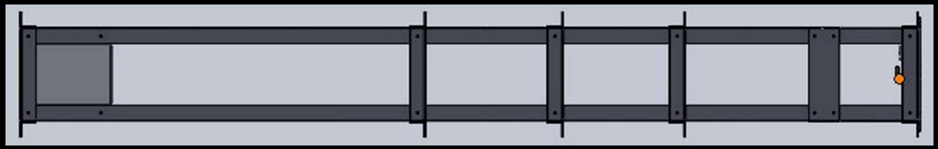
FAR Dollar-Per-Foot PDR

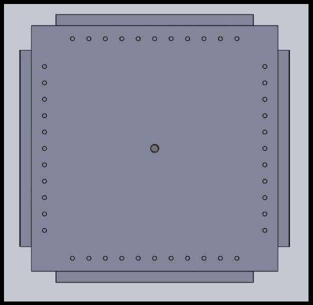
KXR UCF

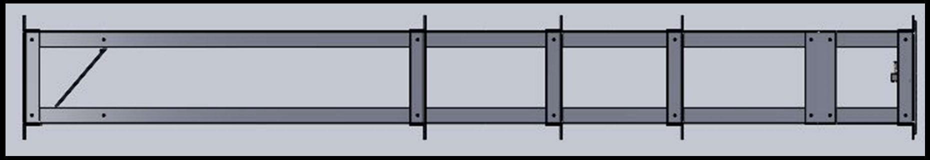
Test Team

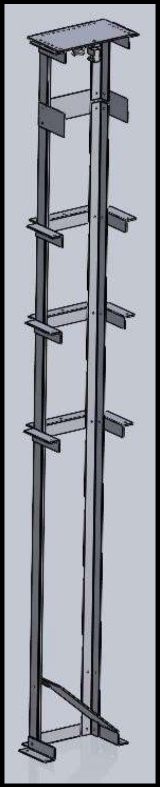
KXR UCF

Test Stand CAD



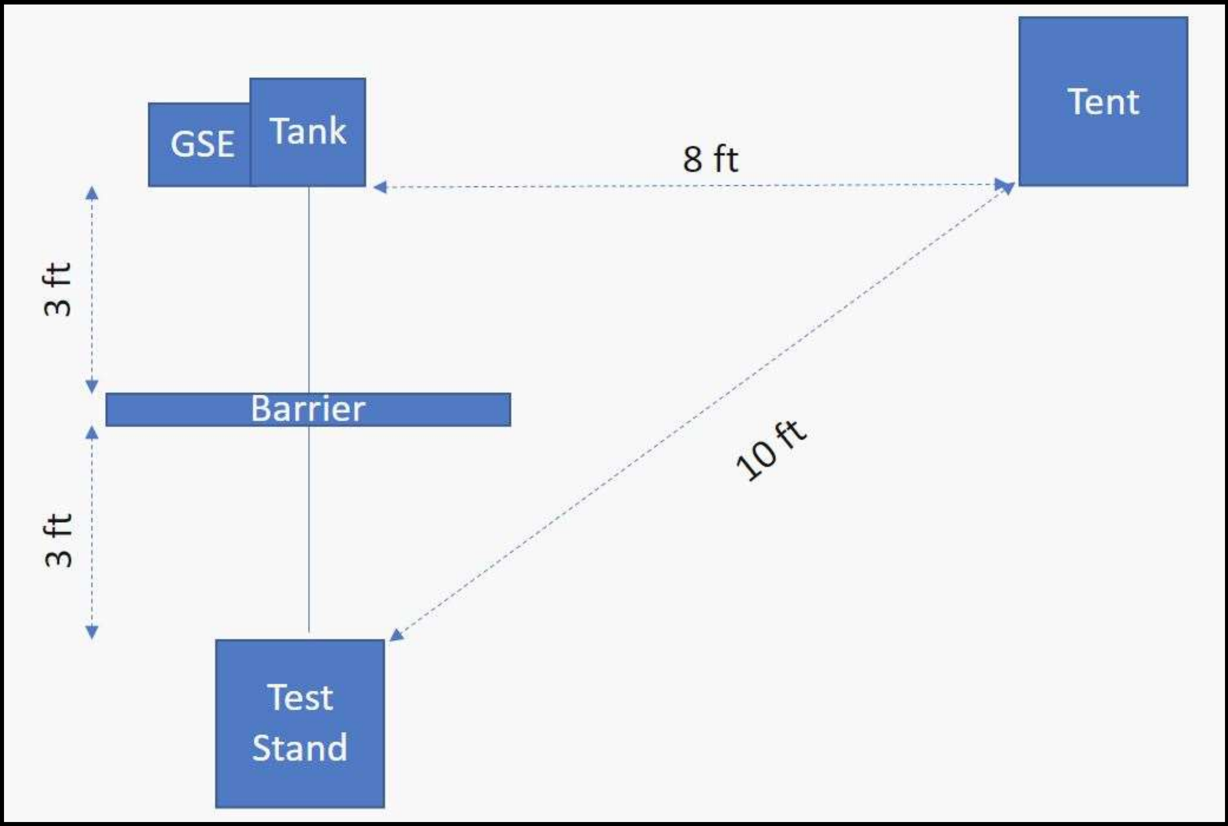






Chungus test stand

Static Fire Test Layout



KXR UCF

Plumbing & GSE Team

KXR UCF

Propellant Choice

Oxidizer Choice: Nitrous Oxide

- Self-Pressurizing
  - does not require inert gas for pressurization
  - Pressurizes to 750 psi at 70° F
- Non-cryogenic
  - Easier to store and use
  - allows for the use of cheaper valves
- KXR provides it for free

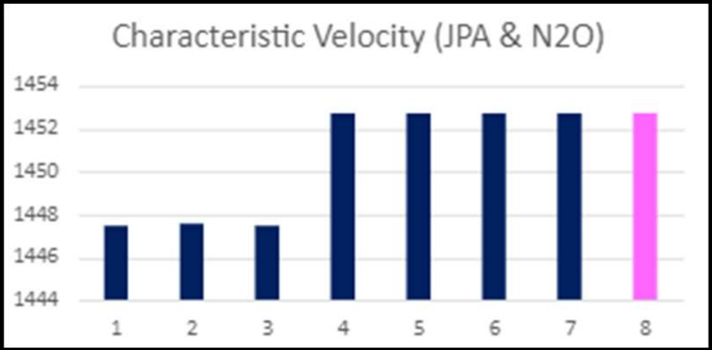
Fuel Choice: Ethanol

- Powerful and Cost Efficient
- Burns "clean"
  - eliminates the need to dismantle and clean the engine

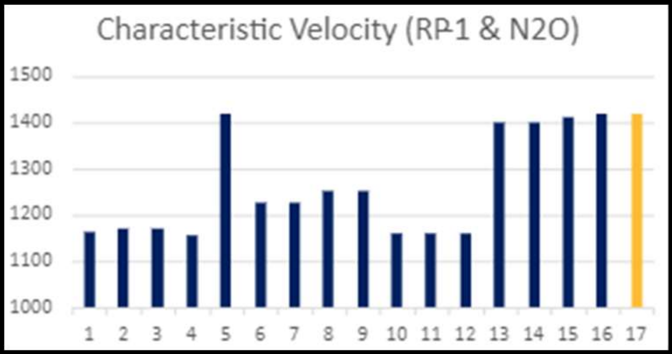
Propellant Choice

Characteristic Velocity Comparisons

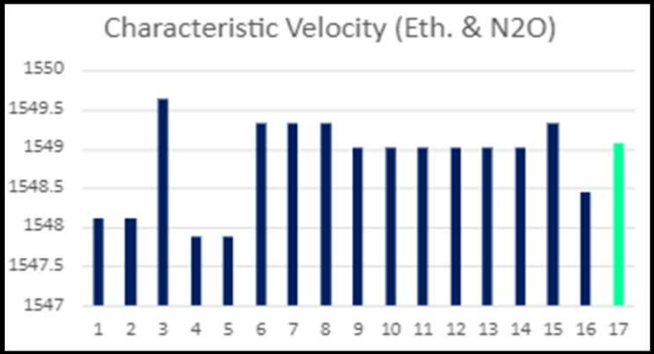
JPA (Aviation-grade Kerosene)
-1452.77 m/s



RP1 (Jet fuel)
-1418.61 m/s

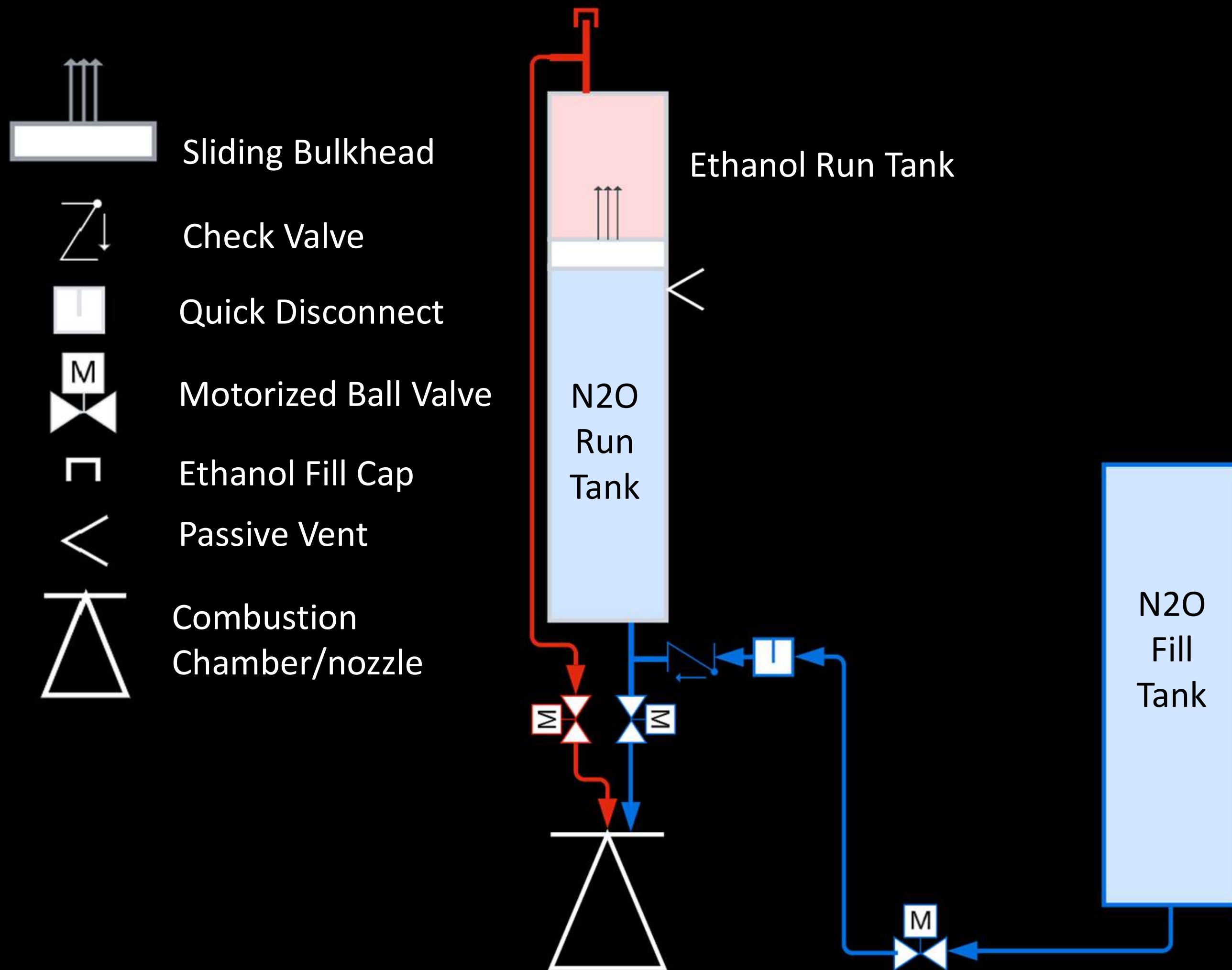


Ethanol
-1509.0.6 m/s



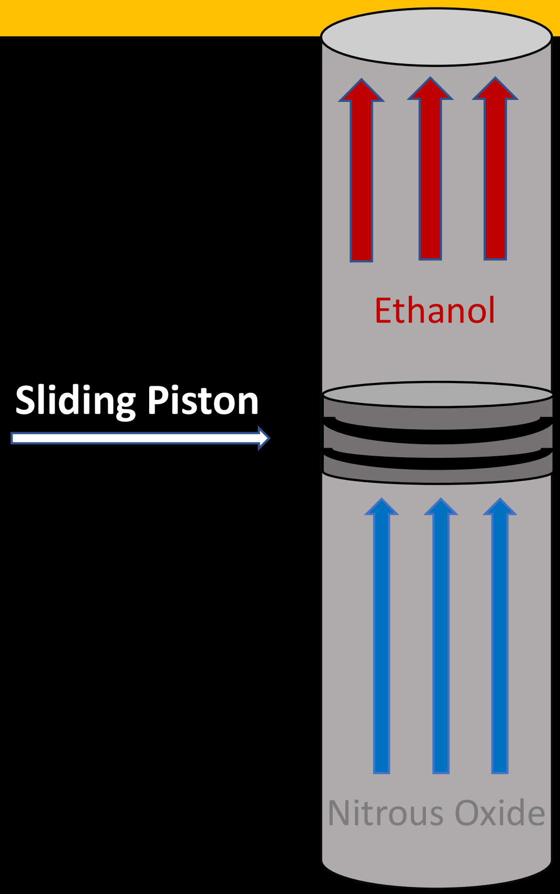
P&ID

- Sliding Bulkhead Provides fuel pressurization.
- Check Valve prevents unwanted backflow after disconnect.
- Motorized Ball Valves allow for remote operation
- Ethanol fill cap allows fueling of Ethanol Run tank prior to launch
  - Both bulkheads have offset holes allowing for fuel and oxidizer lines to run efficiently to their respective destinations
- Fuel runs from top of tank to the center of injector.
- Nitrous Oxide fuels by self-pressurization through a quick disconnect and is passively vented through the side of the tank.



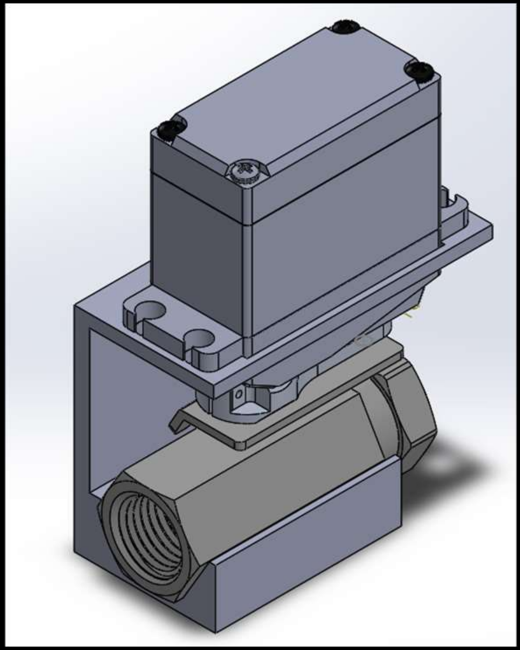
Run Tank "Piston" design

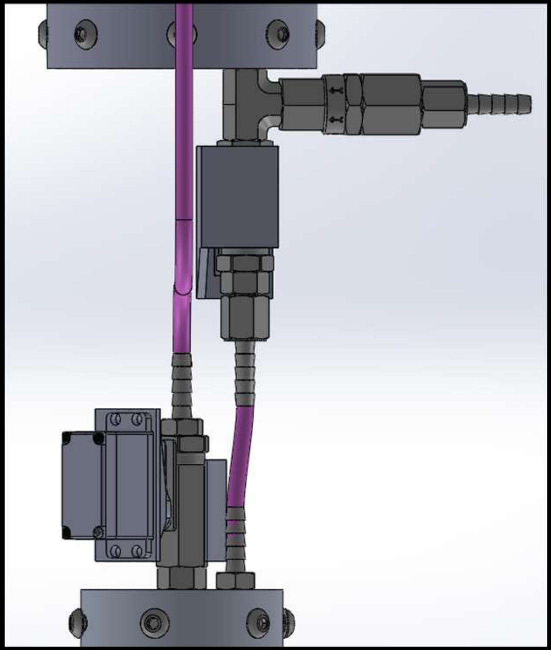
- Eliminates the need for an inert gas
- Less valves and material
  --> significantly cheaper
- Eliminates the need for two separate venting systems
  --> safer and more reliable
- Friction ensures piston stays in position before pressurization

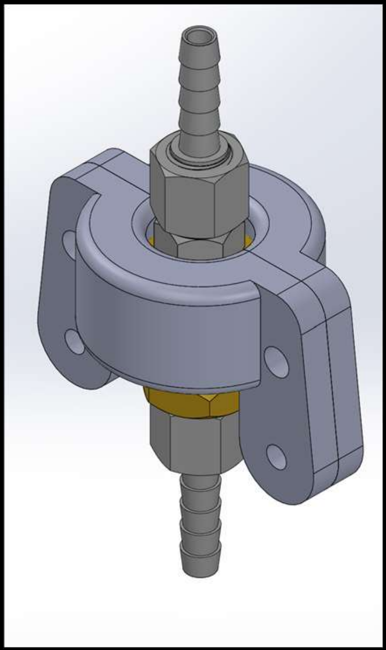


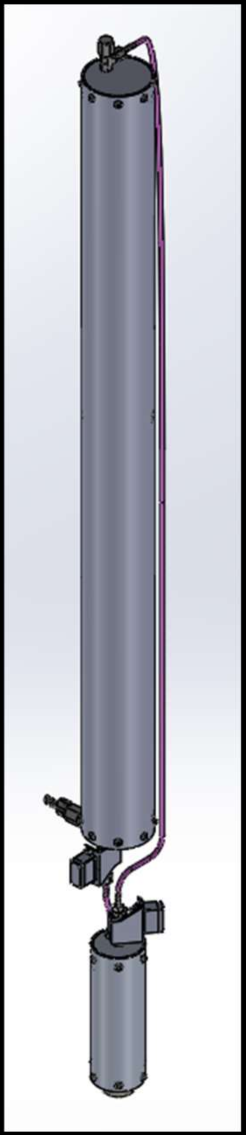
KXR UCF

CAD Assembly



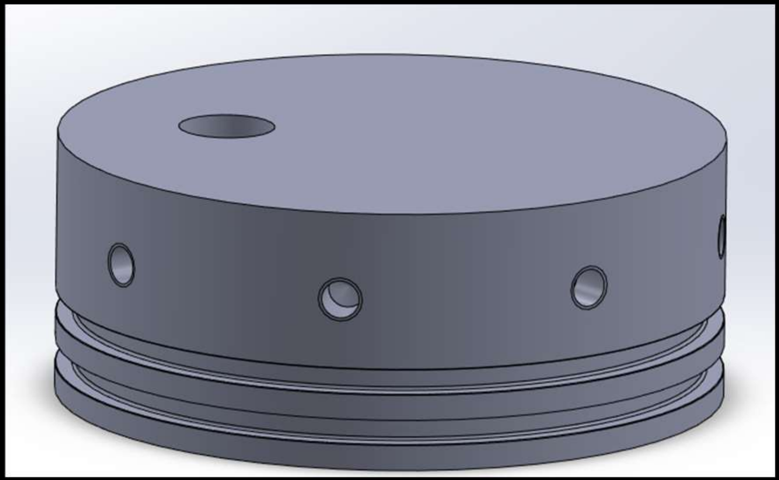






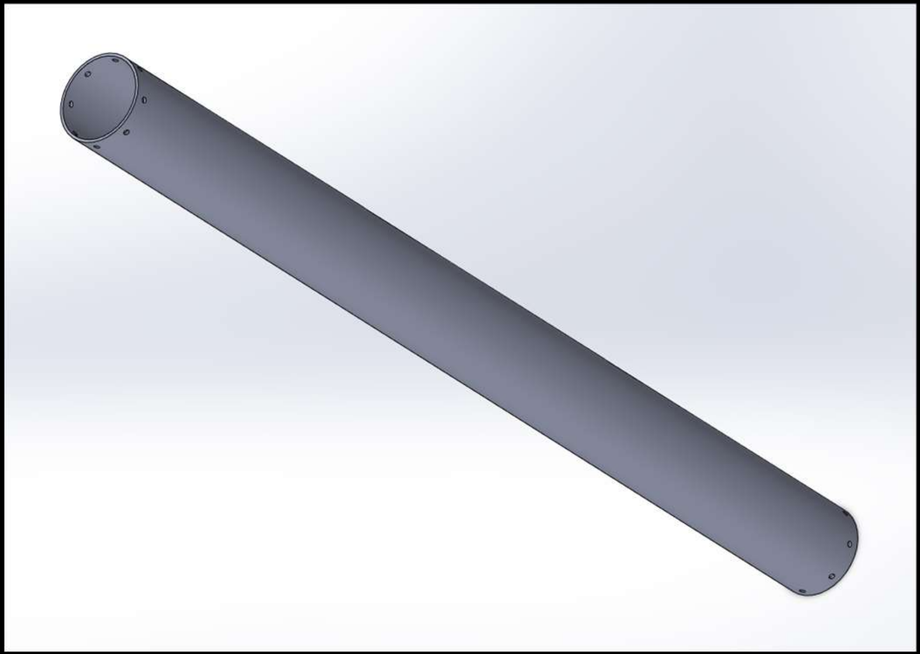
Tank Bulkheads

- 8 bolts per bulkhead
- All 3 have secondary O-rings
- Offset plumbing hole



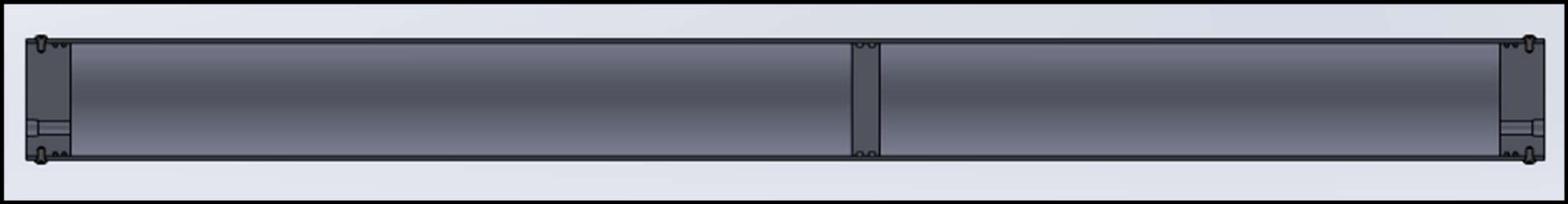
Tank Cylinder

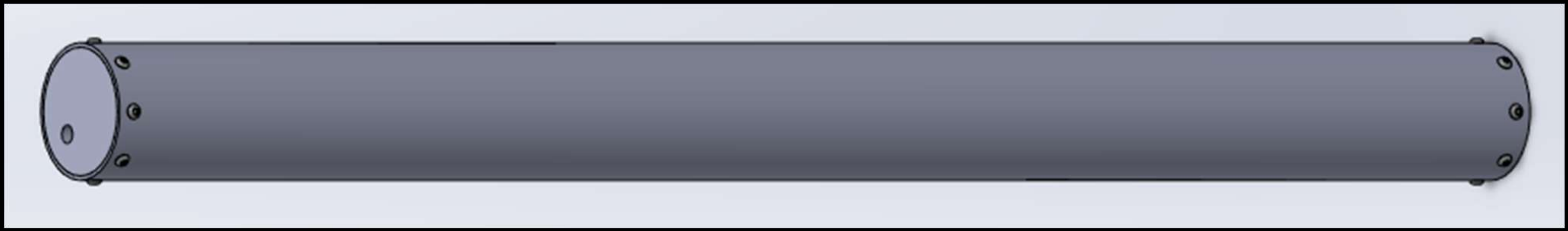
- OD: 4 in
- ID: 3.75 in
- 1/8 in wall thickness
- Total length is based on propellant volume and bulkhead heights



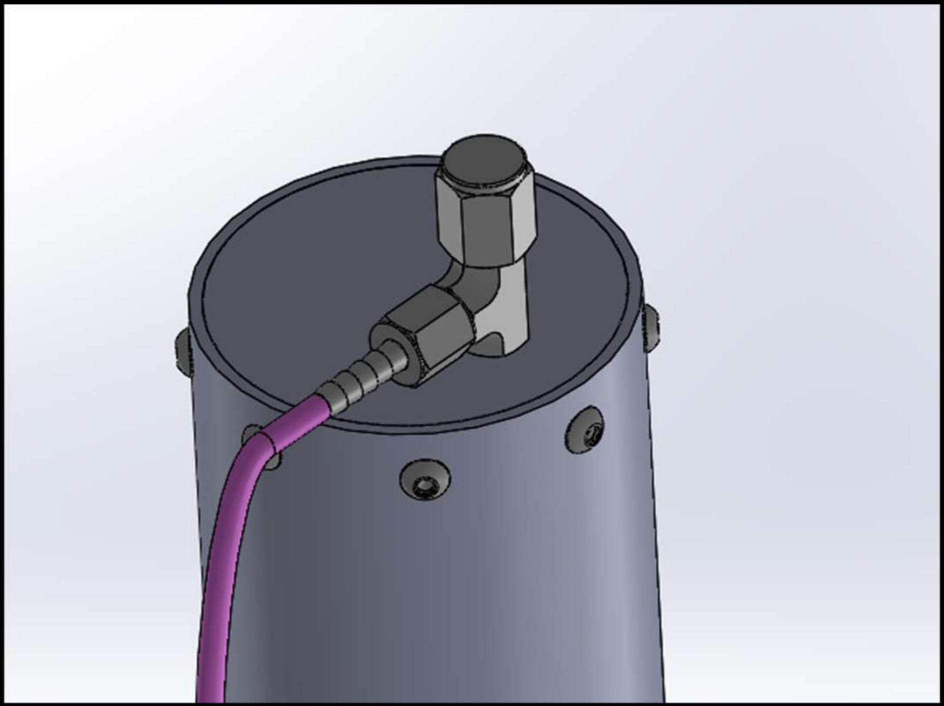
KXR UCF

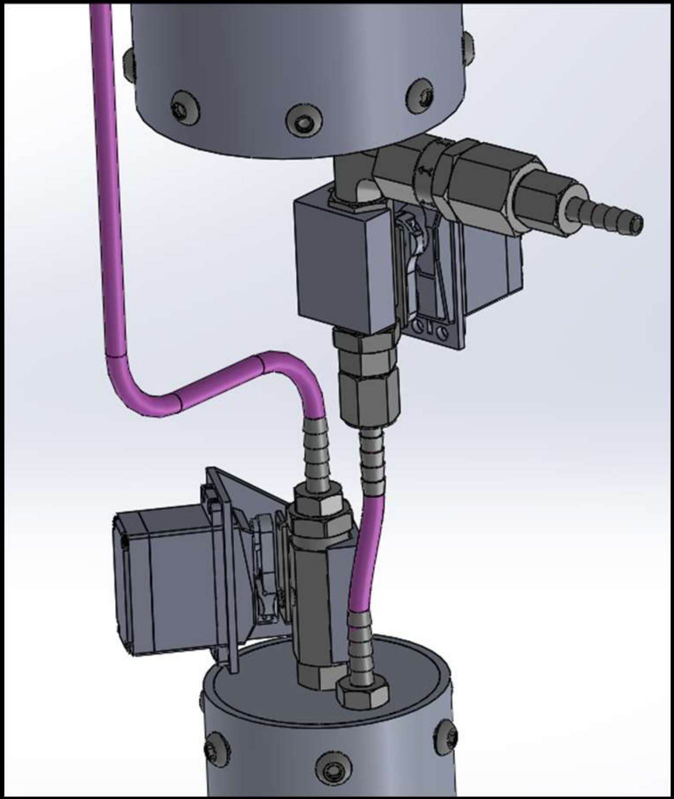
Run tank Assembly





Plumbing Assembly





Tank Dimension Calculations - Ethanol

Material Properties:

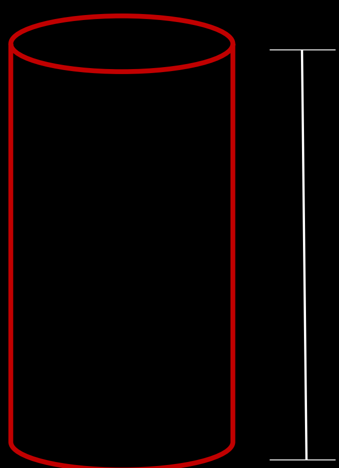
$$Density\ at\ 100°F = 774\frac{kg}{m^3} \approx 0.028\frac{lb}{in^3}$$

$$m_{ethanol} = 3.256\ lb$$

$$v_{o/f} = \frac{\dot{m}_{o/f}t}{\rho}$$

$$\frac{m}{v} = \rho \qquad \frac{m}{\rho} = v = \pi r^2 h \qquad h = \frac{m}{\rho\pi r^2}$$

$$h = \frac{3.256}{0.028 * \pi * 1.875^2} = 10.52868 \approx 10.53\ in$$



h = 10.53 in

Tank Dimension Calculations – Nitrous Oxide

Material Properties:

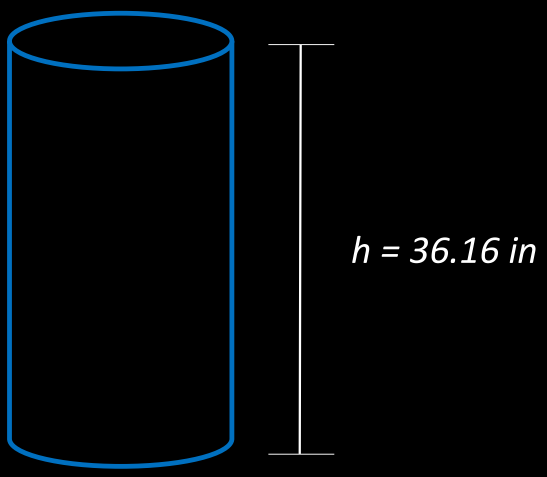
$$Density\ at\ 100°F = 452\frac{kg}{m^3} \approx 0.016\frac{lb}{in^3}$$

$$m_{nitrous} = 6.39\ lb$$

$$v_{o/f} = \frac{\dot{m}_{o/f}t}{\rho}$$

$$\frac{m}{v} = \rho \qquad \frac{m}{\rho} = v = \pi r^2 h \qquad h = \frac{m}{\rho \pi r^2}$$

$$h = \frac{6.39}{0.016 * \pi * 1.875^2} = 36.16\ in$$

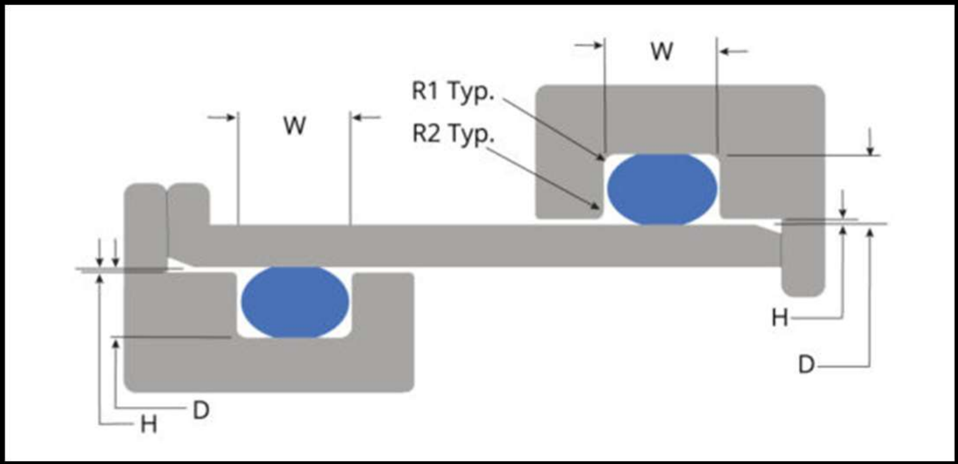


O-Rings & O-Ring Grooves

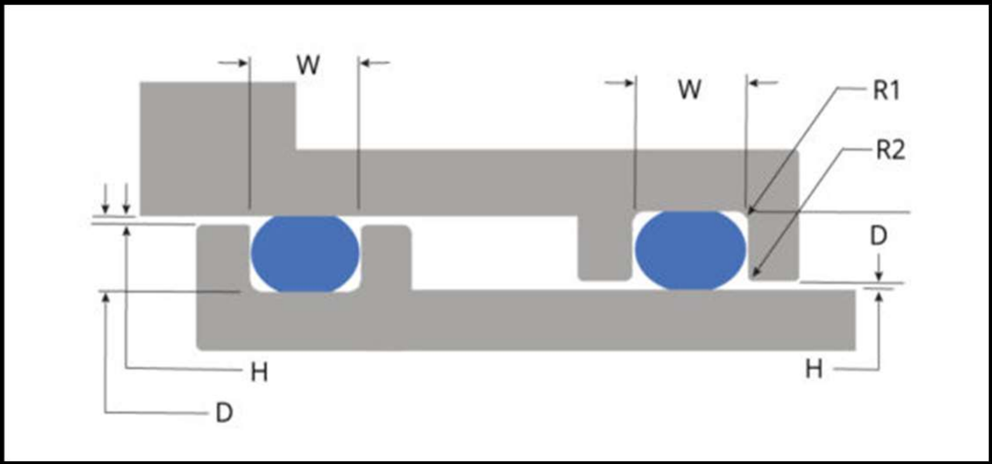
O-Rings: A568A #201-284

Cross sectional diameter: 0.125in

Bulkheads: Static gland seal



Piston: Dynamic gland seal



O-Rings & O-Ring Grooves

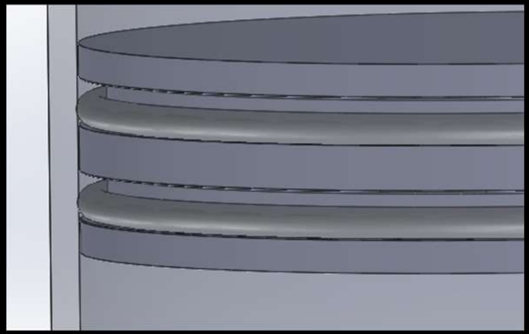
Static Gland Seal

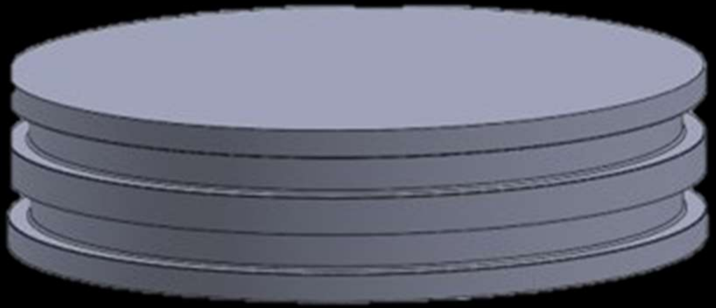
AS568 Series	O-Ring Cross-Section		Gland Depth (D)	Squeeze		Gland Width (W)				Gap (H)	Gland Corner Radii	
	Nominal	TOL (+/-)		Actual	Percent	Nominal	TOL (+/-)	w/ 1 Backup Ring	w/ 2 Backup Rings	MAX	R1	R2
-0XX	0.070	0.003	.050-0.052	.015-.023	22%-32%	0.095	0.002	0.140	0.207	0.002	0.007	0.005
-1XX	0.103	0.004	.081-.083	.017-.025	17%-24%	0.142	0.003	0.173	0.240	0.002	0.007	0.005
-2XX	0.139	0.004	.111-.113	.022-.032	16%-23%	0.189	0.003	0.210	0.277	0.002	0.017	0.005
-3XX	0.210	0.005	.170-.173	.032-.045	15%-21%	0.283	0.003	0.313	0.412	0.003	0.027	0.005
-4XX	0.275	0.006	.226-.229	.040-.055	15%-20%	0.377	0.003	0.410	0.540	0.003	0.027	0.005

O-Rings & O-Ring Grooves

Dynamic Gland Seal

AS568 Series	O-Ring Cross-Section		Gland Depth (D)	Squeeze		Gland Width (W)				Gap (H)	Gland Corner Radii	
	Nominal	TOL (+/-)		Actual	Percent	Nominal	TOL (+/-)	w/ 1 Backup Ring	w/ 2 Backup Rings	MAX	R1	R2
-0XX	0.070	0.003	.055-0.057	.010-.018	15%-25%	0.095	0.002	0.140	0.207	0.002	0.007	0.005
-1XX	0.103	0.004	.088-.090	.010-.018	10%-17%	0.142	0.003	0.173	0.240	0.002	0.007	0.005
-2XX	0.139	0.004	.121-.123	.012-.022	9%-16%	0.189	0.003	0.210	0.277	0.002	0.017	0.005
-3XX	0.210	0.005	.185-.188	.017-.030	8%-14%	0.283	0.003	0.313	0.412	0.003	0.027	0.005
-4XX	0.275	0.006	.237-.240	.029-.044	11%-16%	0.377	0.003	0.410	0.540	0.003	0.027	0.005

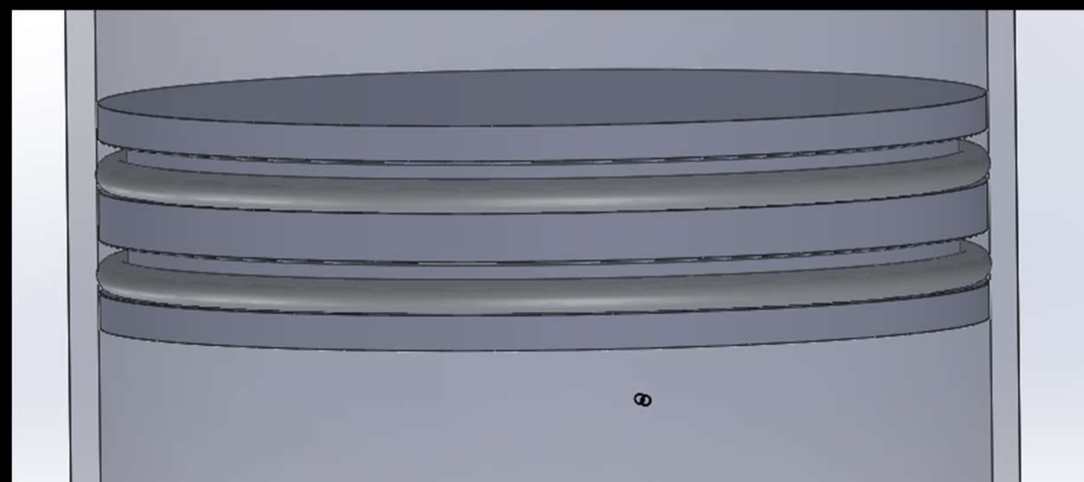




Vent Hole Calculations

Vent hole

- drilled just below the piston (at its unpressurized position)
- We are still determining the dimensions required



Based on Half Cat 25s/3lbs and 2Cat/3 60s/9lbs

KXR UCF

Bolt Shear Calculations

Force acting on the bulkhead as a product of the area of the bulkhead and the maximum expected operating pressure (MEOP).

Force of Bulkhead

$$F_{bulk} = \left(\frac{\pi}{4}(D_i)^2 \times MEOP\right)$$

$$F_{bulk} = \left(\frac{\pi}{4}(3.75)^2 \times 1051.669\right)$$

$$F_{bulk} = \left(\frac{\pi}{4}(14.0625) \times 1051.669\right)$$

$$F_{bulk} = (11.04466167 \times 1051.669)$$

$$F_{bulk} = 11615.32829 psi$$

Maximum Force a bolt can take is a product of its cross-sectional area and shear strength

Max Bolt Force

$$F_{bolt}^{max} = A_{bolt} \times \tau_u$$

$$F_{bolt}^{max} = 0.034966712 \times 72{,}000$$

$$F_{bolt}^{max} = 2517.603264$$

Dividing the expected bulkhead force by the maximum force a bolt can take gives the minimum number of bolts

Minimum Number of Bolts

$$n_{bolts} = \frac{F_{bulk}}{F_{bolt}^{max}}$$

$$n_{bolts} = \frac{11615.32829}{2517.603264}$$

$$n_{bolts} = 3.690916184$$

$$n_{bolts} = 4.61$$

$$n_{bolts} \approx 5$$

Minimum number of bolts multiplied by the targeted safety factor results in the actual number of bolts.

Number of Bolts Based on Safety Factor

$$n_{bolts}^{SF} = SF \times n_{bolt}$$

$$n_{bolts}^{SF} = 1.5 \times 5$$

$$n_{bolts}^{SF} = 7.5$$

$$n_{bolts}^{SF} \approx 8$$

$$n = 8$$

Bolt Shear Calculations

Safety factor can be determined by calculating the force of the bulkhead and dividing it by the product of the cross-sectional area of the bolts and the number of bolts.

Bolt Shear

$$\sigma_{bolt\ shear} = \frac{\left(\frac{\pi}{4}(D_i)^2 \times MEOP\right)}{\left(\frac{\pi}{4}(d_{bolt})^2 \times n\right)}$$

$$\sigma_{bolt\ shear} = \frac{\left(\frac{\pi}{4}(3.75)^2 \times 1051.669\right)}{\left(\frac{\pi}{4}(0.211)^2 \times 8\right)}$$

$$\sigma_{bolt\ shear} = \frac{\left(\frac{\pi}{4}(14.0625) \times 1051.669\right)}{\left(\frac{\pi}{4}(0.044521) \times 8\right)}$$

$$\sigma_{bolt\ shear} = \frac{(11.04466167 \times 1051.669)}{(0.034966712 \times 8)}$$

$$\sigma_{bolt\ shear} = \frac{(11615.32829)}{(0.279733696)}$$

$$\sigma_{bolt\ shear} = 41522.80707psi$$

Shear strength of each bolt (60% of Ultimate Tensile Strength) dived by the bolt shear force yields the actual safety factor.

Safety Factor 60% of UTS

$$FS_{bolt\ shear} = \frac{0.60 \times UTS}{\sigma_{bolt\ shear}}$$

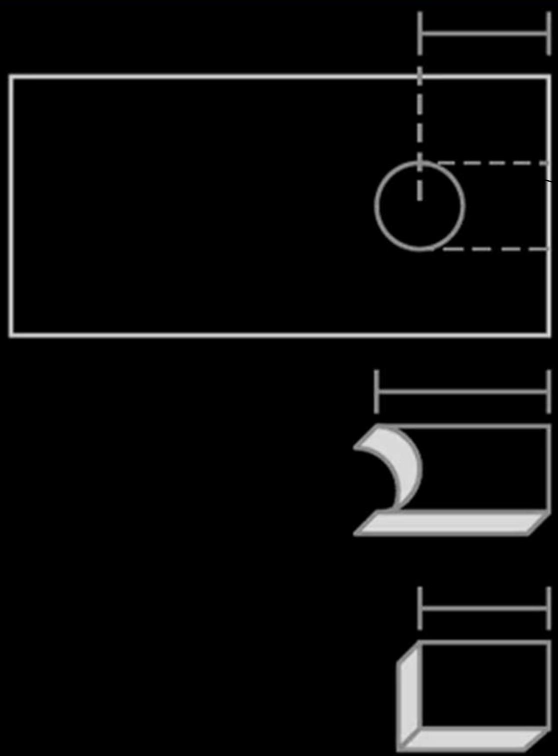
$$FS_{bolt\ shear} = \frac{0.60 \times 120{,}000}{41522.80707}$$

$$FS_{bolt\ shear} = \frac{72{,}000}{41522.80707}$$

$$FS_{bolt\ shear} = 1.733986815$$

$$FS_{bolt\ shear} \approx 1.7$$

Bolt Tear-out Calculations



Recommended distance from the bolt to the edge of casing

Edge Distance

$$E \geq 2 \times d_{bolt}^{major}$$

$$E \geq 2 \times 0.25$$

$$E = 0.5$$

Minimum acceptable distance from bolt to edge of casing

Minimum Distance from Edge

$$E_{min} = E - \frac{d_{bolt}^{major}}{2}$$

$$E_{min} = 0.5 - \frac{0.25}{2}$$

$$E_{min} = 0.5 - 0.125$$

$$E_{min} = 0.375in$$

Run Tank Hoop Stress

- Hoop stress based on a maximum expected pressure of 1051.669psi.

Hoop Stress

$$\sigma_h = \frac{P \times r}{t}$$

$$\sigma_h = \frac{1051.669 \times 2}{0.125}$$

$$\sigma_h = \frac{2103.338}{0.125}$$

$$\sigma_h = 16826.704 psi$$

- Safety Factor of Hoop Stress

Safety Factor of Hoop Stress

$$SF_{hoop} = \frac{\tau_u^{alum}}{\sigma_h}$$

$$SF_{hoop} = \frac{30,000 psi}{16,826.704 psi}$$

$$SF_{hoop} = 1.78$$

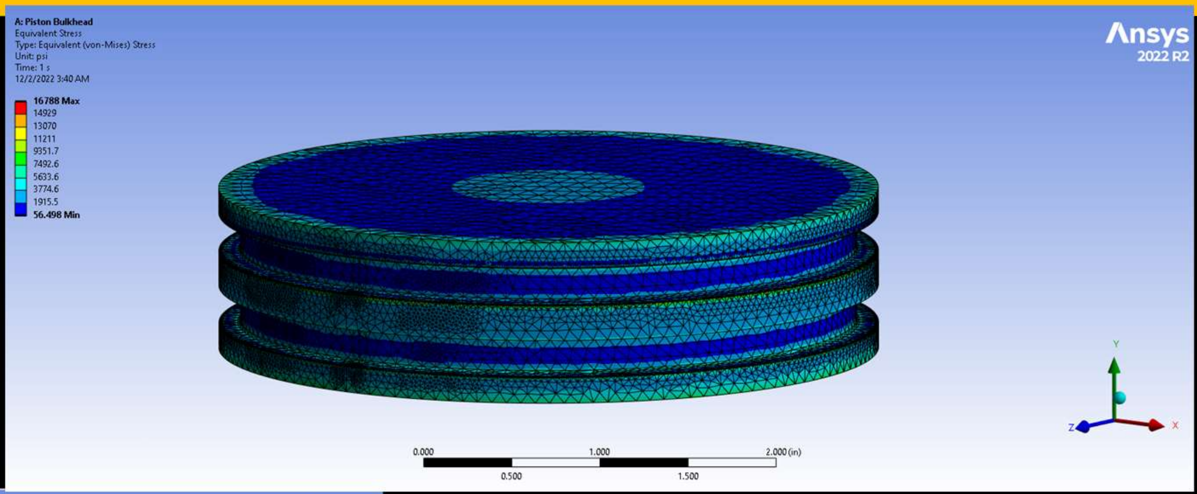
$$SF_{hoop} \approx 1.8$$

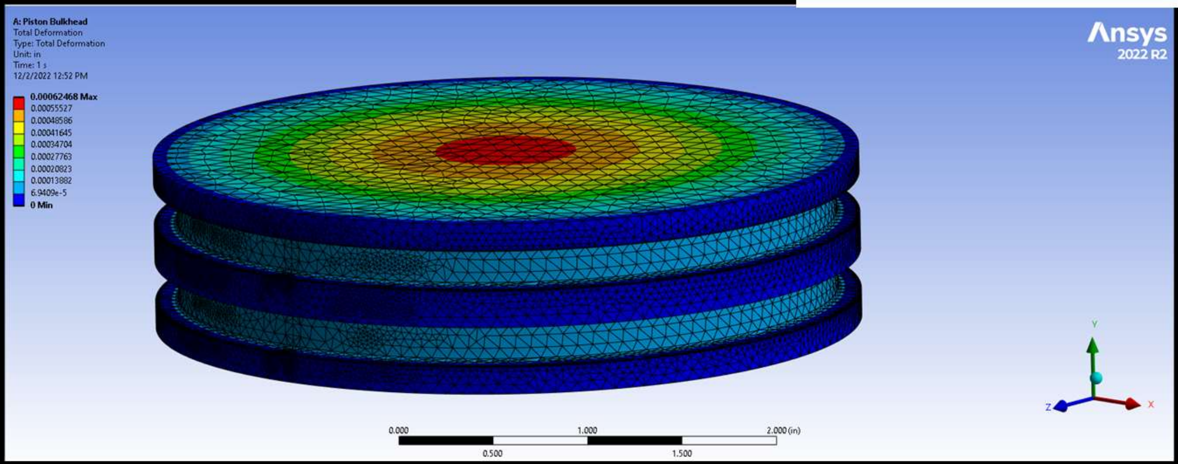
Run Tank FEA Simulations

Piston Bulkhead

Stress at center = 2000 psi

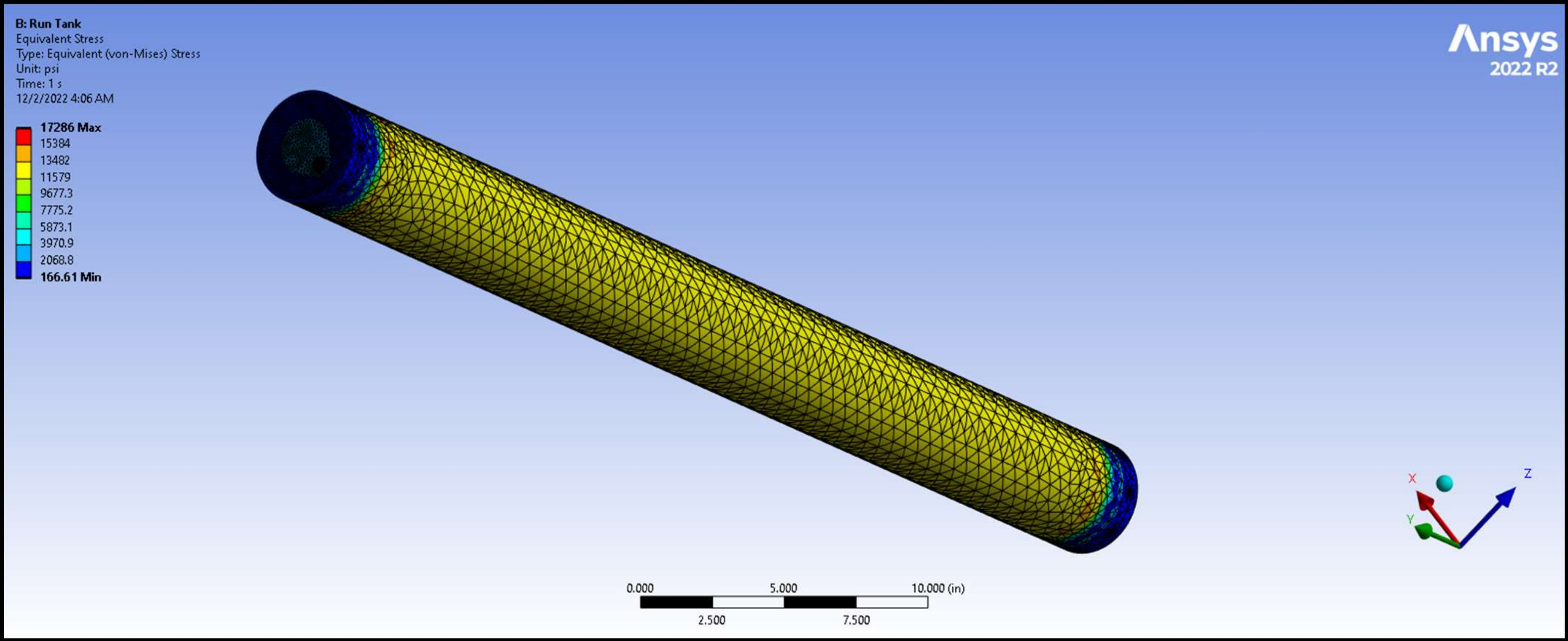
Max deformation < 0.001 in





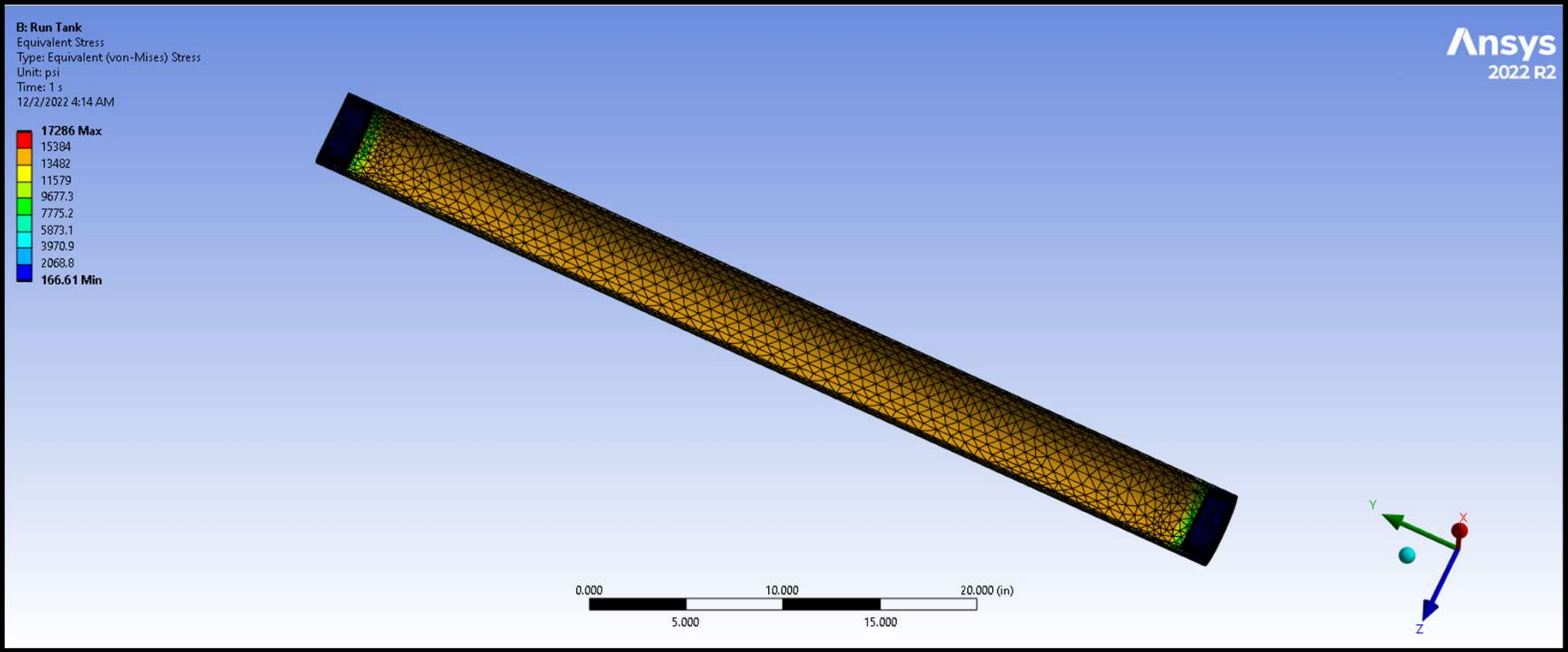
Run Tank FEA Simulations

Run Tank



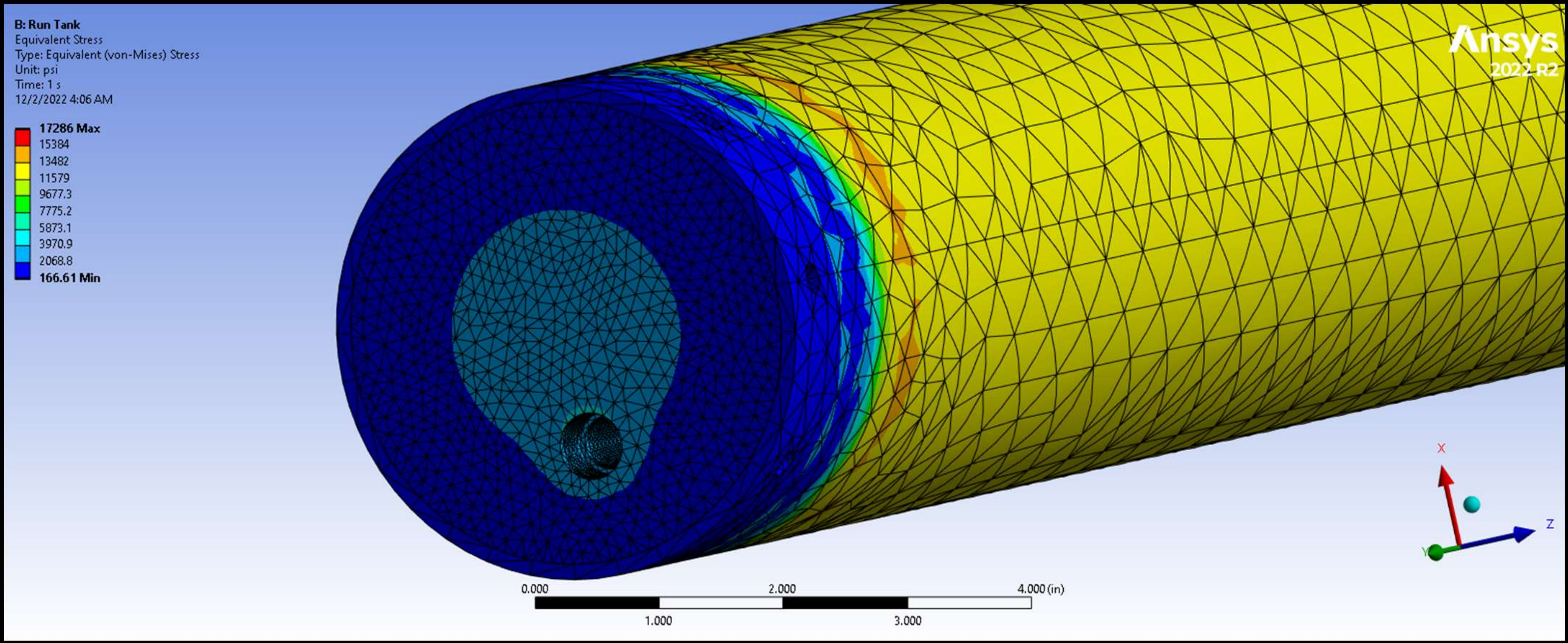
Run Tank FEA Simulations

Run Tank:
Average inner hoop stress: 14500 psi
SF: 2.07



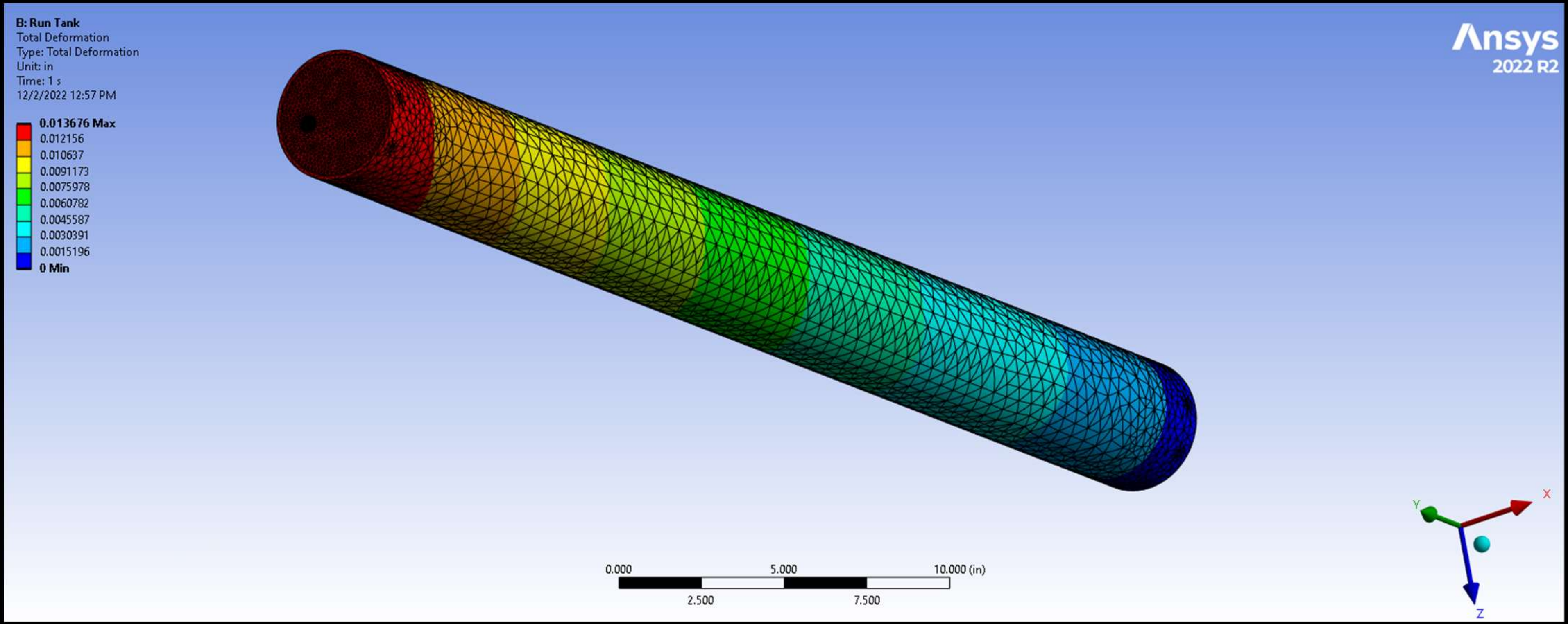
Run Tank FEA Simulations

Run Tank



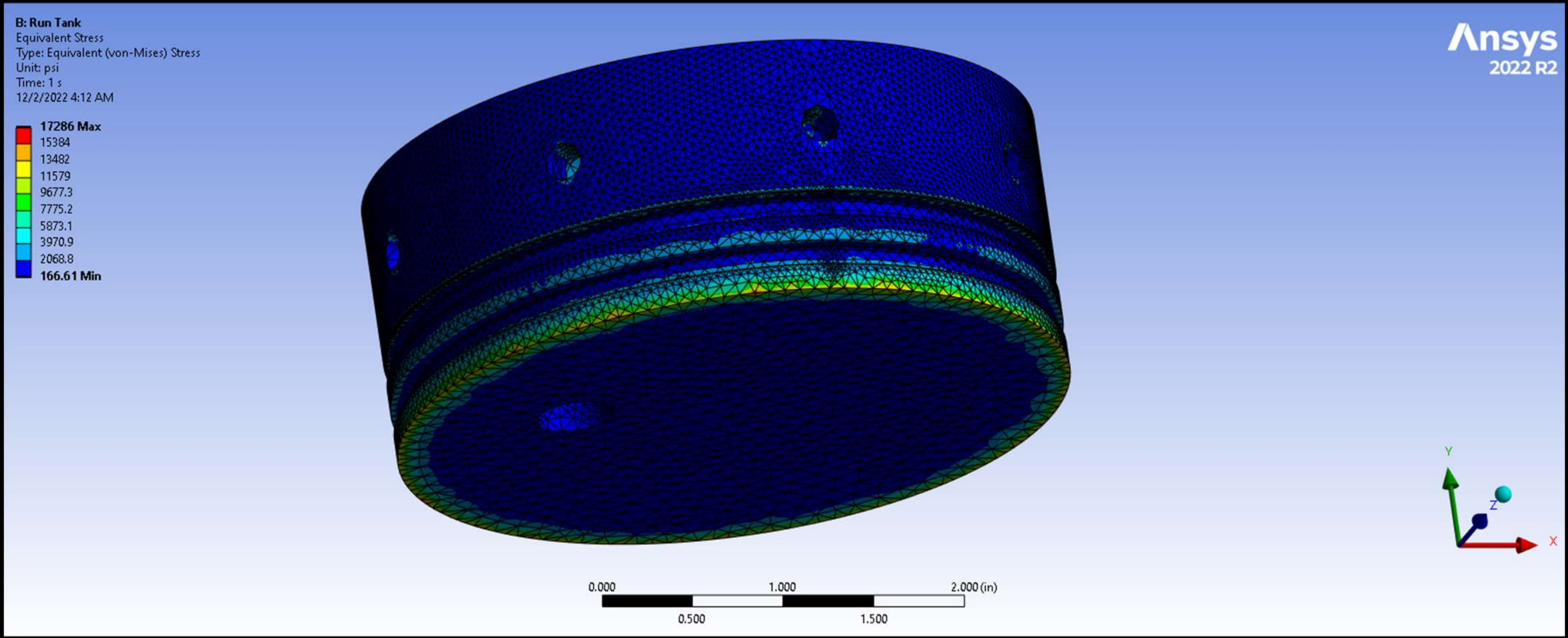
Run Tank FEA Simulations

Run Tank

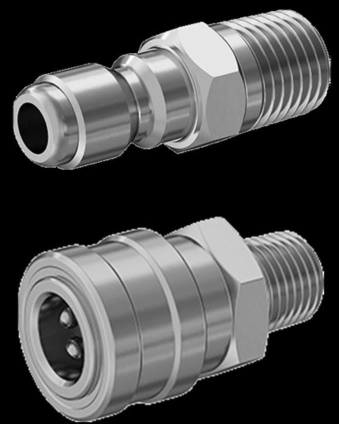


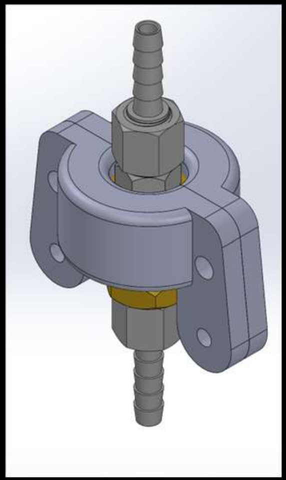
Run Tank FEA Simulations

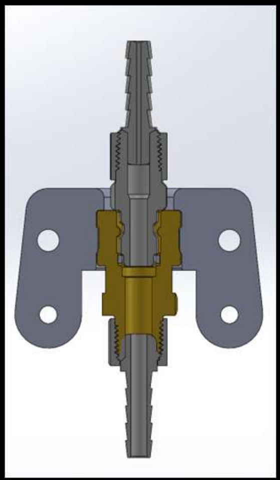
Bulkhead

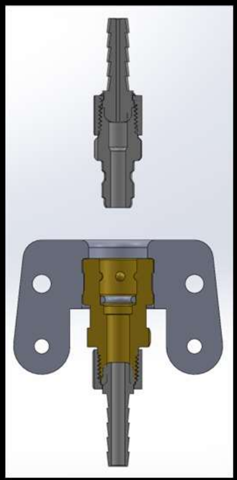


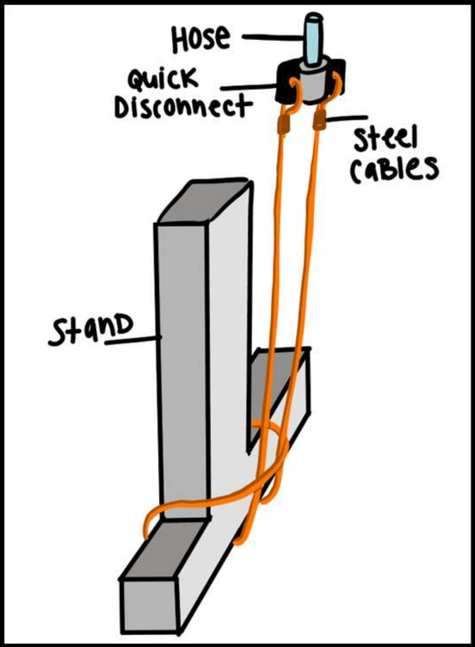
Quick Disconnect











- Quick Disconnect is a hydraulic Quick Disconnect with a sleeve.
- The 3D printed clamp fits over sleeve of the quick disconnect.
- Metal wire looped through the holes in the clamp anchors it down to launch infrastructure.
- At liftoff, the rocket pulls on male end of the disconnect causing the anchored sleep to move disconnecting the line.

Quick Disconnect in Action

Real-Time

Slow-Motion

The combined flexibility of the steel wire and the hose eliminates the need to manufacture a perfectly aligned rigid structure that needs to be bolted to the launch pad

Valve Selection

Design Constraints

- 1.5 factor of safety (minimum)
- Normally open
- Motorized/remotely actuated

Valve Choice

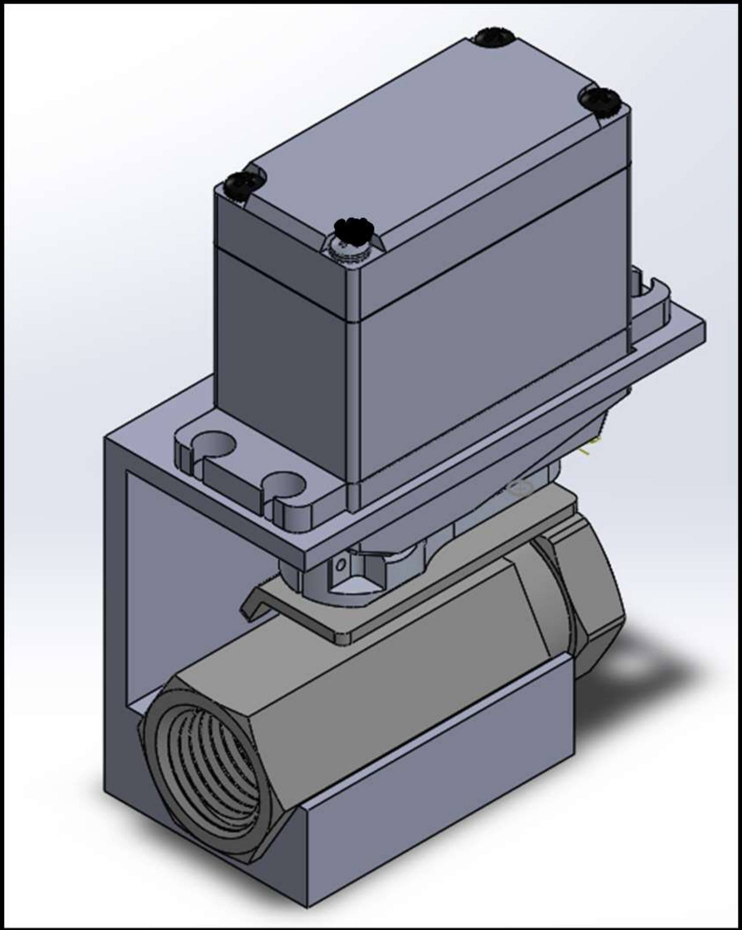
- Ball Valves – less pressure loss compared to solenoid valves
- "Compact" – able to fit inside rocket
- Requires approximately 10 in-lbs of torque

Servo Motor

- 25 kg of torque (more than 17 in-lbs)
- Comes with a servo arm

Servo Mount

- The mount will be 3D printed
- The ball valve lever will be adjusted to lay flat for spacing
- The servo arm and valve lever will be connected by a bolt and nut



RC Servo Remote & Receiver

Aero Sport 2.4GHs FHSS-1

- free (normally $100)
- 5 channel 2.4GHz transmitter
- compatible with both digital and analog servos (we use digital)
- Binds remotely to an inline receiver

RX 500 receiver

- free (normally $80)
- Full Range receiver with dual antennas
- wires inline to the servo's inside the rocket

KXR UCF

Thermal Managment

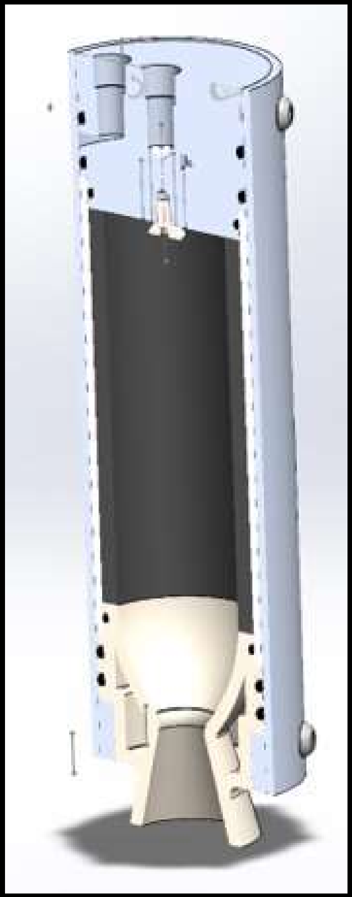
To keep the Nitrous Oxide fill tank at expected temperatures multiple thermal management systems will be employed.

- Before erecting the rocket, the run tanks will be kept cool with damp blanket, which will be removed before moving it to the launch stand.
- The Nitrous Oxide fill tank will be kept continually cool with damp towel while on the pad and thermal reflective material will be used to keep heat off.

Overview

- Liquid Engine
- Target Impulse: ~M Class (~6kNs)
- Initial Thrust ~800N
- Burn Time ~8 seconds

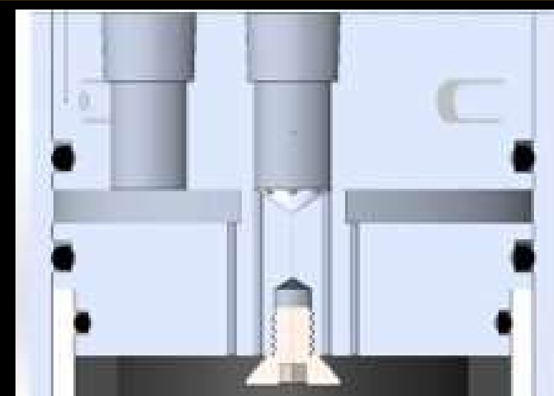
Engine Team



KXR UCF

Injector

- Pintle style injector - "Scrintle"
    - Showerhead isn't as good for atomization.
- Screw is used as main diverter for fuel
- 12 holes for N2O, 8 holes for Ethanol
- Orifice diameter Of 3/64 for both fuel
    - Ease of manufacturing keeping diameter the same



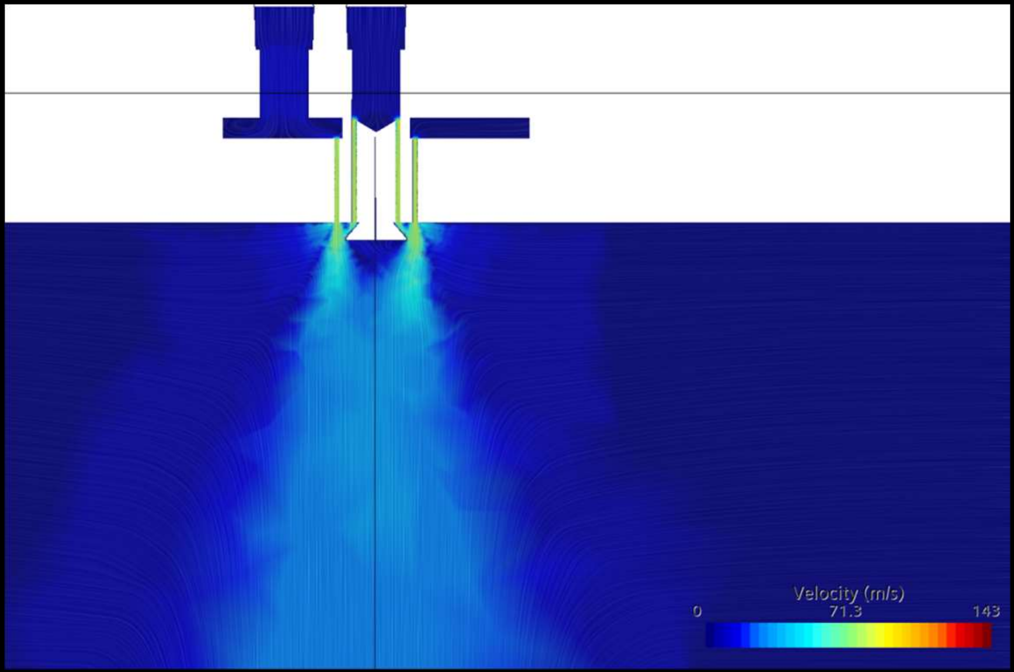
$$.6362538\sqrt{\frac{2.238(1.7)}{46.44016(70)}} = 0.0217665208547$$

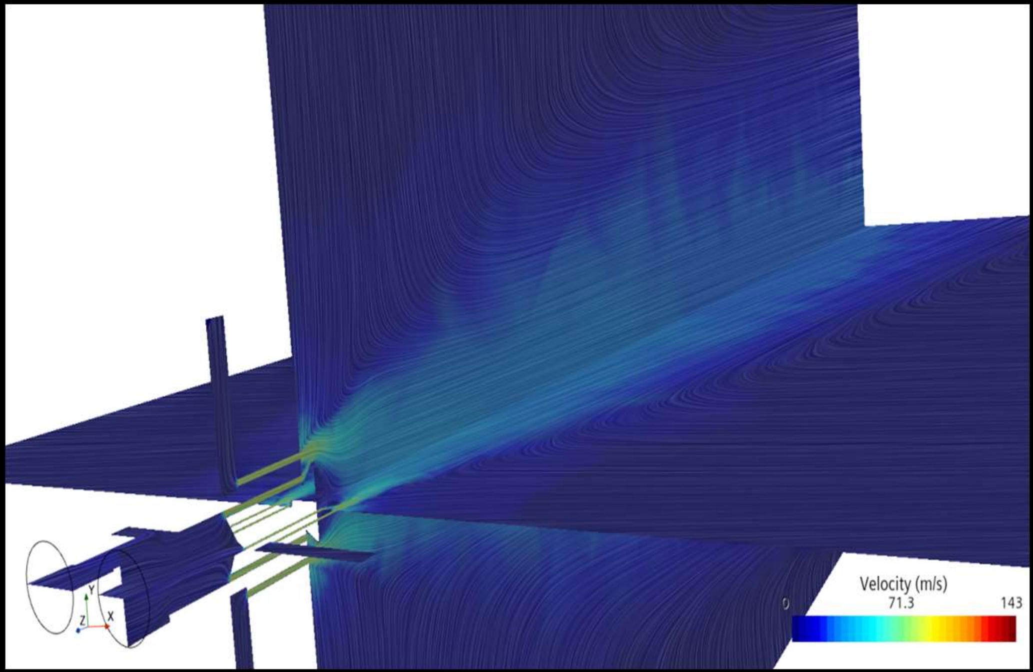
$$\sqrt{\frac{4(0.0217665208547)}{(\pi)12}} \quad N_2O \quad = 0.0480572532711$$

$$0.4241692\sqrt{\frac{2.238(1.7)}{50.112(70)}} = 0.0139692710397$$

$$\sqrt{\frac{4(0.0139692710397)}{\pi(8)}} \quad Eth \quad = 0.0471516546619$$

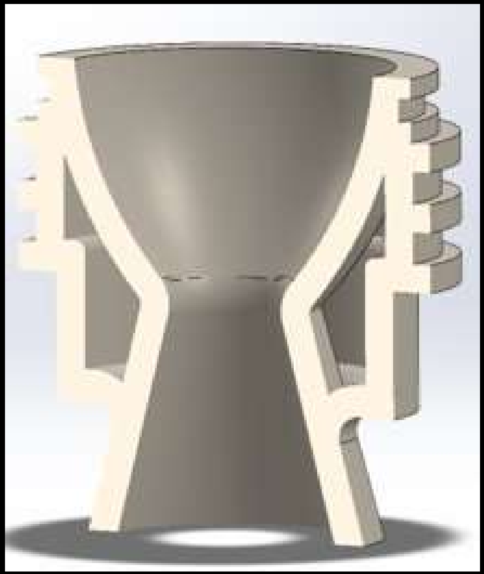
Injector CFD Sims





Nozzle

- Conical nozzle
  - Bell was looked at, but at this size was deemed not worth it
- Inconel vs Copper/Aluminum
  - Inconel, we get for free
  - Copper/Aluminum, didn't like the Al near the hot gas
- Decided on Inconel as it has
  - Fantastic heat properties
  - Super strong, should last for every possible firing
  - Free



Nozzle Cont.

- Throat Diameter of 0.75in
- Exit Diameter of 1.452in
- Area Ratio of 3.75
- Normal divergence angle of 15°

- Calculated Mach Number = 2.75
- Simulated Mach Number = 2.15

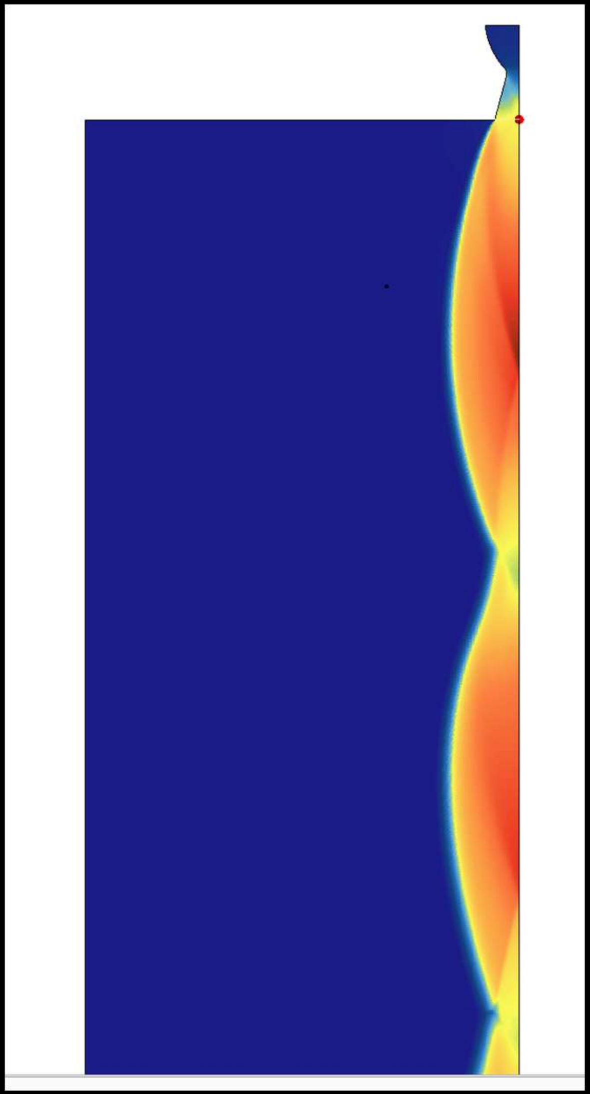
CEA Data

	CHAMBER	THROAT	EXIT
Pinf/P	1.0000	1.8301	23.825
P, BAR	24.132	13.186	1.0129
T, K	1954.72	1705.29	1003.72
RHO, KG/CU M	2.6029 0	1.6304 0	2.1722-1
H, KJ/KG	0.00000	-523.87	-2098.51
U, KJ/KG	-927.12	-1332.62	-2564.80
G, KJ/KG	-23973.7	-21438.4	-14408.6
S, KJ/(KG)(K)	12.2645	12.2645	12.2645
M, (1/n)	17.530	17.531	17.898
(dLV/dLP)t	-1.00016	-1.00016	-1.03168
(dLV/dLT)p	1.0015	1.0011	1.4587
Cp, KJ/(KG)(K)	2.1254	2.0823	5.1445
GAMMAs	1.2881	1.2955	1.1911
SON VEL,M/SEC	1092.8	1023.6	745.3
MACH NUMBER	0.000	1.000	2.749

PERFORMANCE PARAMETERS

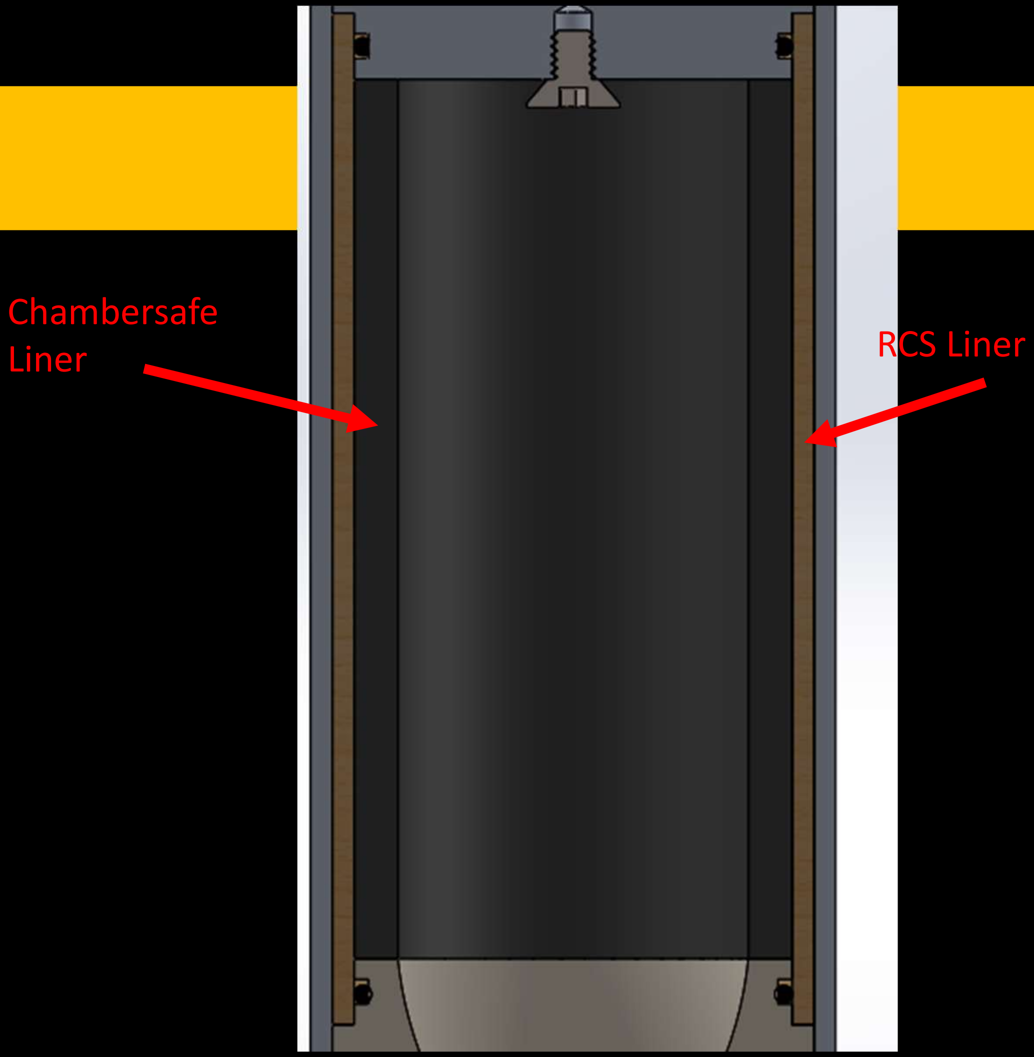
Ae/At	1.0000	3.7500
CSTAR, M/SEC	1446.0	1446.0
CF	0.7079	1.4168
Ivac, M/SEC	1813.7	2276.3
Isp, M/SEC	1023.6	2048.7

Nozzle Sims



Thermal Liner

- Custom made liner
- Gas hot and long enough RCS liner would burn through
- Hybrid of both, RCS liner as backing, custom takes bulk of heat



CHAMBERSAFE

Castable High-temperature Ablative Micro-Balloon Epoxy Resin Syntactic Auto-extinguishing Foam Experimental liner material.

- Moldable liner using Phenolic Micro-balloons,

epoxy and sodium bicarbonate.

Density	Regression Rate Lower Bound*	Regression Rate Upper Bound*
0.578 oz/in^3	0.018 in/s	0.028 in/s
1.01 g/cm^3	0.46 mm/s	0.71 mm/s

*Regression rates measured in Half Cat engine using Nitrous Oxide and Isopropyl Alcohol at an OF Ratio of 3.57

- Composition (by weight)
  - 63.3% Laminating Epoxy (including both resin and hardener)
  - 31.7% Sodium Bicarbonate (baking soda)
  - 5.0% Phenolic Micro-balloons

- Mold will be 3-D printed to fit our specifications inside the combustion chamber
- Epoxy resin releases heat as it cures so the mold will need to be cooled to prevent mold from deforming.
- Ablative properties are comparable to RCS Phenolic liner

Combustion Chamber

- 3in diameter
- L* of 200cm, found to be in the range of other Ethanol/N2O rockets
- Gives us a length of 5in

- OF Ratio of 1.5
- Chamber Pressure = 350psi

$$L = 200$$

$$A = 2.85$$

$$h = \frac{L \cdot A}{\pi(3.81)^2}$$

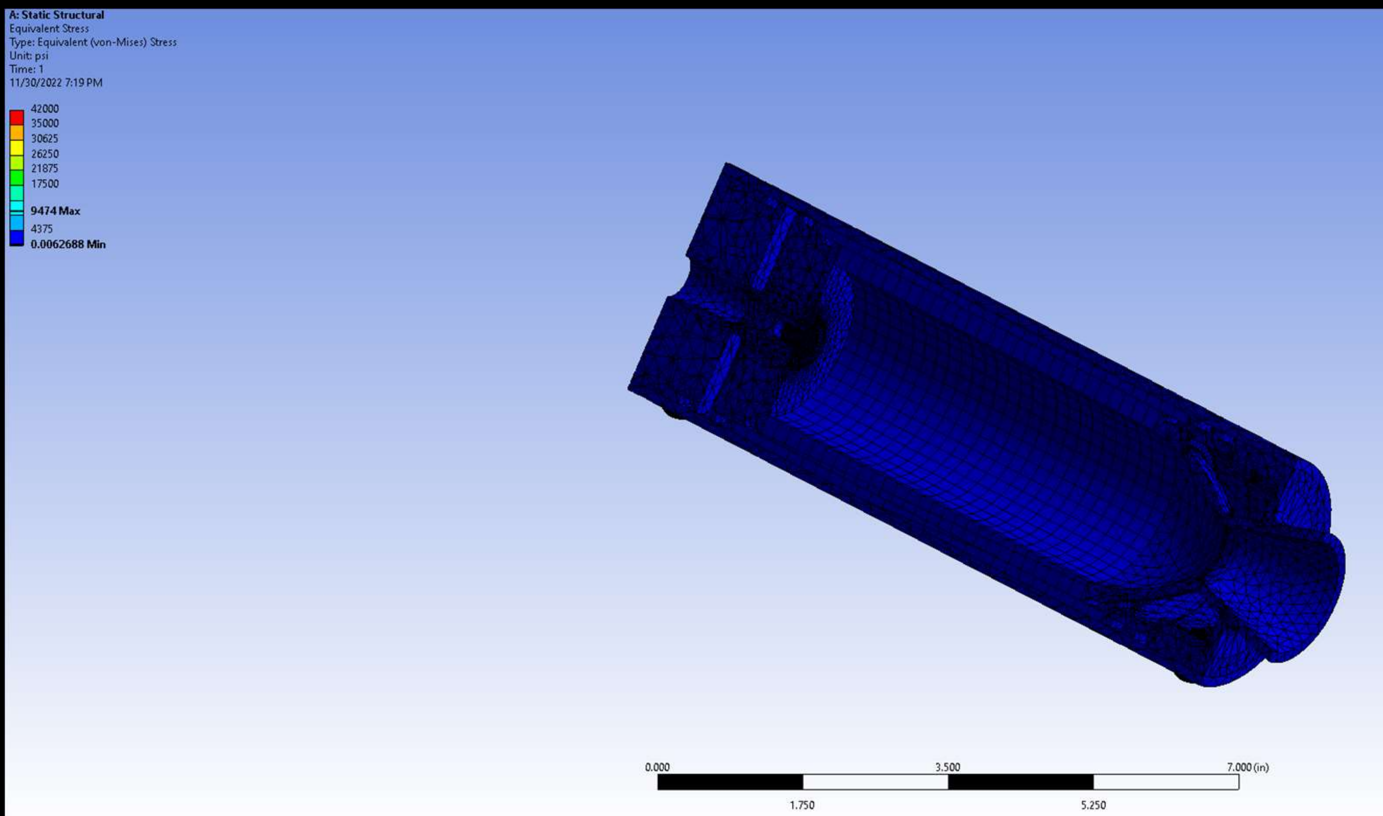
$$h = 12.4989931955$$

$$H = \frac{h}{2.54}$$

$$H = 4.92086346278$$

KXR UCF

Sims



Max Stress seen is 9474psi
We are chillin

Bolt Calculations

Motor Case Hand Calculations:

Constants:

$D_{casingOuter} := 3\ in$

$D_{casingInner} := 2.75\ in$

$P_{max} := 350\ psi$

$D_{boltMinor} := 0.221\ in$

$D_{boltMajor} := 0.25\ in$

$SS := 30\ ksi = (3 \cdot 10^4)\ psi$

$TS := 120000\ psi$

$YTS := 38\ ksi$

$BYS := 56\ ksi$

$N_{bolts} := 6$

$E := 0.5\ in$

$$E_{min} := E - \left(\frac{D_{boltMajor}}{2}\right) = 0.031\ ft$$

$t := 0.125\ in$

Shear Stress in Closure:

$$\sigma_{shearClosure} := \frac{\left(\frac{\pi}{4} \cdot (D_{casingInner}^2) \cdot P_{max}\right)}{\left(N_{bolts} \cdot \frac{\pi}{4} \cdot (D_{boltMinor}^2)\right)} = (9.032 \cdot 10^3)\ psi$$

$$FS_{boltShear} := \frac{0.6 \cdot TS}{\sigma_{shearClosure}} = 7.971$$

Force on Each Bolt:

$$F_{bolt} := \frac{\left(\frac{\pi}{4} \cdot (D_{casingInner})^2 \cdot P_{max}\right)}{(N_{bolts})} = 346.475\ lbf$$

Bolt Tear-Out Stress:

$$\sigma_{tearOut} := \frac{(F_{bolt})}{(E_{min} \cdot 2 \cdot t)} = (3.696 \cdot 10^3)\ psi$$

$$FS_{tearOut} := \frac{(SS)}{(\sigma_{tearOut})} = 8.117$$

Casing Tensile Stress:

$$\sigma_{tensile} := \frac{\frac{\pi}{4} \cdot (D_{casingInner})^2 \cdot P_{max}}{((D_{casingOuter} - 2\ t) \cdot \pi - (N_{bolts} \cdot D_{boltMajor})) \cdot t} = (2.329 \cdot 10^3)\ psi$$

$$FS_{tensileYield} := \frac{(YTS)}{\sigma_{tensile}} = 16.313$$

Bearing Stress

$$\sigma_{bearing} := \frac{F_{bolt}}{D_{boltMajor} \cdot t} = (1.109 \cdot 10^4)\ psi$$

$$FS_{bearing} := \frac{BYS}{\sigma_{bearing}} = 5.051$$

- Running 6 Bolts for forward and aft
- In conclusion, we are fine

O-Rings and Bolts

- Built engine on same basis as FAR motors
- 230 for closures to chamber wall
- 142 for closures to liner
- ¼-28 Hex button head screws
  - Used by the other teams, cheaper to have universalization of parts