences. There are now four 10-32 screws connecting the Rotator Assembly to the Cart Rails.





$W := (0.092 + 0.37 + 5.5 + 1.47 + 4 + 2.26 + 1.63)\,lbf = 15.322\,lbf$

$0.2W = 3.064\,lbf$ $\qquad$ $0.3W = 4.597\,lbf$

$D := 7.25\,in$ $\qquad$ $H := 1.5\,in$

$$L := \frac{0.092\,lbf\cdot 19.626\,in + 0.37\,lbf\cdot 17.595\,in + 5.5\,lbf\cdot 12.855\,in + 1.47\,lbf\cdot 8.48\,in\ ... \\ + 4.0\,lbf\cdot 4.41\,in + 2.26\,lbf\cdot 4.41\,in + 1.63\,lbf\cdot 0.75\,in}{W} = 7.852\,in$$

Seismic plus Dead Weight Loading

Assume only top two screws carry the load.
Now F_z is the tensile force and F_x and F_y are the shear forces.

$F_y := \frac{0.3W}{2} = 2.298\,lbf$ $\qquad$ $F_z := \frac{1.2W}{2} = 9.193\,lbf$

Guess Values

$F_{x1} := 1\,lbf$

$F_{x2} := 1\,lbf$

$F := 1\,lbf$ $\qquad$ Force at Bottom of Plate

Given

$$-F + F_{x1} + F_{x2} = 0.3W \qquad \Sigma Fx = 0$$

$$(F_{x1} + F_{x2}) \cdot H = 1.2W \cdot L + 0.3W \cdot H \qquad \Sigma My = 0$$

$$-F_{x1} \cdot \frac{D}{2} + F_{x2} \cdot \frac{D}{2} = 0.3W \cdot L \qquad \Sigma Mz = 0$$

$$\begin{pmatrix} F_{x1} \\ F_{x2} \\ F \end{pmatrix} := \text{Find}(F_{x1}, F_{x2}, F) = \begin{pmatrix} 45.445 \\ 55.402 \\ 96.25 \end{pmatrix} \text{lbf}$$

$$F_x := F_{x2} = 55.402\,\text{lbf}$$

10-32 Screws

$$A_t := 0.01999\,\text{in}^2$$ Tensile Stress Area

$$A_r := 0.01753\,\text{in}^2$$ Root Area

$$\sigma := \frac{F_z}{A_t} = 459.9\,\text{psi}$$

$$\tau := \frac{\sqrt{F_x^2 + F_y^2}}{A_r} = 3163.1\,\text{psi}$$

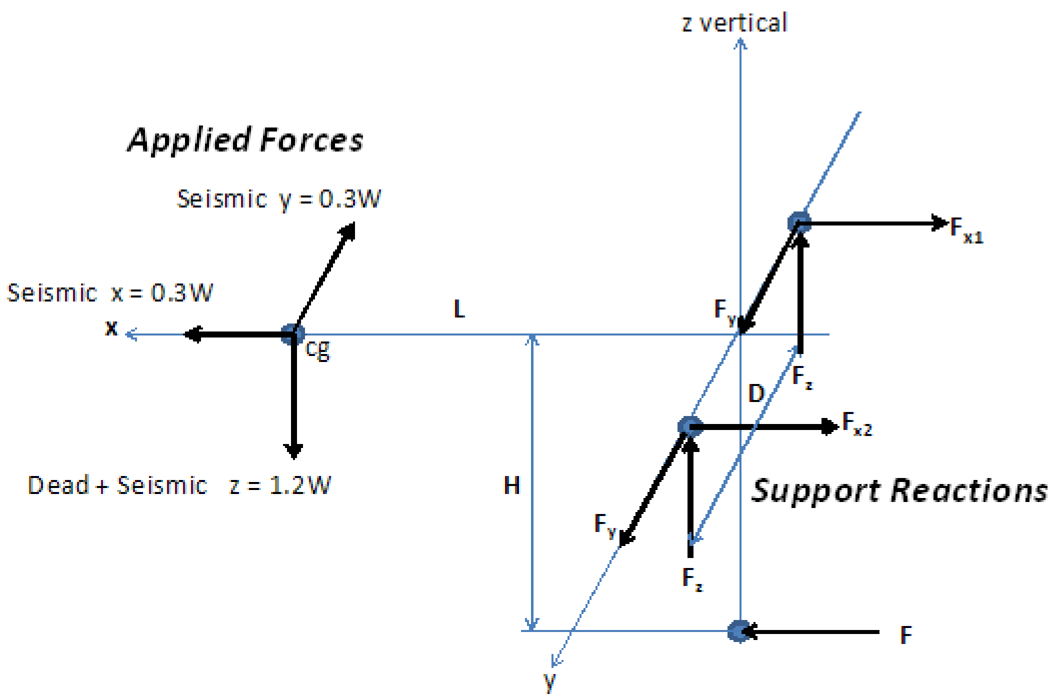
$$\sigma_{vm} := \sqrt{\sigma^2 + 3\tau^2} = 5497.96\,\text{psi}$$

$$SF := \frac{30\,\text{ksi}}{\sigma_{vm}} = 5.5$$ >1 Adequate

Since >3 Dead Load analysis alone is not needed.

8. Support Arm Connection to Rotator Ring for MSPEC

The VSG Box was replaced by the MSPEC (weight 11 pounds) Assembly. All other flanges were kept the same.



$W := (0.092 + 0.37 + 11.0 + 1.47 + 4.0 + 2.26)\,lbf = 19.192\,lbf$

$0.2W = 3.838\,lbf$ $\qquad 0.3W = 5.758\,lbf$

$D := 6.038\,in$ $\qquad H := 1.618\,in$

$$L := \frac{0.092\,lbf\cdot 19.626\,in + 0.37\,lbf\cdot 17.595\,in + 11.0\,lbf\cdot 12.855\,in + 1.47\,lbf\cdot 8.48\,in \ldots + 4.0\,lbf\cdot 4.41\,in + 2.26\,lbf\cdot 4.41\,in}{W} = 9.889\,in$$

Seismic plus Dead Weight Loading

Assume only top two screws carry all of the load

$$F_y := \frac{0.3W}{2} = 2.879\,lbf$$

$$F_z := \frac{1.2W}{2} = 11.515\,lbf$$

Guess Values

$F_{x1} := 1\text{lbf}$

$F_{x2} := 1\text{lbf}$

$F := 1\text{lbf}$ Force at Bottom of Plate

Given

$-F + F_{x1} + F_{x2} = 0.3W$ ΣFx = 0

$(F_{x1} + F_{x2})\cdot H = 1.2W\cdot L + 0.3W\cdot H$ ΣMy = 0

$-F_{x1}\cdot\frac{D}{2} + F_{x2}\cdot\frac{D}{2} = 0.3W\cdot L$ ΣMz = 0

$$\begin{pmatrix} F_{x1} \\ F_{x2} \\ F \end{pmatrix} := \text{Find}(F_{x1}, F_{x2}, F) = \begin{pmatrix} 63.829 \\ 82.689 \\ 140.761 \end{pmatrix}\text{lbf}$$

$F_x := F_{x2} = 82.689\text{lbf}$

10-32 Screws

$A_t := 0.01999\text{in}^2$ Tensile Stress Area

$A_r := 0.01753\text{in}^2$ Root Area

$$\sigma := \frac{F_x}{A_t} = 4136.5\text{psi}$$

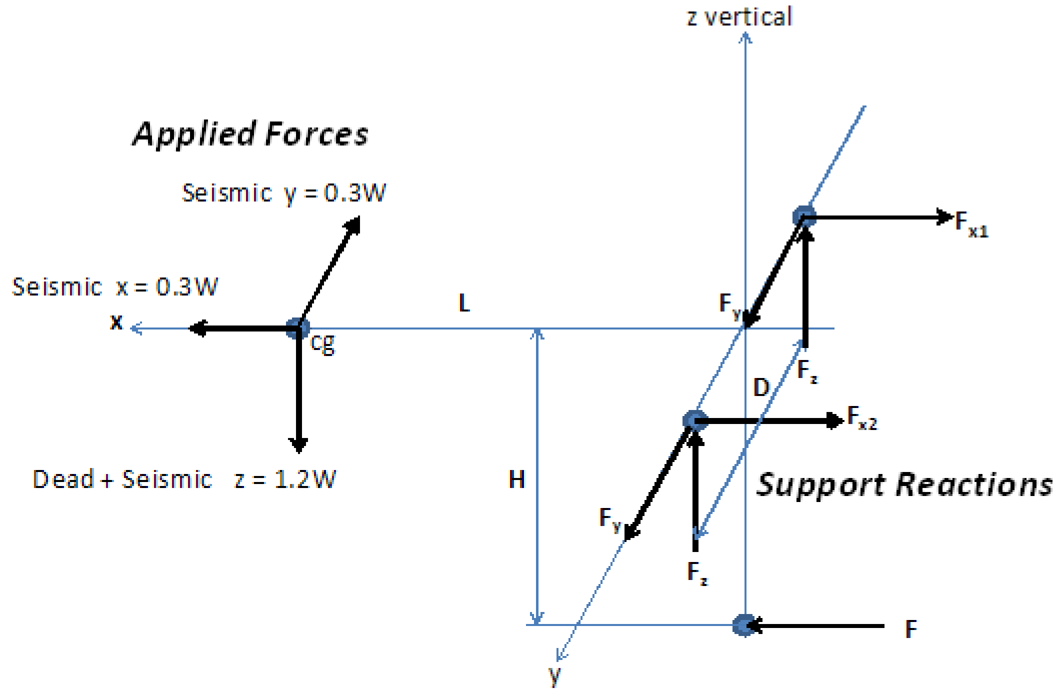
$$\tau := \frac{\sqrt{F_y^2 + F_z^2}}{A_r} = 677.1\text{psi}$$

$$\sigma_{vm} := \sqrt{\sigma^2 + 3\tau^2} = 4299.6\text{psi}$$

$$SF := \frac{30\text{ksi}}{\sigma_{vm}} = 6.98$$ >1 Adequate

Since >3 Dead Load analysis alone is not needed.

9. Rotator Connection to Cart Rails for MSPEC



$W := (0.092 + 0.37 + 11.0 + 1.47 + 4 + 2.26 + 1.63)\,lbf = 20.822\,lbf$

$0.2W = 4.164\,lbf$ $\quad$ $0.3W = 6.247\,lbf$

$D := 7.25\,in$ $\quad$ $H := 1.5\,in$

$$L := \frac{0.092\,lbf \cdot 19.626\,in + 0.37\,lbf \cdot 17.595\,in + 11.0\,lbf \cdot 12.855\,in + 1.47\,lbf \cdot 8.48\,in \ldots + 4.0\,lbf \cdot 4.41\,in + 2.26\,lbf \cdot 4.41\,in + 1.63\,lbf \cdot 0.75\,in}{W} = 9.174\,in$$

Seismic plus Dead Weight Loading

Assume only top two screws carry the load. Now F_Z is the tensile force and F_X and F_Y are the shear forces.

$$F_y := \frac{0.3W}{2} = 3.123\,lbf$$

$$F_z := \frac{1.2W}{2} = 12.493\,lbf$$

Guess Values

$F_{x1} := 1\text{lbf}$

$F_{x2} := 1\text{lbf}$

$F := 1\text{lbf}$ Force at Bottom of Plate

Given

$-F + F_{x1} + F_{x2} = 0.3W$ ΣFx = 0

$(F_{x1} + F_{x2}) \cdot H = 1.2W \cdot L + 0.3W \cdot H$ ΣMy = 0

$-F_{x1} \cdot \frac{D}{2} + F_{x2} \cdot \frac{D}{2} = 0.3W \cdot L$ ΣMz = 0

$$\begin{pmatrix} F_{x1} \\ F_{x2} \\ F \end{pmatrix} := \text{Find}(F_{x1}, F_{x2}, F) = \begin{pmatrix} 71.625 \\ 87.434 \\ 152.813 \end{pmatrix} \text{lbf}$$

$F_x := F_{x2} = 87.434\text{lbf}$

10-32 Screws

$A_t := 0.01999\text{in}^2$ Tensile Stress Area

$A_r := 0.01753\text{in}^2$ Root Area

$$\sigma := \frac{F_z}{A_t} = 625\text{psi}$$

$$\tau := \frac{\sqrt{F_x^{\,2} + F_y^{\,2}}}{A_r} = 4990.8\text{psi}$$

$$\sigma_{vm} := \sqrt{\sigma^2 + 3\tau^2} = 8666.9\text{psi}$$

$$SF := \frac{30\text{ksi}}{\sigma_{vm}} = 3.5$$ >1 Adequate

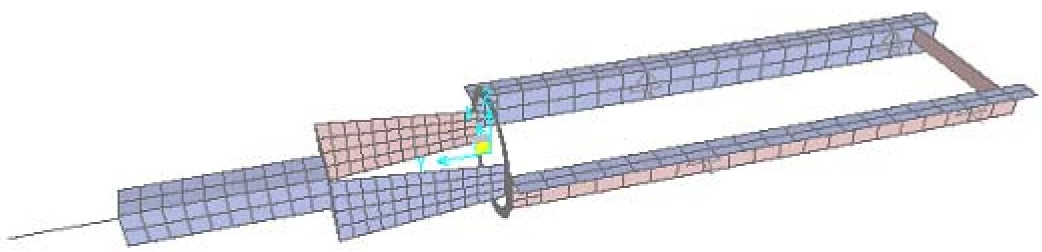
Since >3 Dead Load analysis alone is not needed.

10. SAP2000 Model of VSG-Rotator-Rail Assembly

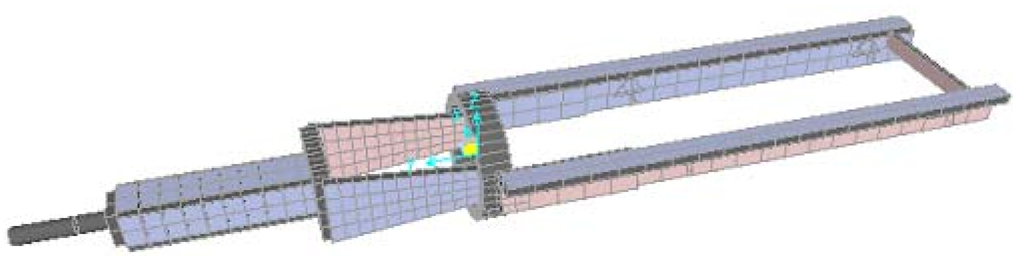
A SAP2000 model of the assembly was constructed and is shown below. The weight of the model is 25.85 pounds. The model is pin connected to the TIM. The main purpose of the model was to calculate the stresses in the components and the forces in the screws connecting the TIM Rails to the TIM.

The following Load Cases were run:

Dead = Weight of Materials + 0.06lb Snout Load
EQx = 0.3 * Dead
EQy = 0.3 * Dead
EQz = 0.2 * Dead
Comb EQ = EQx + EQy + EQz
Comb All = Dead + Comb EQ

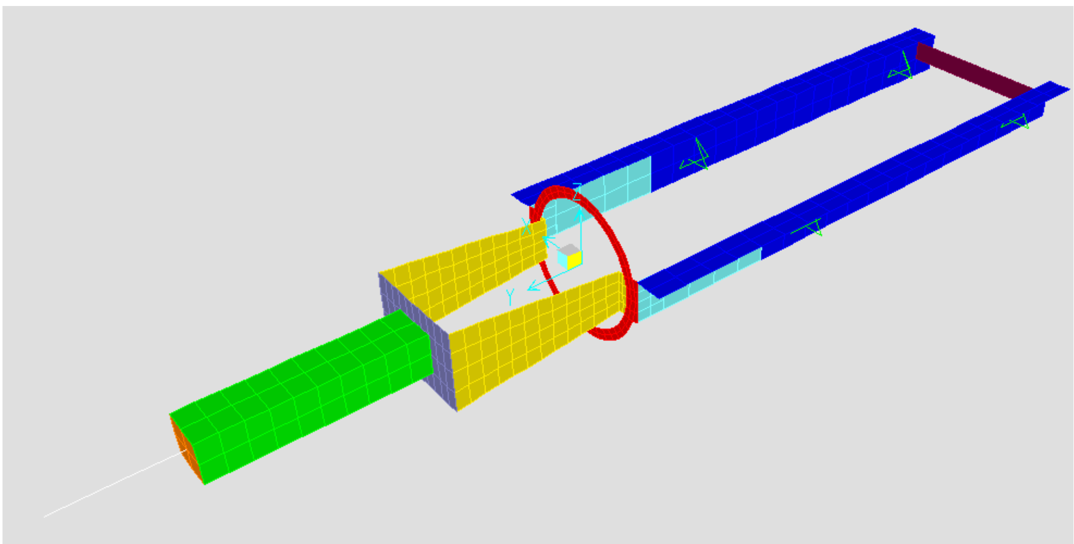


The extruded view shown below indicates the thickness of each of the members. The Snout was modeled as a cylinder with the average diameter of the truncated cone.



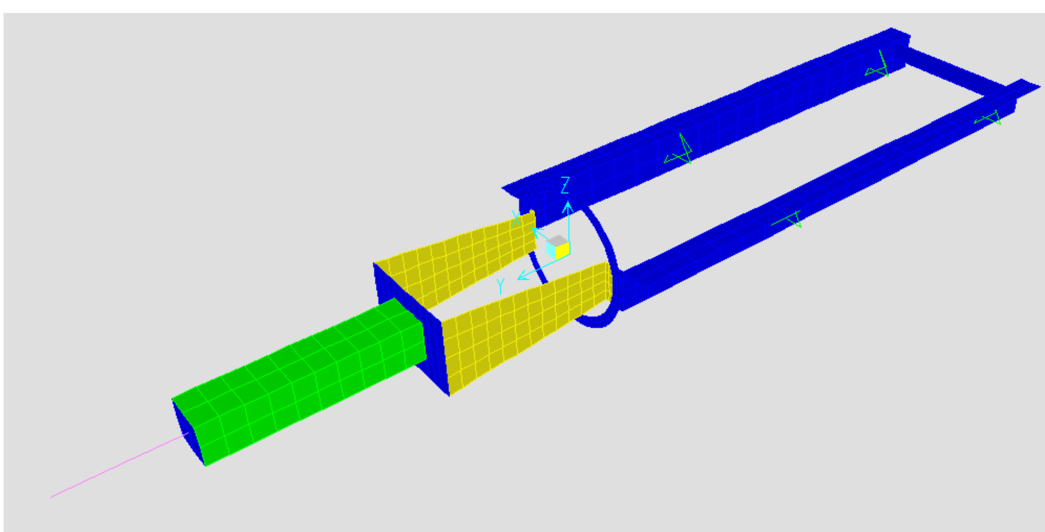
The view shown below indicates the member thickness as follows:

VSG Flange	1in thick	Orange
VSG Box	0.5in thick	Green
Unimount	0.8in thick	Blue/Gray
Rotator Ring	1.5in thick	Red
Arms/Camera	0.5in thick	Yellow
Aluminum	0.5in thick	Dark Blue
Aluminum	1in thick	Light Blue
Handle	0.25in thick	Purple

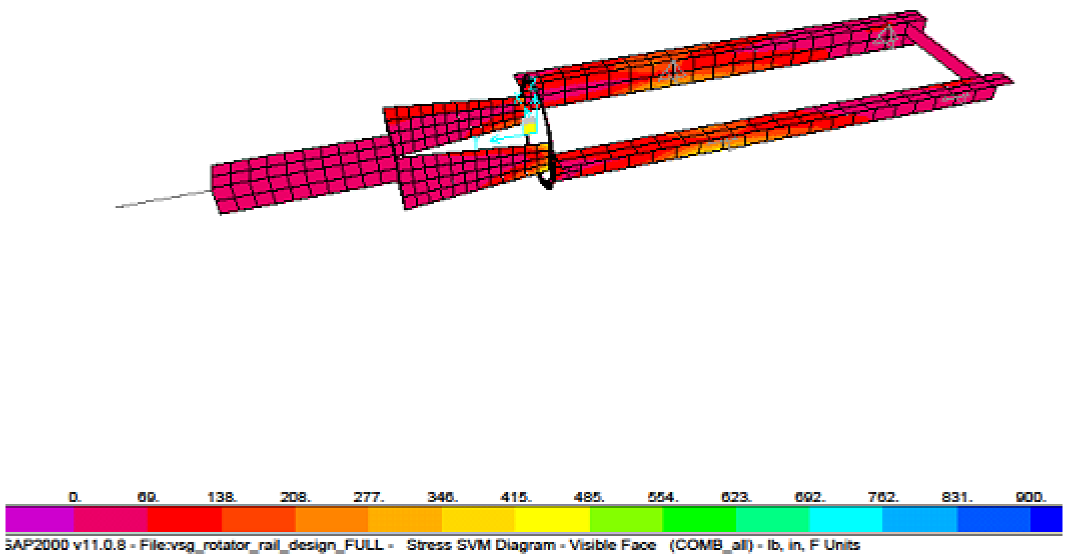


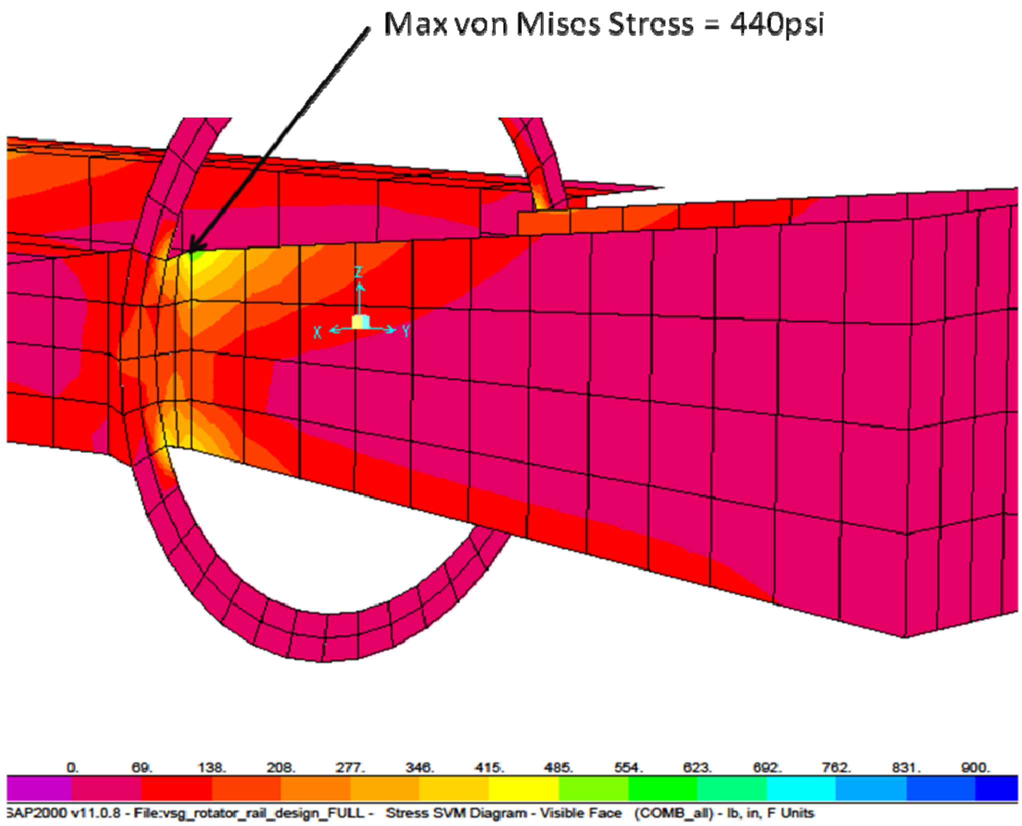
The view shown below indicates the materials as follows:

Snout	Pink
Aluminum	Blue
Aluminum/Camera	Yellow
Steel	Green



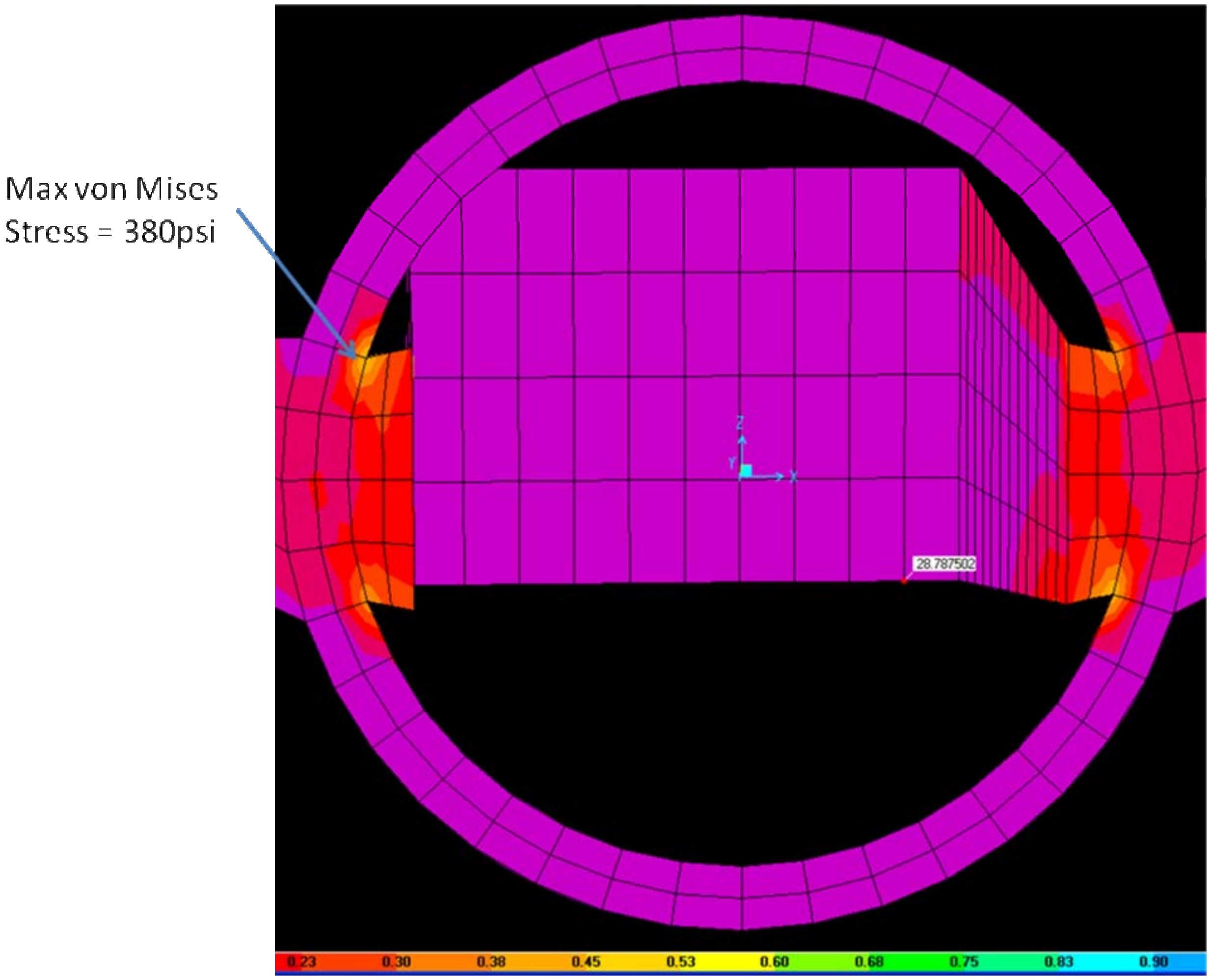
The views below show contour plots of von Mises stress for the ***Comb All*** load case. The maximum von Mises stress in the arms is 440psi.





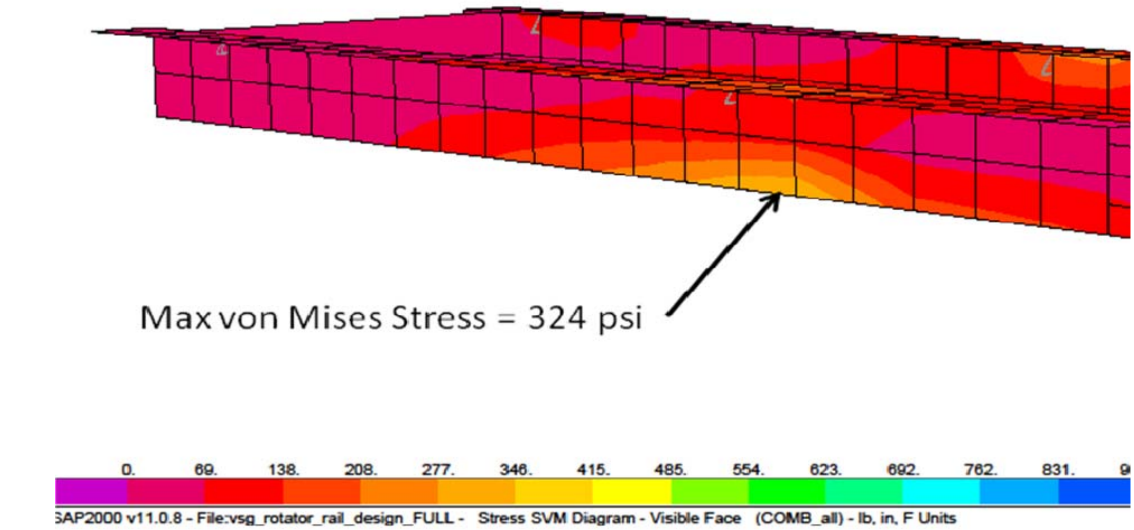
Factor of Safety on Arms = 35ksi/440psi = 79.5

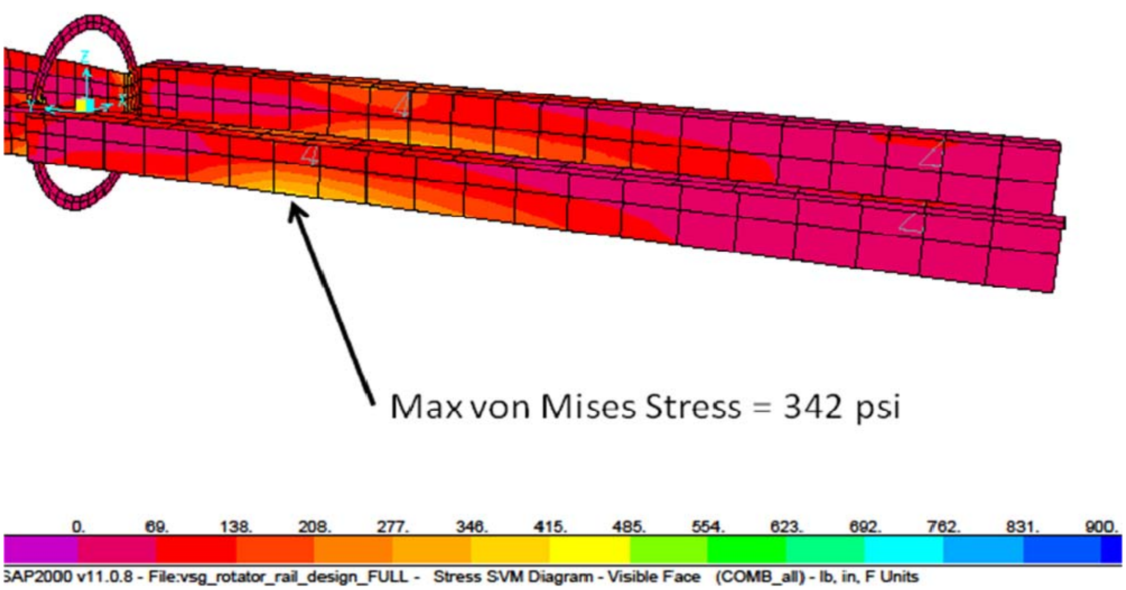
The view below shows the maximum von Mises stress of 380 psi in the Rotator Ring.



SF = 30000psi/380psi = 78.9

The views below show the maximum von Mises stress in the rails. They are 324psi on the right rail and 342 on the left rail. The difference is due to the earthquake loading.





Factor or Safety on Rails = 35ksi/342psi = 102.3

VSG Connection of TIM Rails to TIM

The reactions are shown and tabulated below:

Total Weight = W = 25.86 pounds
0.3 x W = 7.76 pounds
0.2 x W = 5.17 pounds

TABLE: Joint Reactions

Joint	OutputCase	CaseType	F1	F2	F3	V	T
Text	Text	Text	Lb	Lb	Lb	Lb	Lb
336	DEAD	LinStatic	5.71	-37	20.52	37.438	20.52
336	eq_x	LinStatic	4.2	-2.76	0.8	5.025694	0.8
336	eq_y	LinStatic	-0.12	2.17	0.23	2.173315	0.23
336	eq_z	LinStatic	1.14	-7.36	4.09	7.447765	4.09
336	COMB_all	Combination	10.93	-44.95	25.64	46.25978	25.64
336	COMB_eq	Combination	5.22	-7.95	5.12	9.510568	5.12
358	DEAD	LinStatic	-9.48	37.18	-7.56	38.36956	-7.56
358	eq_x	LinStatic	-0.23	-5.64	0.15	5.644688	0.15
358	eq_y	LinStatic	-0.13	1.73	-0.23	1.734878	-0.23
358	eq_z	LinStatic	-1.89	7.4	-1.5	7.637545	-1.5
358	COMB_all	Combination	-11.73	40.66	-9.14	42.31818	-9.14
358	COMB_eq	Combination	-2.25	3.48	-1.58	4.14402	-1.58
572	DEAD	LinStatic	-5.84	-37.24	20.5	37.69513	20.5
572	eq_x	LinStatic	4	3.11	-0.8	5.066764	-0.8
572	eq_y	LinStatic	0.1	2.15	0.23	2.152324	0.23
572	eq_z	LinStatic	-1.16	-7.41	4.09	7.500247	4.09
572	COMB_all	Combination	-2.89	-39.38	24.02	39.4859	24.02
572	COMB_eq	Combination	2.94	-2.14	3.52	3.636372	3.52
602	DEAD	LinStatic	9.61	37.05	-7.6	38.27603	-7.6
602	eq_x	LinStatic	-0.22	5.29	-0.15	5.294573	-0.15
602	eq_y	LinStatic	0.15	1.69	-0.23	1.696644	-0.23
602	eq_z	LinStatic	1.91	7.37	-1.51	7.613475	-1.51
602	COMB_all	Combination	11.45	51.41	-9.49	52.66964	-9.49
602	COMB_eq	Combination	1.84	14.36	-1.89	14.4774	-1.89

	F1	F2	F3
DL=	0	-0.01	25.86
Eqx=	7.75	0	0
Eqy=	0	7.74	0
Eqz=	0	0	5.17

Fastener Safety Factors (Worst Case Screw) shown in yellow in the Table

$T := 9.49\,lbf$

$V := 52.67\,lbf$

$A_t := 0.01999\,in^2$

$A_r := 0.01753\,in^2$

$\sigma := \frac{T}{A_t} = 474.7\,psi$

$\tau := \frac{V}{A_r} = 3004.6\,psi$

$\sigma_{vm} := \sqrt{\sigma^2 + 3\tau^2} = 5225.7\,psi$

$SF := \frac{30\,ksi}{\sigma_{vm}} = 5.7$

Location of center of gravity from SAP2000 Model

Sum moments about front supports.
Supports are 15.33 in apart
Front support is 9.76 in behind Rotator.
Use Dead Load reactions from table.

$y_{bar} := \frac{(7.56 + 7.6)\,lbf \cdot 15.33\,in}{25.86\,lbf} = 8.987\,in$

$yy_{bar} := 9.76\,in - y_{bar} = 0.773\,in$ Behind Rotator

10. Cart Rail Handle

From SAP2000 the system center of gravity is obtained which is 0.773 inch behind the Rotator Ring. The ring is used as one handle, F_1. The attached handle is the other lifting point, F_2.

$F_1 := \frac{27.027\,in \cdot 25.86\,lbf}{27.8\,in} = 25.141\,lbf$

$F_2 := \frac{0.773\,in \cdot 25.86\,lbf}{27.8\,in} = 0.719\,lbf$

The handle is attached with the rails through 2x 10-32 screws on each side. By observation, the force on the handle connection is very low so there is no safety hazard.

11. MSPEC Connection of TIM Rails to TIM

The reactions are shown and tabulated below:

Total Weight = W = 31.36 pounds
0.3 x W = 9.40 pounds
0.2 x W = 6.26 pounds

TABLE: Joint Reactions							
Joint	**OutputCase**	**CaseType**	**F1**	**F2**	**F3**	**V**	**T**
Text	Text	Text	Lb	Lb	Lb	Lb	Lb
336	DEAD	LinStatic	8.18	-53.2	27.26	53.8252	27.26
336	eq_x	LinStatic	5.28	-4.39	0.97	6.866622	0.97
336	eq_y	LinStatic	-0.16	2.63	0.28	2.634862	0.28
336	eq_z	LinStatic	1.63	-10.6	5.44	10.72459	5.44
336	COMB_all	Combination	14.92	-65.57	33.96	67.24605	33.96
336	COMB_eq	Combination	6.74	-12.37	6.7	14.08703	6.7
358	DEAD	LinStatic	-13.43	53.47	-11.58	55.13081	-11.58
358	eq_x	LinStatic	-0.46	-8.03	0.22	8.043165	0.22
358	eq_y	LinStatic	-0.16	2.1	-0.29	2.106086	-0.29
358	eq_z	LinStatic	-2.68	10.66	-2.31	10.99172	-2.31
358	COMB_all	Combination	-16.72	58.2	-13.95	60.55409	-13.95
358	COMB_eq	Combination	-3.29	4.73	-2.37	5.761684	-2.37
572	DEAD	LinStatic	-8.35	-53.56	27.27	54.20697	27.27
572	eq_x	LinStatic	5.03	4.86	-0.97	6.994319	-0.97
572	eq_y	LinStatic	0.15	2.61	0.29	2.614307	0.29
572	eq_z	LinStatic	-1.67	-10.68	5.44	10.80978	5.44
572	COMB_all	Combination	-4.84	-56.77	32.04	56.97595	32.04
572	COMB_eq	Combination	3.51	-3.2	4.76	4.749747	4.76
602	DEAD	LinStatic	13.61	53.3	-11.59	55.0102	-11.59
602	eq_x	LinStatic	-0.45	7.56	-0.22	7.573381	-0.22
602	eq_y	LinStatic	0.17	2.06	-0.29	2.067003	-0.29
602	eq_z	LinStatic	2.71	10.62	-2.31	10.96031	-2.31
602	COMB_all	Combination	16.05	73.54	-14.41	75.27107	-14.41
602	COMB_eq	Combination	2.44	20.25	-2.82	20.39647	-2.82

DL=	0.01	0.01	31.36
Eqx=	9.4	0	0
Eqy=	0	9.4	-0.01
Eqz=	-0.01	0	6.26

MSPEC Connection to TIM

$T := 14.41\,lbf$

$V := 75.27\,lbf$

$A_t := 0.01999\,in^2$

$A_r := 0.01753\,in^2$

$\sigma := \frac{T}{A_t} = 720.9\,psi$

$\tau := \frac{V}{A_r} = 4293.8\,psi$

$\sigma_{vm} := \sqrt{\sigma^2 + 3\tau^2} = 7471.9\,psi$

$SF := \frac{30\,ksi}{\sigma_{vm}} = 4.015$

12. Torque Requirement for VSG Fasteners

VSG screws shown in Figure-5 and Figure-6 are made of stainless steel and obtained from the McMaster Carr Company. The fasteners specifications are attached in Appendix-C.

Stainless steel screws properties:

Minimum tensile strength = 70000 psi
Minimum yield strength = 30000 psi
Rockwell Hardness = B70
Stainless steel type = 18-8 Stainless steel

VSG Screw Torques

Torque is calculated from (See Refenece-1)

Torque = K.x dn x 0.6 σ_{ySST}

Where:

$\sigma_{ySST} := 30\text{ksi}$ — Yield strength of fastener material

$K := 0.2$ — Thread friction factor

dn = Nominal diameter

The preload stress is 60% of the yield stress in this equation.
The safety factor is SF = $\sigma_y/0.6*\sigma_y$ or 1.67

<u>4 - 40 Screw</u>

$d_n := 0.112\text{in}$ — Nominal diameter

$TPI := \frac{40}{\text{in}}$ — Thread per inch

$d_m := d_n - \frac{0.9743}{TPI} = 0.0876\,\text{in}$ — Mean diameter

$A_t := \frac{\pi \cdot d_m^2}{4} = 0.0060\,\text{in}^2$ — Tensile stress area

$P_{440} := 0.6 \cdot \sigma_{ySST} \cdot A_t$ — Preload

$P_{440} = 108.6\,lbf$

$T_{440} := K \cdot d_n \cdot P_{440} = 2.4\,in \cdot lbf$ Preload torque

$\sigma_{440} := \frac{P_{440}}{A_t} = 18000\,psi$ Preload Stress

$SF := \frac{\sigma_{ySST}}{\sigma_{440}} = 1.67$ Safety Factor

$d_r := d_n - \frac{1.299038}{TPI} = 0.07952\,in$ Root diameter

$A_r := \frac{\pi \cdot d_r^2}{4} = 0.00497\,in^2$ Root diameter area

$L_e := 2d_n = 0.224\,in$ Engagement length

$A_s := \pi \cdot d_m \cdot \frac{L_e}{2} = 0.031\,in^2$ Thread shear area

$\tau := \frac{P_{440}}{A_s} = 3521.4\,psi$ Thread shear stress

$SF := \frac{\frac{\sigma_{ySST}}{\sqrt{3}}}{\tau} = 4.919$ Thread Safety Factor

6 - 32 Screw

$d_n := 0.138\,in$

$TPI := \frac{32}{in}$

$d_m := d_n - \frac{0.9743}{TPI} = 0.108\,in$

$A_t := \frac{\pi \cdot d_m^2}{4} = 0.009\,in^2$

$P_{632} := .6\sigma_{ySST} \cdot A_t$

$P_{632} = 163.5\,lbf$

$T_{632} := K \cdot d_n \cdot P_{632} = 4.5 \cdot in \cdot lbf$

$\sigma_{632} := \frac{P_{632}}{A_t} = 18000 psi$

$SF := \frac{\sigma_{ySST}}{\sigma_{632}} = 1.67$

$d_r := d_n - \frac{1.299038}{TPI} = 0.09741 \cdot in$

$A_r := \frac{\pi \cdot d_r^{\,2}}{4} = 0.00745 in^2$

$L_e := 2 d_n = 0.276 in$

$A_s := \pi \cdot d_m \cdot \frac{L_e}{2} = 0.047 \cdot in^2$

$\tau := \frac{P_{632}}{A_s} = 3507.2 psi$

$SF := \frac{\frac{\sigma_{ySST}}{\sqrt{3}}}{\tau} = 4.939$

8 - 32 Screw

$d_n := 0.164 in$

$TPI := \frac{32}{in}$

$d_m := d_n - \frac{0.9743}{TPI} = 0.134 \cdot in$

$A_t := \frac{\pi \cdot d_m^{\,2}}{4} = 0.014 \cdot in^2$

$P_{832} := .6 \cdot \sigma_{ySST} \cdot A_t$

$P_{832} = 252.2 lbf$

$T_{832} := K \cdot d_n \cdot P_{832} = 8.3 \cdot in \cdot lbf$

$\sigma_{832} := \frac{P_{832}}{A_t} = 18000 psi$

$SF := \frac{\sigma_{ySST}}{\sigma_{832}} = 1.67$

$d_r := d_n - \frac{1.299038}{TPI} = 0.12341 \cdot in$

$A_r := \frac{\pi \cdot d_r^{\ 2}}{4} = 0.01196 in^2$

$L_e := 0.38 \cdot in$

$A_s := \pi \cdot d_m \cdot \frac{L_e}{2} = 0.08 \cdot in^2$

$\tau := \frac{P_{832}}{A_s} = 3163.1 psi$

$SF := \frac{\frac{\sigma_{ySST}}{\sqrt{3}}}{\tau} = 5.5$

10 - 32 Screw

$d_n := 0.190 \cdot in$

$TPI := \frac{32}{in}$

$d_m := d_n - \frac{0.9743}{TPI} = 0.16 \cdot in$

$A_t := \frac{\pi \cdot d_m^{\ 2}}{4} = 0.02 \cdot in^2$

$P_{1032} := 0.6 \cdot \sigma_{ySST} \cdot A_t$

$P_{1032} = 359.9 lbf$

$$T_{1032} := K \cdot d_n \cdot P_{1032} = 13.7 \cdot in \cdot lbf$$

$$\sigma_{1032} := \frac{P_{1032}}{A_t} = 18000 psi$$

$$SF := \frac{\sigma_{ySST}}{\sigma_{1032}} = 1.67$$

$$d_r := d_n - \frac{1.299038}{TPI} = 0.14941 \cdot in$$

$$A_r := \frac{\pi \cdot d_r^{\,2}}{4} = 0.01753 in^2$$

$$L_e := 2d_n = 0.38 \cdot in$$

$$A_s := \pi \cdot d_m \cdot \frac{L_e}{2} = 0.095 in^2$$

$$\tau := \frac{P_{1032}}{A_s} = 3778.9 psi$$

$$SF := \frac{\frac{\sigma_{ySST}}{\sqrt{3}}}{\tau} = 4.583$$

$$L_e := 0.41 in$$

$$A_s := \pi \cdot d_m \cdot \frac{L_e}{2} = 0.103 in^2$$

$$\tau := \frac{P_{1032}}{A_s} = 3502.4 psi$$

$$SF := \frac{\frac{\sigma_{ySST}}{\sqrt{3}}}{\tau} = 4.9$$

0.25 - 20

$d_n := 0.25 in$

$TPI := \frac{20}{in}$

$d_m := d_n - \frac{0.9743}{TPI} = 0.2 \cdot in$

$A_t := \frac{\pi \cdot d_m^2}{4} = 0.0318 in^2$

$P_{2520} := 0.6 \cdot \sigma_y \cdot A_t = 572.777 lbf$

$T_{2520} := K \cdot d_n \cdot P_{2520} = 28.6 \cdot in \cdot lbf$

$\sigma_{2520} := \frac{P_{2520}}{A_t} = 18000 psi$

$SF := \frac{\sigma_{ySST}}{\sigma_{2520}} = 1.67$

$d_r := d_n - \frac{1.299038}{TPI} = 0.18505 in$

$A_r := \frac{\pi \cdot d_r^2}{4} = 0.0269 in^2$

$L_e := 0.38 in$

$A_s := \pi \cdot d_m \cdot \frac{L_e}{2} = 0.12 \cdot in^2$

$\tau := \frac{P_{2520}}{A_s} = 4767.3 psi$

$SF := \frac{\frac{\sigma_{ySST}}{\sqrt{3}}}{\tau}$

$SF = 3.6$

Summary

4 - 40

$P_{440} = 108.6\text{lbf}$

$T_{440} = 2.4\cdot\text{in}\cdot\text{lbf}$

$T_{440} = 0.2\cdot\text{ft}\cdot\text{lbf}$

6 - 32

$P_{632} = 163.5\text{lbf}$

$T_{632} = 4.5\cdot\text{in}\cdot\text{lbf}$

$T_{632} = 0.4\cdot\text{ft}\cdot\text{lbf}$

8 - 32

$P_{832} = 252.2\text{lbf}$

$T_{832} = 8.3\cdot\text{in}\cdot\text{lbf}$

$T_{832} = 0.7\cdot\text{ft}\cdot\text{lbf}$

10 - 32

$P_{1032} = 359.9\text{lbf}$

$T_{1032} = 13.7\cdot\text{in}\cdot\text{lbf}$

$T_{1032} = 1.1\cdot\text{ft}\cdot\text{lbf}$

0.25 - 20

$P_{2520} = 572.8\text{lbf}$

$T_{2520} = 28.6\cdot\text{in}\cdot\text{lbf}$

$T_{2520} = 2.4\cdot\text{ft}\cdot\text{lbf}$

Appendix B – LLE Seismic Requirements Memo

Recommended Seismic Criteria for LLNL Equipment Located at LLE NIF-0116027

Revision AC

Bob Murray
December 18, 2009

Background

Building Codes (References 1-6) have used equations of the following form for equivalent static lateral seismic forces, F_p, for design of equipment anchorage:

$$F_p = Z\ I\ C_p\ W_p$$

where :	Z	=	Seismic Zone Factor
	I	=	Importance Factor
	C_p	=	Horizontal Force Factor
	W_p	=	Equipment or Component Weight

For LLE, located in Rochester, New York, the following values have been selected based on Reference 1, The New York City Seismic Code, which is based on the Uniform Building Code (References 3 and 4):

Z	=	0.15g
I	=	1.0
C_p	=	1.0 for ground-mounted Equipment or Components or 2.0 for Elevated Equipment or Components

This results in $F_H = (0.15) \times (1.0) \times (1.0 \text{ or } 2.0) \times W_p = 0.15W_p$ or $0.30W_p$ for the horizontal seismic force, F_H, for LLE.

The New York City Seismic Code states that the vertical component of ground motion may be defined by scaling the corresponding horizontal accelerations by a factor of two thirds. A similar criterion has also been used in the Nuclear Regulatory Commission Seismic Design Criteria for Nuclear Facilities and in US National Standards. This results in $F_V = (2/3) \times (0.15) \times (1.0) \times (1.0 \text{ or } 2.0) \times W_p = 0.10W_p$ or $0.20W_p$ for the vertical seismic force, F_V, for LLE.

Recommended Seismic Criteria

Horizontal Seismic Force (F_{Hg}, F_{He}**)**

F_{Hg} = 0.15 W_p for ground-mounted equipment or components (subscript g)

F_{He} = 0.30 W_p for elevated equipment or components (subscript e)

Vertical Seismic Force (F_{Vg}, F_{Ve}**)**

F_{Vg} = 0.10 W_p for ground-mounted equipment or components (subscript g)

F_{Ve} = 0.20 W_p for elevated equipment or components (subscript e)

Load Combinations

The two horizontal and vertical seismic forces shall be assumed to occur simultaneously and act through the center of gravity of the equipment or component. These forces shall be assumed to act in either direction.

Seismic forces shall be combined with dead load (equipment or component weight) and any operating loads (pressure, vacuum, thermal, magnetic, etc) as appropriate. Load factors of 1.0 are acceptable, (i.e. 1.0 x Dead Load + 1.0 x Operating Loads + 1.0 x Seismic Loads).

Acceptable Safety Factors

Safety Factors to be used are defined in the LLNL Engineering Design Safety Standards Manual, Section 1.1, Reference 7, as follows:

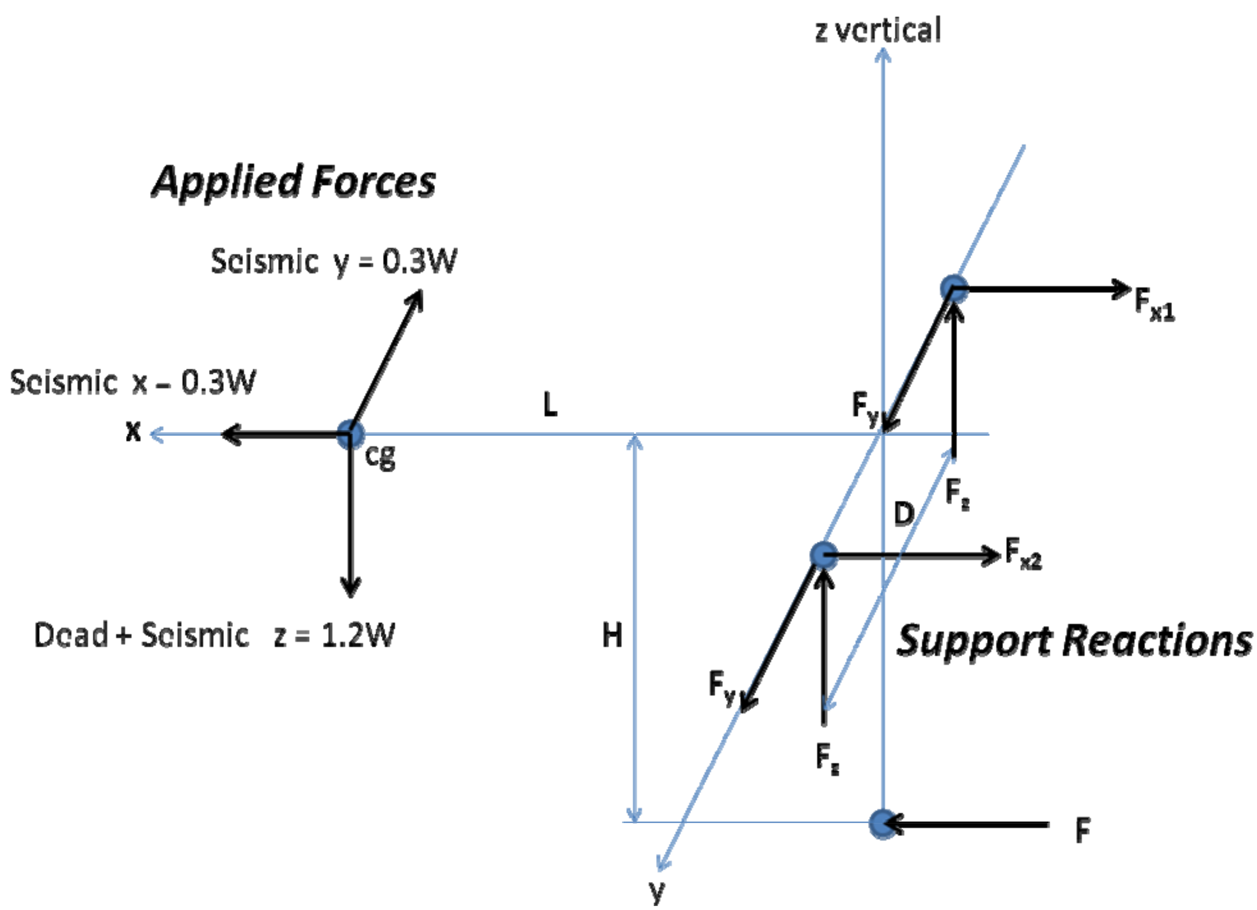
GPSF = General Purpose Safety Factor
Used for Dead Load and Operating Loads only
≥ 3 on yield stress or ≥ 4 on ultimate stress

RESF = Rare Event Safety Factor
Used for Dead Load + Operating Loads + Seismic Loads
≥ 1 on yield stress or ≥ 1.25 on ultimate stress

Approach for LLE Equipment

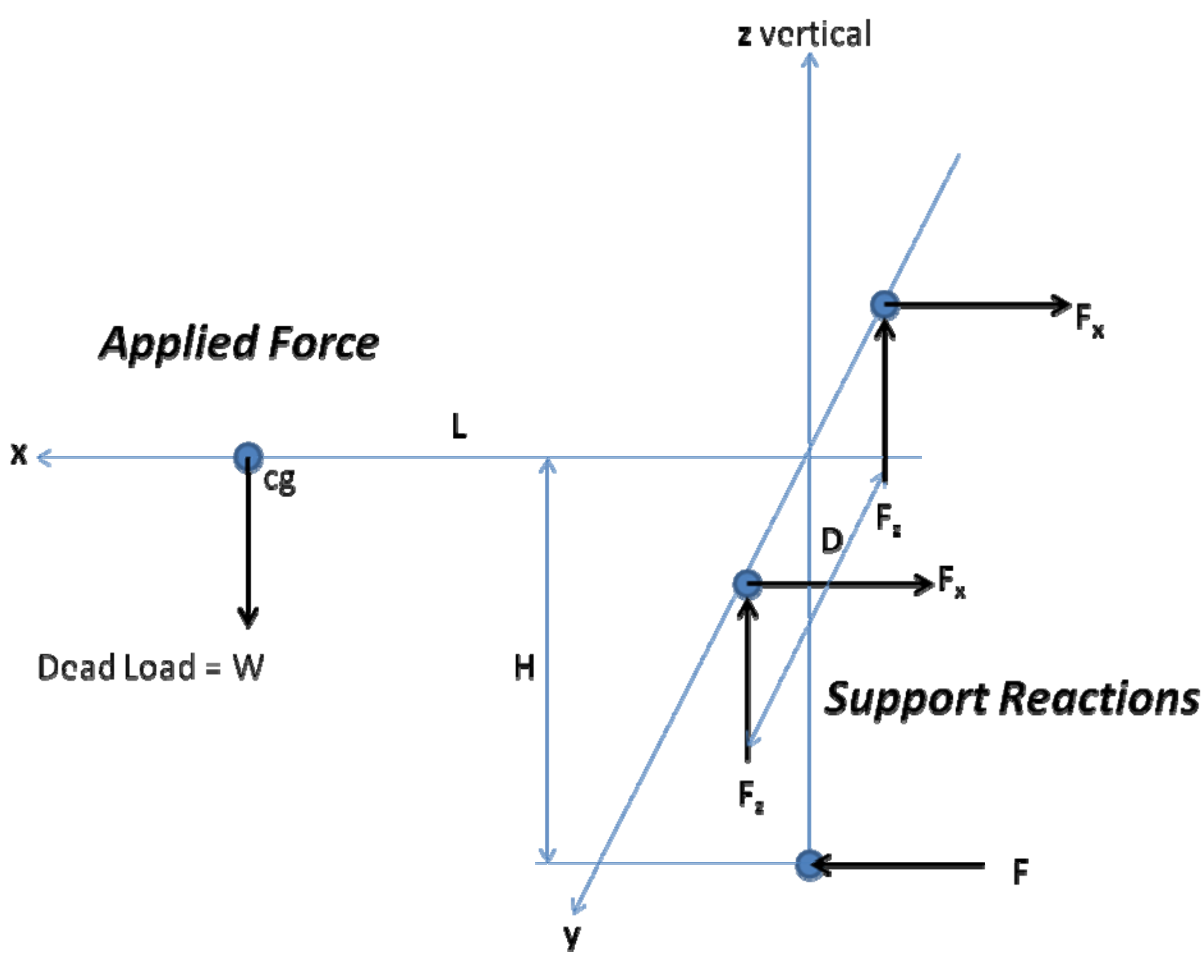
- Determine if equipment is ground-mounted or elevated.
- Conduct an analysis of the equipment for Dead Load plus Seismic Loads as shown below. Include any Operating Loads (pressure, vacuum, thermal, etc.), if applicable. Appendix A contains Sample Calculations.

Model for Dead Load plus Seismic Analysis



- Determine the Safety Factor
    - A Safety Factor of ≥1 on yield stress is acceptable.
    - If the Safety Factor on yield stress is ≥ 3, a separate analysis for Dead Load and Operating Loads only is not necessary
    - If the Safety Factor on yield stress is < 3, conduct a separate analysis for Dead Load and Operating Loads only as shown below. A Safety Factor on yield stress of ≥ 3 is acceptable.

Model for Dead Load Analysis Only



Labeling

The Engineering Directorate Safety Note (EDSN) Number, documenting the design, should be indicated on the equipment or component.

If this LLE Seismic Criteria was used in the design of the equipment or component, label the equipment or component with the following:

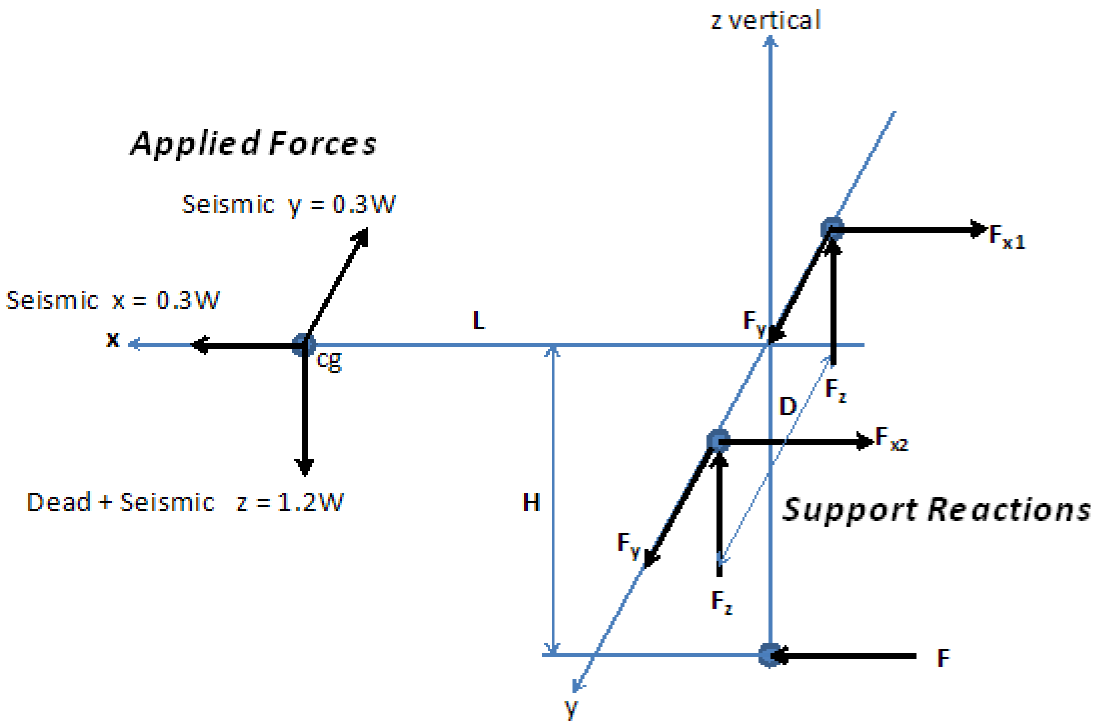
"For Use at LLE Only".

References

1. New York City Seismic Code, Article 5 Wind Loads and Earthquake Loads.
2. Department of Navy, Army, and Air Force, "*Tri-Services Manual: Seismic Design of Buildings"*, Navy NAVFAC -355, Army TM 5-809-10, Air Force AFM88-3, Chapter 13, Washington, D.C. 1992.
3. International Conference of Building Officials, *"Uniform Building Code"*, 1994 Edition, Whittier, California, 1994.
4. International Conference of Building Officials, *"Uniform Building Code"*, 1997 Edition, Whittier, California, 1997.
5. Building Code, International Code Council, Inc. March 2000.
6. American Society of Civil Engineers, ASCE/SEI 7-05, *"Minimum Design Loads for Buildings and Other Structures"*, 2006.
7. Lawrence Livermore National Laboratory, LLNL Engineering Design Safety Standards Manual, UCRL-TM-226502, 2009.

Appendix A - Sample Dead Load Plus Seismic Load Calculations

Direct Method for Dead Load plus Seismic Loading



$L := 7.372\,in$ $\qquad D := 3.562\,in$ $\qquad H := 2\,in$

$W := 3\,lbf$ $\qquad 0.2W = 0.6\,lbf$ $\qquad 0.3W = 0.9\,lbf$

Seismic Loading

$$F_y := \frac{0.3W}{2} = 0.45\,lbf$$

$$F_z := \frac{1.2W}{2} = 1.8\,lbf$$

Guess Values

$F_{x1} := 5\,lbf$

$F_{x2} := 5\,lbf$

$F := 5\,lbf$ Force at Bottom of Plate

Given

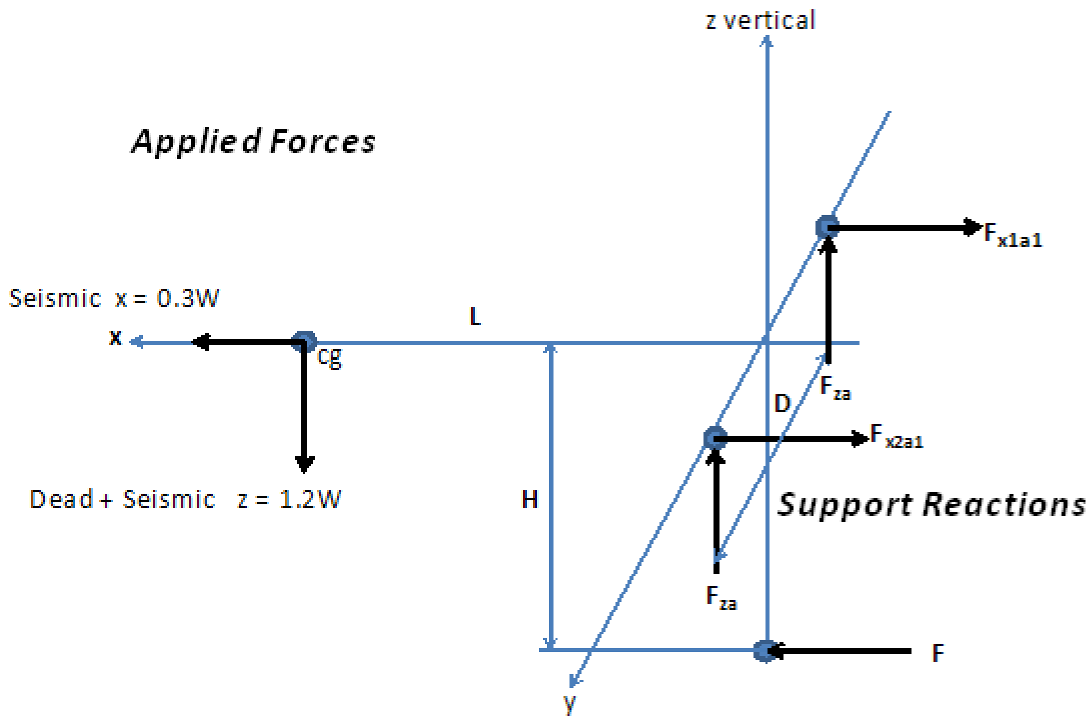
$$-F + F_{x1} + F_{x2} = 0.3W \qquad \Sigma Fx = 0$$

$$(F_{x1} + F_{x2}) \cdot H = 1.2W \cdot L + 0.3W \cdot H \qquad \Sigma My = 0$$

$$-F_{x1} \cdot \frac{D}{2} + F_{x2} \cdot \frac{D}{2} = 0.3W \cdot L \qquad \Sigma Mz = 0$$

Alternate Method for Dead Load plus Seismic Loading

$$\begin{pmatrix} F_{x1} \\ F_{x2} \\ F \end{pmatrix} := \text{Find}(F_{x1}, F_{x2}, F) = \begin{pmatrix} 5.222 \\ 8.947 \\ 13.27 \end{pmatrix} \text{lbf}$$



$$F_{za} := \frac{1.2W}{2} = 1.8\,lbf$$

Guess Values

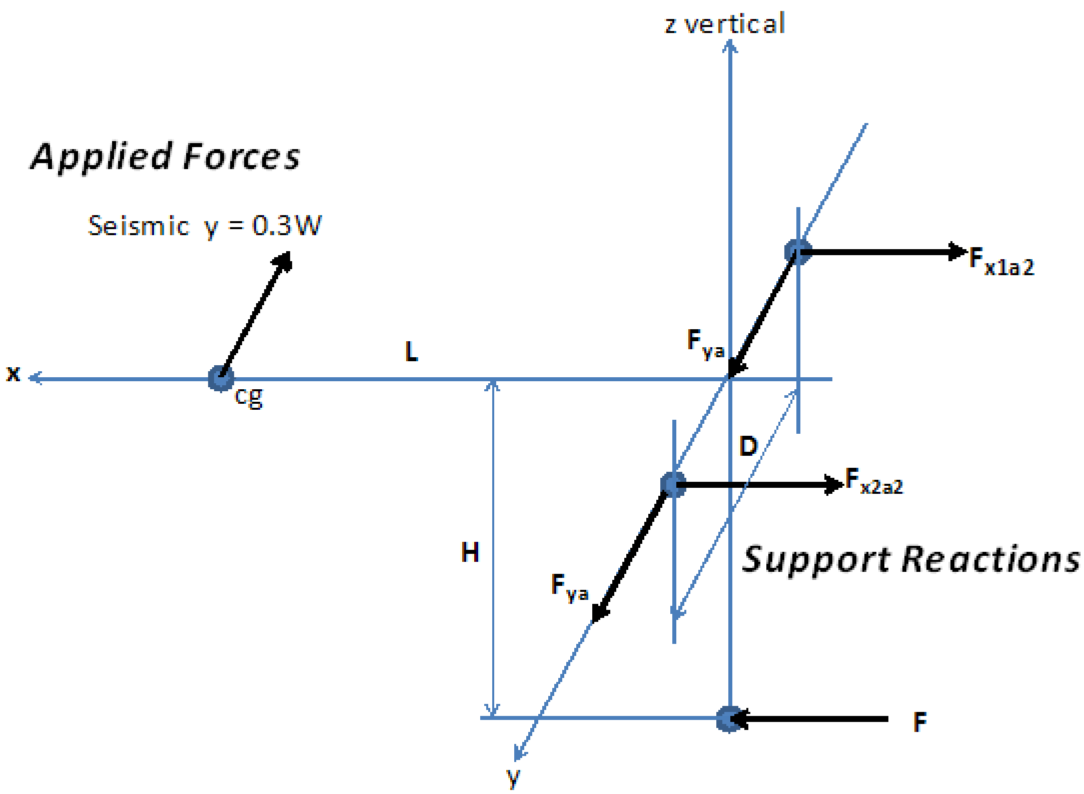
$$F_{x1a1} := 5\,lbf$$

$$F_{x2a1} := 5\,lbf$$

$$F_{x1a1} = F_{x2a1}$$

Given

$$\left(F_{x1a1} + F_{x2a1}\right)\cdot H = 1.2W\cdot L + 0.3W\cdot H$$ ΣMy = 0



$$F_{ya} := \frac{0.3W}{2} = 0.45\,lbf$$

Guess Values

$$F_{x1a2} := 5\,lbf$$

$$F_{x2a2} := 5\,lbf$$

Given

$$-F_{x1a2} \cdot \frac{D}{2} + F_{x2a2} \cdot \frac{D}{2} = 0.3W \cdot L$$ ΣMz = 0

$$F_{x1a2} = -F_{x2a2}$$

$$\begin{pmatrix} F_{x1a2} \\ F_{x2a2} \end{pmatrix} := \text{Find}(F_{x1a2}, F_{x2a2}) = \begin{pmatrix} -1.863 \\ 1.863 \end{pmatrix} lbf$$

Results by Alternative Method (Same Results as Direct Method)

$$F_{x1a} := F_{x1a1} - F_{x2a2} = 5.222\,lbf$$

$$F_{x2a} := F_{x2a1} + F_{x2a2} = 8.947\,lbf$$

$$F_{ya} = 0.45\,lbf$$

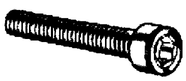
$$F_{za} = 1.8\,lbf$$

$$F_a := F_{x1a} + F_{x2a} - 0.3W = 13.27\,lbf$$

Appendix – C
Screw Fasteners Specifications and Component Drawings

Socket Cap Screws (4-40)

Socket Cap Screws

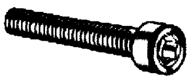


Part Number: **92196A108** $2.87 per Pack of 100

Head Style	Standard
Standard Head Style	Standard
Material Type	Stainless Steel
Finish	Plain
Class	Not Rated
Stainless Steel Type	18-8 Stainless Steel
Drive Style	Hex Socket
Inch Thread Size	4-40
Length	3/8"
Thread Length	Fully Threaded
Thread Direction	Right Handed
Tip Type	Plain
Self-Locking Method	None
Screw Quantity	Individual Screw
Hex Size	3/32"
Head Diameter	.183"
Head Height	.112"
Rockwell Hardness	Minimum B70
Minimum Tensile Strength	70,000 psi
Thread Fit	Class 3A
Specifications Met	Not Rated

Socket Cap Screw (6-32)

Socket Cap Screws



Part Number: **92185A147**	$2.88 per Pack of 25
Head Style	Standard
Standard Head Style	Standard
Material Type	Stainless Steel
Finish	Plain
Class	Not Rated
Stainless Steel Type	316 Stainless Steel
Drive Style	Hex Socket
Inch Thread Size	6-32
Length	3/8"
Thread Length	Fully Threaded
Thread Direction	Right Handed
Tip Type	Plain
Self-Locking Method	None
Screw Quantity	Individual Screw
Hex Size	7/64"
Head Diameter	.226"
Head Height	.138"
Rockwell Hardness	B70
Minimum Tensile Strength	70,000 psi
Thread Fit	Class 3A
Specifications Met	Not Rated

Socket Cap Screw (8-32)

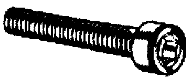
Socket Cap Screws

Part Number: **92200A194** — $3.95 per Pack of 10

Head Style	Standard
Standard Head Style	Standard
Material Type	Stainless Steel
Finish	Plain
Class	Not Rated
Stainless Steel Type	300 Series Stainless Steel
Drive Style	Hex Socket
Inch Thread Size	8-32
Length	1/2"
Thread Length	Fully Threaded
Thread Direction	Right Handed
Tip Type	Plain
Self-Locking Method	None
Screw Quantity	Individual Screw
Hex Size	9/64"
Head Diameter	.270"
Head Height	.164"
Rockwell Hardness	Not Rated
Minimum Tensile Strength	80,000 psi
Thread Fit	Class 3A
Specifications Met	Federal Specifications (FED), Military Specifications (MIL), National Aerospace Standards (NAS)
FED Specification	FF-S-86, QQ-P-35
MIL Specification	MIL 16995
NAS Specification	NAS 1352C
MIL 16995 Dash #	26
NAS 1352C Dash #	08-8

Socket Cap Screw (10-32)

Socket Cap Screws

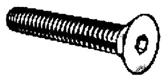


Part Number: **92185A989** — $4.71 per Pack of 25

Head Style	Standard
Standard Head Style	Standard
Material Type	Stainless Steel
Finish	Plain
Class	Not Rated
Stainless Steel Type	316 Stainless Steel
Drive Style	Hex Socket
Inch Thread Size	10-32
Length	1/2"
Thread Length	Fully Threaded
Thread Direction	Right Handed
Tip Type	Plain
Self-Locking Method	None
Screw Quantity	Individual Screw
Hex Size	5/32"
Head Diameter	.312"
Head Height	.190"
Rockwell Hardness	B70
Minimum Tensile Strength	70,000 psi
Thread Fit	Class 3A
Specifications Met	Not Rated

Socket Cap Screw (1/4-20)

Socket Cap Screws

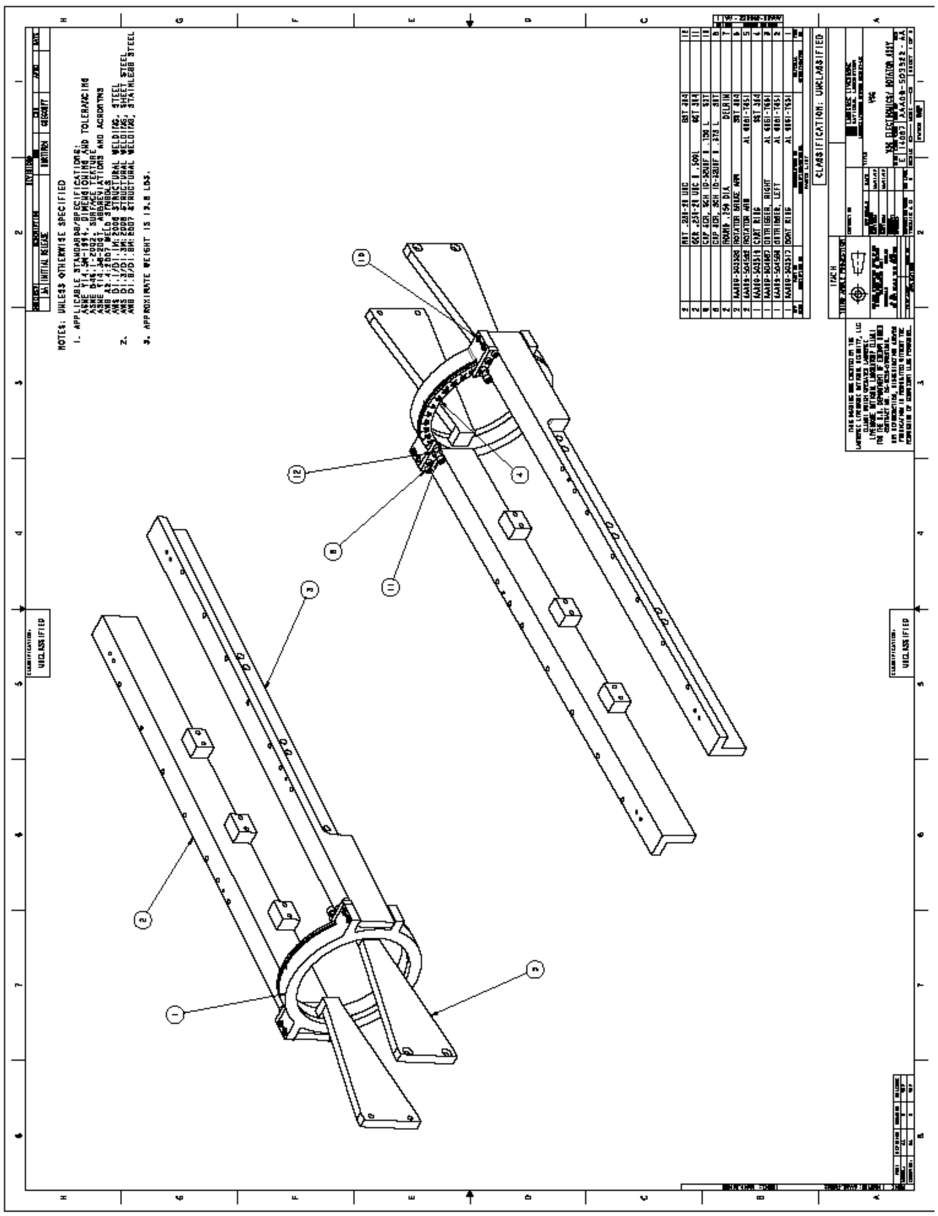


Part Number: **90585A540** — $6.35 per Pack of 10

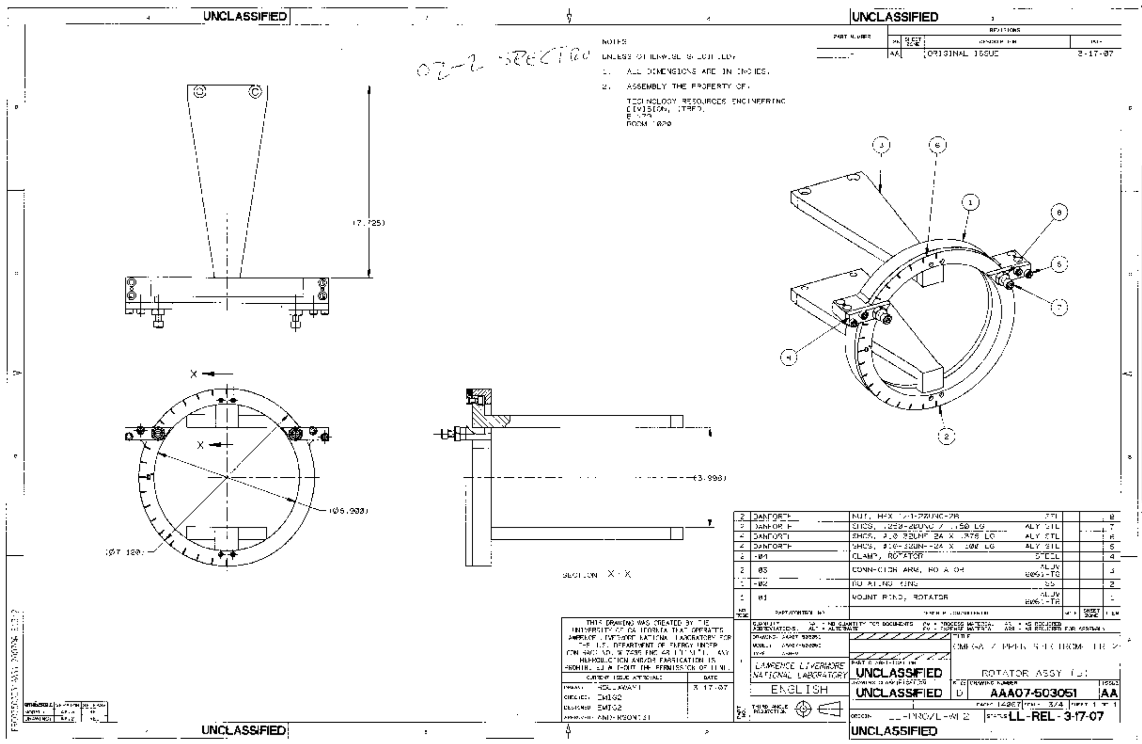
Head Style	Flat
Material Type	Stainless Steel
Finish	Plain
Class	Not Rated
Stainless Steel Type	316 Stainless Steel
Drive Style	Hex Socket
Inch Thread Size	1/4"-20
Length	3/4"
Thread Length	Fully Threaded
Thread Direction	Right Handed
Tip Type	Plain
Self-Locking Method	None
Screw Quantity	Individual Screw
Hex Size	5/32"
Head Diameter	.531"
Head Height	.161"
Head Angle	82°
Rockwell Hardness	B70
Minimum Tensile Strength	70,000 psi
Thread Fit	Class 3A
Specifications Met	Not Rated
Note	To select the right size countersink, the body diameter of the countersink must be equal to or larger than the head diameter of the screw being countersunk. The angle of the countersink must also match the head angle of the screw.

Drawings:

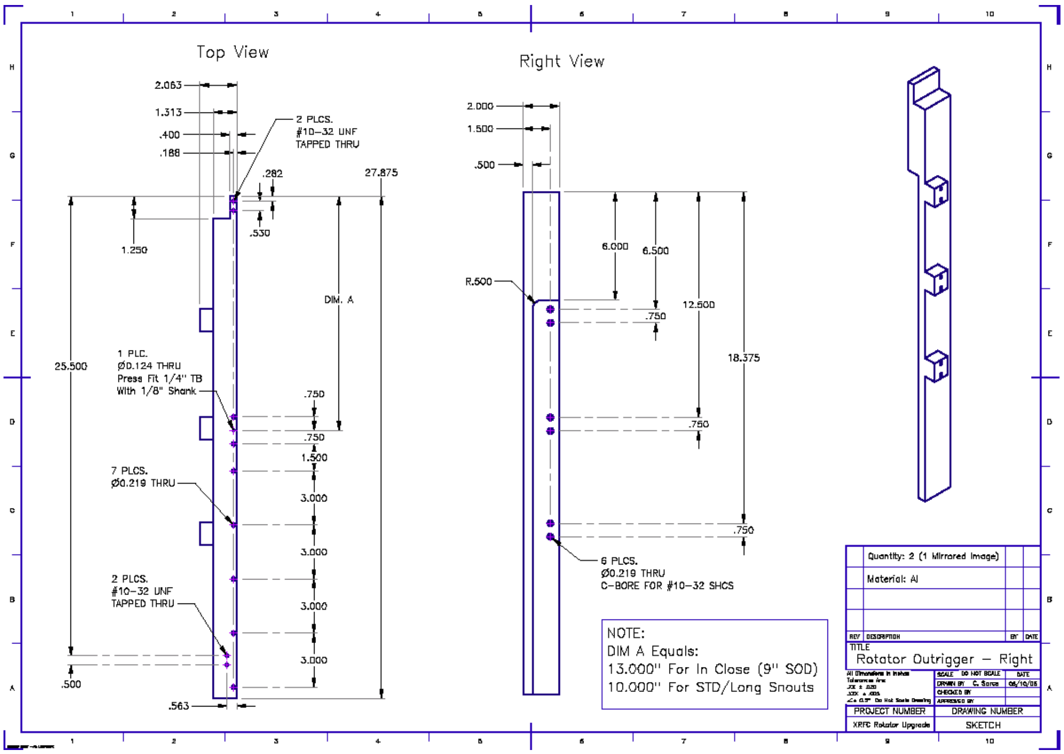
Rotator and cart rails support modified



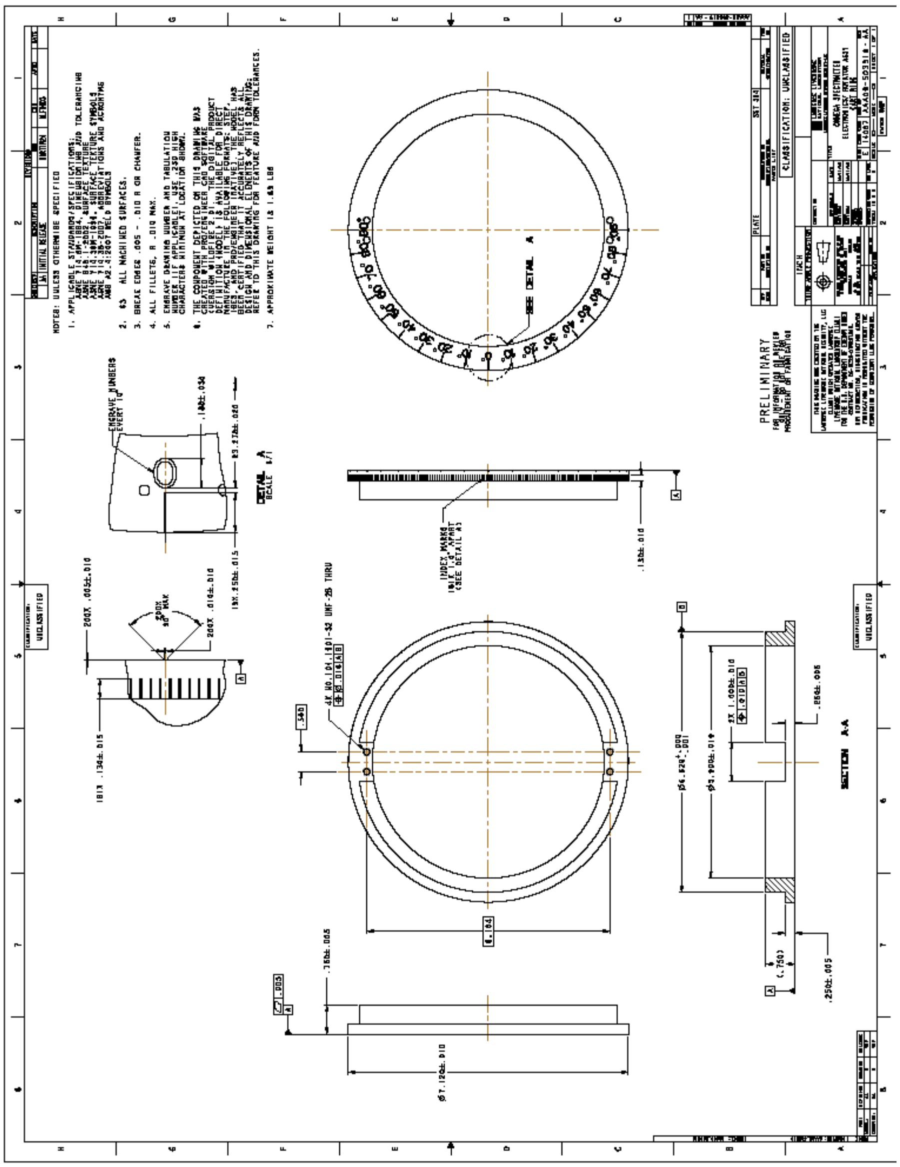
Rotator Assembly



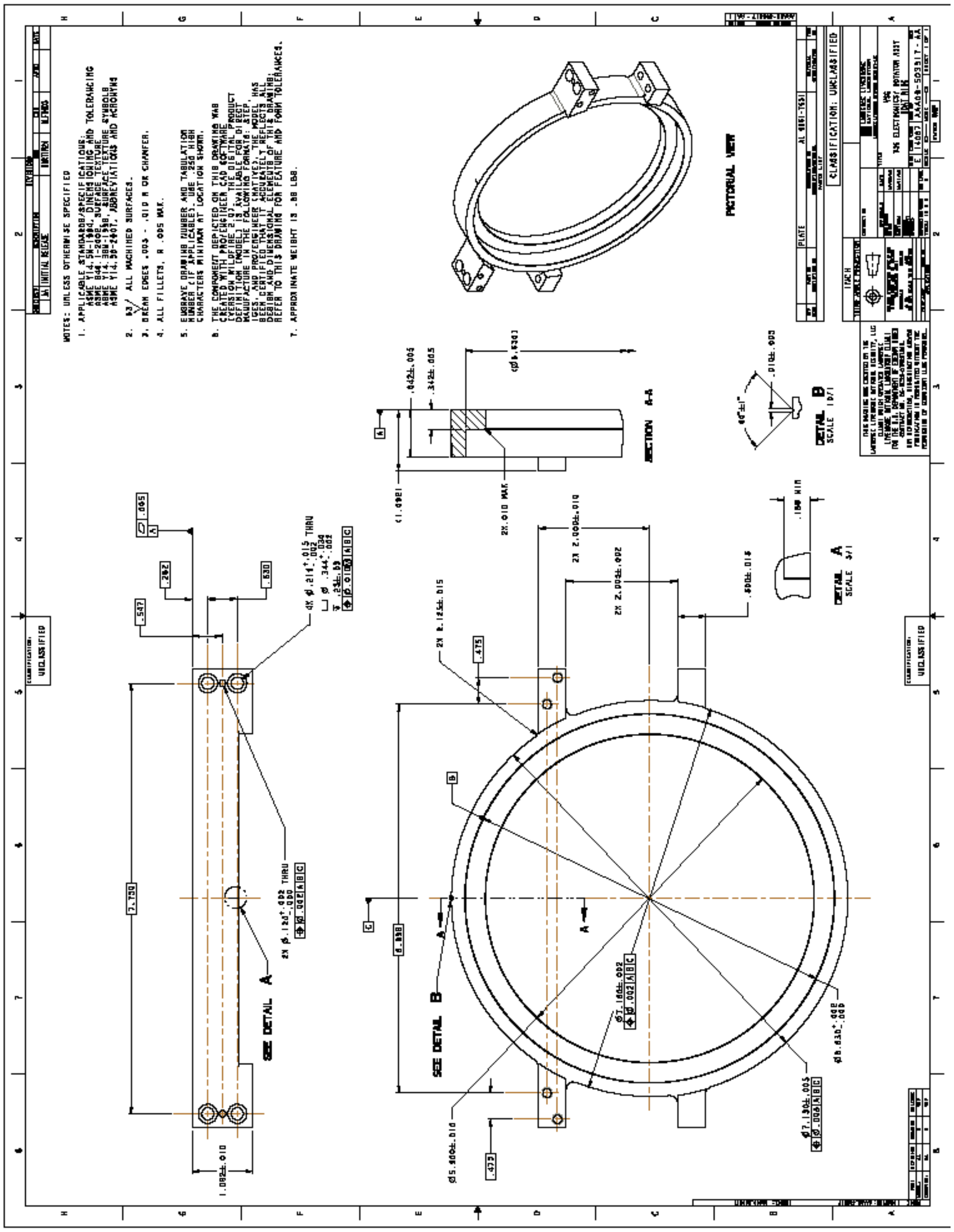
Rotator Outrigger Rail (Right side shown)



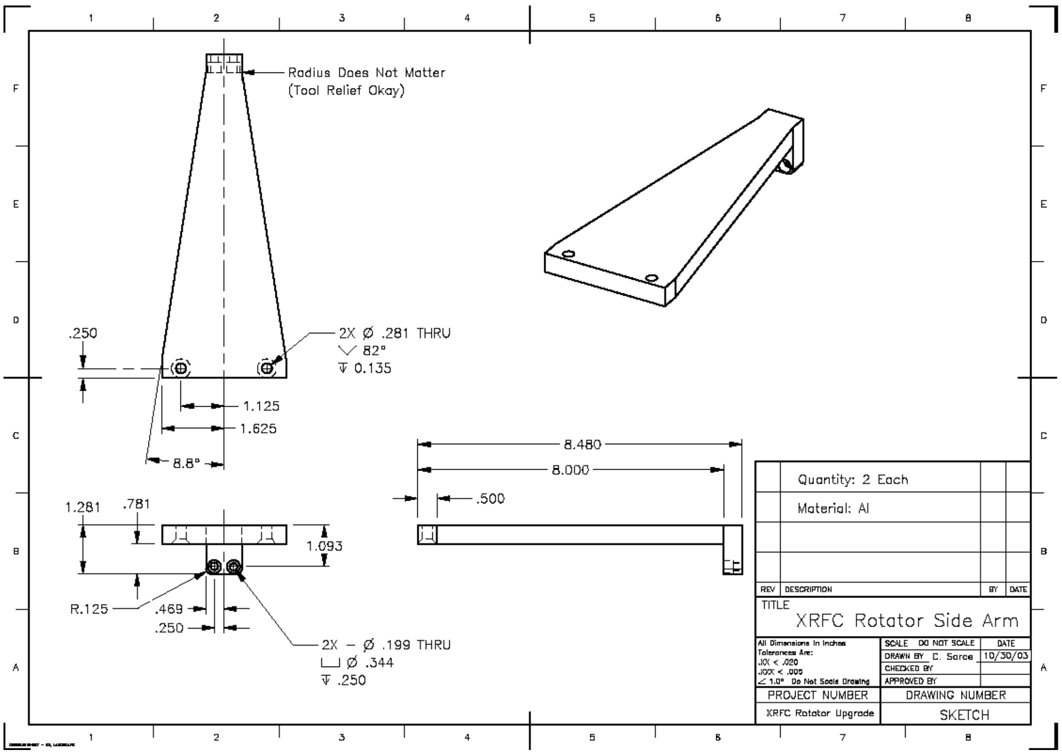
Rotator Steel Ring



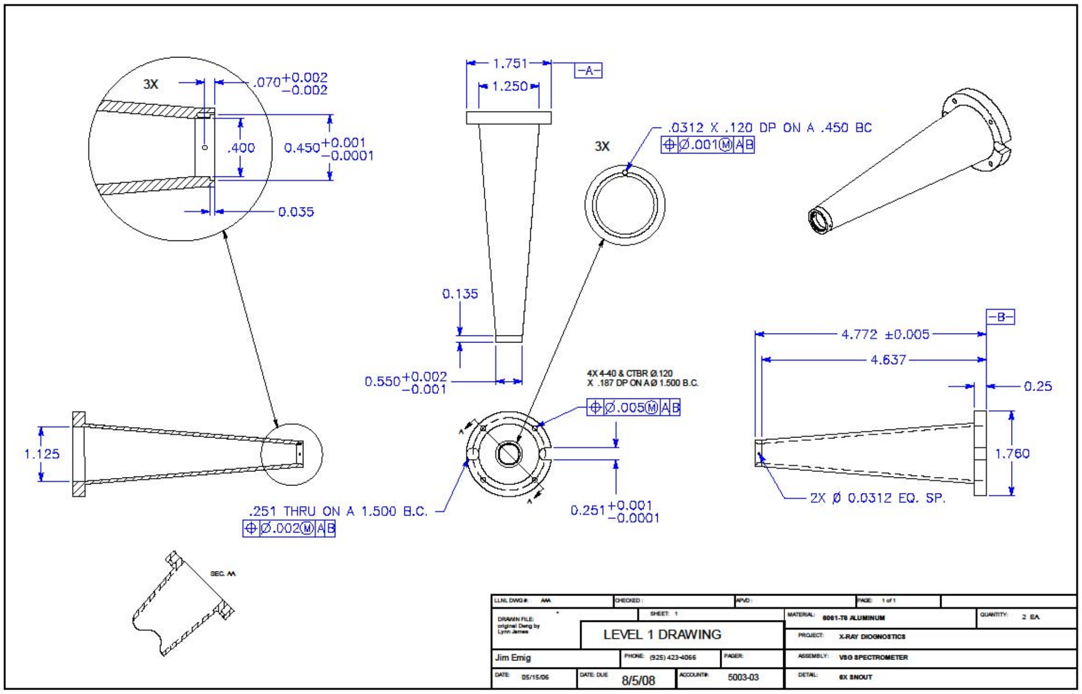
Rotator Aluminum Ring (Design modified with two support tabs)



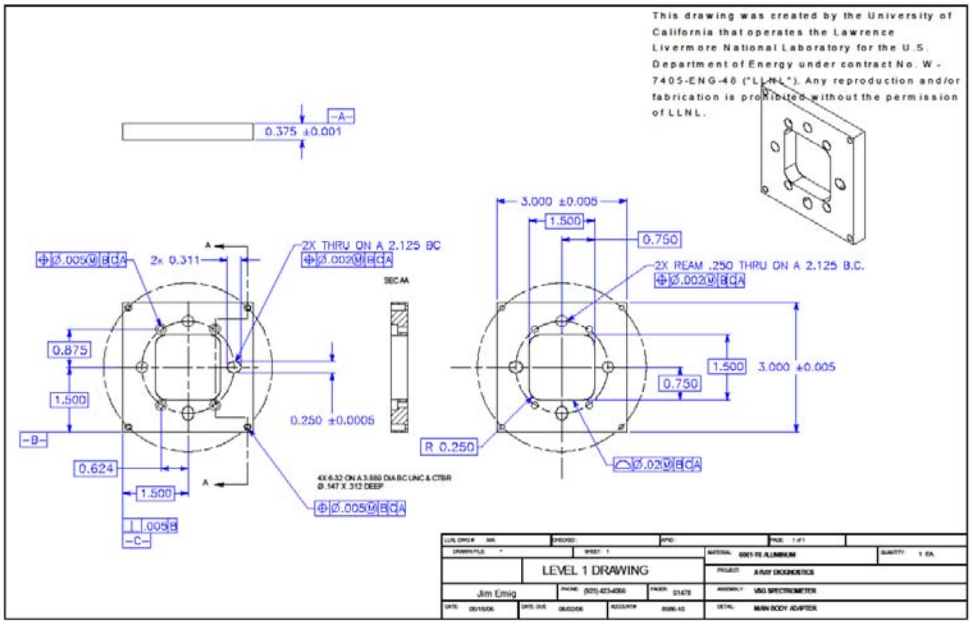
Rotator Side Arm



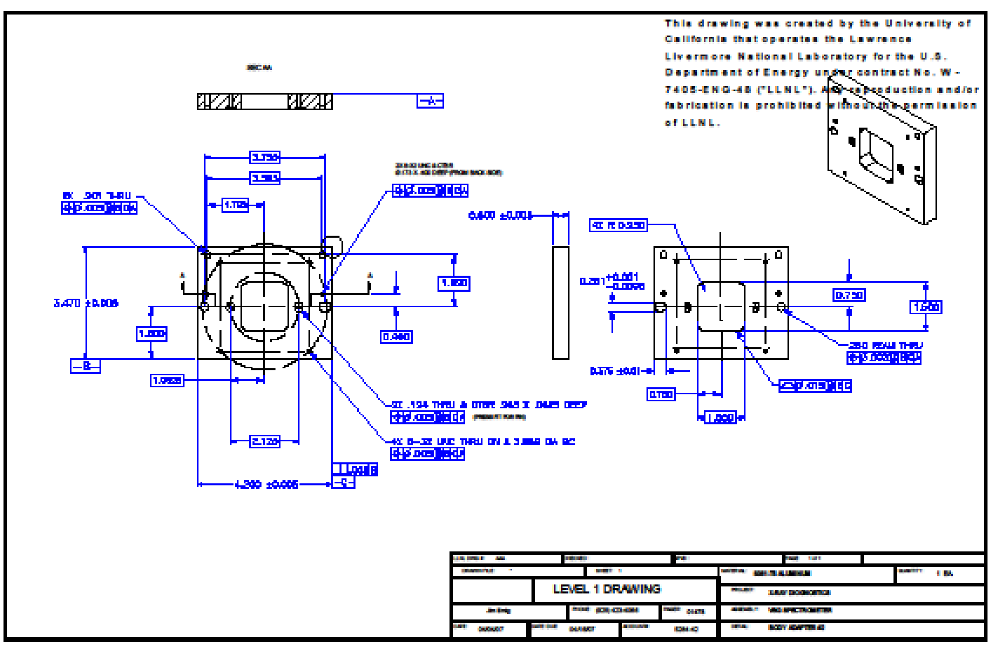
VSG Snout Cone



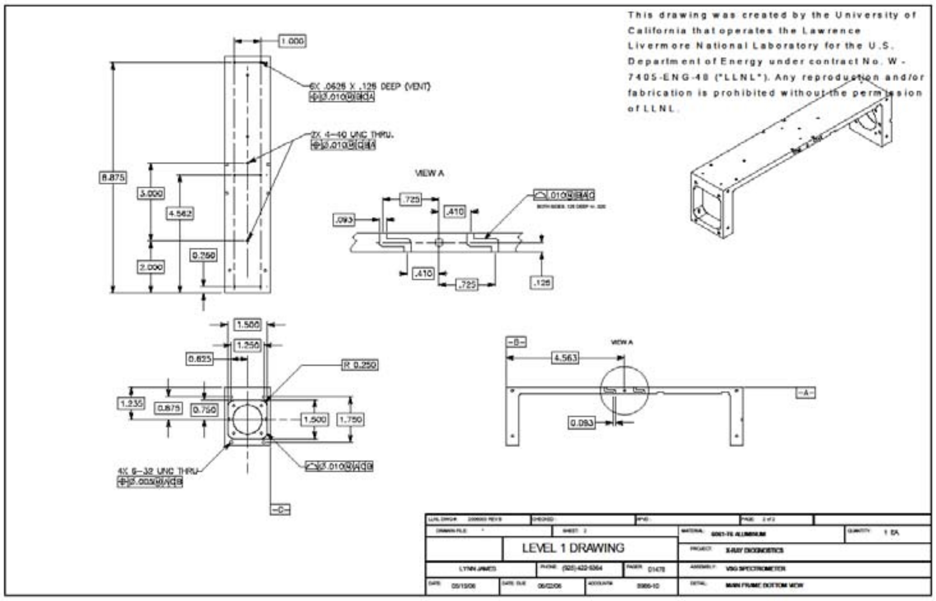
VSG Main Body Adapter Flange

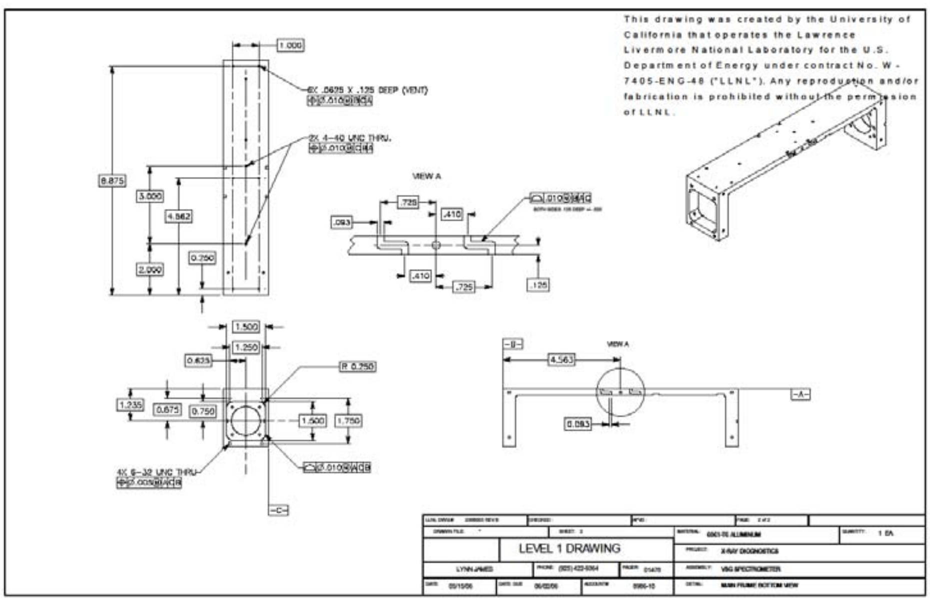


VSG Unimount Adapter Flange

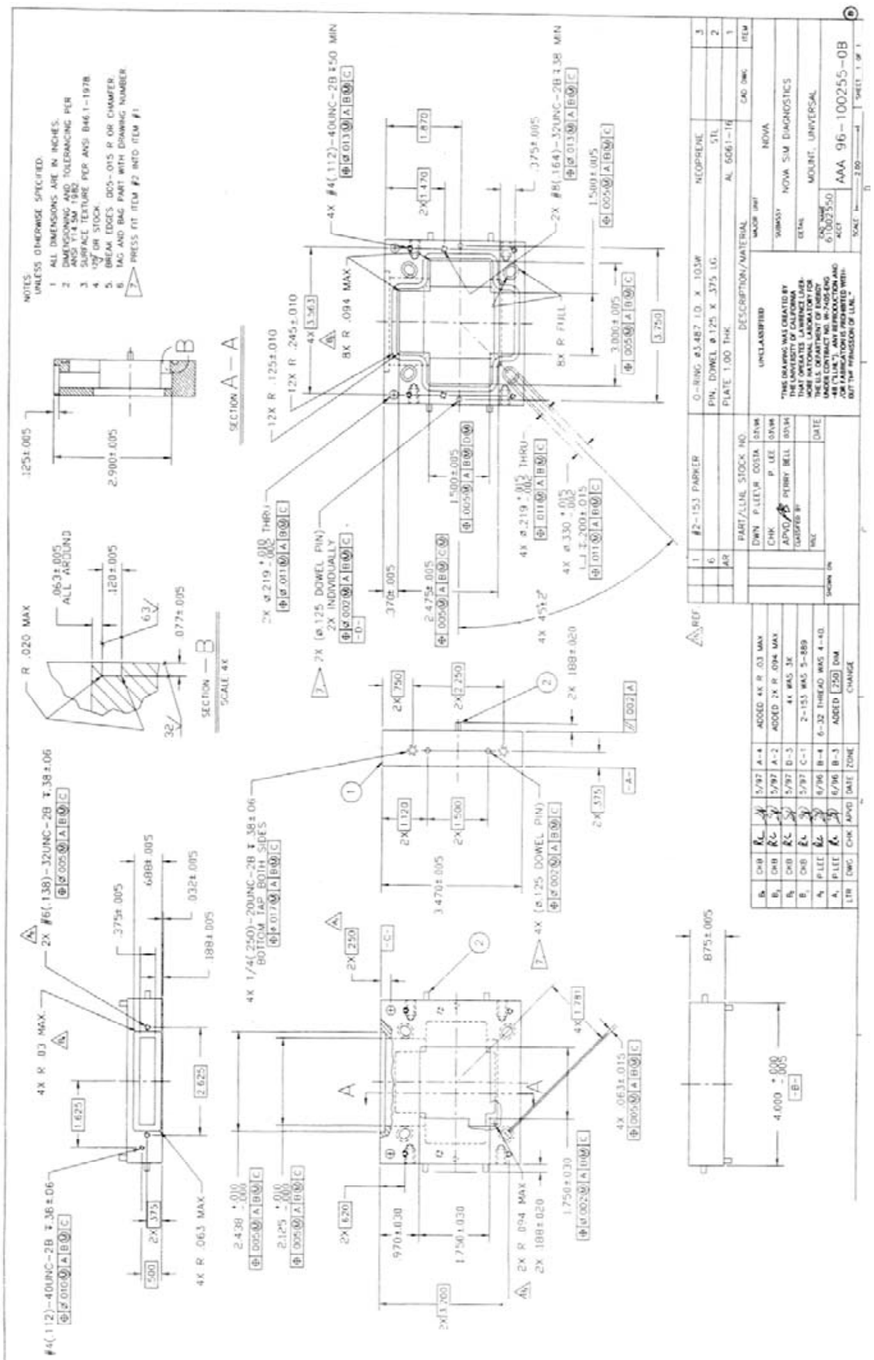


VSG Main Body Frame

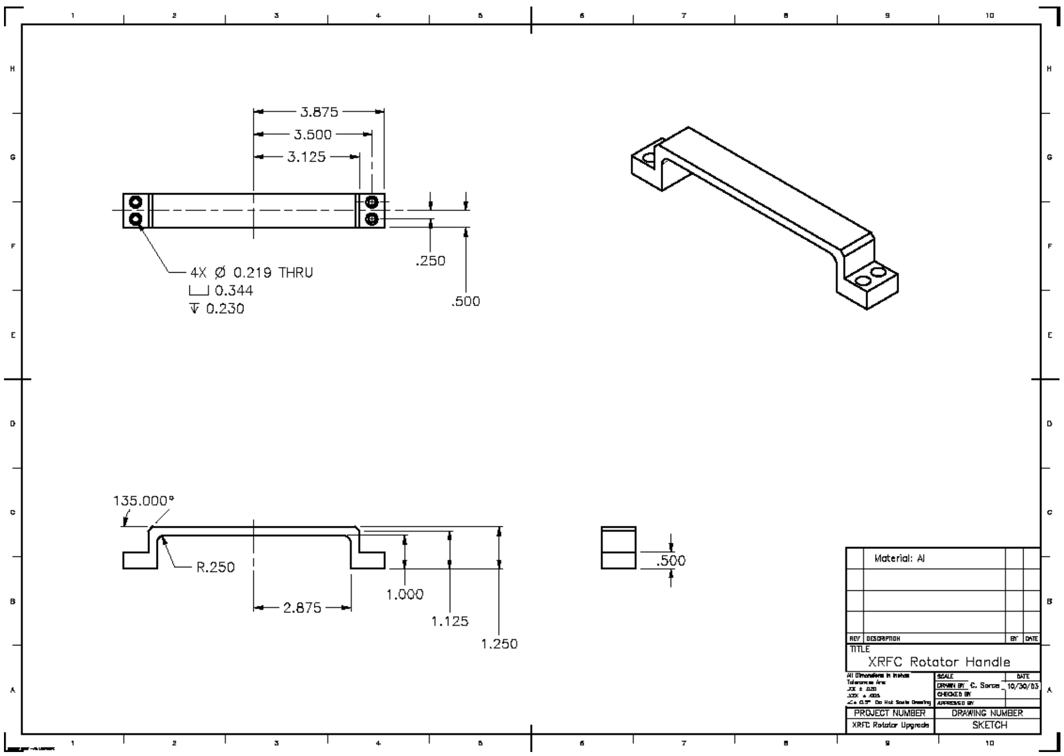




Unimount Flange (LLE design)



Rotator Cart Rail Handle



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