HETS Horizontal Thrust Structure CDR

POCs:

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Outline

i. Requirements & Considerations
ii. Overview
iii. Design & Analysis
    i. Thrust Structure
    ii. Blast Sheild
iv. Logistics
    i. Transportation
    ii. BOM
    iii. Timeline

Engine Testing Requirements

HETS Requirements

- The system shall be capable of testing engines for the Daedalus vehicle
  - The system's thrust structure shall be able to support 10,000lbf of thrust*
    - The thrust structure must not be the root cause of any engine anomalies
    - The thrust structure shall allow for engines of different sizes and configurations to be mounted
    - The thrust structure shall constrain off-axis force while allowing linear force data to be collected
    - All components of the thrust structure shall have a minimum FOS of 3
    - The thrust structure shall not apply the main thrust load directly to the system holding the fluids

*Given testing site is unknown right now, concrete vs soil is the only thing not rated for this

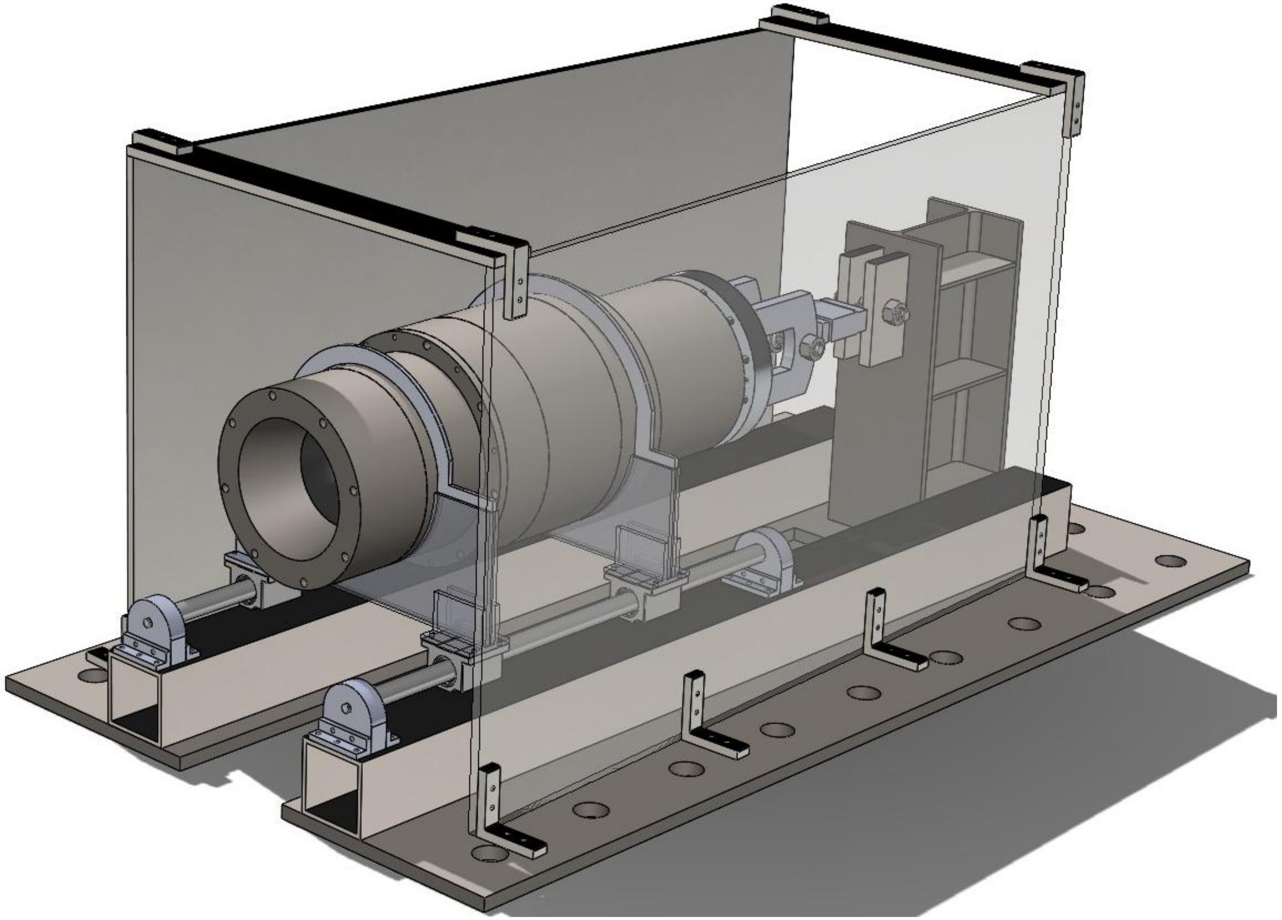
Frequency Requirements

- The system shall support rapid engine testing
  - The system shall be transportable to and from test sites potentially far from Atlanta
  - The system must be capable of multiple hot fire tests in a single day
  - The system shall be modular
    - The thrust structure must have the ability to mount multiple engines of different sizes for testing purposes
    - The system shall use standardized mounting systems to allow lines and components to be replaced
  - The system must not require assembly at the beginning of each test
    - All components of the system that are required to be insulated shall remain insulated if they are required on the system

Other Considerations

- Overall Requirements
  - Horizontal
  - Engine nozzle 1ft from ground for plume
  - Can be mounted via earth anchors or concrete
  - Engines up to 14” diameter
  - Space for propellant lines and fittings
  - Be able to test
    - Subscale Heatsink, Ablative, Regen
    - Vespula Heatsink, Ablative, Regen
    - Darcy Space
- Environmental Requirements
  - Everything painted for corrosion resistance
  - COTS parts are rated for outdoor usage
  - Tarp to cover system

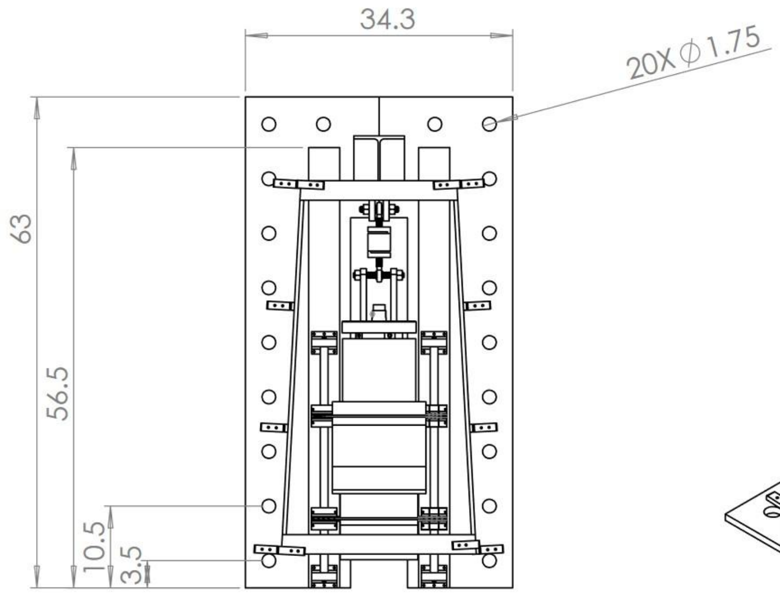
System Overview

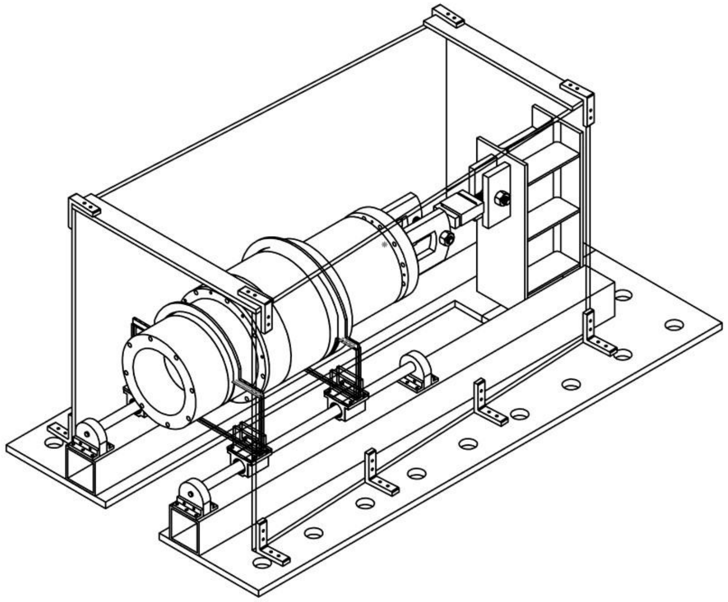


- I Beam will handle all deflection
- Mostly welds
- Fluids should mount easily
- Main Features
    - Railing
    - Bearings
    - Rings
    - Brackets
    - Ball Joints
    - Load Cells
    - I beam

System Overview: Dimensions

- Total height: 28.75”
- Height from center of engine to ground: ~14.93”
- Length: 63"
- Width: 34.3”
- Spacing of Earth Anchors: 14”



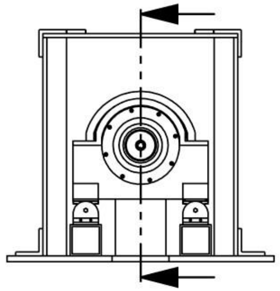


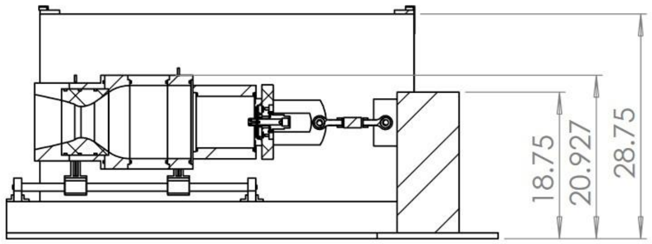
Estimated Total Mass 346.26 kg (+- 5%)

Blast Shield: 185.08576 kg

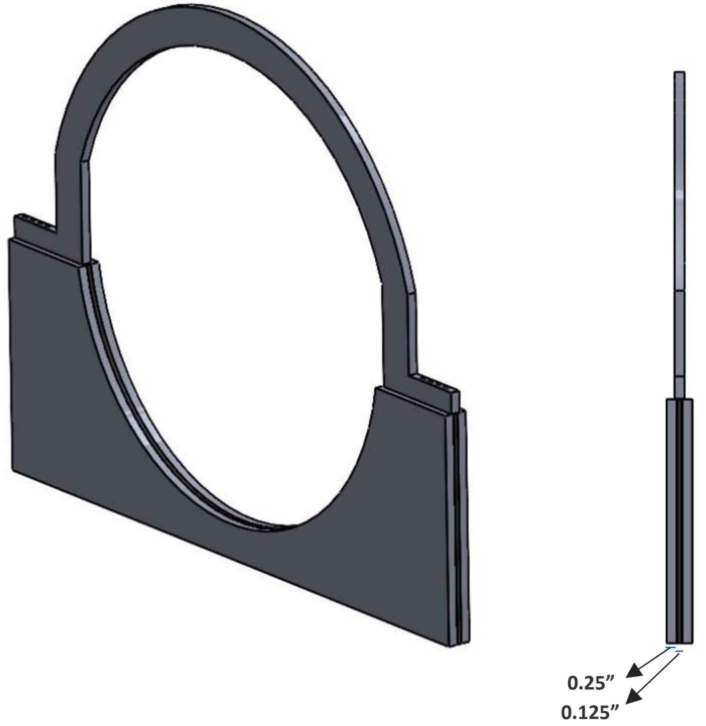
Ground Plates 56.44 kg

Others 104.72 kg





Design: Rings



- Two plates on the bottom, one on top
- Shear Load of 1000lbf ;

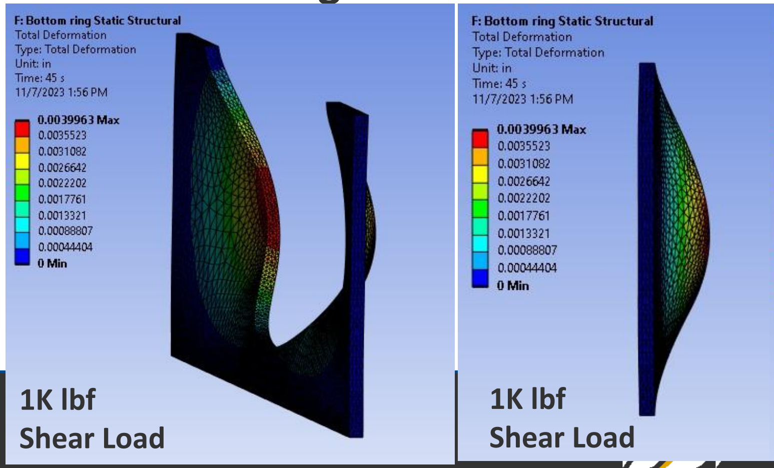
  Ring top max. deformation: 1.1605 in

  Ring bottom max. deformation: .0042452 in

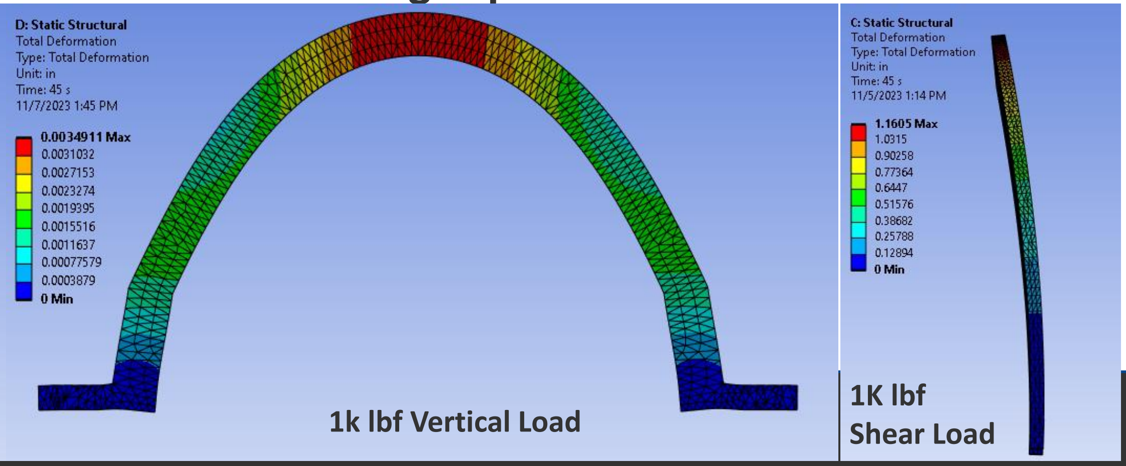
(won't really experience shear load, only vertical load)

- 3D printed spacer (with holes to screw everything in into)

Ring Bottom Piece

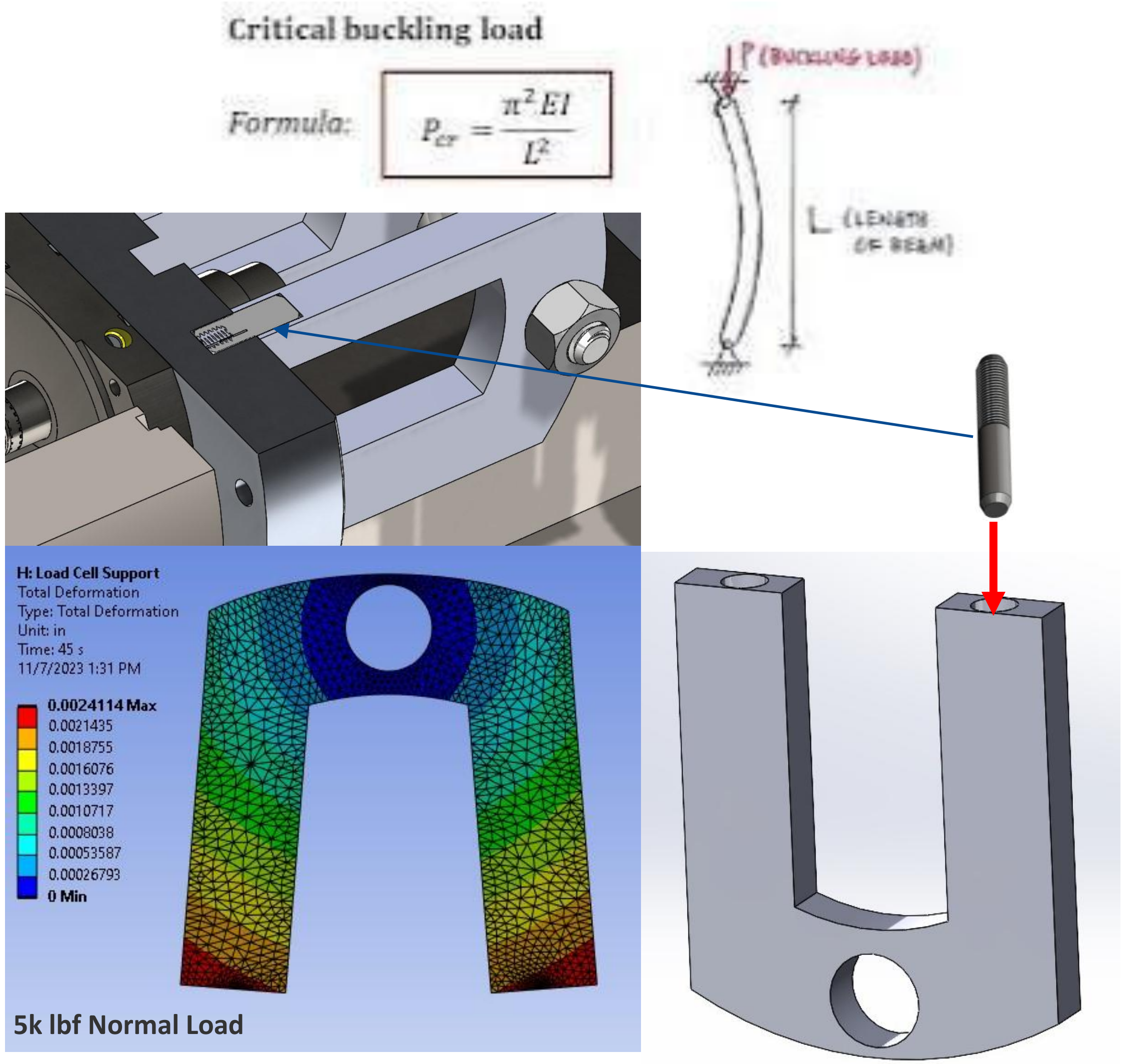


Ring Top Piece



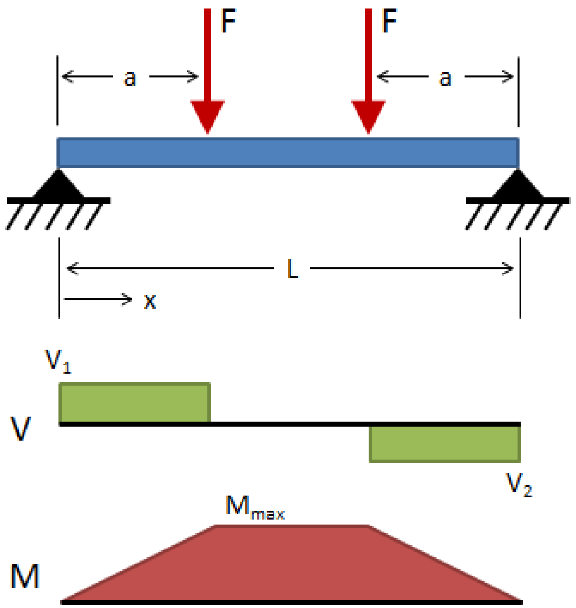
Brackets

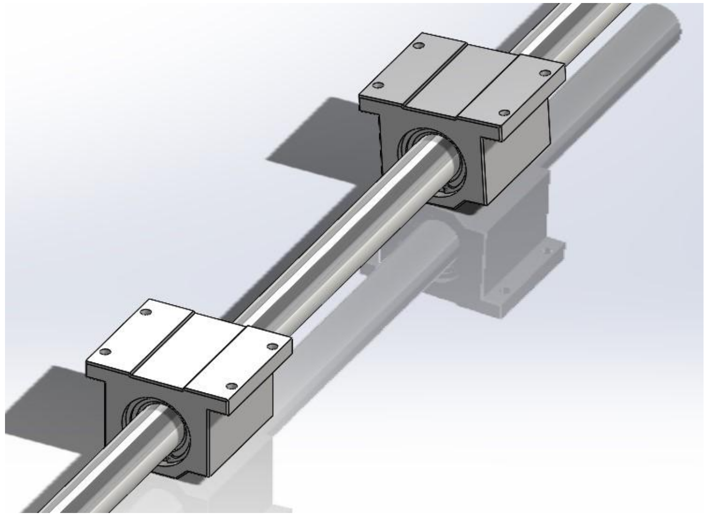
- Motivation: need room for fluids, connects rings to Load Cell
- Carbon Steel (waterjetting)
  - Outer Arc: R 5.76”
  - Inner Arc: R 3.26”
  - Gap Width: 2.389”
  - Top Hole: D 0.75”
  - Side Holes: D 0.68”
- Able to handle load?
  - Euler Buckling on one segment, one fixed and one free end
  - Pcr = 8290 lbf x 4 = 33160 lbf >> 10k lbf



COTS Bearings and Shaft

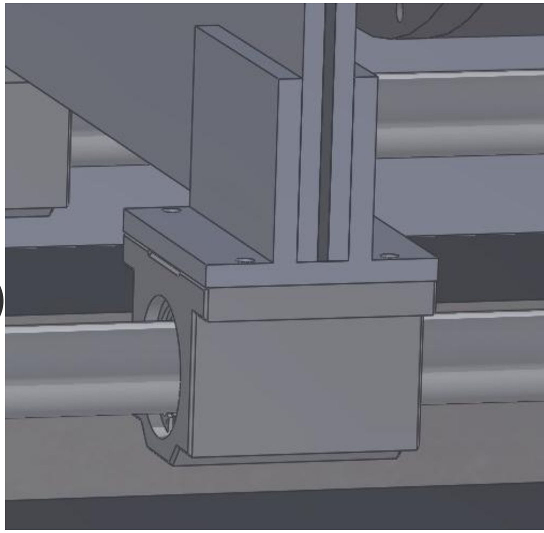
- 304 Stainless Steel Rods from McMaster (2x~$50)
  - Corrosion resistant up to 1500F
  - 2 Forces Loading Case: max deflection at L/2= .05in with 2000lbf (will likely be closer to 200-300lbf nominal)
    - Deflection Calculations Lines 1-8
- 1" Bearings (4x~$100)
  - Dynamic Load rating: 850lbf
    - 4x850=3500lbf >> 1000lbf off axis + ~200 lbf engine weight
  - Self-aligning bearings compensate for shaft misalignment <= 1deg

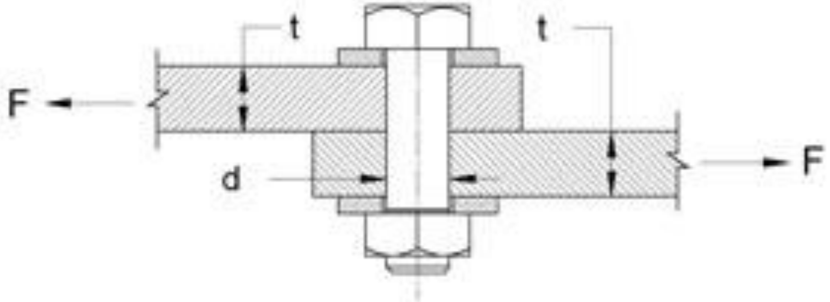




Bearing Brackets

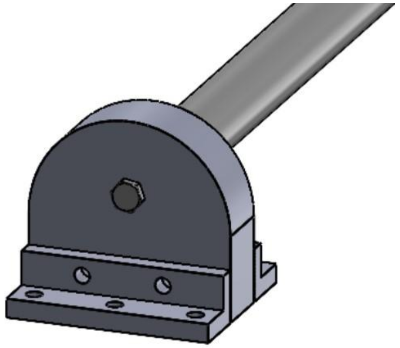
- Connect the rings to the bearings
- Cantilevered Beam Analysis:
  - 1000lbf acting at the edge of the bracket: deflects ~0.002 in.
- Close up of bolts attaching the bearings to the rings
  - 1000lbf per bolt, shear stress / bolt = (allowable stress = 40000 lbf/in^2)
- Will mill these with angle iron stock

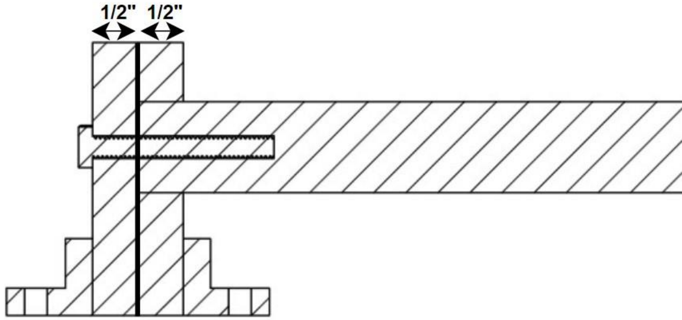


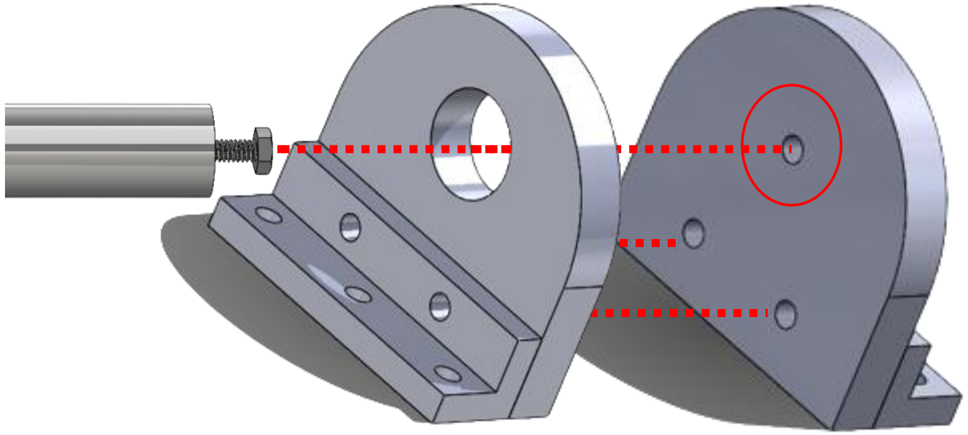


Shaft End Supports

- Screw holes are slotted so we can easily align the rods to make them parallel (if we machine things outside of 1deg tolerance)
- ¼-20 screws to bolt the rod to these shaft end supports
  - For a 1000lbf load acting on just one of the bolts: 20ksi stress (65ksi allowable, FOS=2)
  - 1000 being distributed across 4 bolts. No chance of failure
- Shaft end supports
  - Made from 2x ½" carbon steel plates (cost optimal)
  - First plate has a larger hole for the rod to sit on
- Brackets
  - Angle Iron
  - Machining: mill

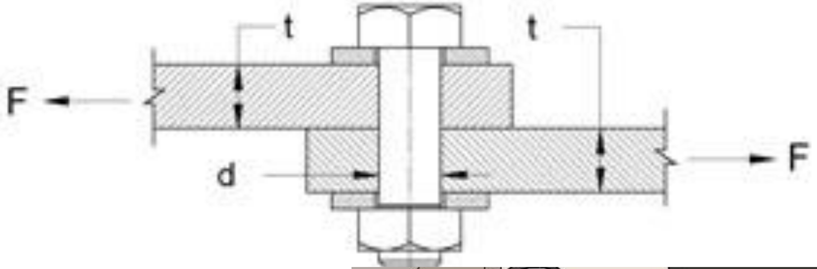


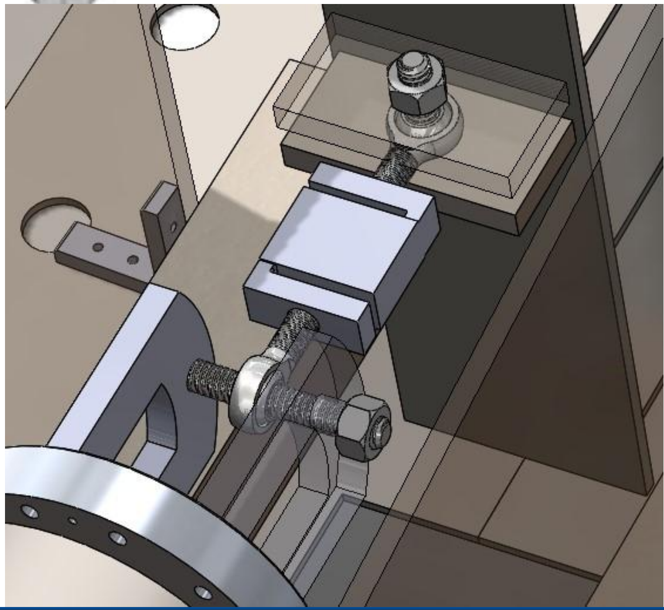




Ball Joints

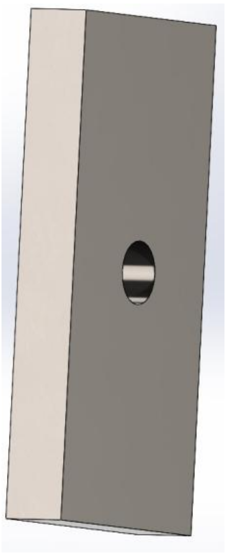
- [Ball Joint Rod End, 3/4"-16]
  - Rated for 15.850lbf ($15.33 per)
    - Only really need to rate this for off axis forces, the 10,000 lbf would go axially through the rod, but other requirements drove the large size
  - Requires lubrication
  - Zinc plated: moderate corrosion resistance
- Chose this size because it directly interfaces with the Load Cell
  - Bolt Calcs: 65ksi allowed, FOS of 2
  - ½" --> 51ksi stress / bolt ($10.20)
  - ¼" --> 203ksi stress / bolt (would fail) ($5.43)
  - ¾" --> 22ksi stress / bolt ($15.33)
- Design has 2 in perpendicular directions so that the entire load of the engine is in one direction
  - prevents off axis forces
  - More accurate reading

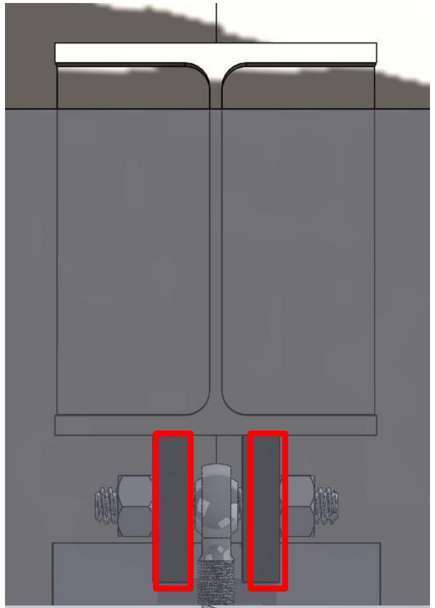


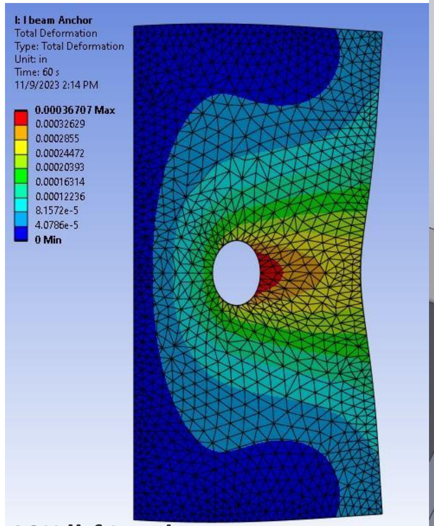


Design: Ball Joint Connector

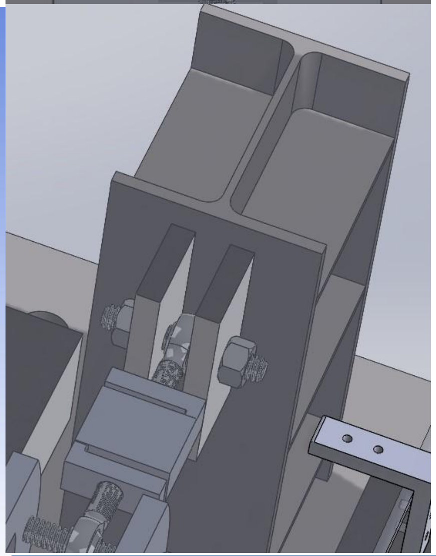
- Motivation: need to connect ball joint to I-beam
- Analysis:
  - 3.6707e-004 in Max. Deformation for 10K lbf.
  - 1.8354e-004 in Mas. Deformation for 5K lbf considering 2 supports transmitting 10K lb. to I-Beam
  - Threaded rod with nuts locking up the support with the ball joint.
- Manufacturing:
  - Connect three 1/8" plates together and then weld that assembly to the I-beam.



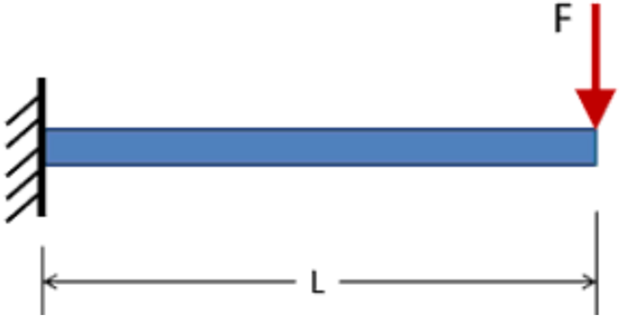


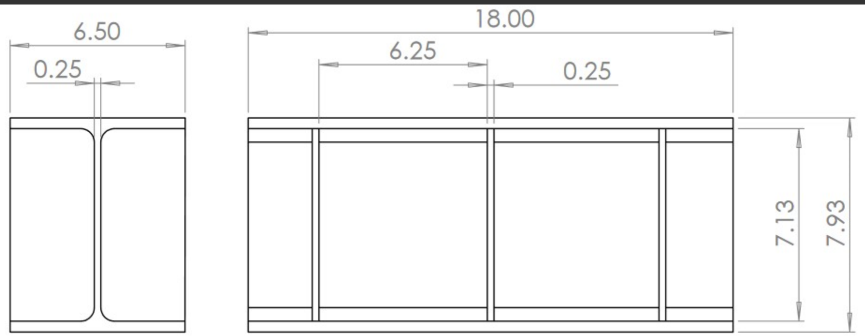


10K lbf Load

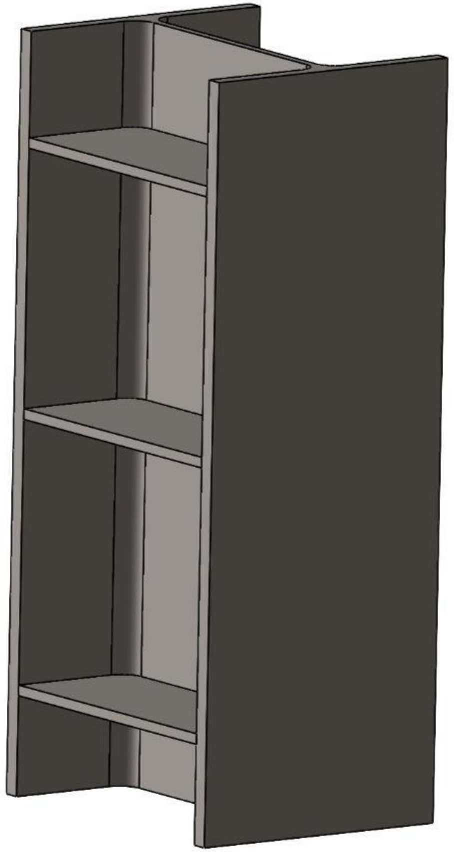


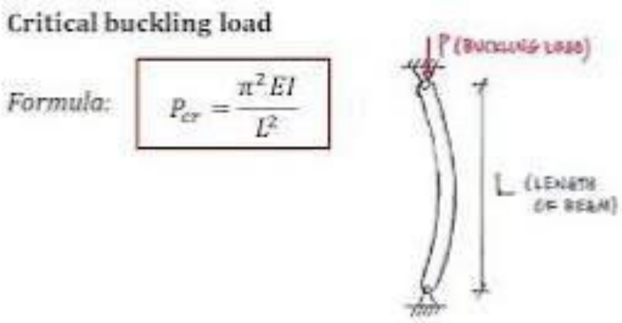
I Beam





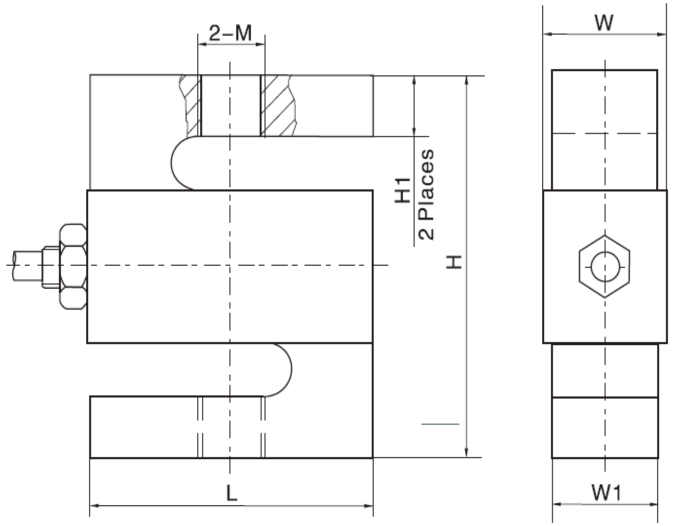
- W8x24 I-Beam, 18" Long, ~$58.54, Ixx=82.8
  - Cantilever beam deflection done on beam
  - Deflection at 14in with 10,000lbf = .00544in ; 50,000lbf = .027in
    - Even with any potential dynamic loading cases, this will be sturdy
    - I Beam Deflection Calculations, Lines 9-16
  - To account for I beam flange deflection, we will weld plates onto it, wherever the load is being attached.
    - Euler Buckling on those flanges: Pcr = 408 Mlbf. Will not fail compared to 10klbf load max
    - Calculations, Lines 17-20

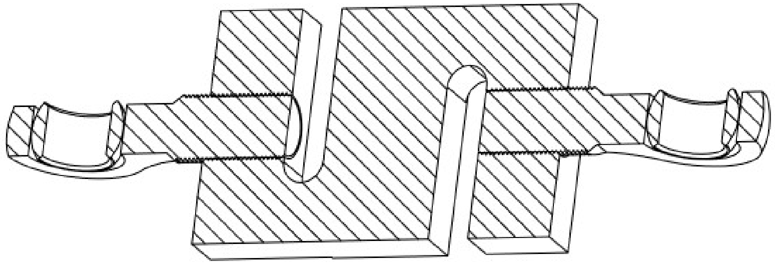


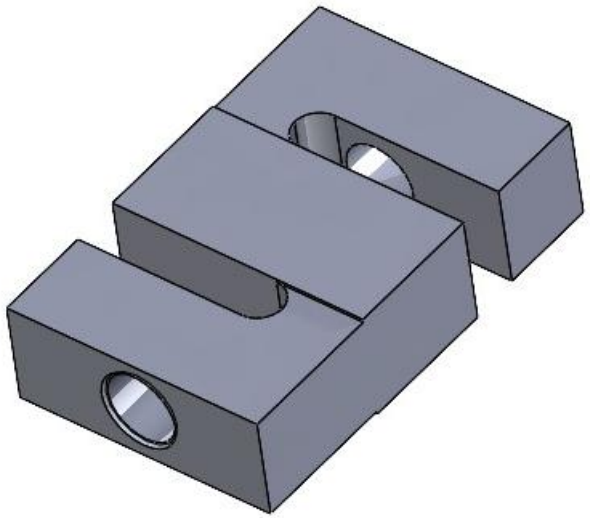


Load Cell

- 1 10k lbf Load Cell mounted to prevent static indeterminacy
  - Interfaces with our electrical system (already have 1)
  - Rated for 10,000lbf ±0.02% ($380.25)
    - Can safely go up to 15,000lbf without any failure
  - Rated IP67: anti-corrosion
    - No ingress of dust; complete protection against contact.
    - Immersion up to 1m in water (will be fine outside)

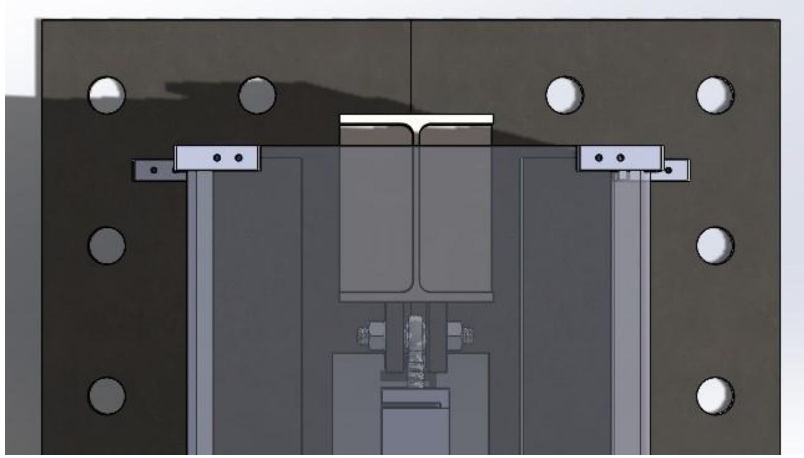






Ground Plate

- Weld Calcs
  - Assuming E60 electrode is used
  - Top plate to main beams:
    - Net force on each of four welds: 11.127N = 2.5014 kips
    - Weld sizing: 0.5625 in. Fillet weld leg --> minimum 5/16"
    - 60 in. Weld on each side of main beams
  - I-Beam:
    - Net Force on welds = 10000 lbf
    - Weld sizing: 0.39 in. - 0.6075 in. Fillet weld leg --> minimum 5/16"
    - 72.56 in weld



Earth Anchors

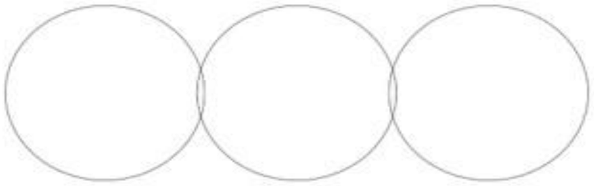
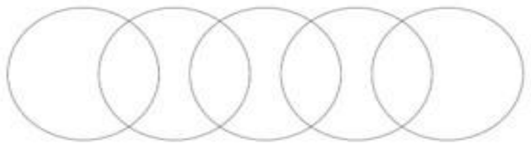
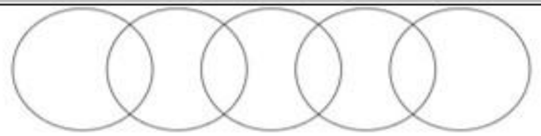
Penetrators

18” Penetrators		
Parameter	**Value**	**Note**
Length	20”	Corrosion-resistant cast Aluminum
Diameter	1 3/4”	
Inclination Angle	0	Minimal soil disturbance (unlike helical anchors)
Spacing		Use wrench to install Two rows, with 5 anchors in ea.
Load		
Parameter	**Description**	**Note**
Axial Load Capacity	350 lbf (loose soil) vs 2500 lbf (grout/asphalt)	Per anchor
Lateral Load Capacity	510 lbf (loose soil)	Per anchor

Earth Anchors

- Assuming that EA Load is linearly corrrelated to volume:
  - Max Load in loose soil with 3: 1530lbf; Max Load with 5 = 2287lbf.
  - Same numbers for concrete. 3: 10925lbf and 5: 16332 lbf
- **For subscale testing, we can use soil, but for engines >1500lbf, we won't be able to.**
  - **would need to pour our own concrete or find a testing site that has concrete we can go into**

18” Penetrators

(1 Cone)	**Overall** Volume 2035.752 in^3	Depth 18 in Angle 120 degrees
(3 Cones)	**Overall Volume** 6105.645 in^3	Spacing 20 in
Interference - Total 0.02637845%		
(5 Cones)	**Overall Volume** 9126.986 in^3	Spacing 12.5 in
Interference Total 10.333026%		
Selected		
(5 Cones)	**Overall Volume** 9525.969in^3	Spacing 14 in
Interference Total %6.4132664489		

Total interference = 1 - (merged cones vol /n*cone vol)

Sizing Blast Shield

- Calculating Initial Speed + Mass of Fragments
  - Taken from NASA Paper, treating the engine like a pressure vessel
  - Velocity = 270 m/s
  - Mass = 80g
  - KE = 2916J
- Looking at equivalent plates for bullets:
  - 6.5 Creedmoor rounds with a KE of 3380J are stopped comfortably by a 3/8" steel plate
  - 5.56 rounds go through a ¼" steel plate with a KE of 1767J
  - Therefore 3/8" is the minimum measurement for thickness

Tensile Strength of Steel (Yield) = 50,000 psi = **3.447 * 10^8 Pa**

Thickness of Cylinder = 1.32 inches = **0.033528 m**

Outside radius = 6 inches = **0.1524 m**

Burst Pressure according to Barlow's equation = 22,000 psi = **1.517 * 10^8 Pa**

Density of air = **1.293 kg/m^3**

Density of steel = **7800 kg/m^3**

$$\text{Mass ratio} = \frac{(1.293)(0.1524)^2}{(7800)(0.1524^2 - 0.1189^2)} = \mathbf{4.236 * 10^{-4}}$$

$$\text{Pressure ratio} = \frac{(1.517 \cdot 10^8)}{1.01 \cdot 10^5} = \mathbf{1502}$$

Mass ratio below = **1.73 * 10^-4**
V1 = **.6**

Mass ratio above = **5.19 * 10^-4**
V3 = **.9**

$$V2 = (0.9 - 0.6)\left(\frac{(4.236 - 1.73)}{(5.19 - 1.73)}\right) + 0.6 = \mathbf{0.817}$$

Vi = 0.817 * 331 = **270 m/s**

Burst Pressure = **1.52 * 10^8 P**

Tank Volume = **.0061 m^3**

PV = **9.27 * 10^5**

PV/E0 = **221.24**

Using graph

0.08 kg mean mass

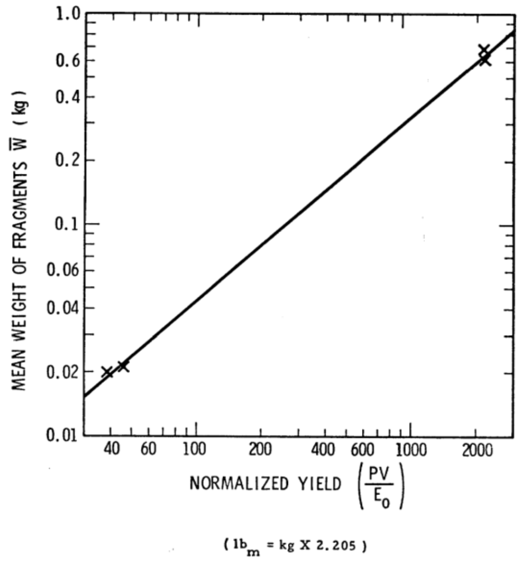
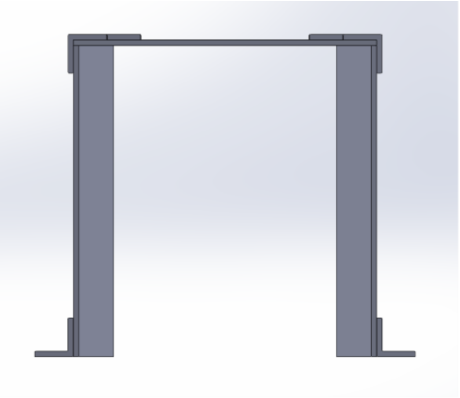
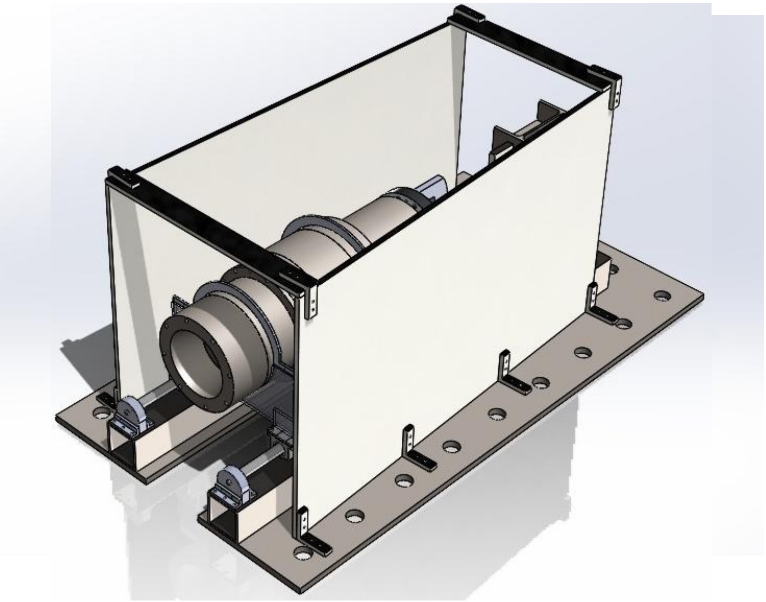


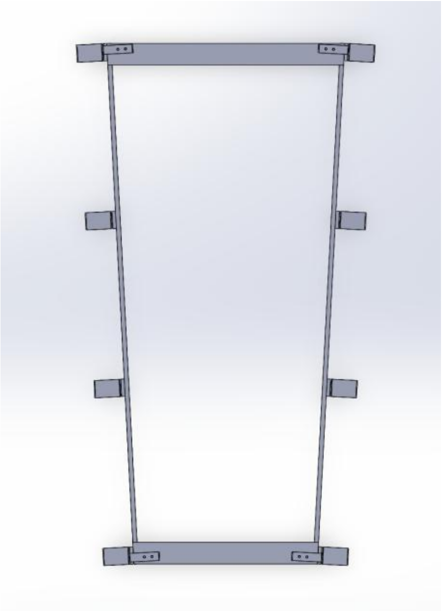
Figure 4-56. Normalized Yield Vs Mean Fragment Mass for Bursting Tanks

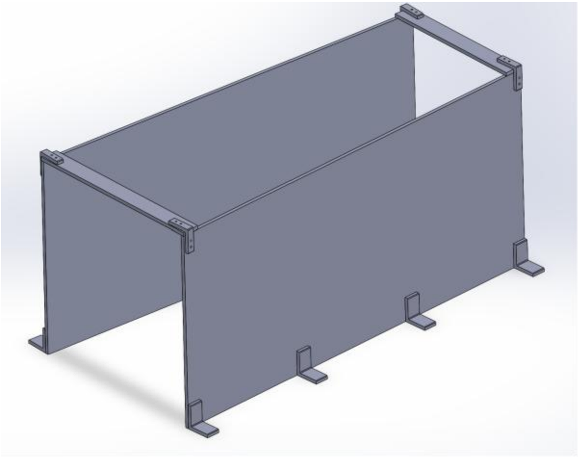
Blast Shield Design

- Left top open to make room for plumbing
- Plates are at an angle so fragments can be deflected and full force is not on the shield (also helps with blast wave)
- Steel Plates are a big driver of cost
- Just a bunch of carbon steel plate
- Brackets can be angle iron
  - Chopsaw to cut them to length and quick mill operation to make the holes
- Will require 48 screws









Transportation

- Would need to separate the structure into multiple components to transport this
- Ground plate would be one assembly
  - Rods + bearings + rest of the engine carriage assembly would be the second part
- This way we could assemble the plates and then screw the rest of the assembly together.

BOM

*already have Load Cell (around ~380)

Item	Quantity	Unit	Total
18" Penetrator Earth Anchors	12	$ 29.34	$ 352.08
W8x24 I-Beam, 24"	1	$ 58.54	$ 58.54
Ball Joint Rod End, 1/2"-20	2	$ 15.33	$ 30.66
304 Stainless Steel Rods from McMaster	2	$ 51.91	$ 103.82
1" Bearings	4	$ 97.52	$ 390.08
Steel	2	113.79	$ 227.58
Rod Brackets (Metal Plate 7 in x 12 in)	1	$ 46.02	$ 46.02
Square Tubes (4X4X1/2") L 56.5"	2	$ 106.49	$ 212.98
Ring tops & Bottom (1X4 ft 1/2") -P114	1	$ 83.48	$ 83.48
Ball Joint Back Support (6X6X3/4")	1	$ 36.54	$ 36.54
Ball Joint Front Support (7X6X3/4")	2	$ 39.36	$ 78.72
I-Beam Welded Support (6.5X7" 1/2")	3	$ 15.33	$ 46.00
			$ 1,666.50

BOM Blast Shield

- Total including Thrust Structure = $2190.64

Item	Quantity	Unit	Total
0.38" Thickness 28"x48" Standard Use Carbon Steel Plate	2	$241.91	$ 483.82
Grade 8 Steel, 1/4-20" thread size, 1.25" long screws	2	$ 8.91	$ 17.82
Grade 8 Steel, 1/4-20" nuts	1	$ 7.21	$ 7.21
3" x 3" x 3/16" x 2ft Angle steel	1	$15.29	$15.29
			524.14

Next Steps

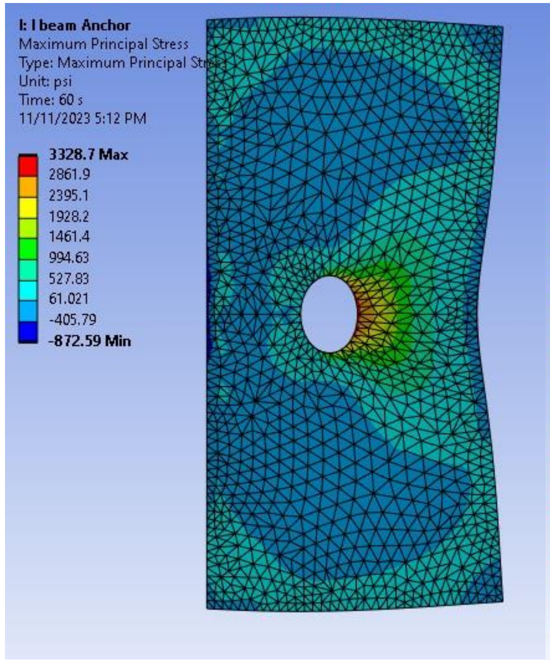
- ANSYS Analysis – Check modes of vibration (first 6 should be 0)
  - Expecting this to be fine
- Ordering materials (lead times all within a week)
- Building (1-2 weeks)
  - Cutting/Welding
  - Waterjetting
  - Mill for any holes not done by waterjet

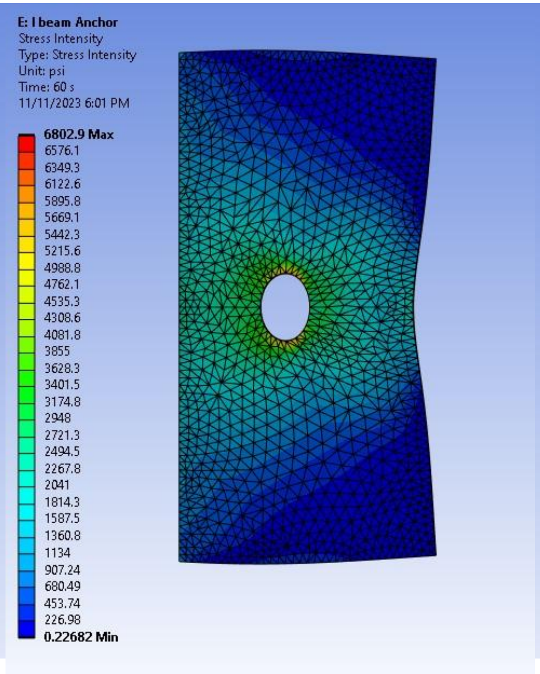
Thank You!

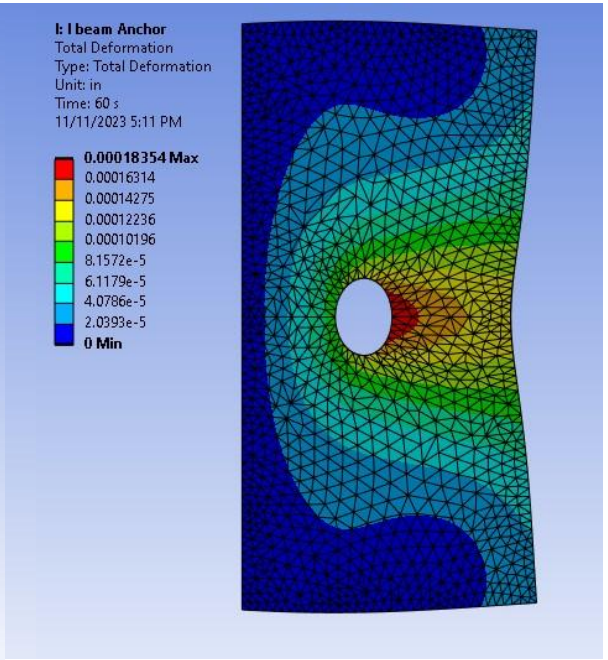
Any Questions?

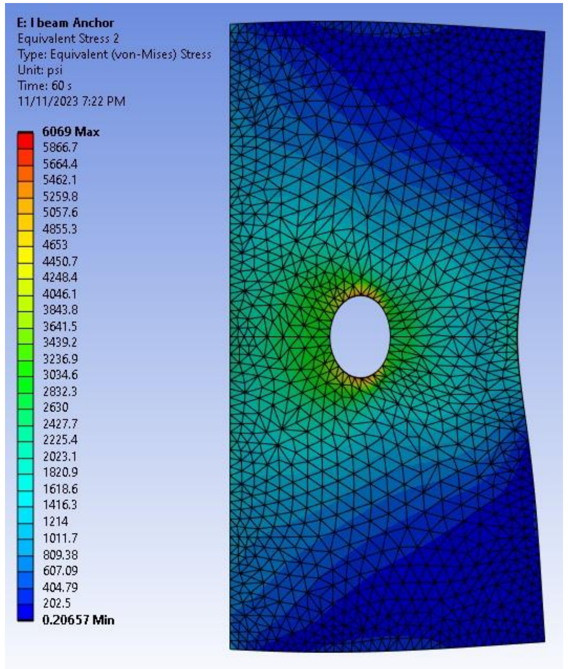
Appendix: Ansys sims

BCs: Face welded to I beam is a fixed support







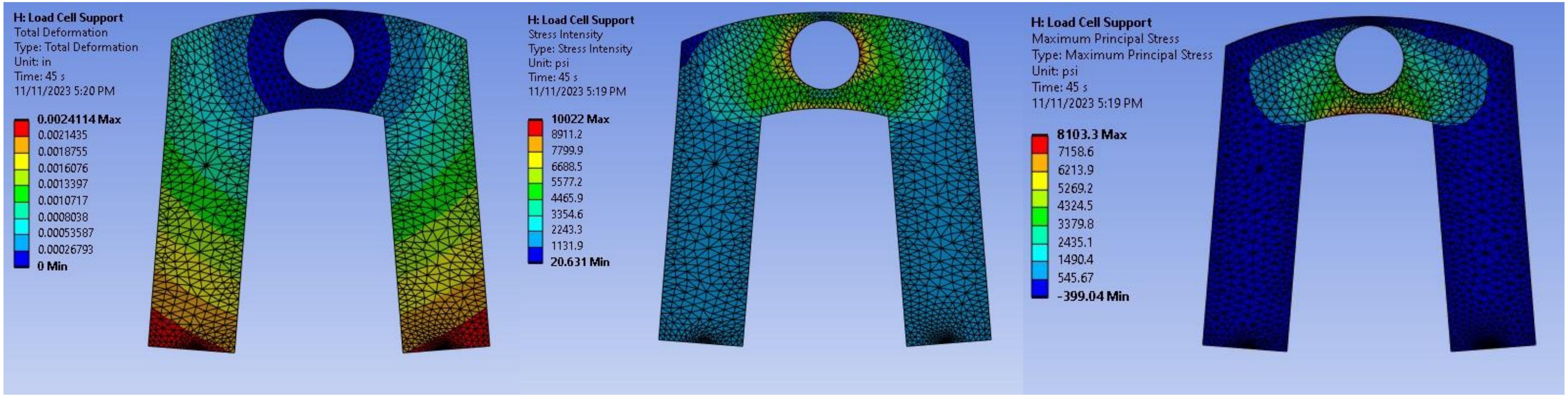


Ball Joint Connector

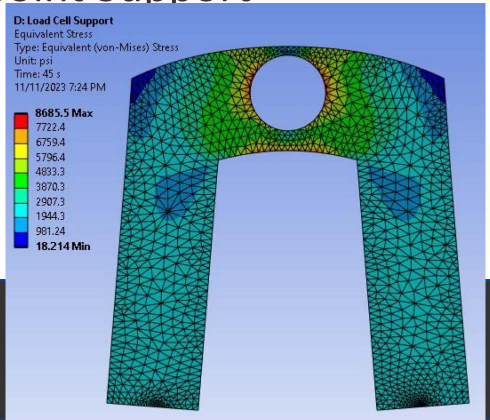
5K lbf Load applied on the surface area of the hole

Appendix: Ansys sims continued

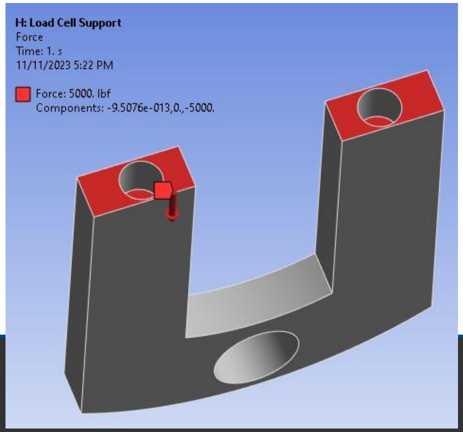
BCs: fixed support hole – transmitting force through it to the ball join then load cell



Engine to Ball Joint Support

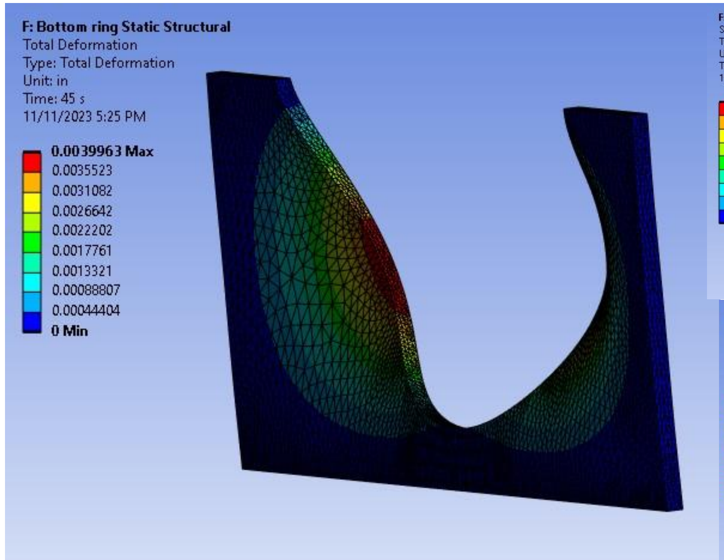


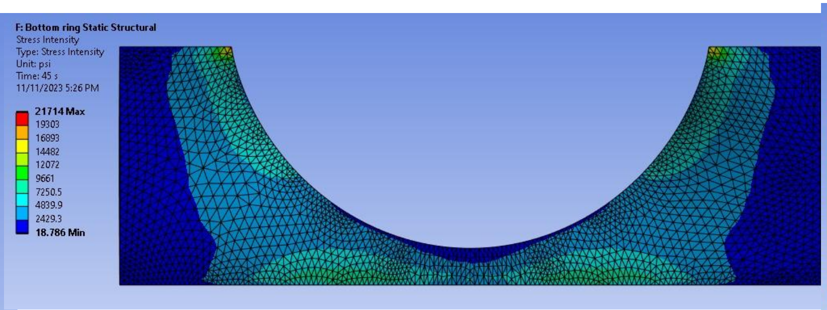
5K lbf Load applied normally as shown

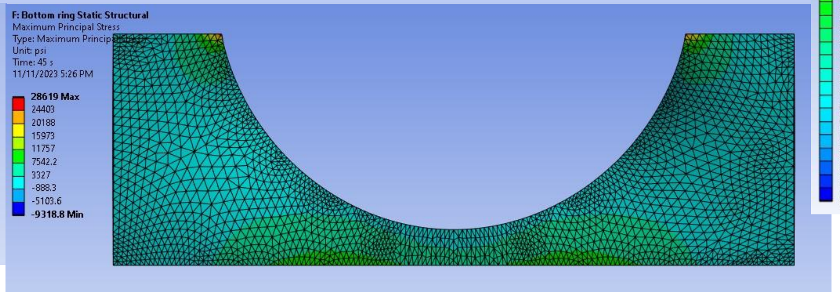


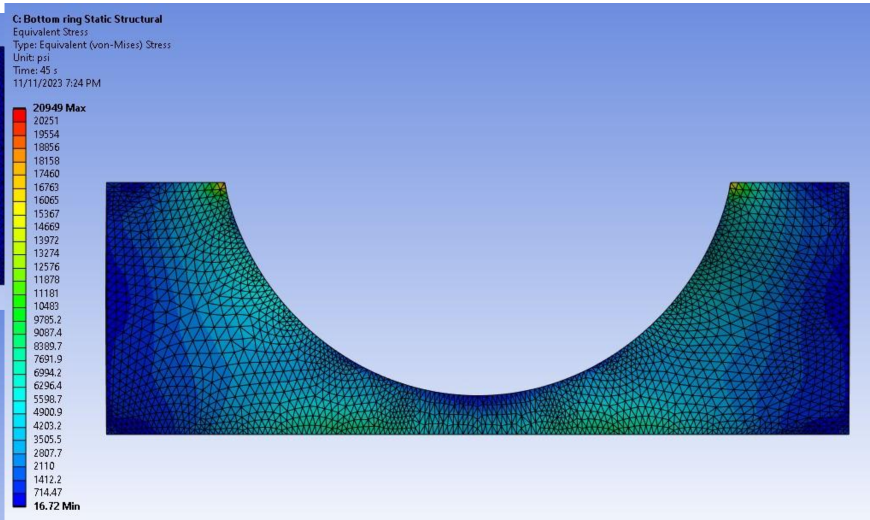
Appendix: Ansys sims continued

BCs: bottom face is a fixed support assuming being held in place by bearing brackets







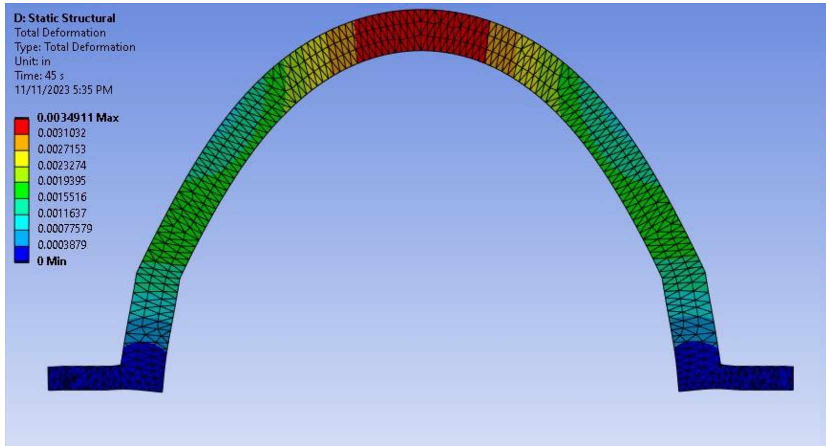


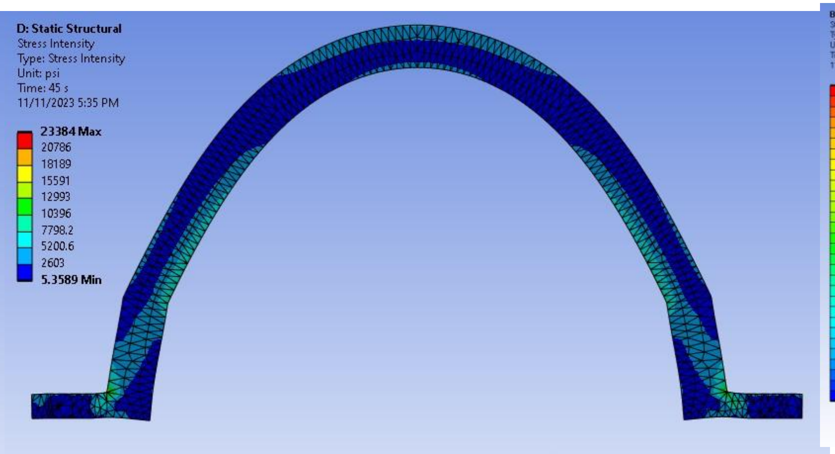
Ring Bottom Piece

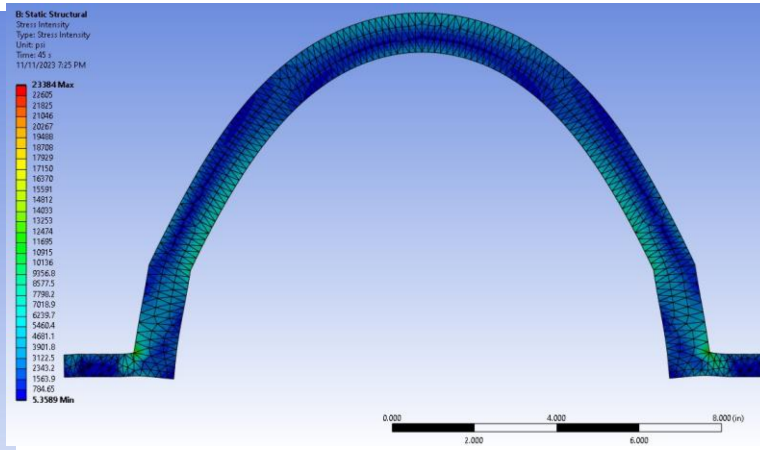
1K lbf Load applied axially in shear to the inner surface

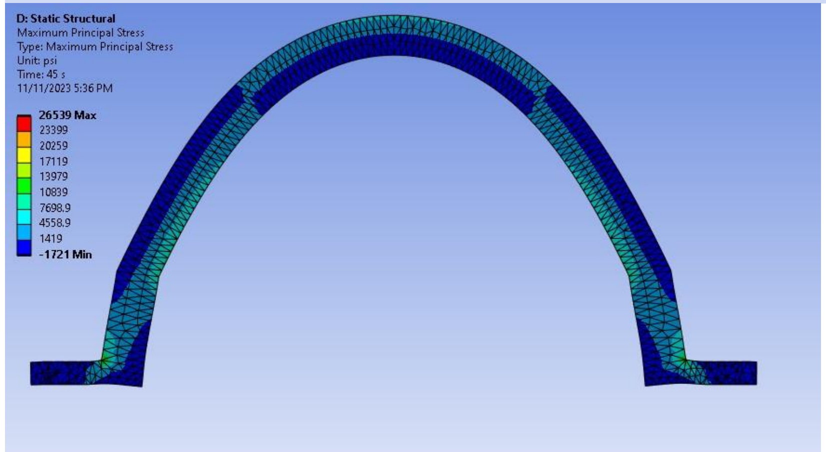
Appendix: Ansys sims continued

BCs: holes of bolts are fixed support – assuming they are strong enough to handle the load





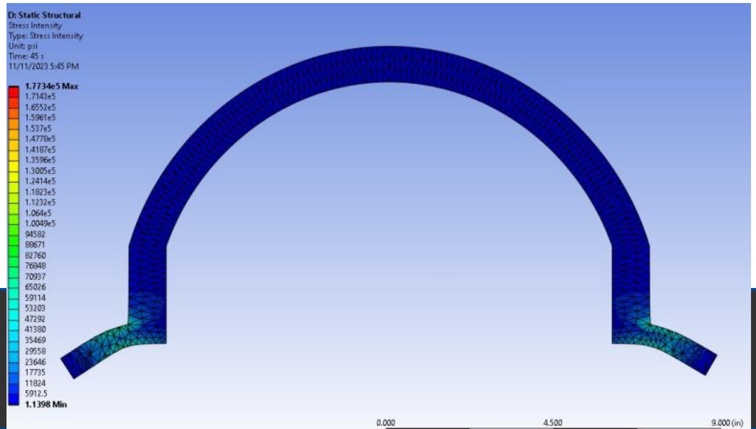




1K lbf Load applied axially in vertical direction to the inner surface upwards and downwards for the top face of the ends

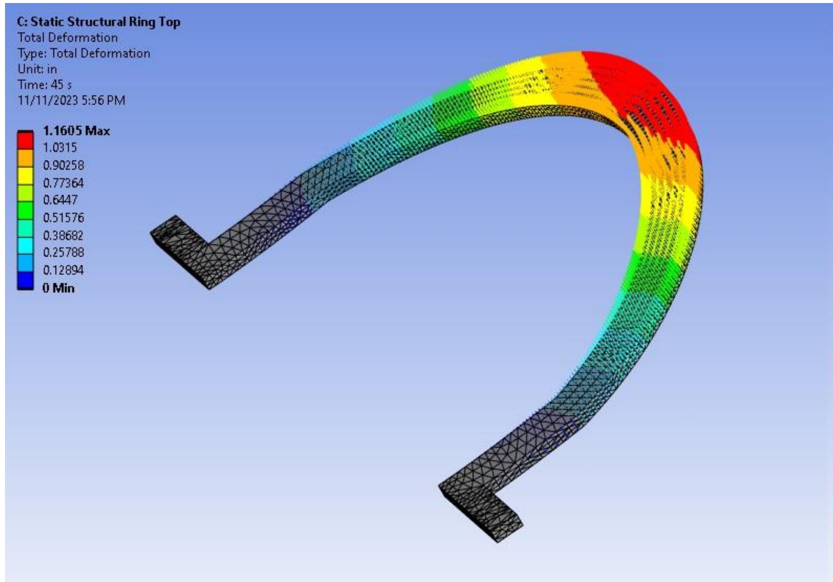
Ring Bottom Piece

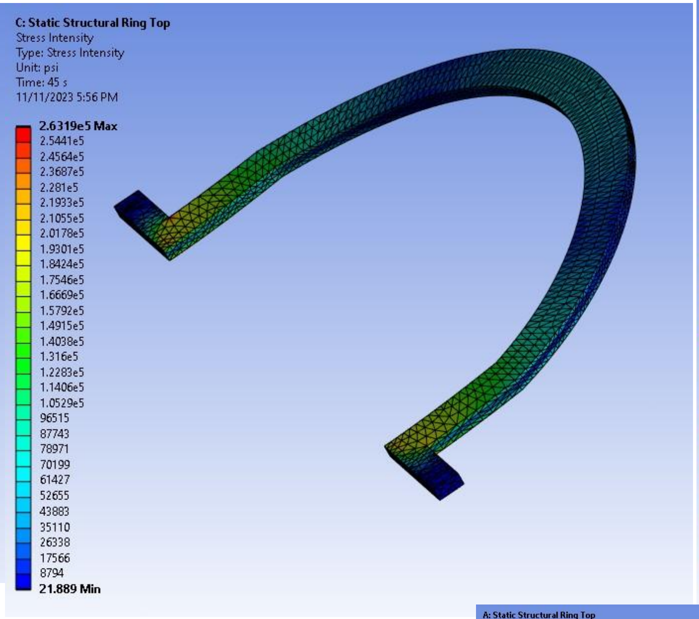
Stress intensity excluding the BCs

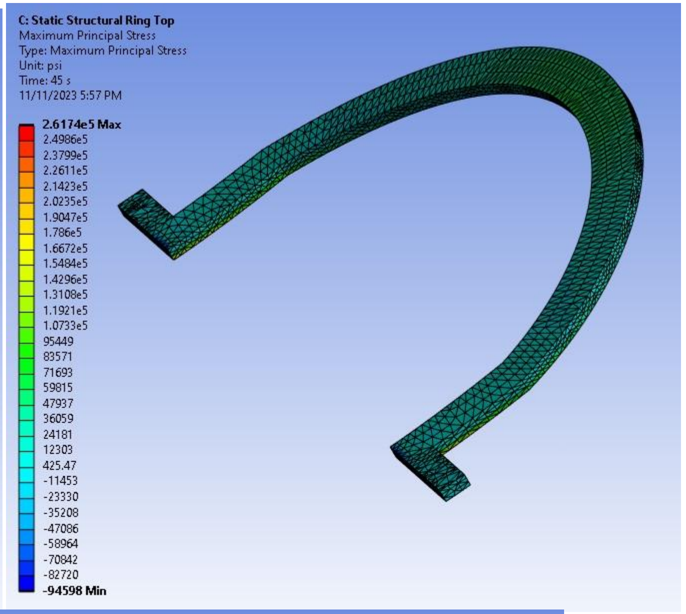


Appendix: Ansys sims continued

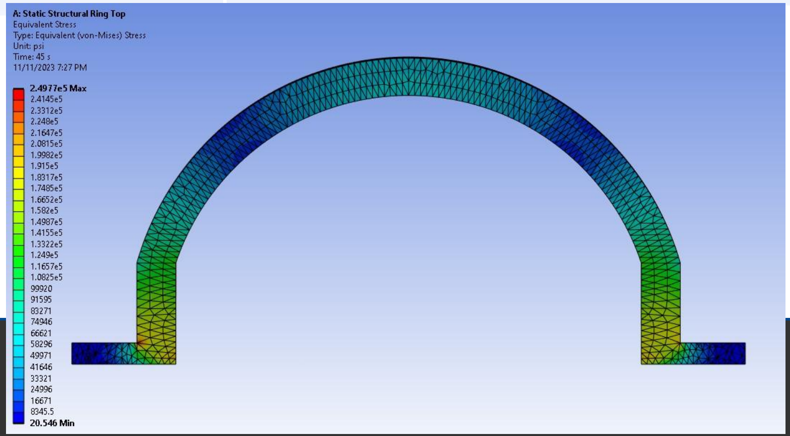
BCs: holes of bolts are fixed support – assuming they are strong enough to handle the load







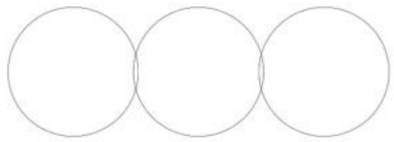
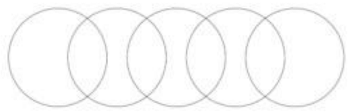
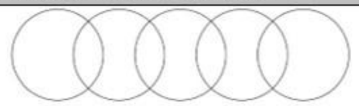
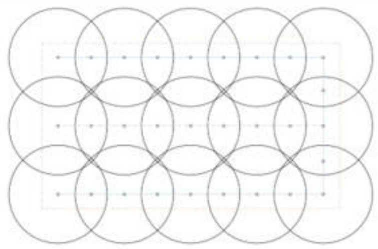
1K lbf Load applied in shear to the inner surface



Appendix: Additional Earth Anchors

- Added additional line of EAs in the soil
- Only 10.85% interference
- 510 lb x 15 x .8915 =6,819.975 shear max load of EAs in soil

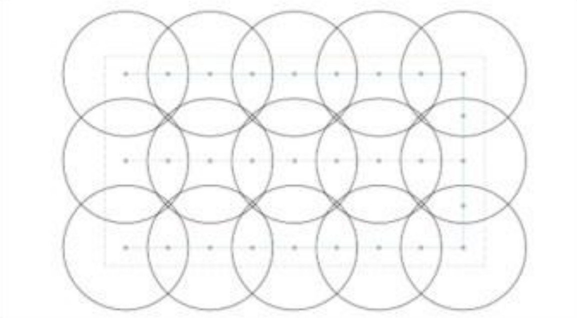
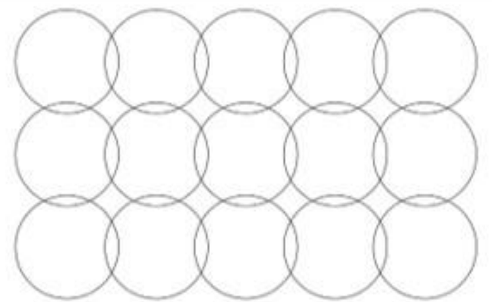
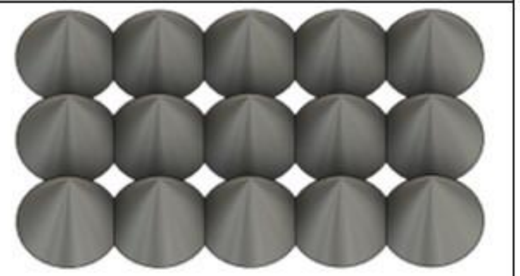
18" Penetrators

(1 Cone)	**Overall** Volume 2035.752 in^3	Depth 18 in Angle 120 degrees
(3 Cones)	**Overall Volume** 6105.645 in^3	Spacing 20 in
Total Interference 0.02637845%		
(5 Cones)	**Overall Volume** 9126.986 in^3	Spacing 12.5 in
Total Interference 10.333026%		
	Selected	
(5 Cones)	**Overall Volume** 9525.969in^3	Spacing 14 in
Total Interference %6.4132664489		
	Arrangment	
(15 Cones)	**Volume 27221.313 in^3**	Spacing 14 in 14.5 in between rows
Total Interference %10.85583116		

Total interference = 1 - (merged cones vol /n*cone vol)

Appendix: EAs Not All The Way In

- simulation where we dont get the EAs in all the way, so instead of the whole depth being 18in, it becomes 14"
- 47.05% of the volume (15 EAs total) that it would normally affect
- Very little interference, but much less volume = much less strength
- 6,819.975lbf * .4705 =3208lbf

	Arrangment	
(15 Cones)	**Overall Volume 27221.313 in^3**	Spacing 14 in - 18 in (depth) 14.5 in between rows
Total Interference %10.85583116		
(15 Cones)	**Overall Volume 14217.134 in^3** **Individual 957.837 in^3**	Spacing 14 in - 14 in (depth) 14.5 in between rows
Total Interference %1.046949185		

Total interference = 1 - (merged cones vol /n*cone vol)