Structure Redesign CDR

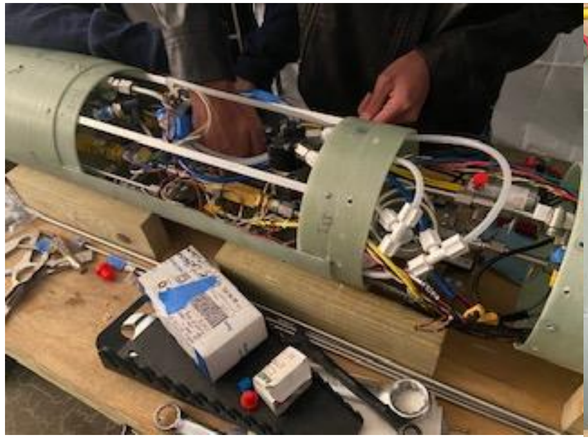
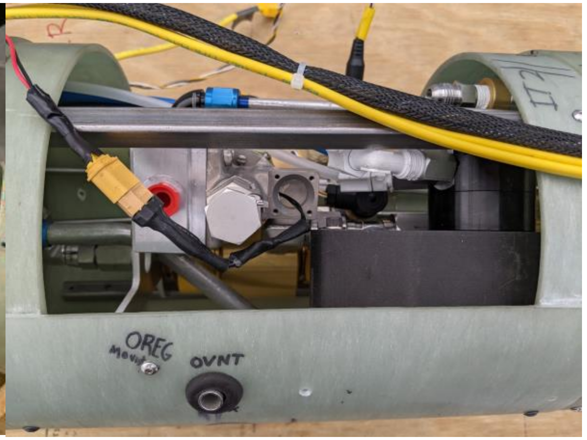
Structures and Flight Feed System Integration

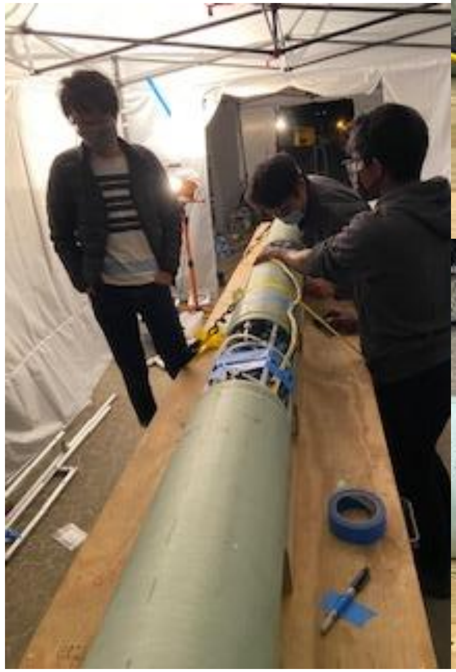
Outline

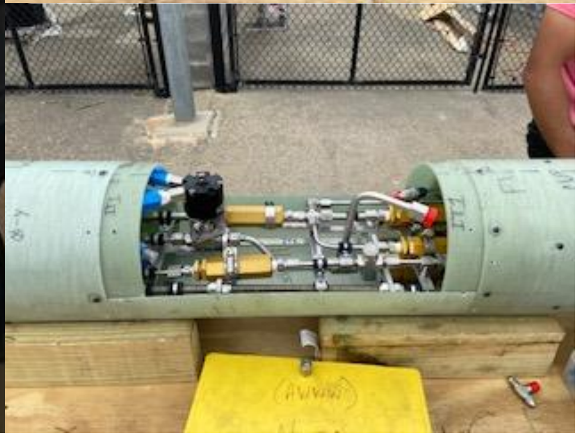
- Prior FFS and STR Issues
- Vehicle Layout
- Structures Changes
- FFS Changes
- Assembly Procedures

Prior FFS Issues

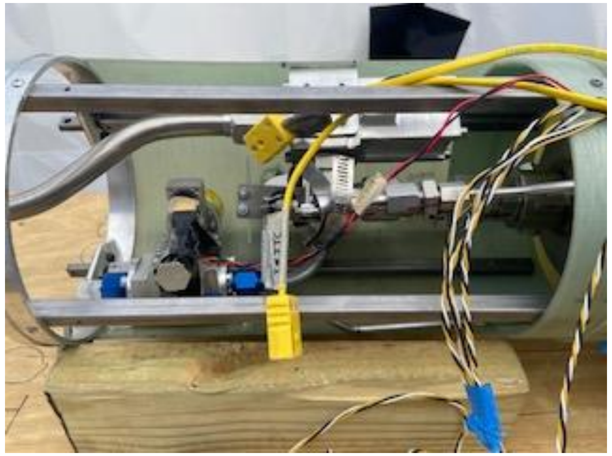
- Access To All Components
    - Wrench Clearance
- Assembly Procedures not defined
    - Concentricity and clocking not well defined
- Tolerances, Wobbly Airframe, Difficult to align airframe
- Order of Operations for assembly required disassembling way too much if one thing was off

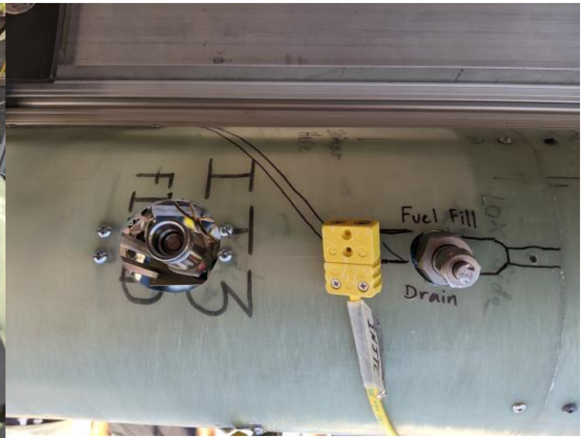



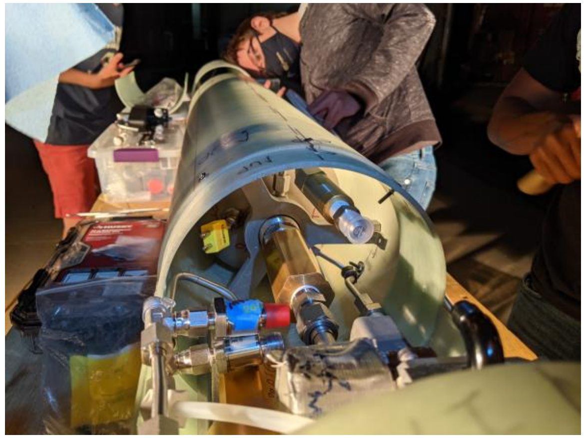


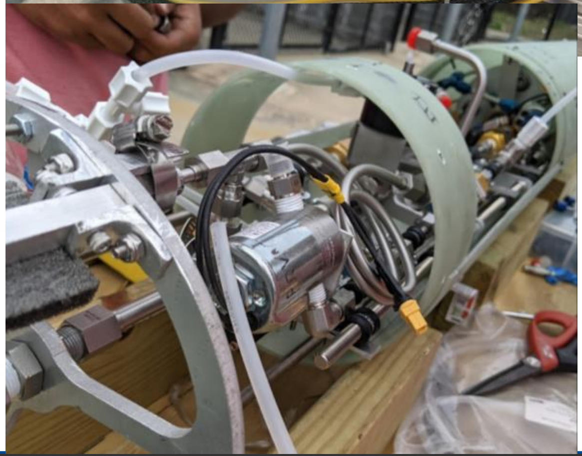


Old Design





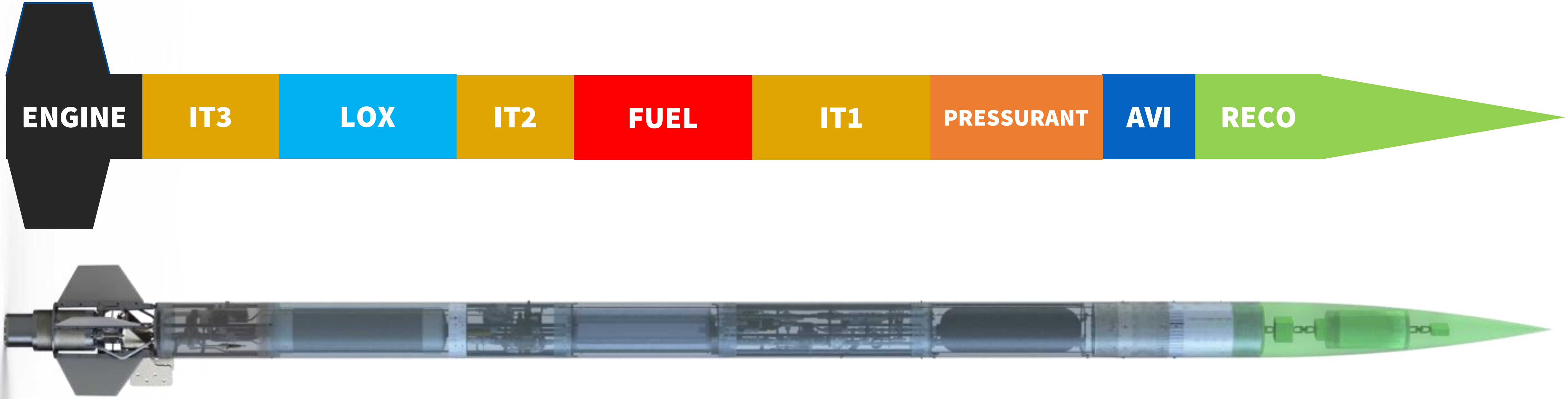




Prior STR Issues

- Wobbly and difficult to align airframe
  - Bad manufacturing techniques led to bad tolerancing and misalignment of airfame-coupler holes
- Too Many Airframe Holes and some unused
- Interferance with FFS
  - Component inaccessibility

Vehicle Layout



Structures Changes

- Increased Intertank Lengths
  - New Coupler Positions
  - Longer Stringers
  - Validated with Calculations
- Improved Manufacturing Methods
- Tank Mounts
- Load Cell Structure

Increased Intertank Lengths

- Purpose:
  - Wrench Clearance to all FFS Components and Fittings
- Tradeoffs:
  - Stringer Length Increases
    - Lowered Buckling FOS
    - Higher moment loads
  - Coupler length decreases
    - Ratio of bolt diameter to distance from edge decreases
      - Kept >3
    - Less coupler within airframe section to resist bending load
  - Solution
    - Beefed up stringers
    - Further research into composite bearing stresses

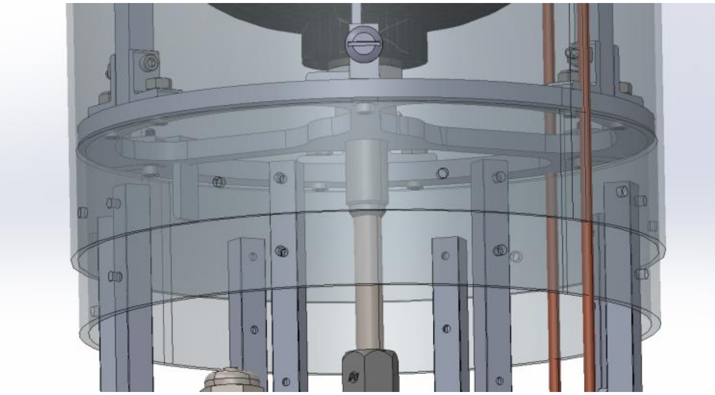
Mounting to Stringers

- Stringers now have more holes in them for mounting all plates to stringers instead of airframe
  - Pros: Better access without clamshells, less airframe holes, easier to manufactor
  - Cons: Weakens stringers
- Buffed Up Stringer FOS
  - Solid aluminum used for IT2 and IT3 stringers
  - 8 stringers for IT1

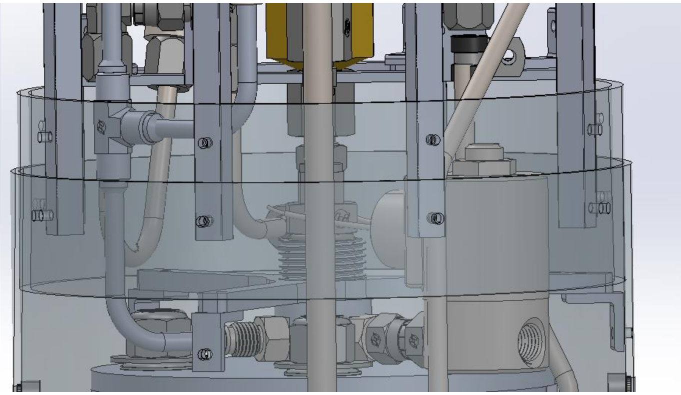
Intertank 1 (IT1)

Changes

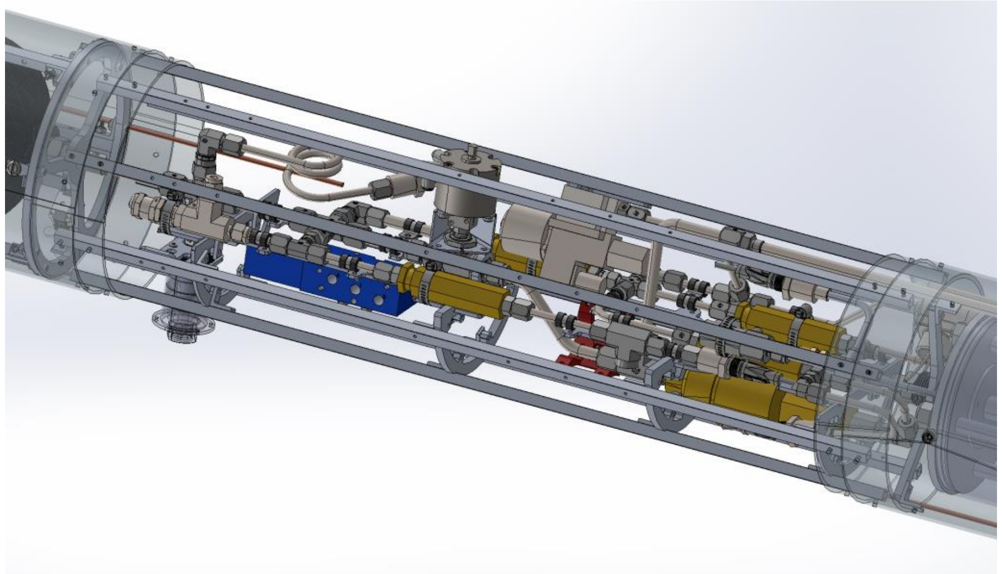
- 8 Stringer Configuration – 3/8 Aluminum Hollow Stringers
- Increased Stringer Length to 28.3 in
- Top Coupler moved up to COPV Bottom Plate
- Bottom Coupler moved down to Fuel Tank Top Plate



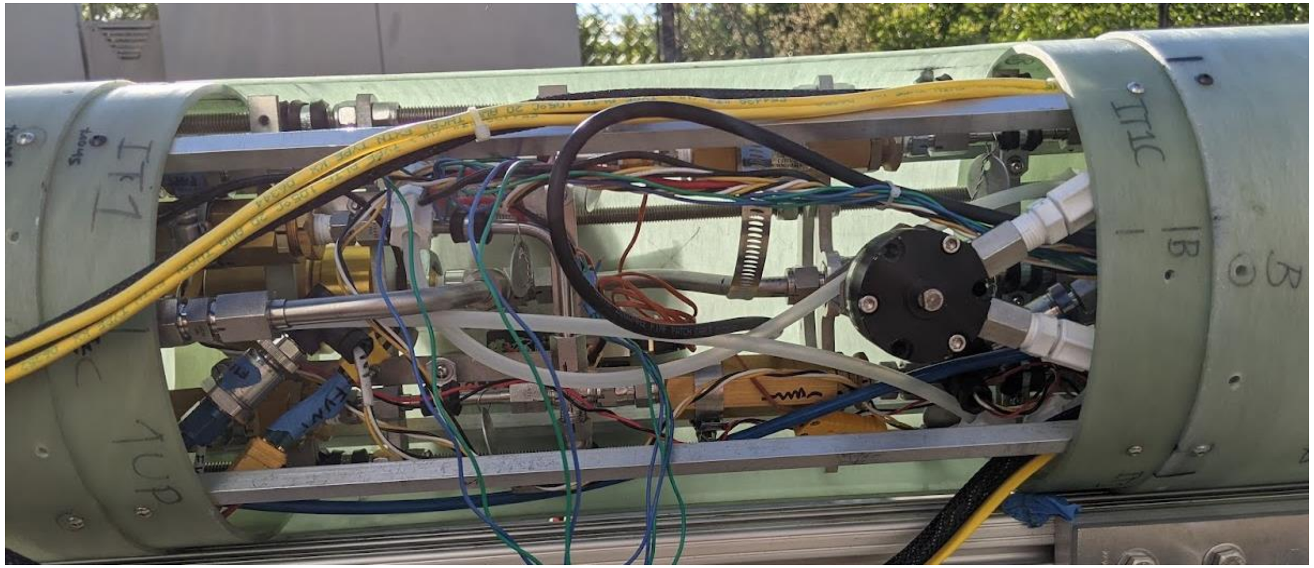
Top Coupler



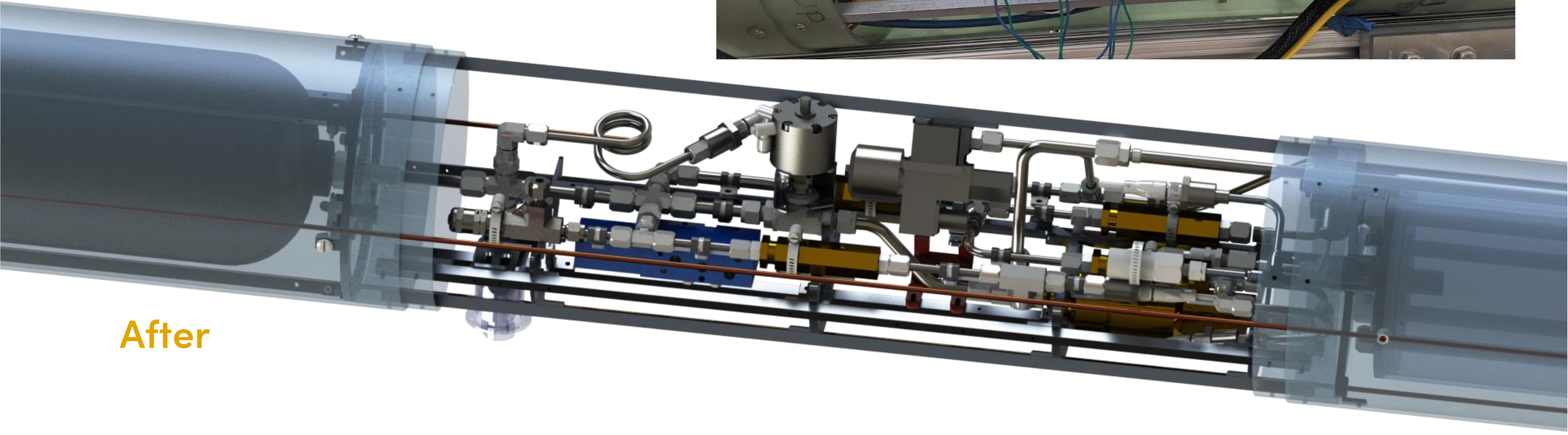
Bottom Coupler



Intertank 1 (IT1)



Before

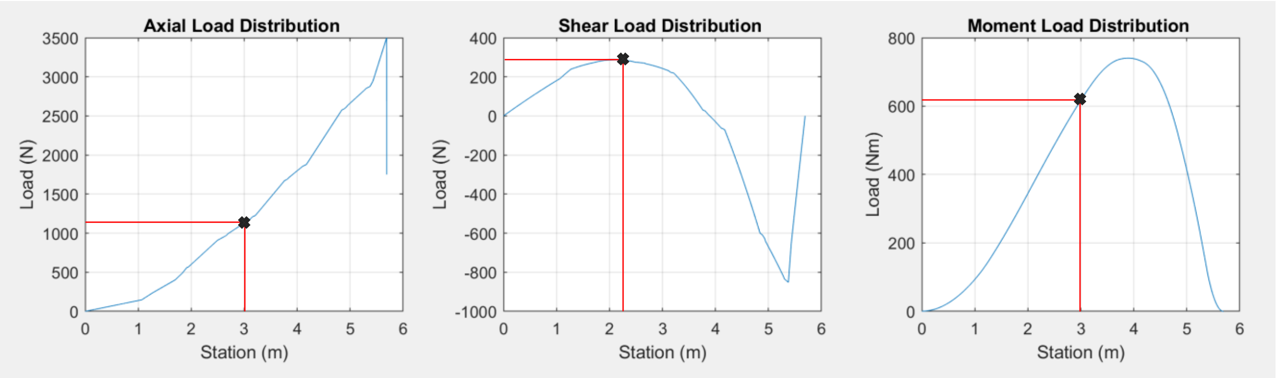


After

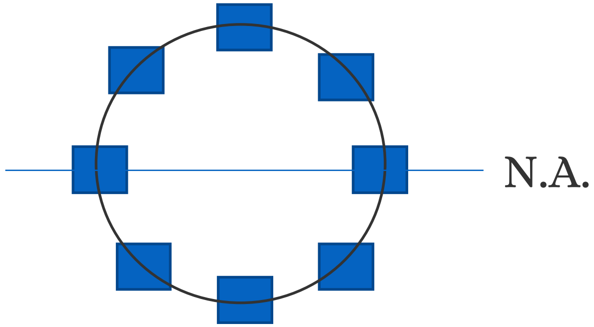
Intertank 1 (IT1)

Calculations

- **Expected loads calculated as:**
  - 620 Nm moment
  - 285 N shear
  - 1100 N axial
- **Loads placed on IT1 stringer configuration & maximum stresses calculated**
  - Assume stringers take all load
  - Assume loads constant over IT section
  - Assume N.A. passes thru 2 stringers
  - Axial FOS = 4.2 (Kt = 2.3)
  - Buckling FOS = 2.4 (single stringer)
- **Total stringer mass of 391g**



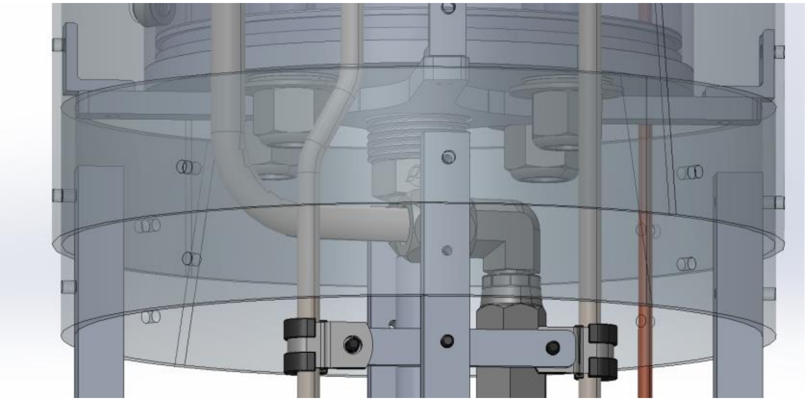
Tension	28.48370955	MPa
Compression	-39.71315404	MPa
Shear	0.003813771	MPa
Bolt Hole Kt	2.3	-
Max Tension	65.51253197	MPa
Max Compression	-91.3402543	MPa
Yield Strength, Tension	276	MPa
Young's Modulus	200	GPa
FS Yield	**4.212934407**	-



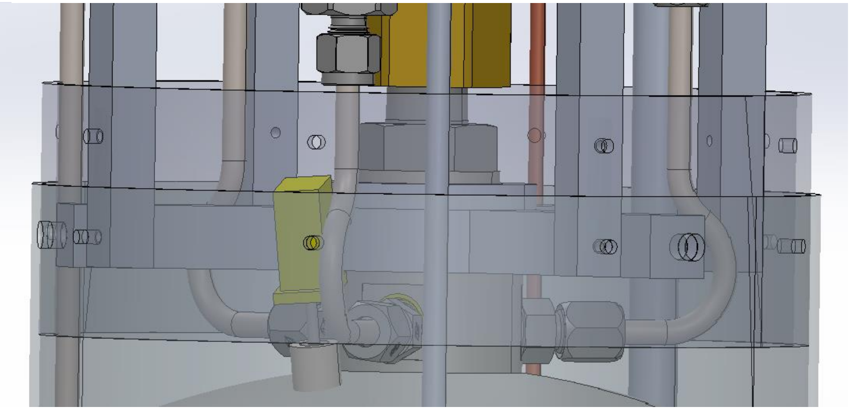
Intertank 2 (IT2)

Changes

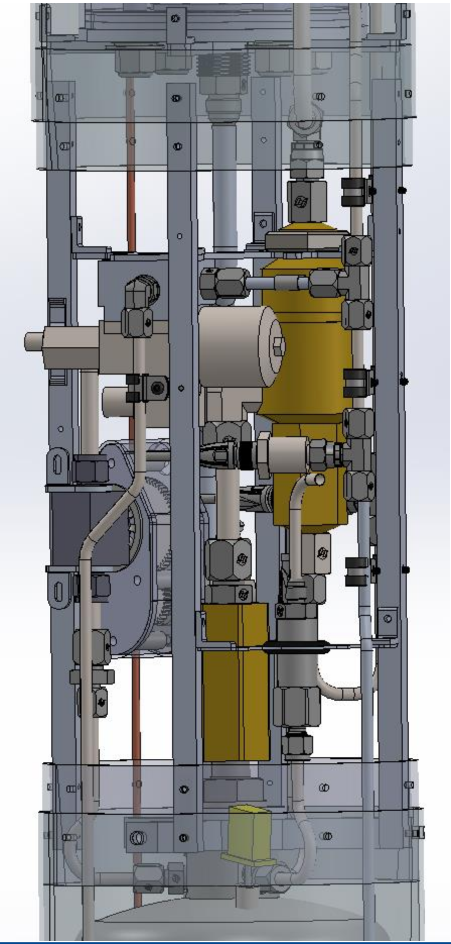
- 4 Stringer Configuration – 1/2 Aluminum Solid Stringers
- Increased Stringer Length to 15.8 in
- Top Coupler moved up to Fuel Tank Bottom Plate
- Bottom Coupler moved down to LOX Tank Plate



Top Coupler



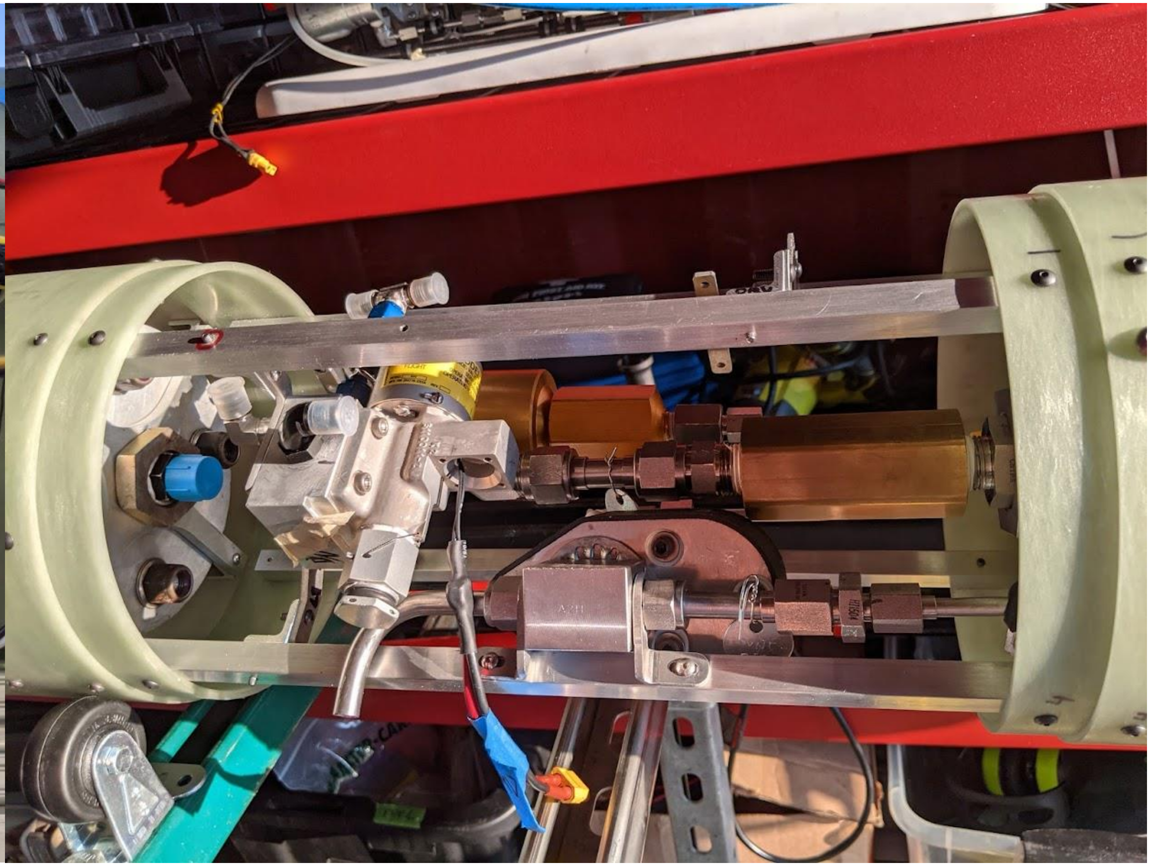
Bottom Coupler



Intertank 2 (IT2)

Before

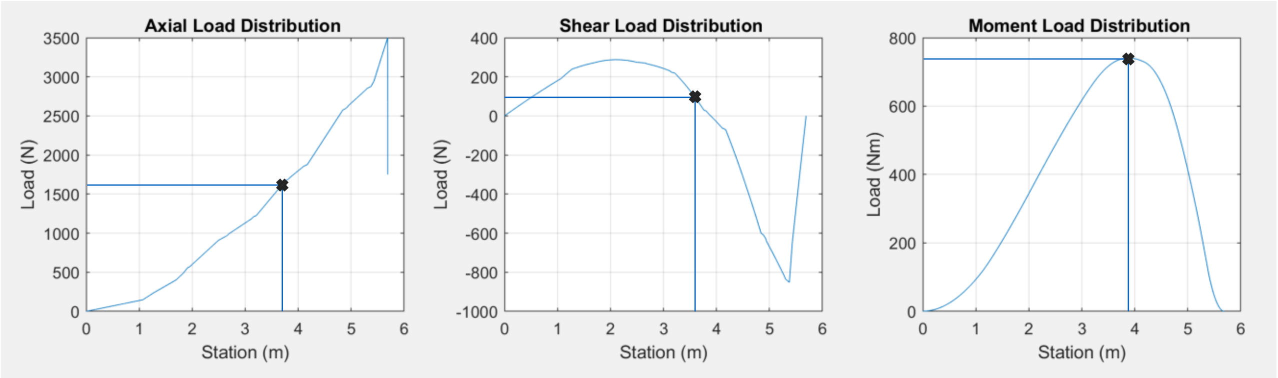
After



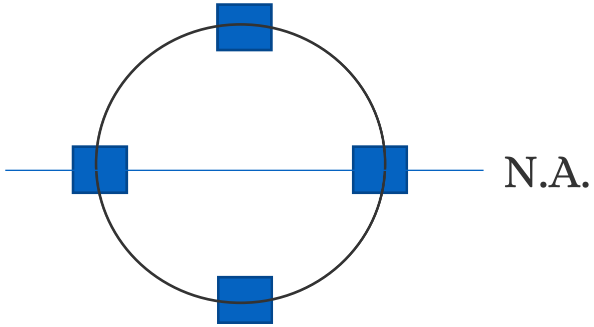
Intertank 2 (IT2)

Calculations

- **Expected loads calculated as:**
  - 740 Nm moment
  - 50 N shear
  - 1600 N axial
- **Loads placed on IT1 stringer configuration & maximum stresses calculated**
  - Assume stringers take all load
  - Assume load constant over IT section
  - Assume N.A. passes thru 2 stringers
  - Axial FOS = 2.4 (Kt = 2.3)
  - Buckling FOS = 20.9 (single stringer)
- **Total stringer mass of 703g**



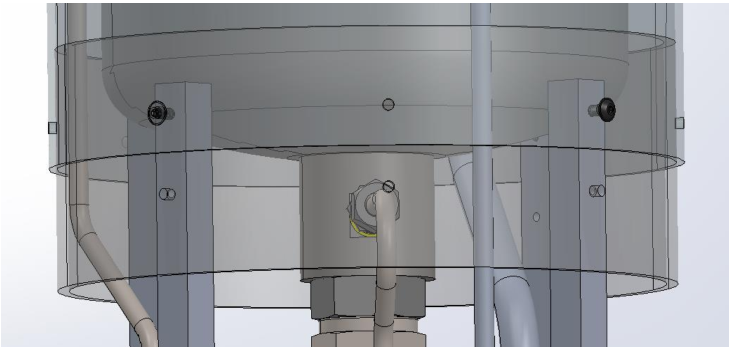
Tension	50.23233595	MPa
Compression	-55.19234587	MPa
Shear	0.002713671	MPa
Bolt Hole Kt	2.3	-
Max Tension	115.5343727	MPa
Max Compression	-126.9423955	MPa
Yield Strength, Tension	276	MPa
Young's Modulus	200	GPa
FS Yield	**2.388899456**	-



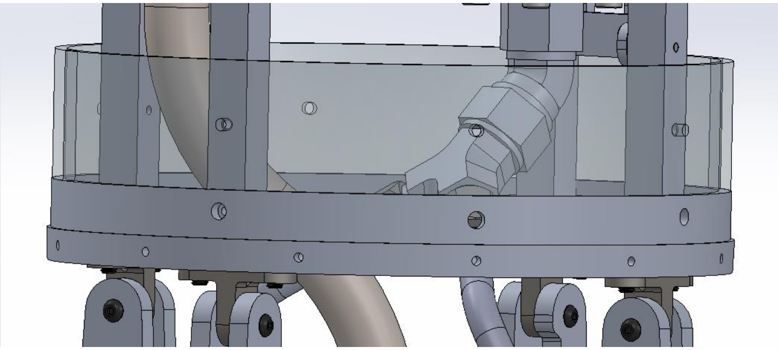
Intertank 3 (IT3)

Changes

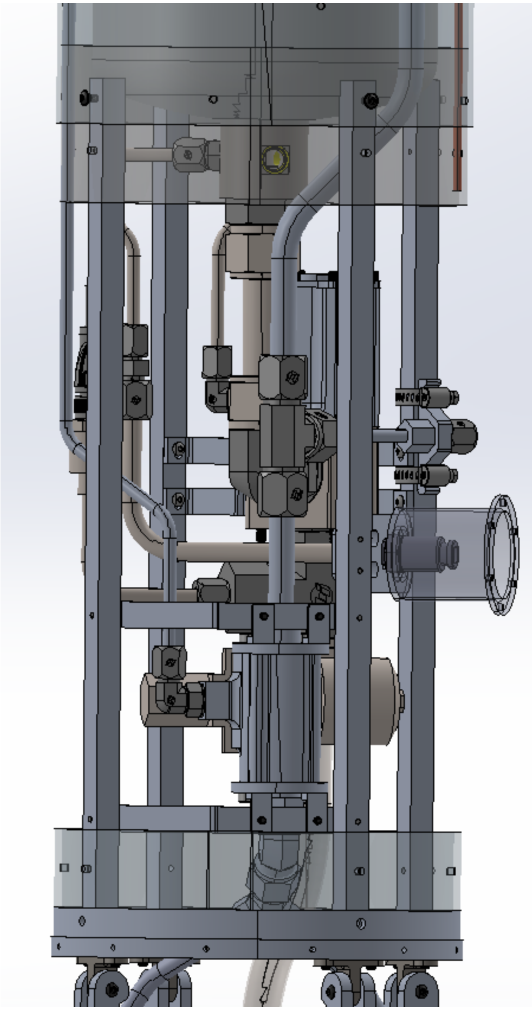
- 4 Stringer Configuration – 1/2 Aluminum Solid Stringers
- Increased Stringer Length to 16.375 in
- Length increase due to added fitting for OIPT
- Top Coupler moved up slightly
- Added Bottom Coupler



Top Coupler

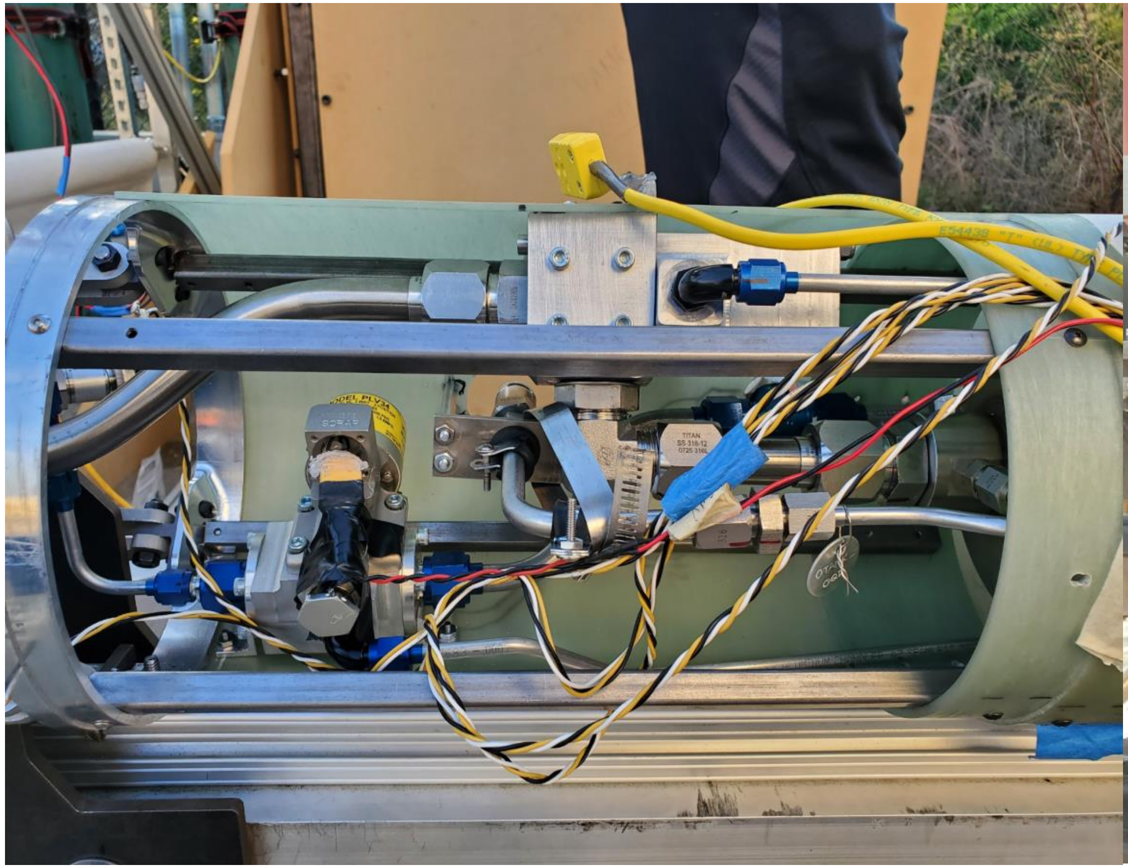


Bottom Coupler



Intertank 3 (IT3)

Before

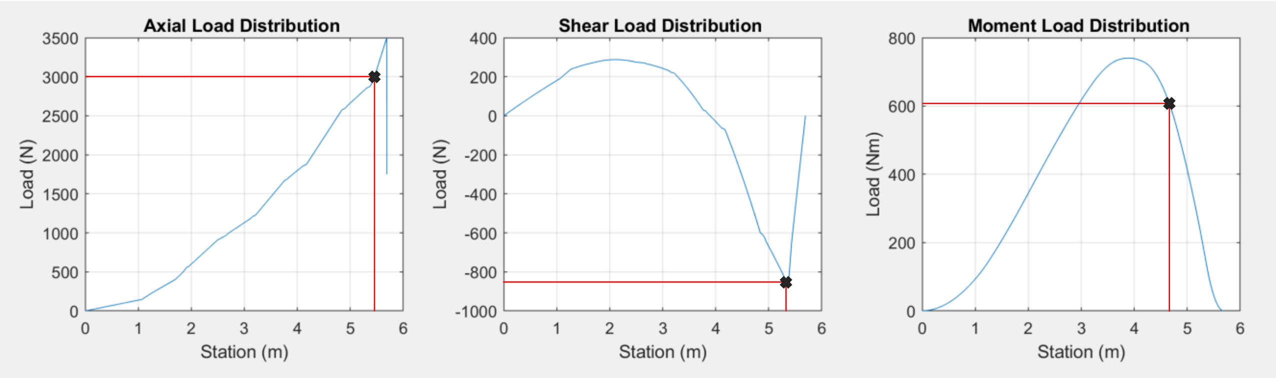


After

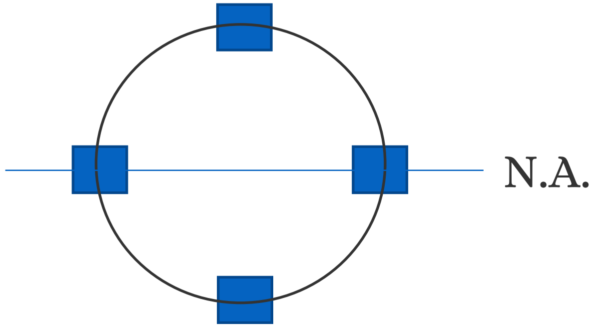
Intertank 3 (IT3)

Calculations

- **Expected loads calculated as:**
  - 631 Nm moment
  - -850 N shear
  - 3000 N axial
- **Loads placed on IT1 stringer configuration & maximum stresses calculated**
  - Assume stringers take all load
  - Assume load constant over IT section
  - Assume N.A. passes thru 2 stringers
  - Axial FOS = 3.0 (Kt = 2.3)
  - Buckling FOS = 10.5 (single stringer)
- **Total stringer mass of 724g**



Stress	Value	Unit
Tension	40.29794626	MPa
Compression	-49.59796486	MPa
Shear	-0.046224668	MPa
Bolt Hole Kt	2.3	-
Max Tension	92.6852764	MPa
Max Compression	-114.0753192	MPa
Yield Strength, Tension	276	MPa
Young's Modulus	200	GPa
FS Yield	**2.977819247**	-

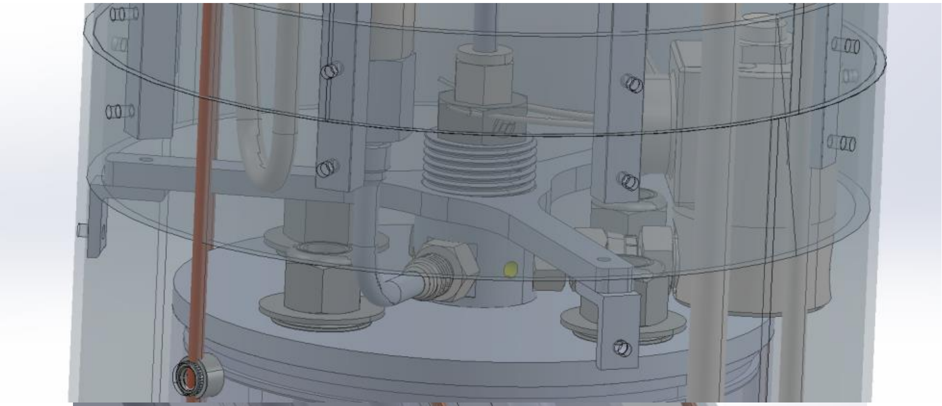


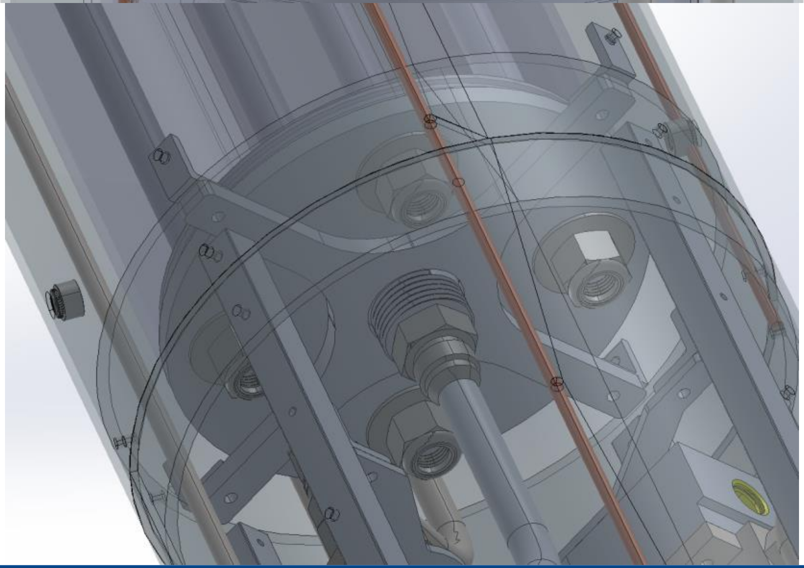
Manufacturing

- Flatness of ends minimized to within 10 thou
  - Slow cut of long airframe on bandsaw regularly gives flat surface within this limit
  - Indicate spindexer to ensure alignment
  - Meticulous edge finding on this flat surface to ensure alignment for couplers
  - Custom V block to ensure alignment for longer airframe
  - Milling of surfaces that are not flat
- Hole clocking within ~0.2 deg
  - Estimate based on spindexer capability
- Simply put, the holes fit
- Rapid iteration of parts

Fuel Tank Plates

- Top Plate
  - Mainly for holding tank concentricity
  - Narrow for wrench clearance to radial ports
  - 3 Spokes to not cover ports
  - Aluminum ¼" Thickness
- Bottom Plate
  - Holds Load
  - 4 Spokes to fit around tank nuts
  - Chamfered ID to fit around weld
  - Aluminum ¼" Thickness

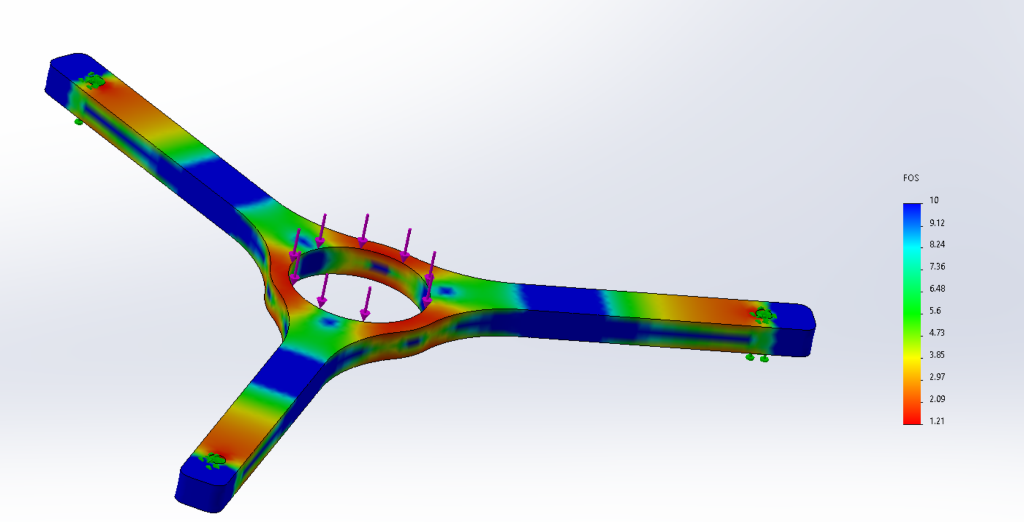


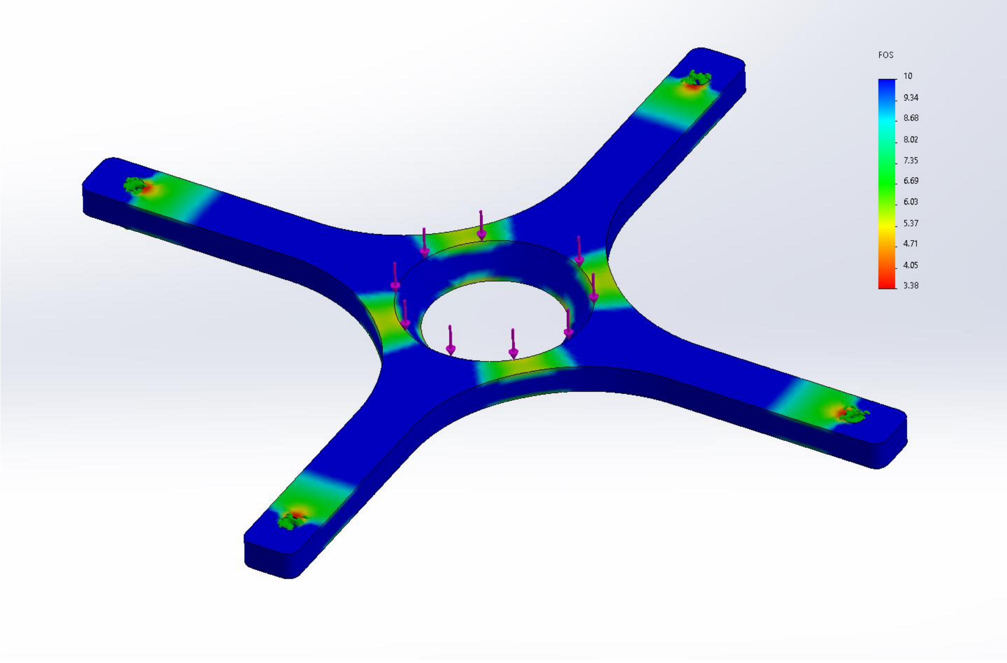


Fuel Tank Plates

FEA

- Top Plate
  - Min FOS: 1.2 (1.7 for SS 316)
  - Yield Stress
- Bottom Plate
  - Min FOS: 3.4





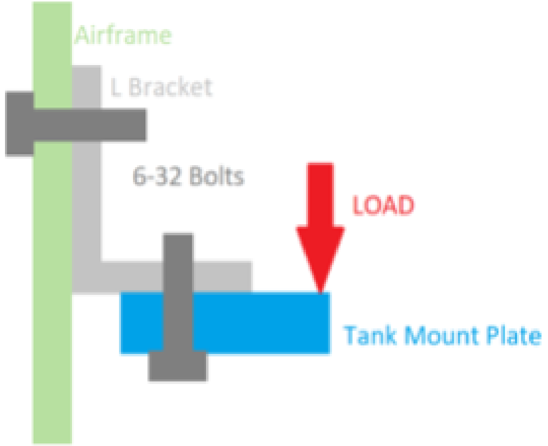
Variable	Value	Units
Acceleration	49	m/s^2
Dry Mass	3	kg
Fuel Mass	6	kg
Wet Mass	9	kg
Force	441	N
Bottom Plate min FOS:	**3.5**	-
Top Plate Min FOS 316 sheet:	**1.2**	-
Top Plate Min FOS AL 6061-T4:	**1.7**	-

Fuel Tank Plate Fasteners

Analysis of 6-32 bolted connections

- Failure Modes of Bolts
  - Tensile yielding
  - Yielding in shear
- All load is assumed to go through only 2 of the four bolts
- Tensile failure is higher because of preload estimate
  - Preload is roughly approximated to be the expected tensie load times 1.35
  - Preload should be higher than expected load to prevent sepearation of surfaces
  - I cannot shear threads by hand with an allen key

Tightening Method	Accuracy
By feel	±35%

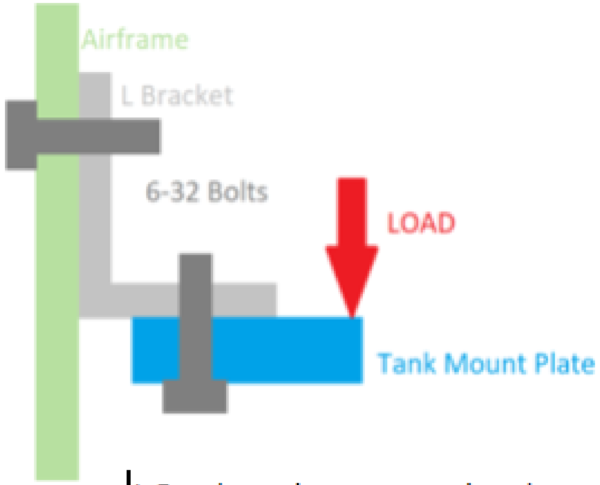


6-32 Minor Diam	0.104	in
Applied Load	49.5703845	lb
Preload	66.92001908	lb
Total Tensile Load in Bolt	116.4904036	lb
AL 6061 Yield Strength	35000	psi
Bolt Tensile Yeild Strength	29732	psi
Bolt Shear Yeild Strength	17839.2	psi
Bolt Cross-sectional Area	0.008494616	in^2
Tensile Stress	13713.43962	psi
FOS Bolt Tensile Yield	**2.168092093**	-
Shear Stress	5835.506219	psi
FOS Bolt Yield in Shear	**3.057009851**	-

Fuel Tank Plate L-Brackets

Analysis of L-bracket connection

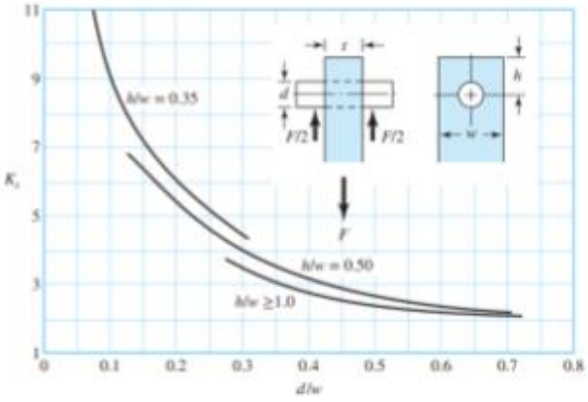
- **Failure Modes of L-Bracket:**
  - Thread shear of aluminum threads
  - Bearing stress on L bracket
    - Pin through hole case
- **Both cases have pretty good FOS**
  - Thread shear could happen if preload is very close to failure though



$$A_{ts.ext} = \frac{5}{8}\pi\, d_{p.ext}\, L_E$$

Figure A–15–12

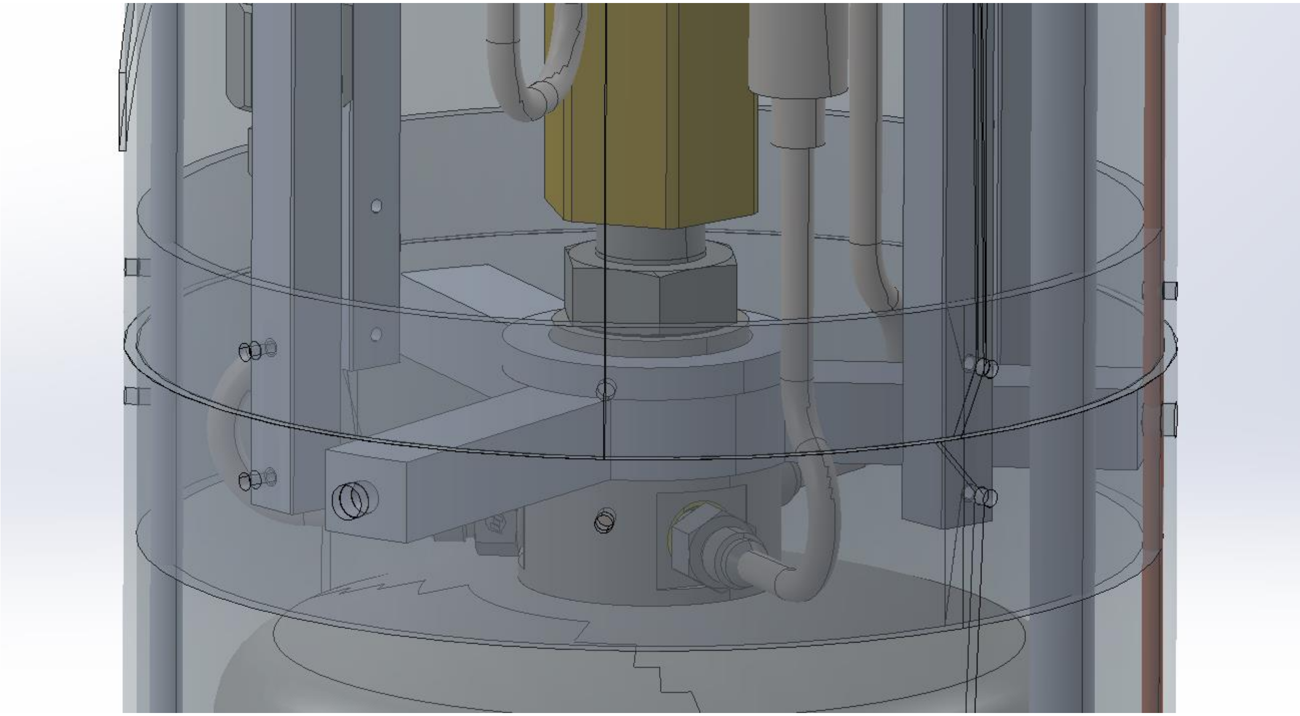
Plate loaded in tension by a pin through a hole. $\sigma_0 = F/A$, where $A = (w - d)t$. When clearance exists, increase K_t 35 to 50 percent. (*M. M. Frocht and H. N. Hill, "Stress-Concentration Factors around a Central Circular Hole in a Plate Loaded through a Pin in Hole," J. Appl. Mechanics, vol. 7, no. 1, March 1940, p. A-5.*)



L Bracket min cross-sectional area	0.0325	in^2
sigma_0	1525.2426	psi
d/w	0.35	-
h/w	0.5	-
Stress concentration factor, K_t	3.5	-
Max stress in L bracket	5338.3491	psi
FOS L Bracket Yield	**6.556334055**	-
Thread engagement length, L_e	0.125	in
External thread shear area, A_ts_ext	0.0255125	in^2
Shear stress, tau_ts_ext	4566.012879	psi
FOS Thread Shear	**3.9069535**	-

LOX Tank Plate

- 3 Spokes and narrow ring to not cover radial ports
- ½" Thickness for radial threaded holes
- Mounted through coupler to allow for more clearance
- ¼" Spacer due to tank threads



LOX Tank Plate

Factors of Safety

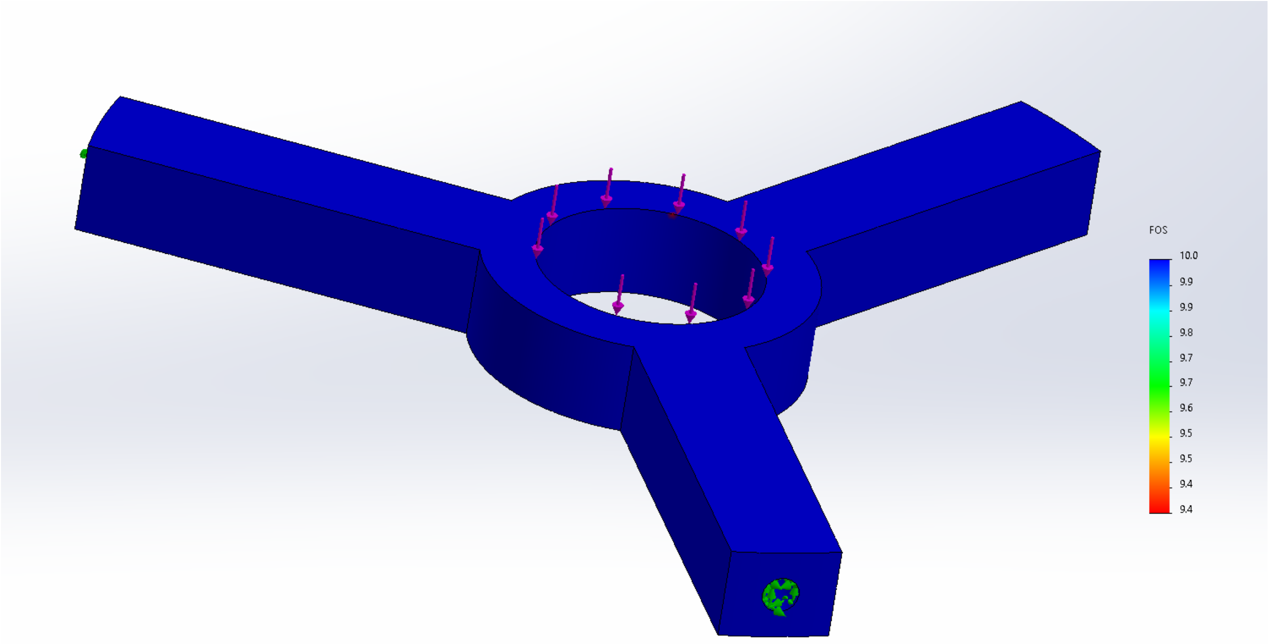
- Min FOS: 9.4

Variable	Value	Units
Acceleration	49	m/s^2
Dry Mass	10	kg
LOX Mass	10.5	kg
Wet Mass	20.5	kg
Force	1004.5	N

- Bolt FOS: 15.4

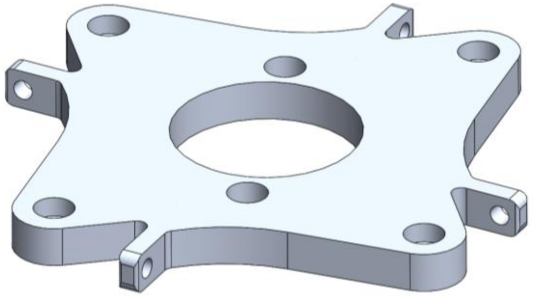
LOX Tank Plate

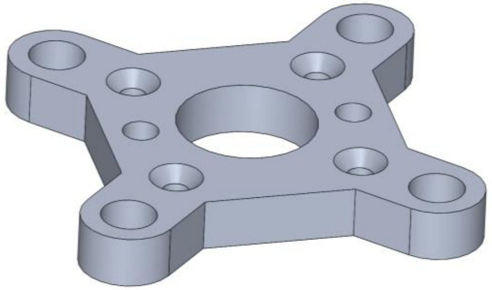
Bolt Calc	Value	Unit	Value2	Unit2
Shear Force	1004.5	N		
Area	0.0276271	in^2	17.8239	mm^2
Number of Bolts	3			
Shear Stress	18.785637	MPa		
Tensile Strength	482.63301	MPa	70000	PSI
Shear Strength	289.57981	MPa		
Bolt FOS	**15.414958**			

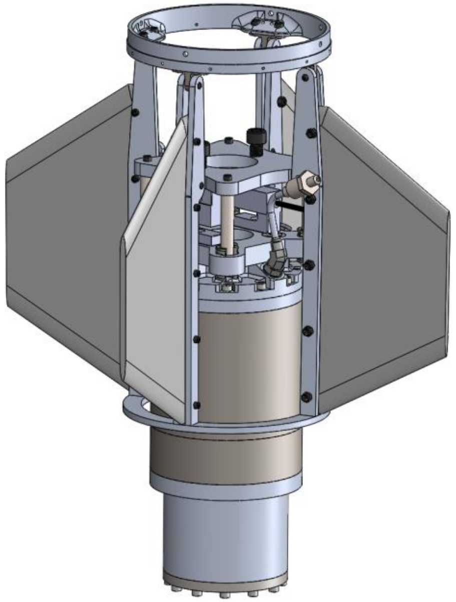


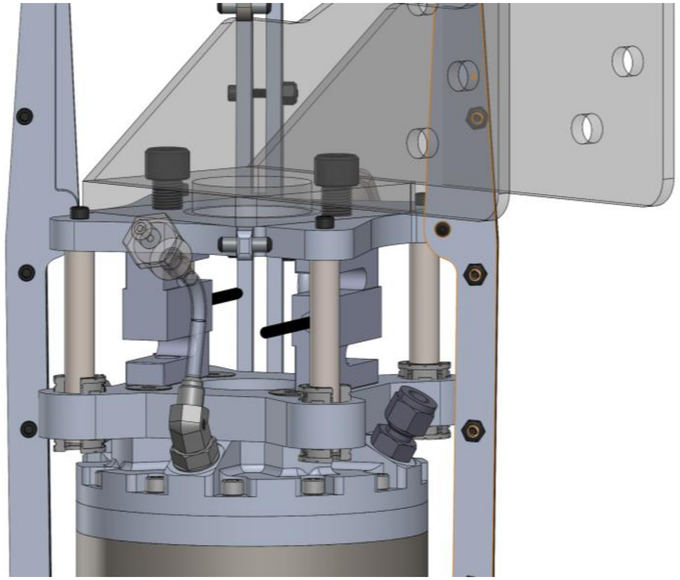
Load Cell Structure

- Thrust structure modified to include load cells for static fire
  - New upper and lower engine plates
  - Load cells mounted between
  - 4 linear guide rails
- Mounting to hold downs kept the same
  - Engine lower down on vehicle
- Changed engine clocking (20 degrees)
  - Fix fuel injector plumbing interference with initial load cell design



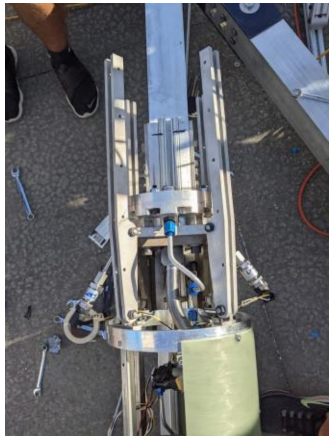






Load Cell Structure Issues

- Wrench Clearance to LOX Inlet on Engine
  - Solution: Custom Wrenches and turning Load Cells
- Assembly Order must be very exact
  - Bolts under load cells
  - Solution: Slot for bottom bolts
  - LCH Rail and Holddown mate



FFS Changes

- PRVNT Replaced with Normally Open Vent
- Fuel Check Valve Added
- Fuel Injector Plumbing changed to reduce pressure drop
- New Mounts (Too Many to Mention Here)
  - IT1
  - Fuel Section
  - IT2
  - LOX Section
  - IT3
  - Engine Section

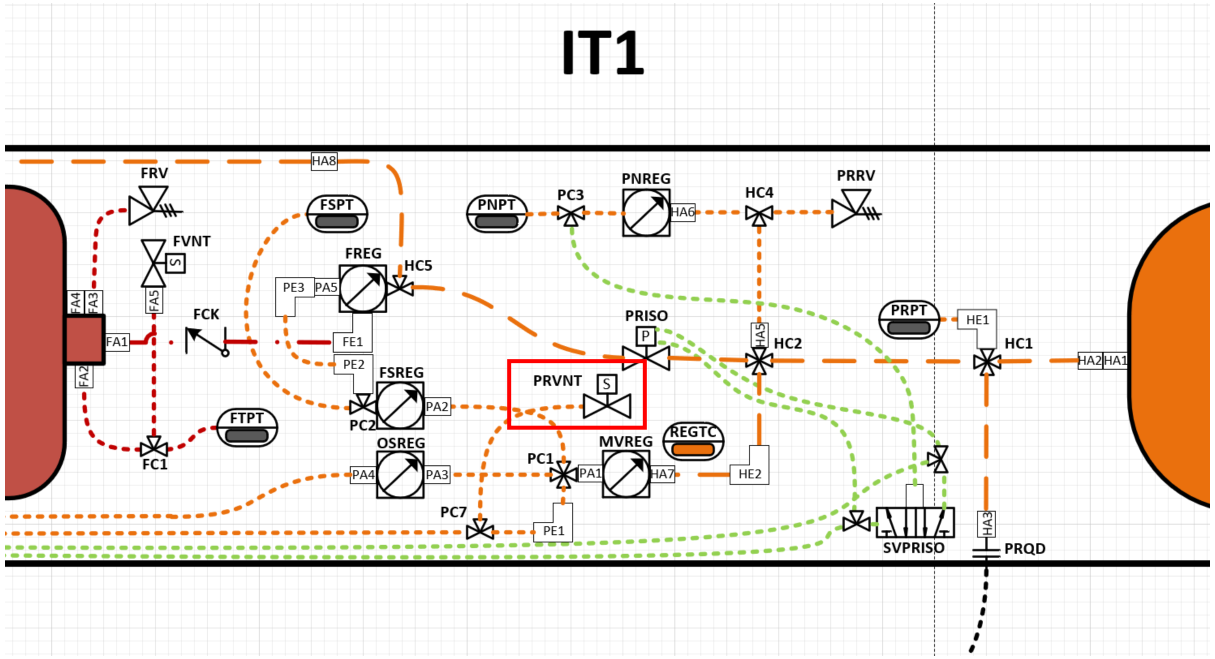
IT1 Changes

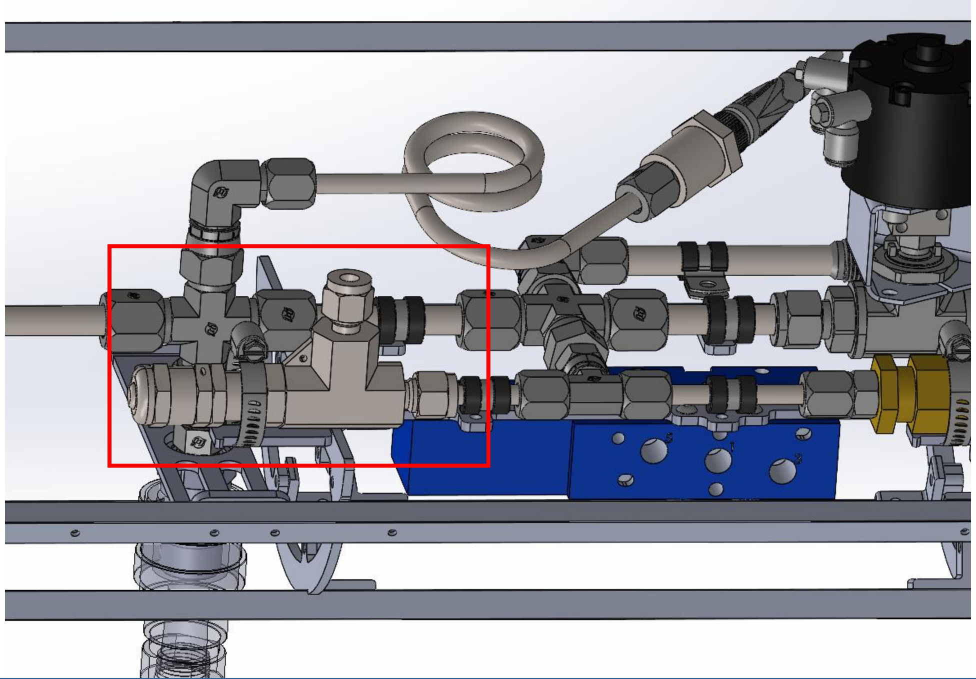
Overview

- Removed PRVNT
- PRVNT-2 Manifold and Mount
- New Maren Plates (Skeleton Mount)
- Umbilical Location
- PRQD Mount
- SVPRISO Mount
- PRISO Push to Connect Fittings
- Fuel Check Valve

Replaced PRVNT

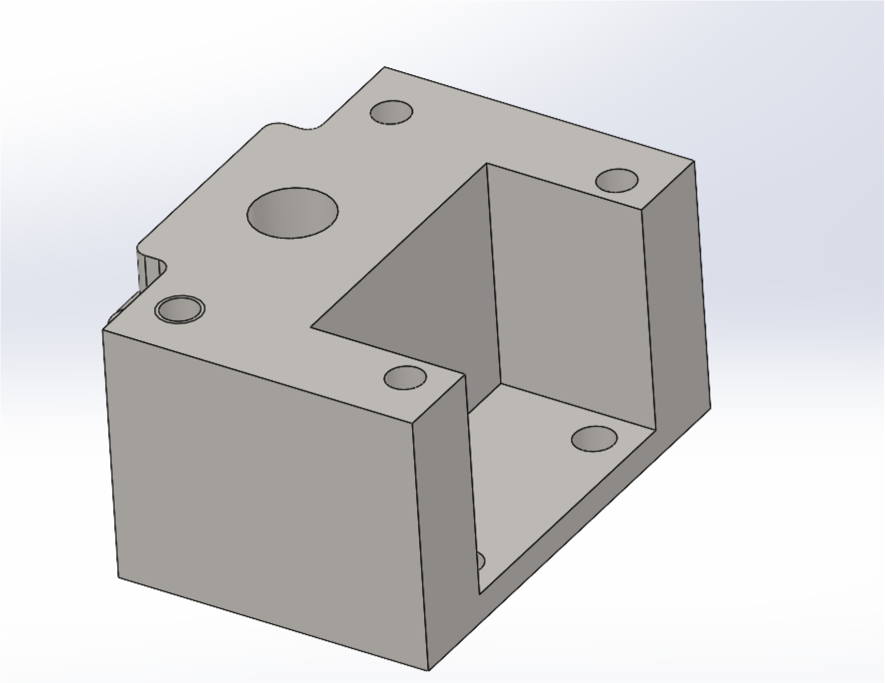
- Replaced PRVNT with a Normally Open Valve (PLV-34)
- Moved it downstream of MVREG (550 PSI)
- Moved PRRV to where PRVNT was





PRVNT-2 Manifold

- Altered manifold to only have vent capabilities
- Bushings modified to use backup rings in case of higher pressures
- Stainless steel or 6061 construction for fitting compatibility
- Theoretical MEOP of 4500 PSI in case of MVREG failure, possible LFS use



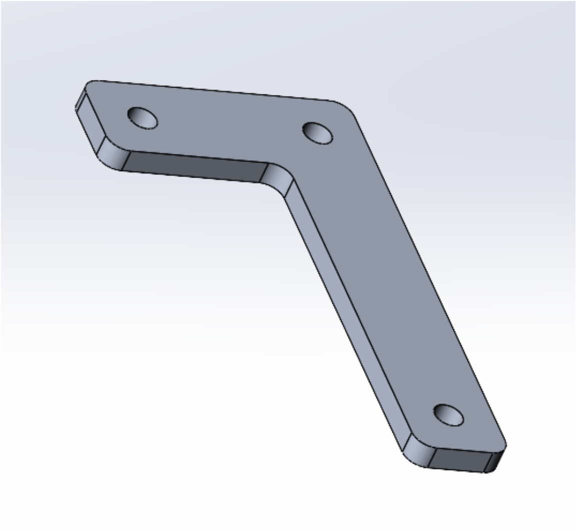
PRVNT-2: Material Choice

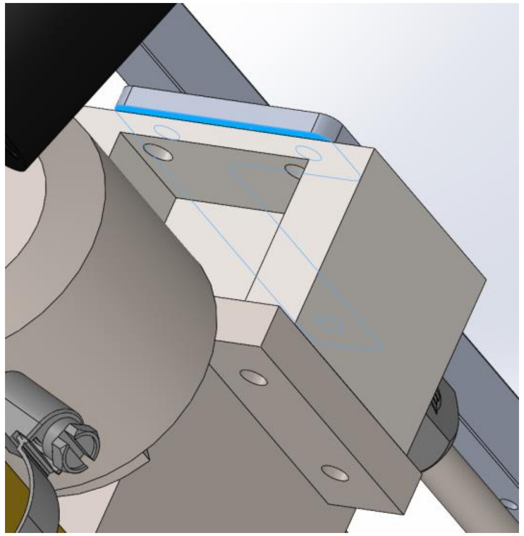
Port Hole	
N2 MEOP (PSI)	5000
Hole Effective OD (in)	0.75
ID	0.56
Effective OR	0.375
Effective IR	0.28
Maximum Hoop Stress (PSI)	17599.43753
Radial Stress	-5000
Axial Stress	6299.718763
Von Mises Stress	19571.68701
FOS - 316 Stainless (Yield)	2.145957065
FOS - 6061 Al Yield	1.926504678

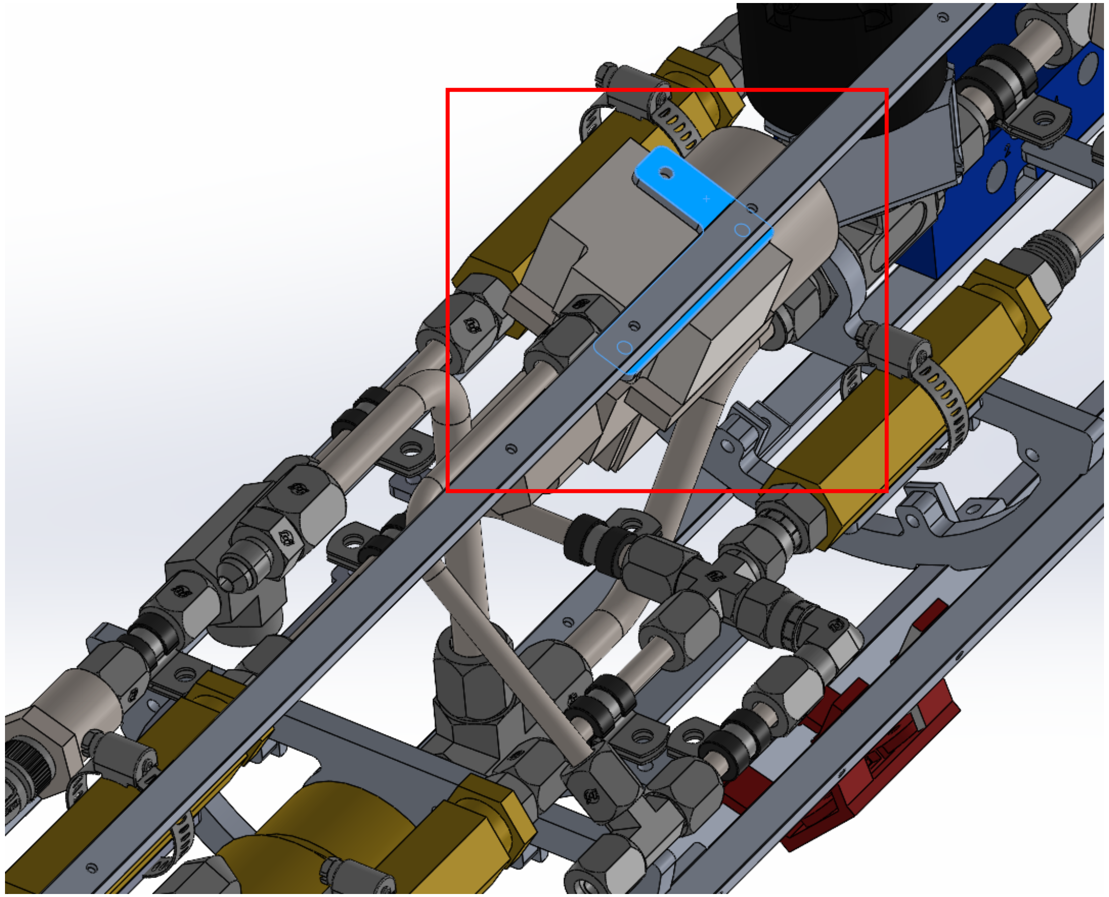
- Stainless steel is 3x denser than 6061 (mass of 0.69lbs vs 0.23lbs)
- In case of regulator failure, stainless steel has slightly higher FOS on yield
- LOX Compatability Issue with Aluminum
    - PRVNT is off of the main line and this is a pneumatics line
- Fitting Compatibility
- Aluminum is easier to machine
- FOS Percent Difference: 10.8%
- Low Risk of Catastrophic Failure:
  Down regulated, no personnel near when at high pressure
- Decision: Aluminum, mass saving and low risk

PRVNT-2 Mount

- 1/8" Aluminum
- Mounted to top stringer
- Two bolts through manifold
- Two bolts into threaded stringer holes

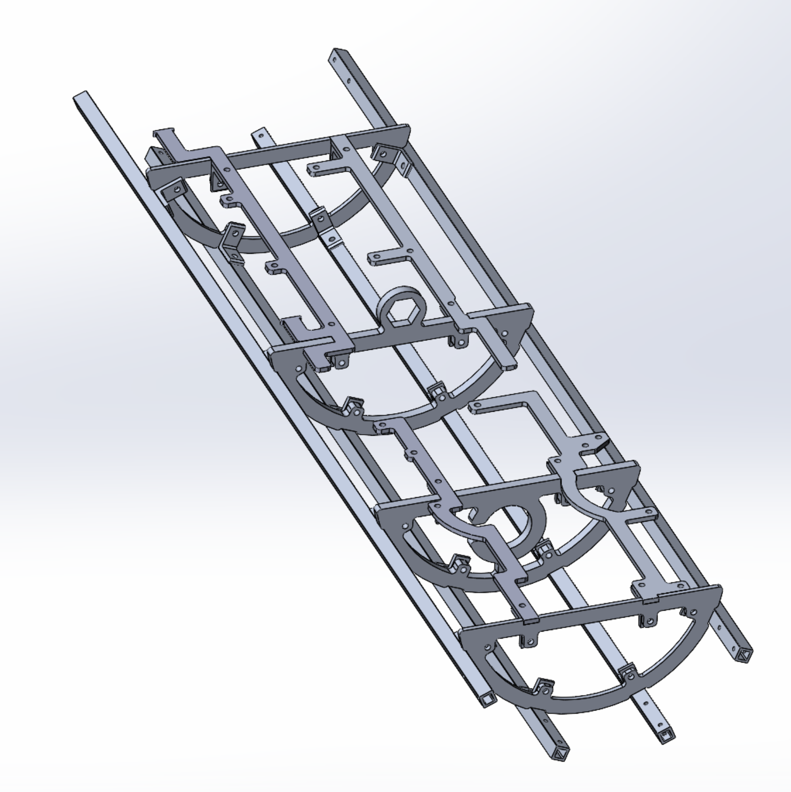


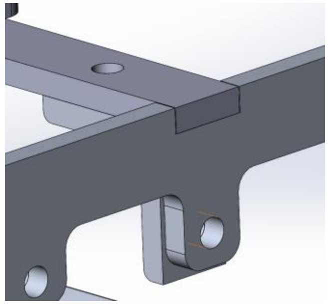


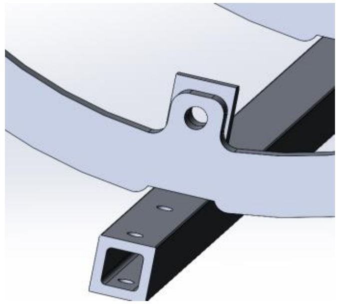


Improved Maren Plates

- 4 Half Circle Plates hold the Vertical Plates
- Two Half Circle Plates still hold PRISO and FREG, 1/4 in aluminum
- Two end plates are 1/8" aluminum
- Grove on top for vertical plates
- Grove where stringers attach (20 thou)
- Slot in FREG Plate for ease of disassembly

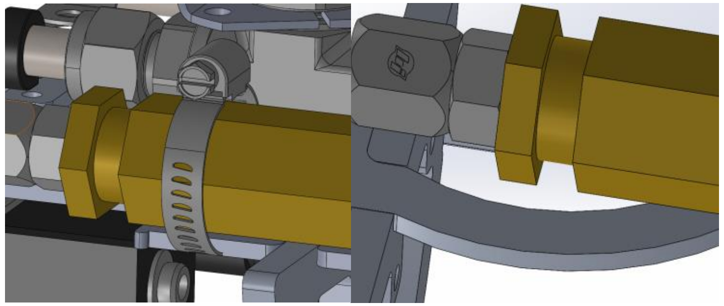


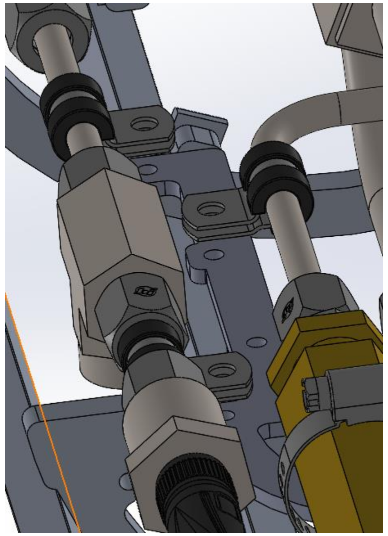


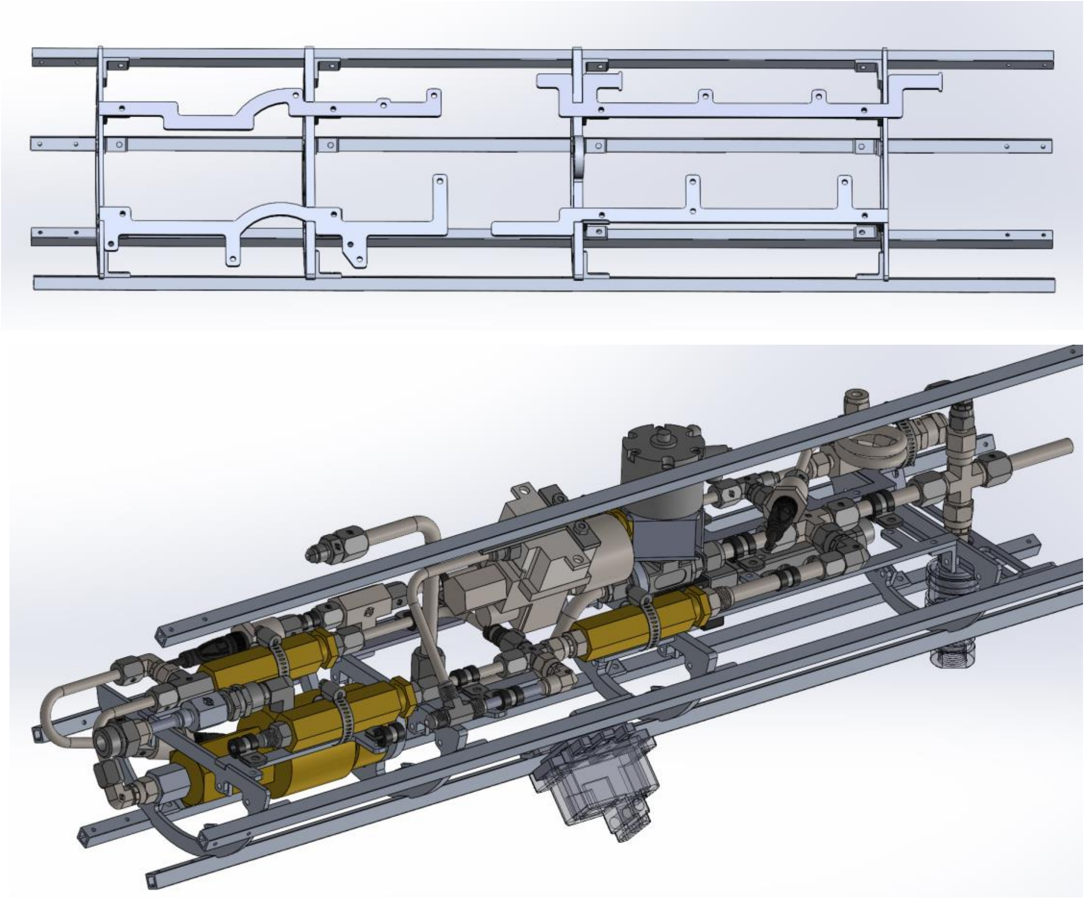


Improved Maren Plates

- 4 Vertical Plates (1/8" Aluminum)
  - Multiple parts for easier assembly / disassembly, less plate stock needed
- Loop clamp holes for mounting lines
- Hose clamp around plate and components
- Room under regs for rotating



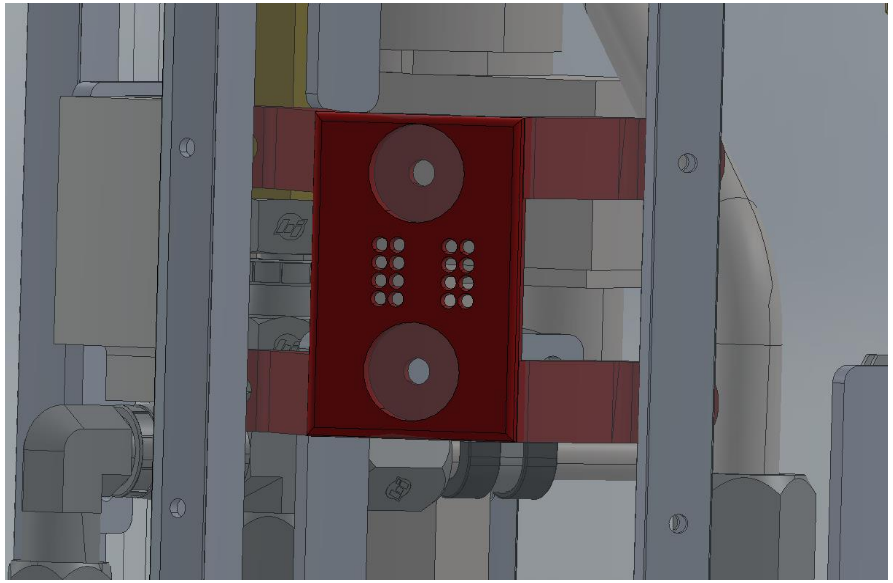


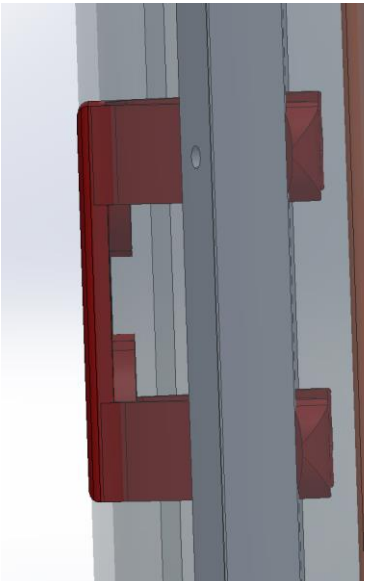


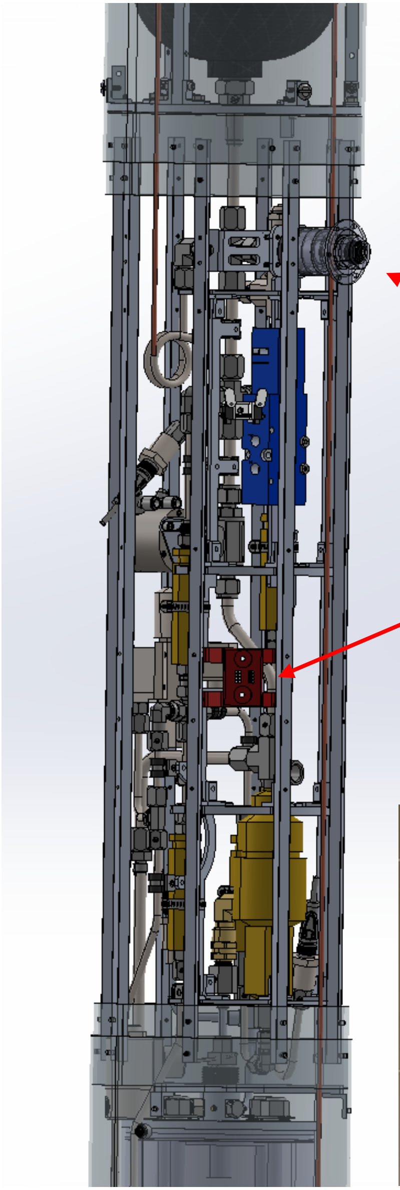
Umbilical

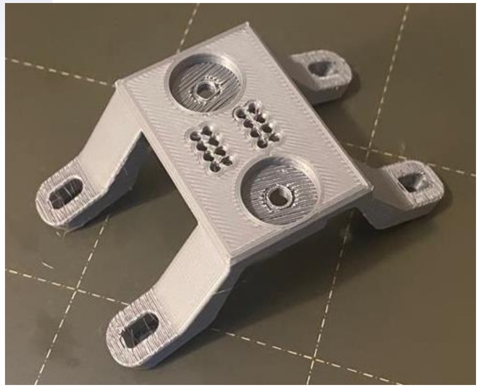
Vehicle Side Mount

- Mounts to stringers so that clam shells are not needed for testing
- Removed tabs for easier slide off disconnect
- 45 degrees left of PRQD





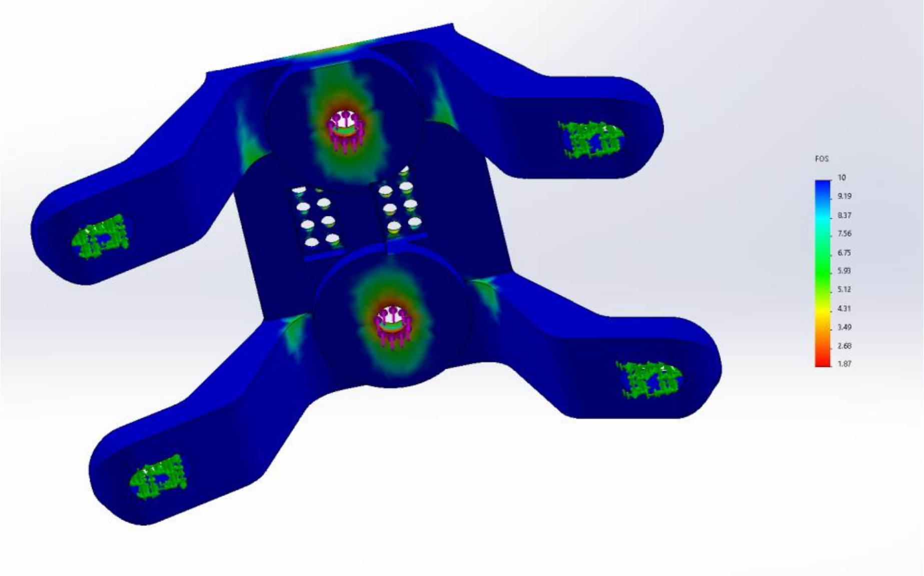


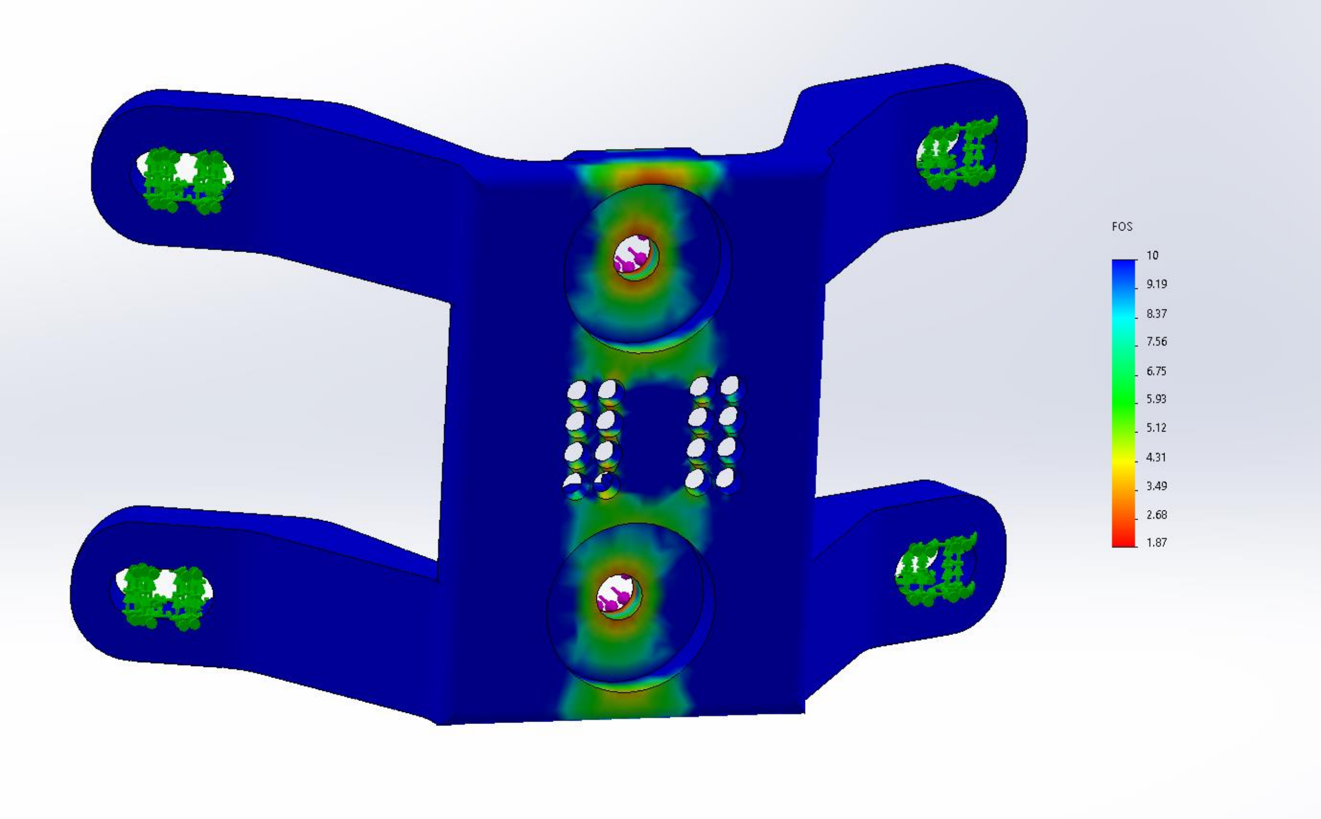


Umbilical

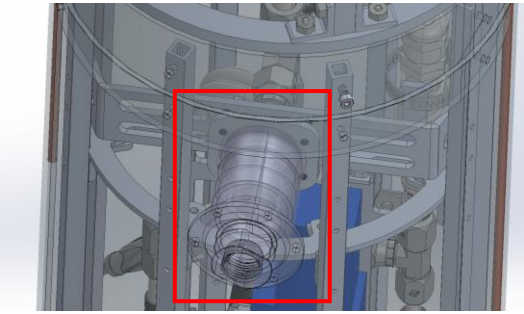
Vehicle Side Mount

- FEA:
  - Yeild Strength of PLA: 26 MPa
  - Force of 20 lbs / 90 N
  - Min FOS: 1.9

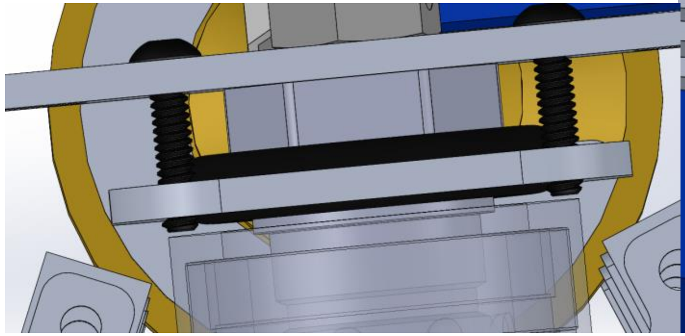


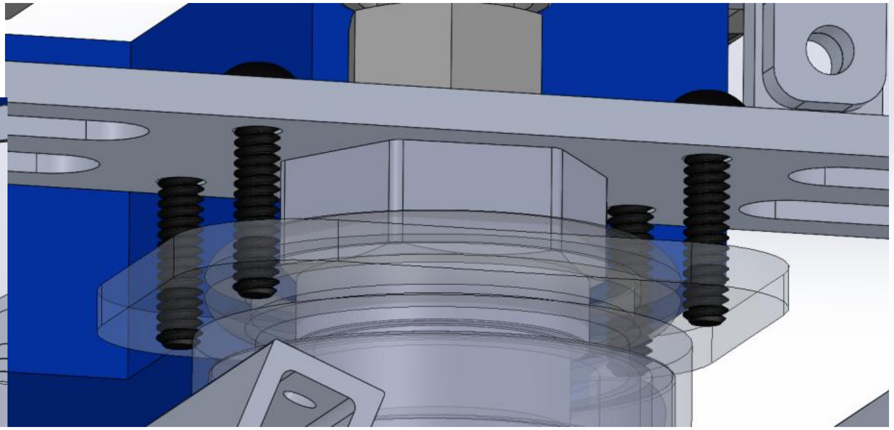


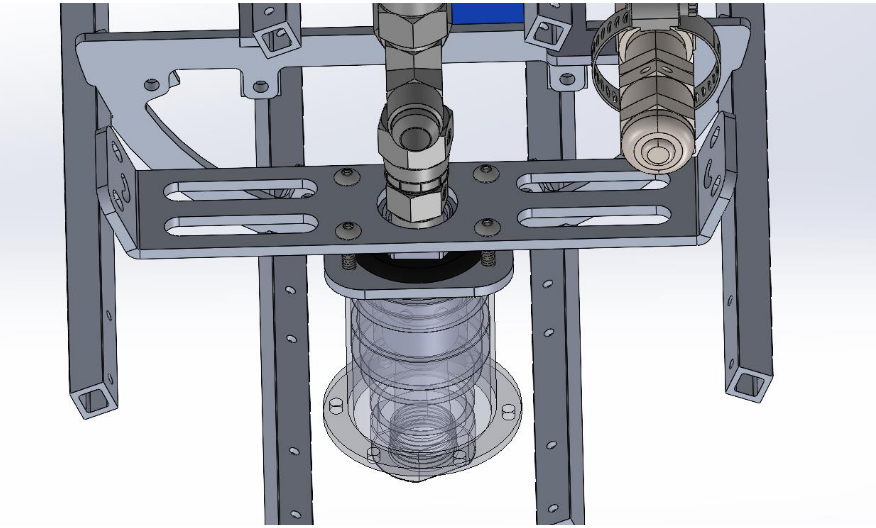
PRQD Mount



- Bent 1/8" Aluminum
- Attaches to two stringers with slots for
- Two plates clamp onto each side of the hex part of PRQD
- Rubber grommet holds bottom of hex
- Threaded bottom plate for shroud clearance



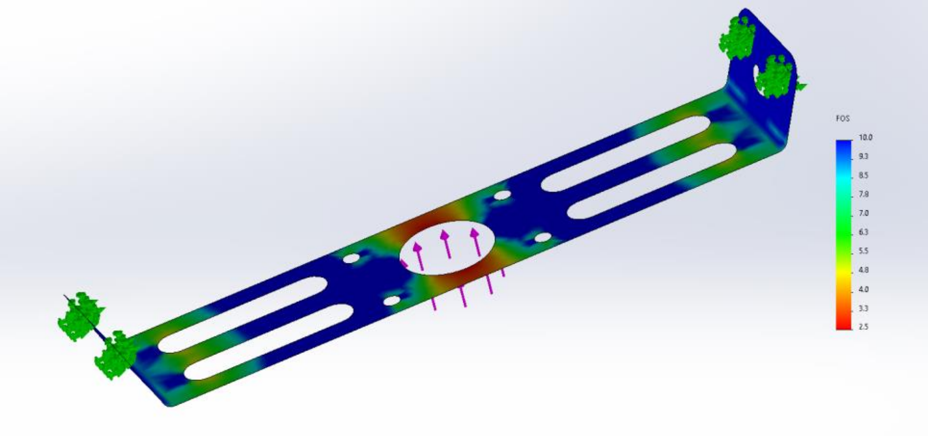


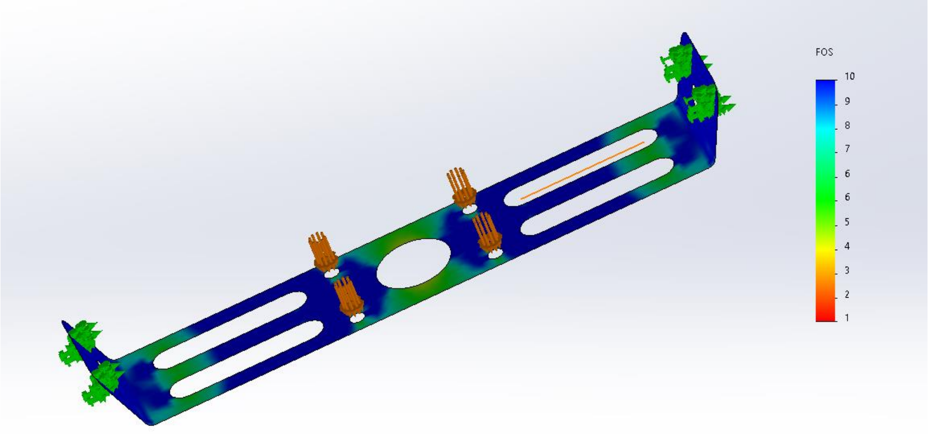


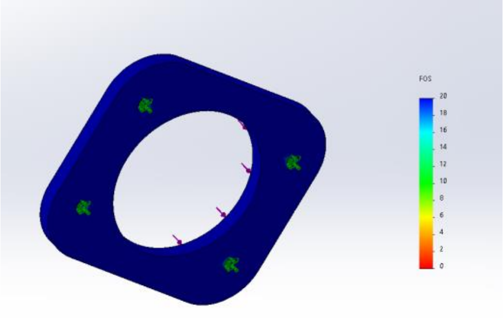
PRQD Mount

FEA

- Top Plate
  - Force: 20 lbs / 90 N
  - Attach
    - Min FOS: 2.5
  - Detach
    - Min FOS: 4
- Bottom Plate
  - Force: 20 lbs / 90 N
  - Detached
  - Min FOS: 14
- Bottom plate threads experience 5X less load than fuel tank L Bracket threads, so we're good on thread shear

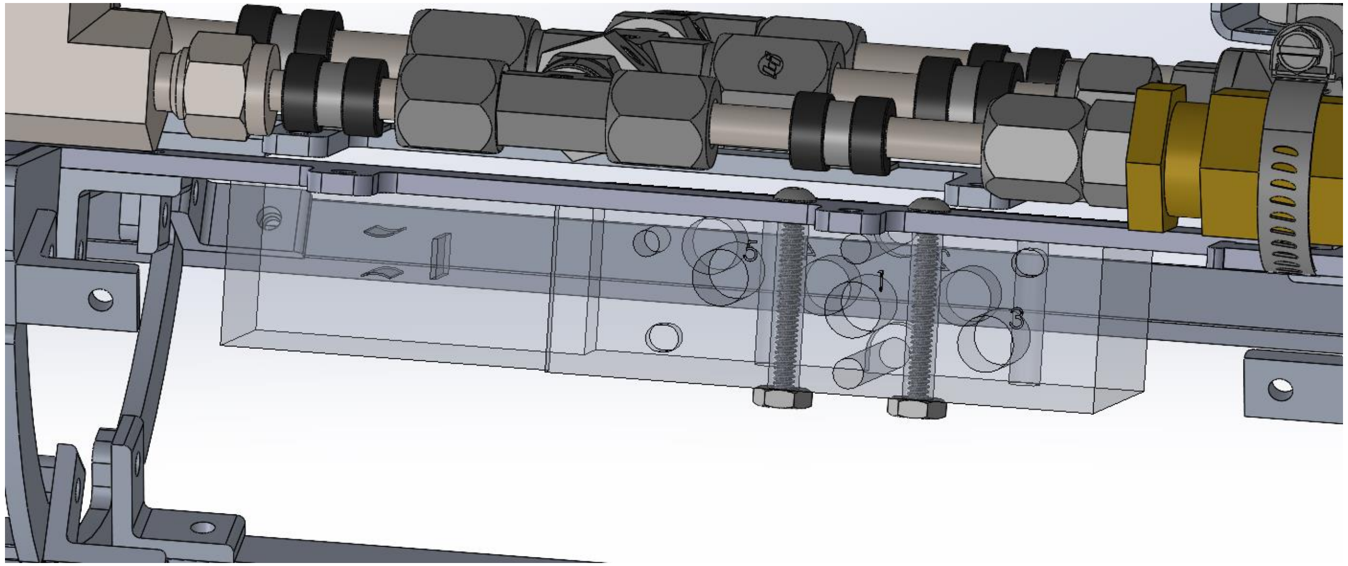
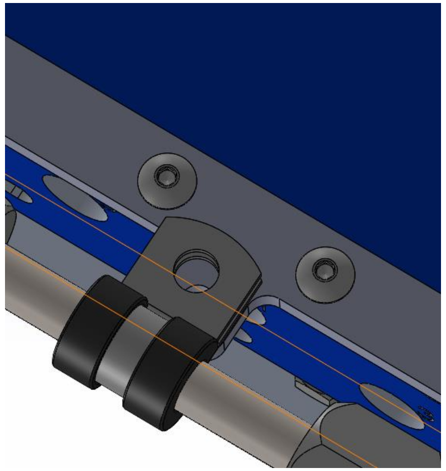






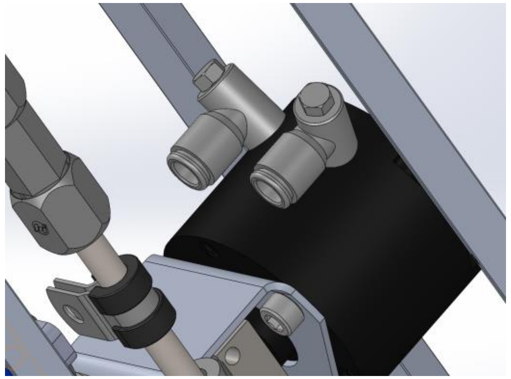
SVPRISO Mount

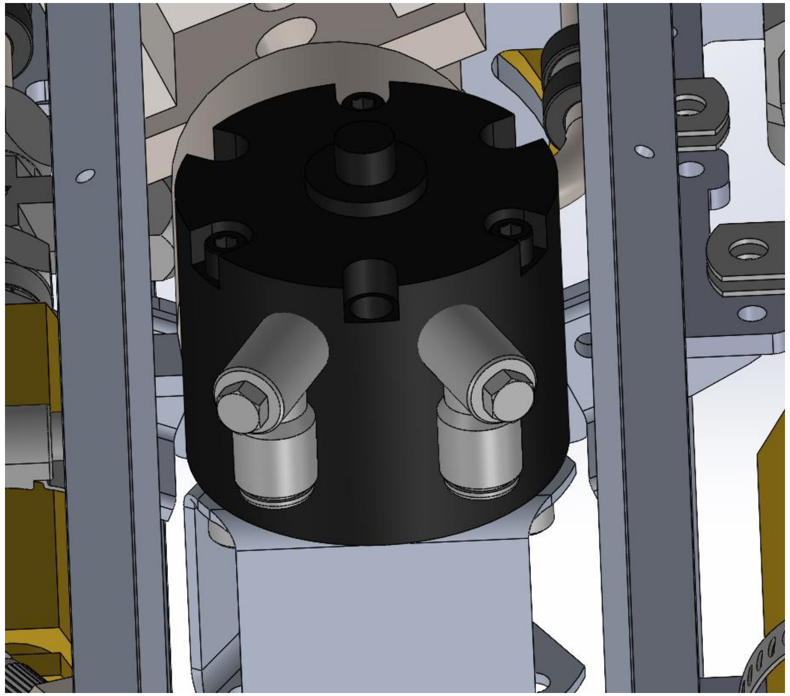
- Mounted to Maren Plates via two long bolts
- Simple for easy assembly/disassembly

PRISO Clearance

- Using Push-To-Connect Fittings
  - 10-32 UNF to ¼ Tube
  - 290 PSI MOP
  - 100 PSI MEOP
  - 2.9 FOS
  - 0.3 in clearance

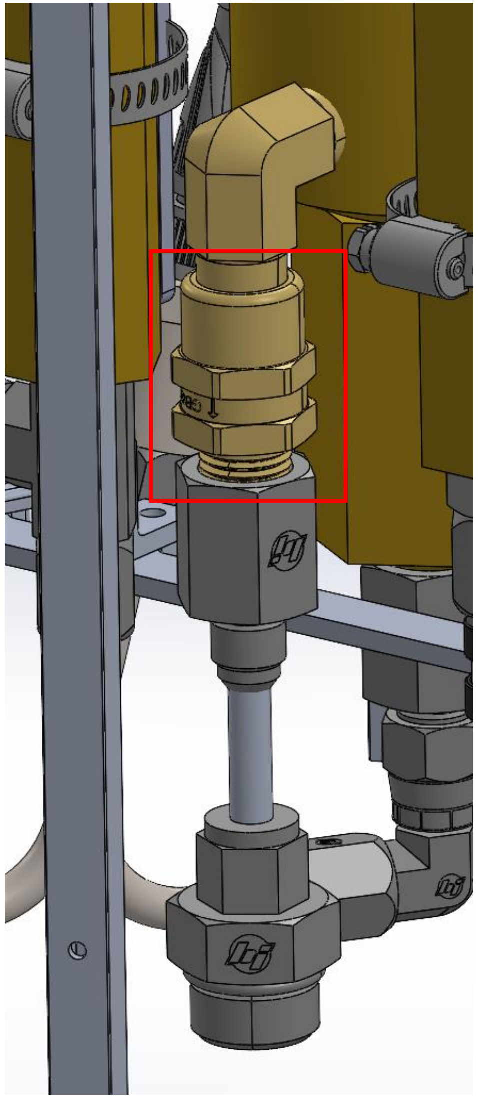




Fuel Check Valve

FCK

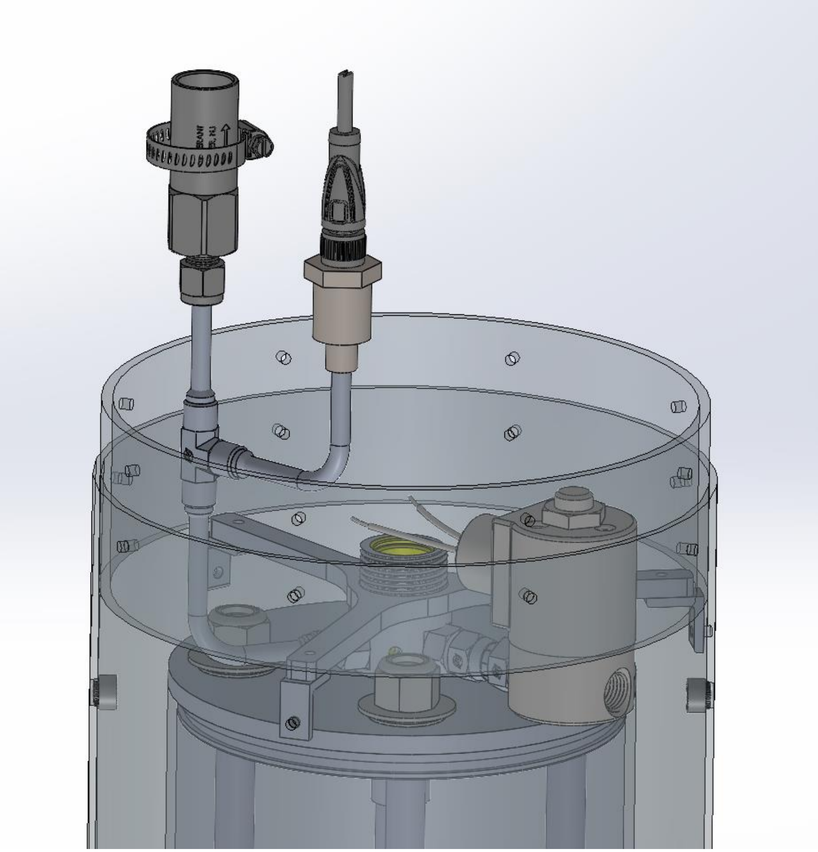
- Very small to keep the reg to tank distance the same
- MNPT Elbow, FNPT-MNPT Check Valve, FNPT-MAN, Swage-ORB
- MOP 500 PSI
- Issue: May need to increase tank pressure above 500 PSI due to pressure drop
    - Possible Solution: Very cheap so we bought two and can proof test one to 700 PSI



Fuel Section Changes

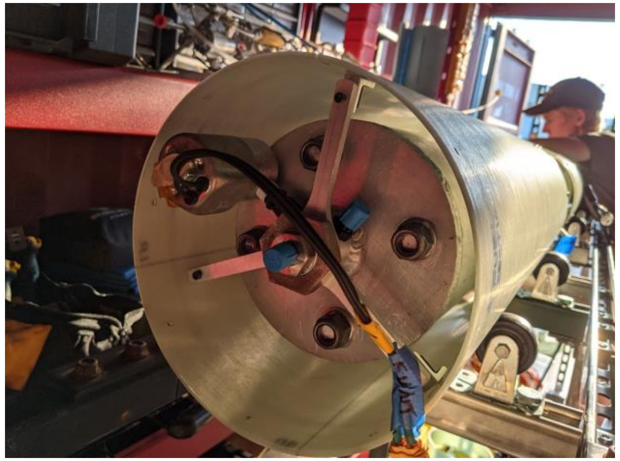
Overview

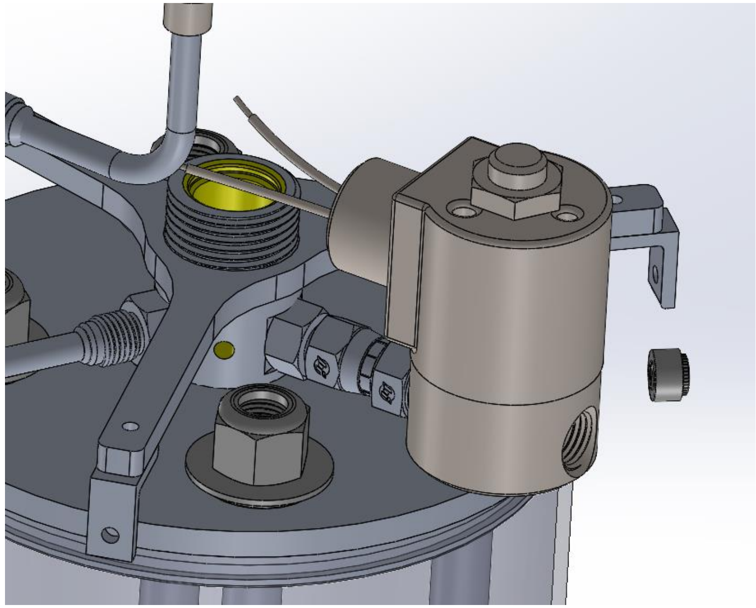
- FVNT and FRV are a part of the Fuel Node
- FVNT Directly on Tank
- FRV Mount
- Fuel Tank Port Clearance



FVNT

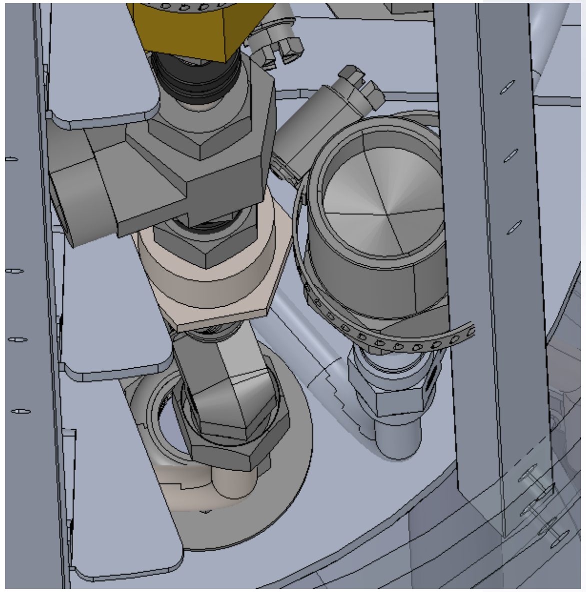
- Directly on fuel tank
- 04 ORB – 04 MAN to 04 FAN – 04 MNPT
- IRL there is a small gap between the bottom of the valve and tank
- Issue: FVNT (NO) gets really hot when closed (powered)

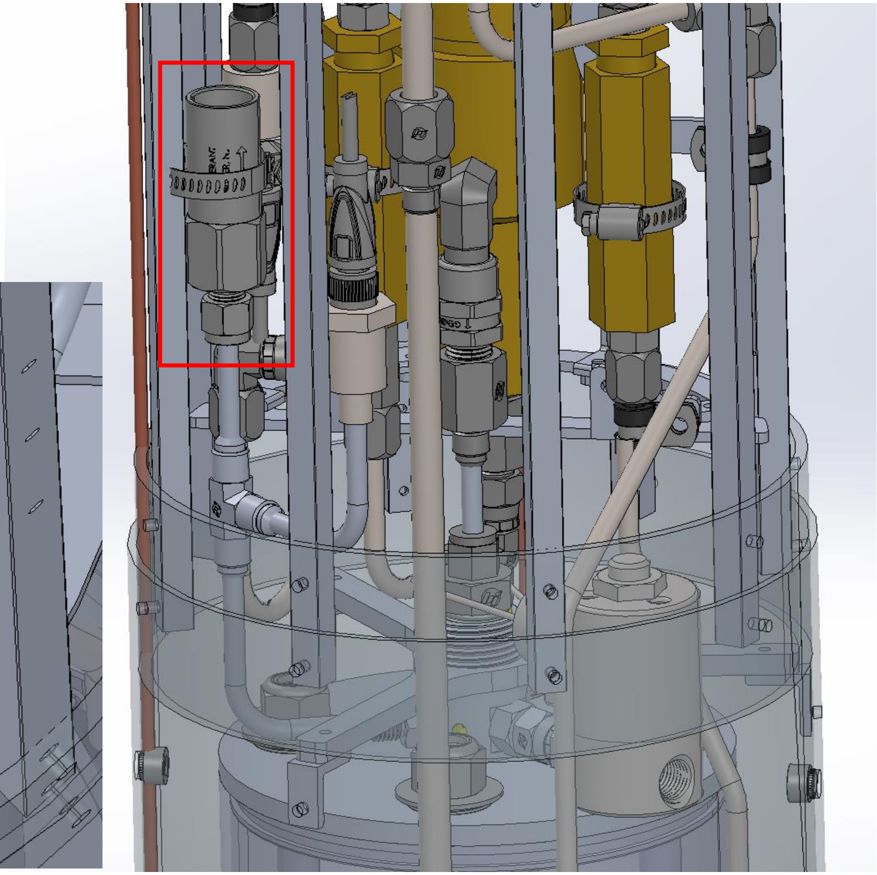




FRV

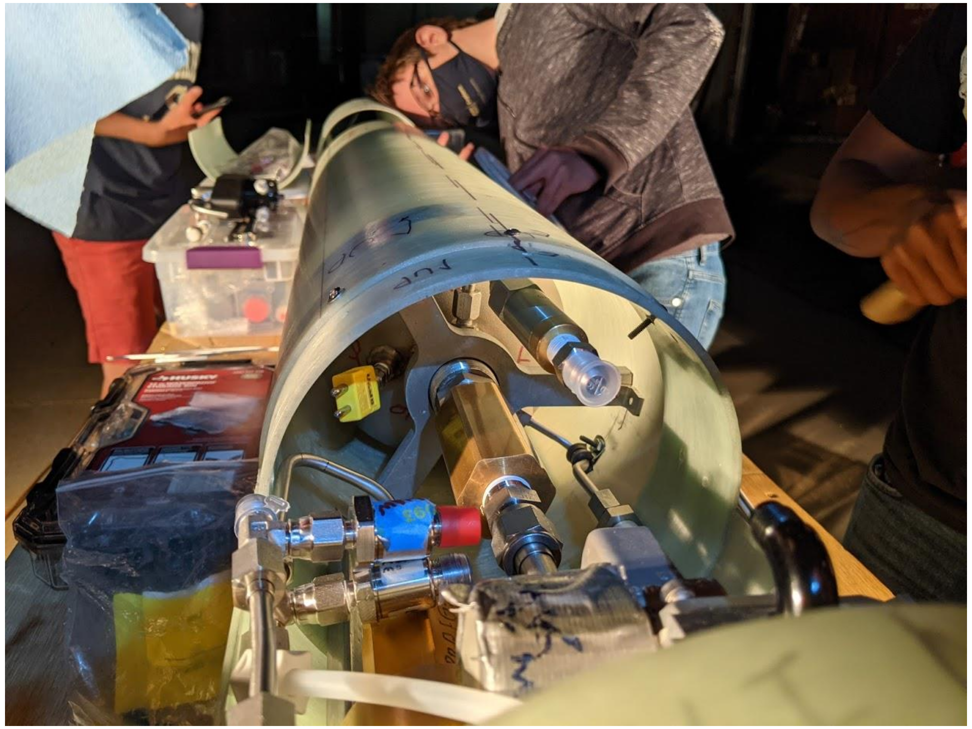
- Hose clamped to stringer
- Close to PNPT
  - But its going to be close to something no matter what





IT2 Changes
Overview

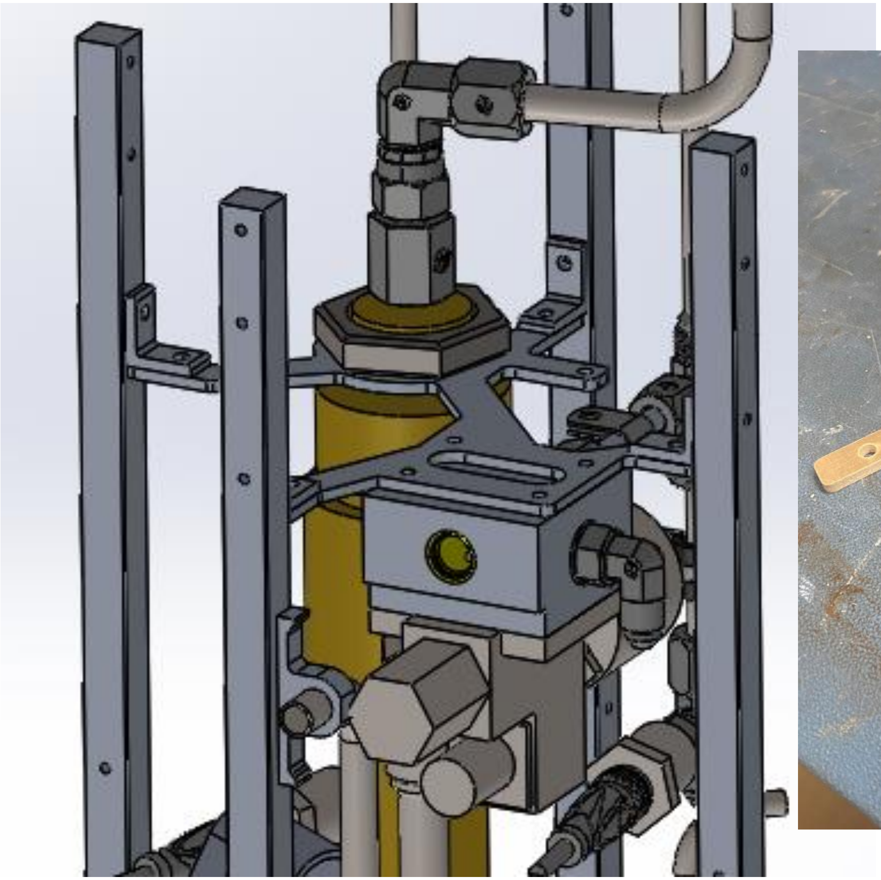
- SVOMV/OREG Plate
- OVNT Mount and Push to Connect Fittings
- ORV Mount
- Long Line Mounts



SVOMV/OREG Plate

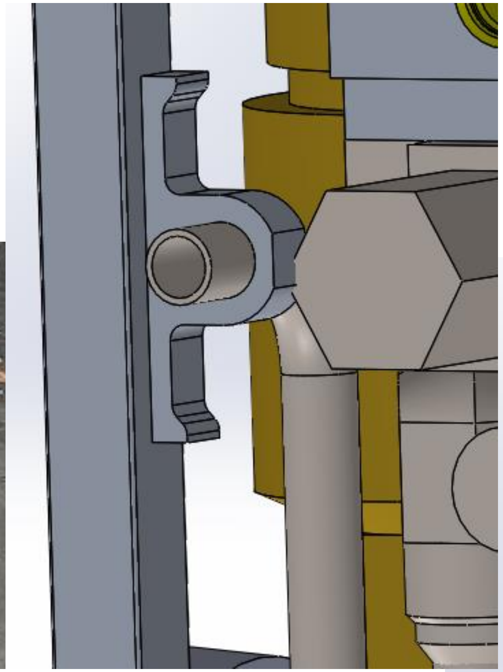
IT2 Main Plate

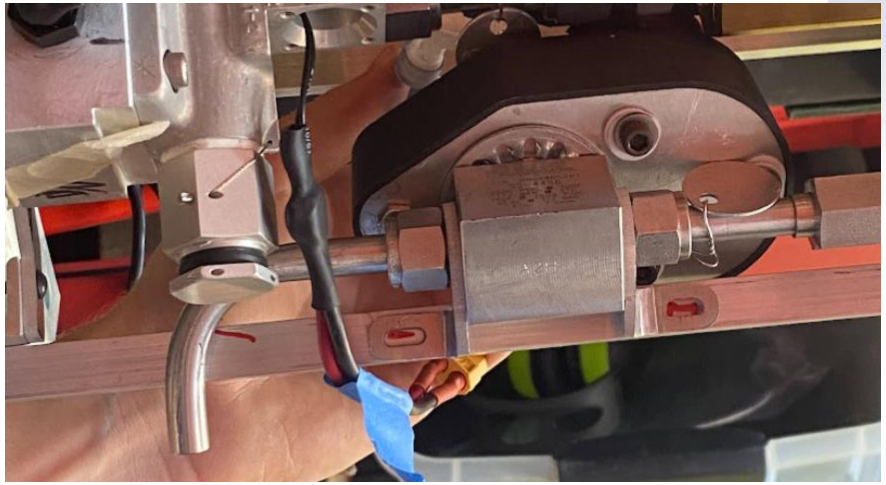
- Provides rigidity
- Keeps components within airframe
- 1/8" aluminum plate

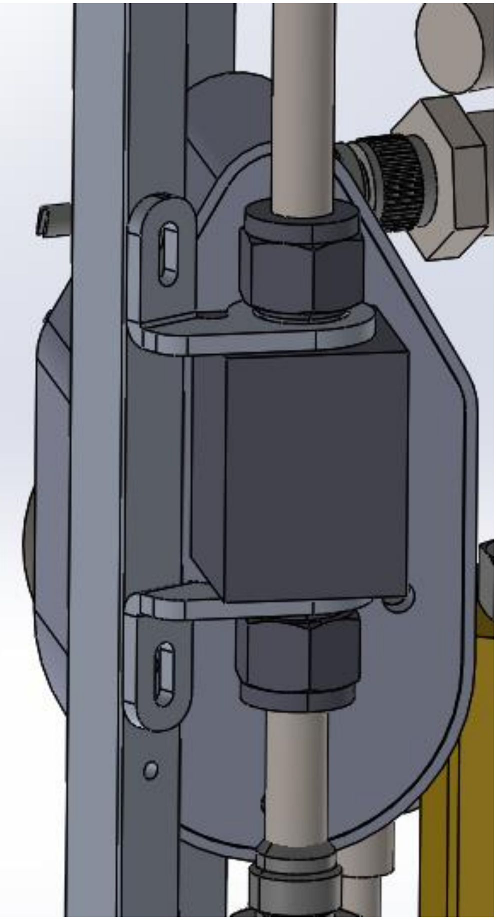


OVNT Mounting

- Provides rigidity
- Bent 1/8" aluminum
- Slots for slop
- Will try to pipe clamp outlet line, but may need to make a custom part if not solid

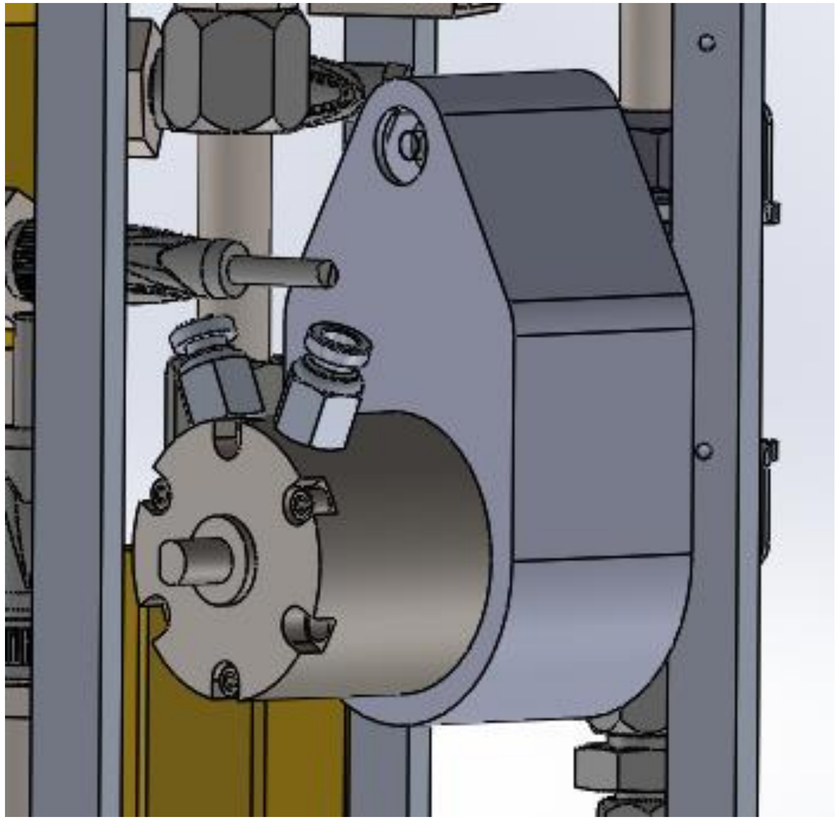




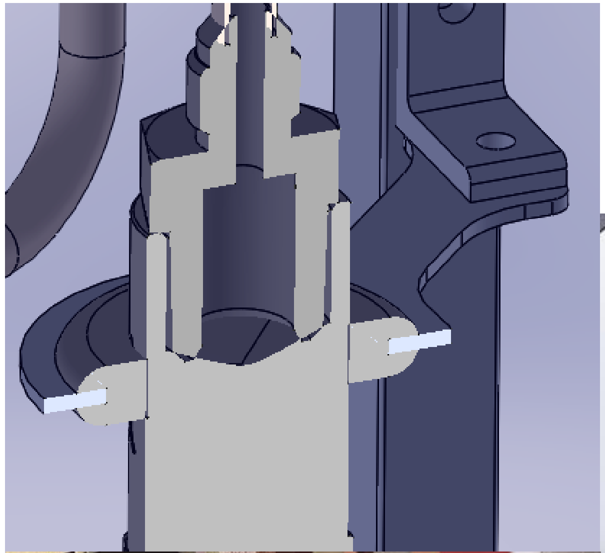


OVNT Push to Connect

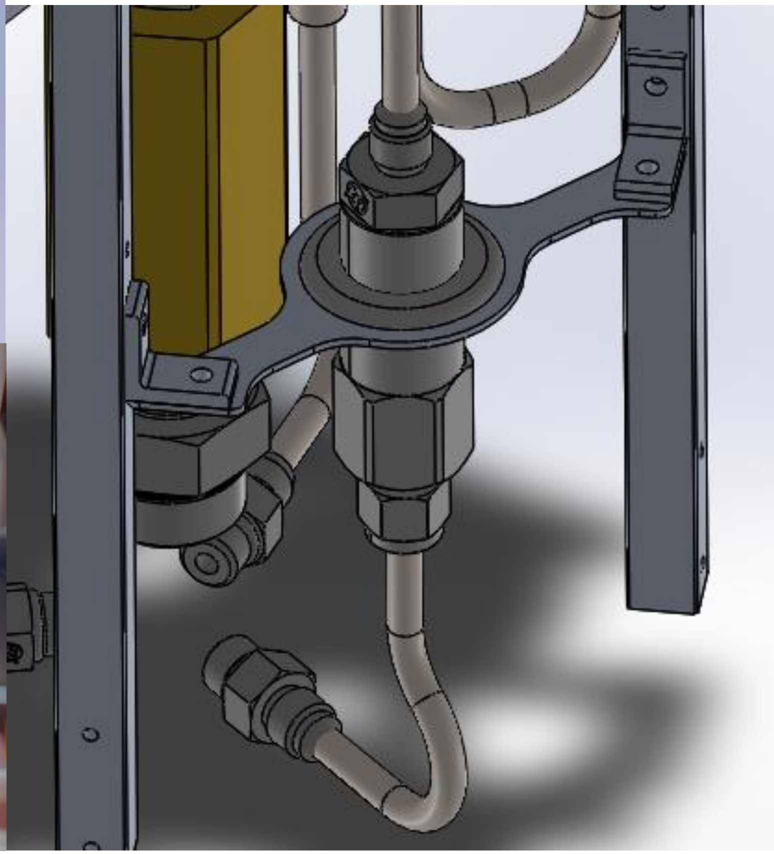
- Better Clearance
- MOP: 290 psi

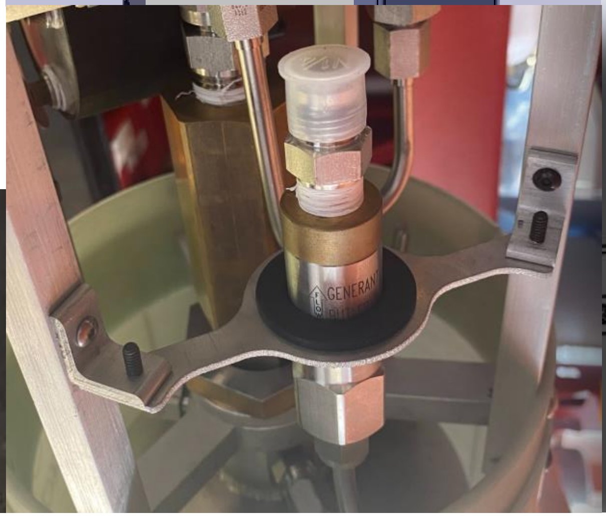


ORV Mount

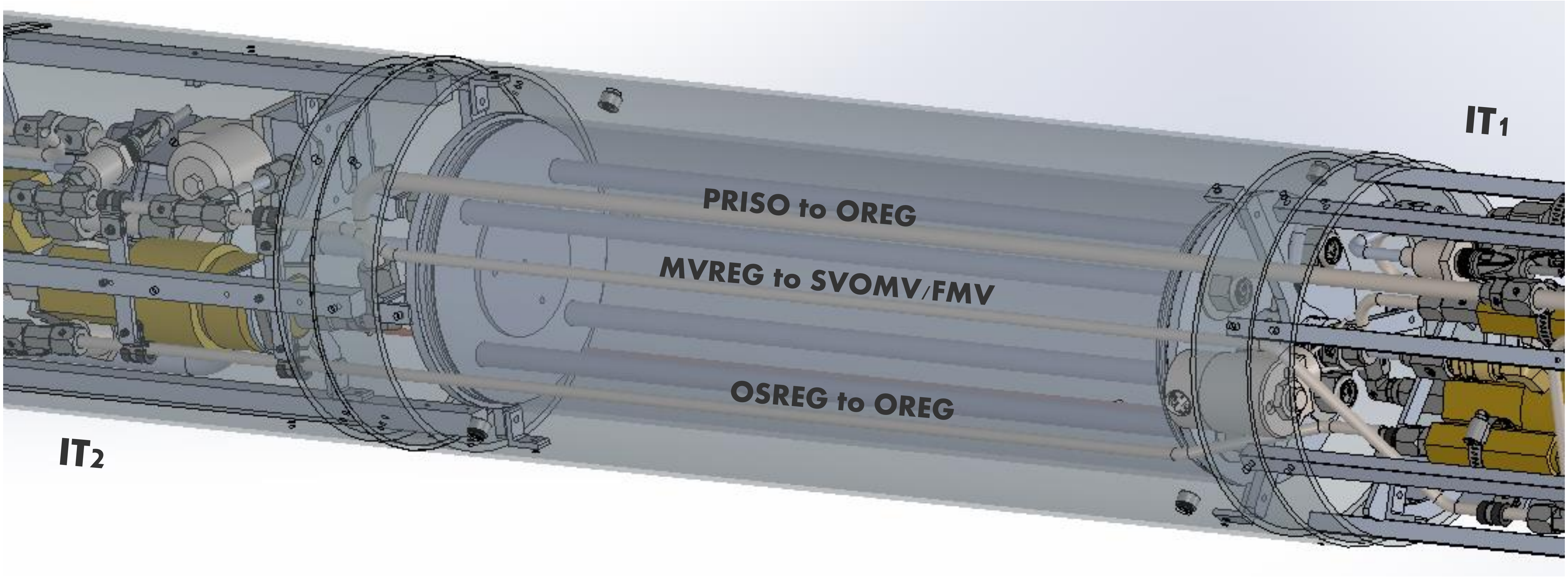


- Provides rigidity
- 1/16" aluminum
- Uses a rubber grommet to dampen vibration and prevent scratching





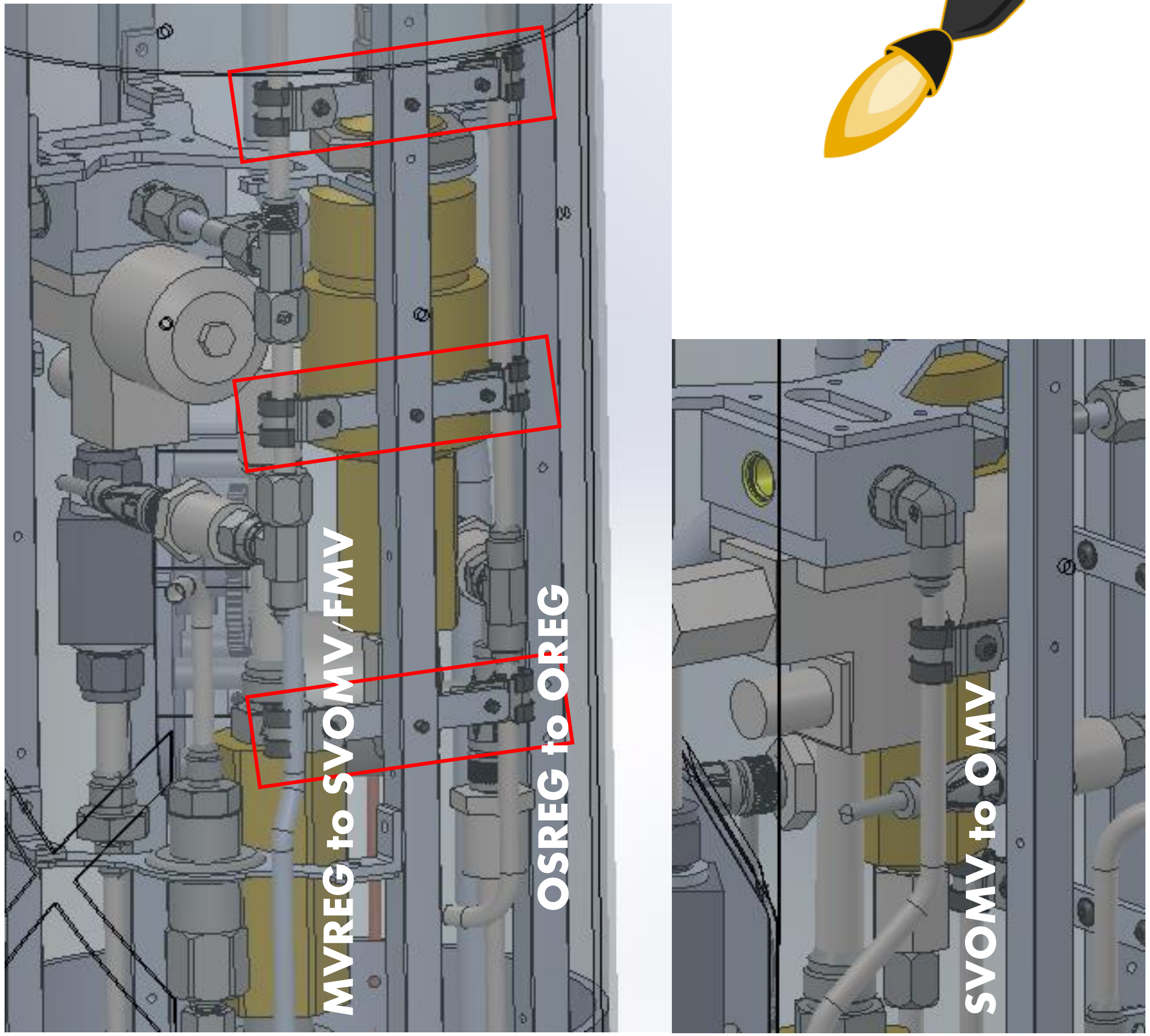
Long Lines



Long Line Mounts

To OSPT and MVPT

- Secure long lines in IT2
  - SVOMV inlet and outlet
  - OREG set line
  - Set Line to FMV
- 1/8" aluminum struts with pipe clamps
- Mounted to stringers through tapped holes

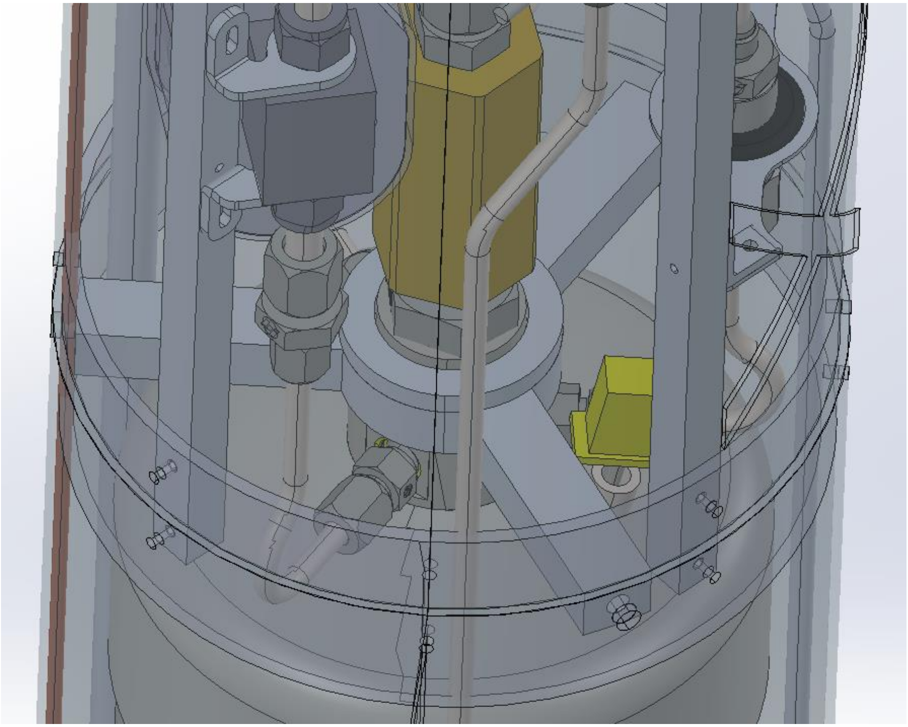


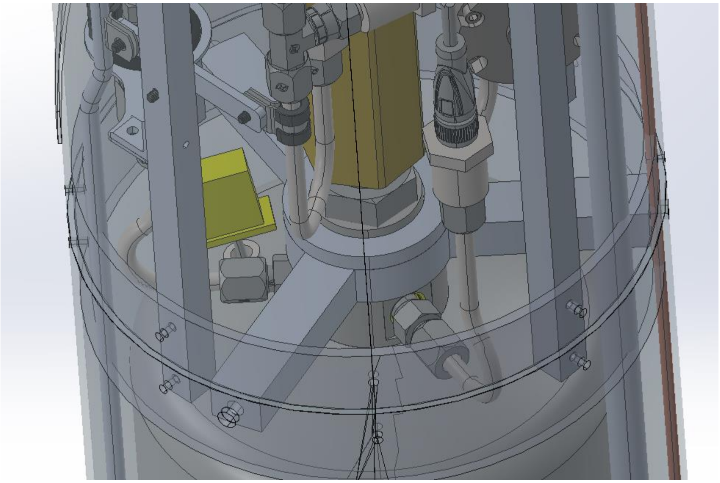
LOX Section Changes

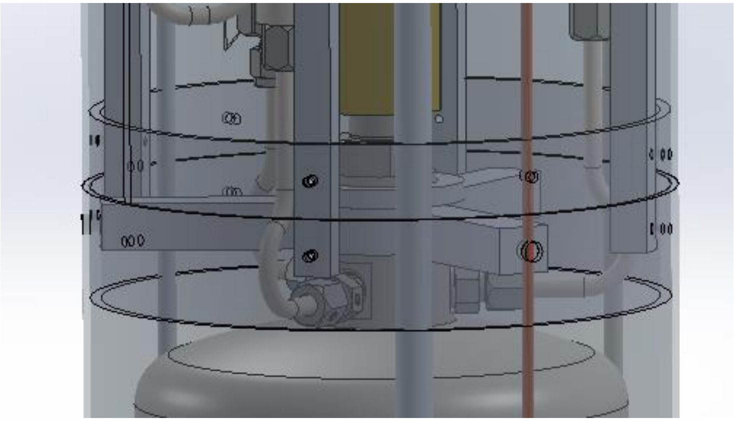
Overview

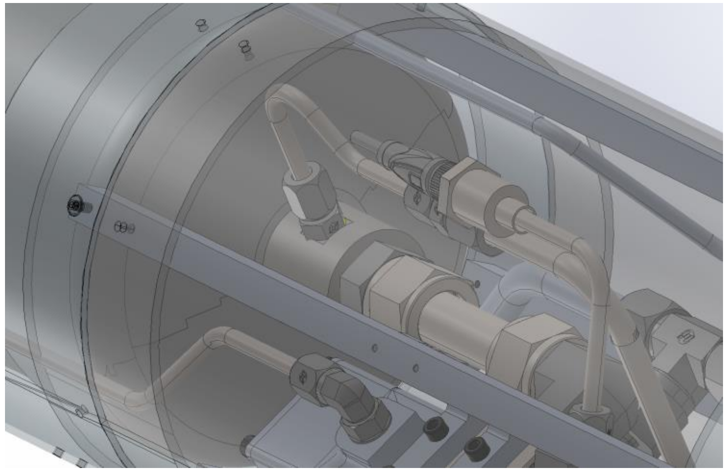
- LOX Tank Port Clearance
- Long Lines
- Insulation
- Fuel Main Line Clearance Issue

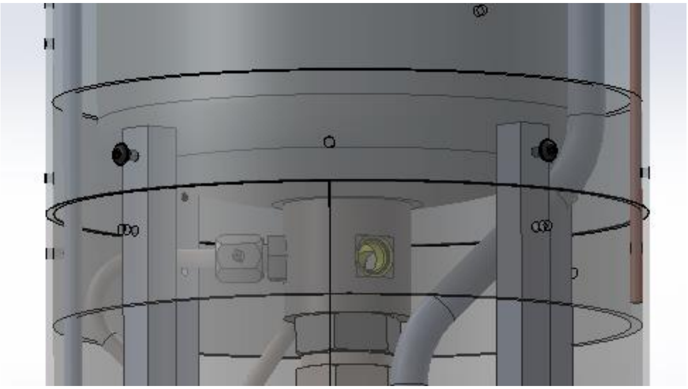
LOX Tank Port Clearance











Long Lines

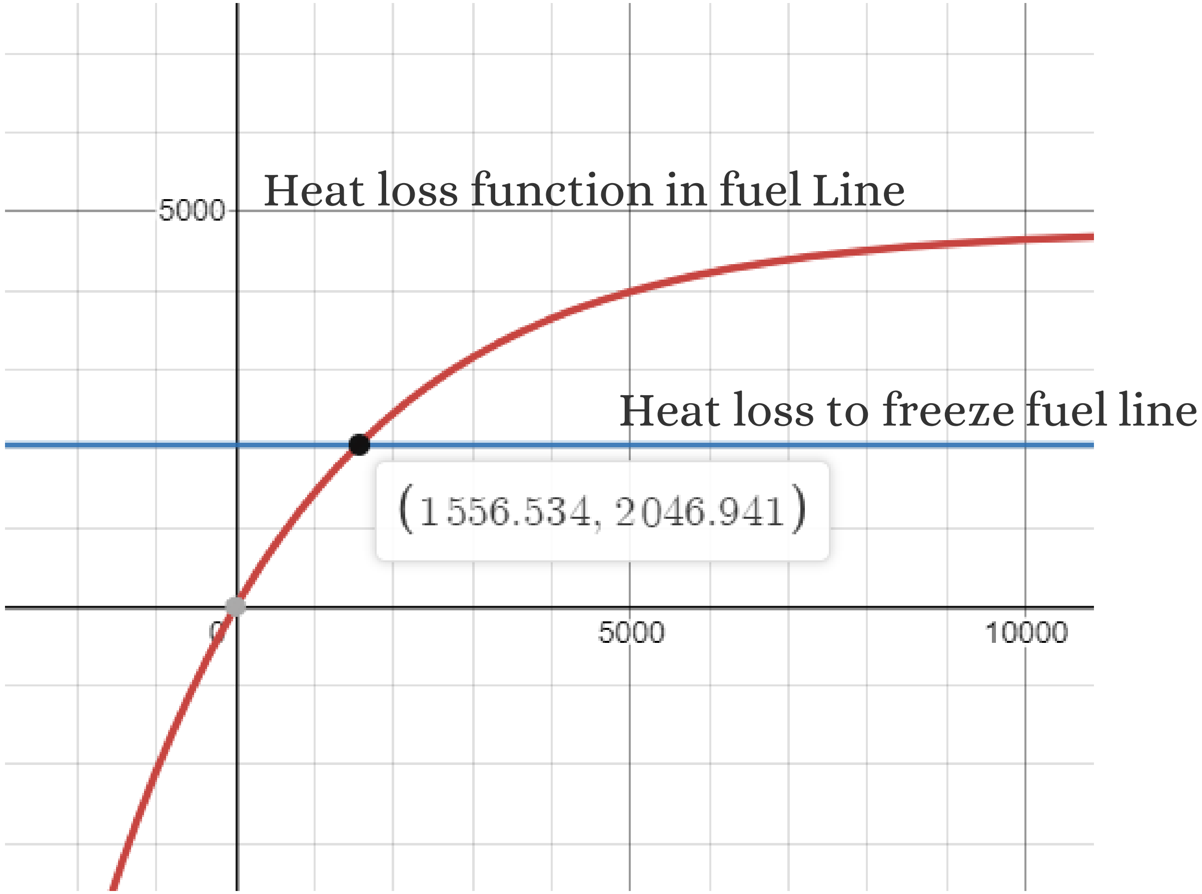
LOX Tank Insulation

$$\frac{dQ}{dt} = -KA\frac{dT}{dx}.$$

- Time for the fuel line to begin freezing was calculated using a 1d model using both an analytical and numerical approach.
- Total thermal energy losses of the fuel long line were calculated using Fourier's law (top right) and the thermal insulation constants provided by insulation manufacturer
- Freeze time given a ¼" gap of insulation was calculated at a conservative ~34 minutes (2046 seconds) for the fuel to reach freezing temperature

Assumptions

- insulation is only resistance to heat transfer
- all heat transfer through insulation serves to cool fuel only in section directly touching LOX tank
- all heat transfer occurs perpendicular to tank wall directly to line
- assumes density of Jet-A is constant across pressure and temperature(standard density i.e. lowest possible density)
- Fuel freezes when freezing temperature is met(ignores latent energy of fuel)(conservative assumption)



Fuel Main Line Clearance

- Issues
  - Assembly
    - Squeezed between couplers/airframe and tank
  - Fuel Freezing
    - 25 min with 0.25 in Insulation
    - 0 min with no insulation and full contact
    - 10 min with 0.05 in insulation (0.25 in compressed to 0.05 in)
  - Solution:
    - Insulate Fuel Line
      - 20 min with one layer of Ultra-Thin Aerogel Pipe Insulation, assuming 0.05 in tank insulation

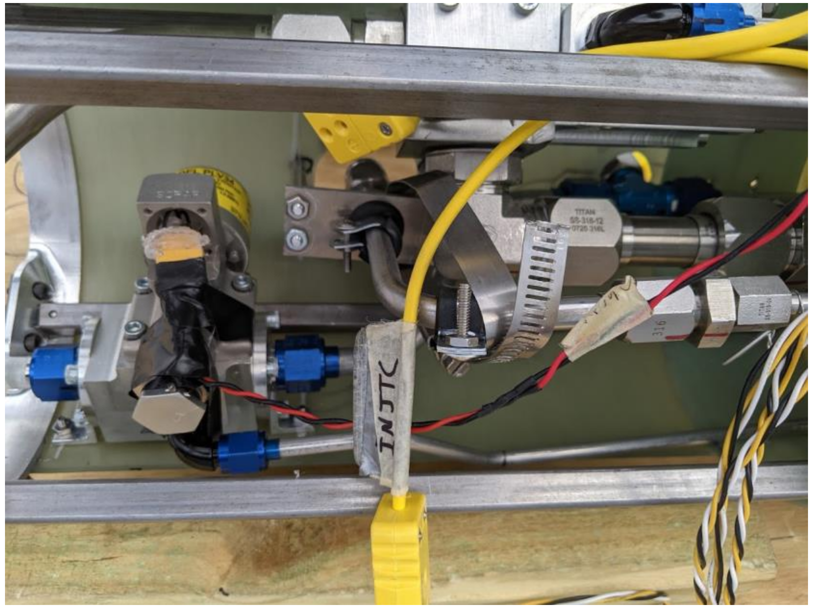
IT3 Changes

Overview

- OMV Mount
- FMV Mount
- OQD Mount
- Fuel Fill Port

New

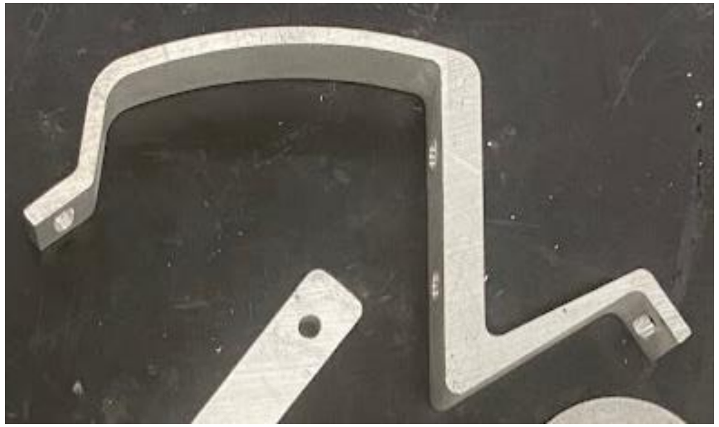
Old

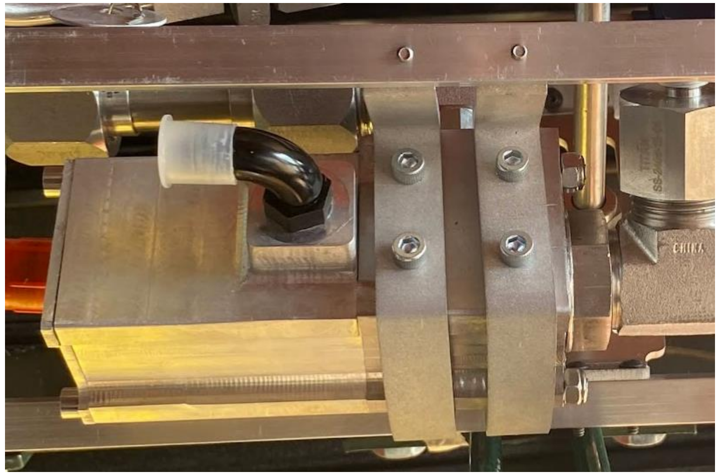


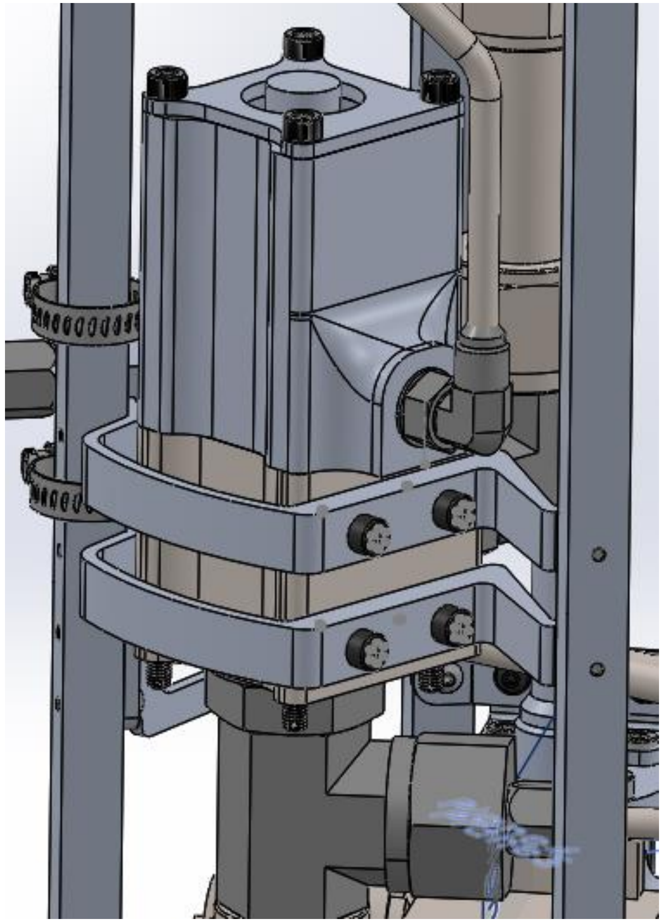
OMV Mount

Oxygen Main Valve Mount

- Keeps OMV rigid
- Waterjet 5/8" aluminum
    - Milled slots and holes
- Attaches to stringers, not airframe
    - Allows for ease of clamshell removal

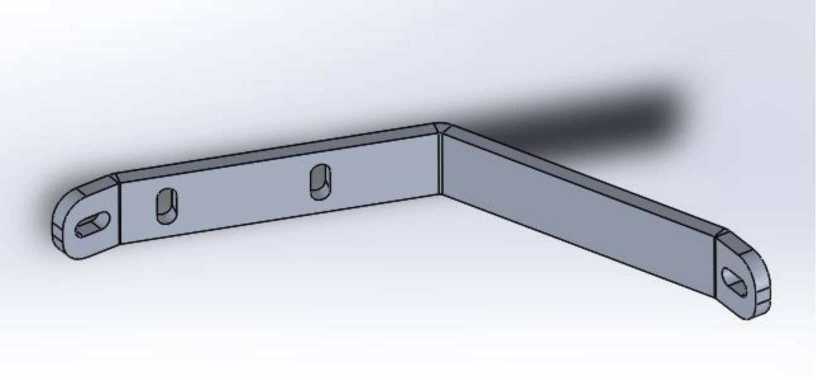


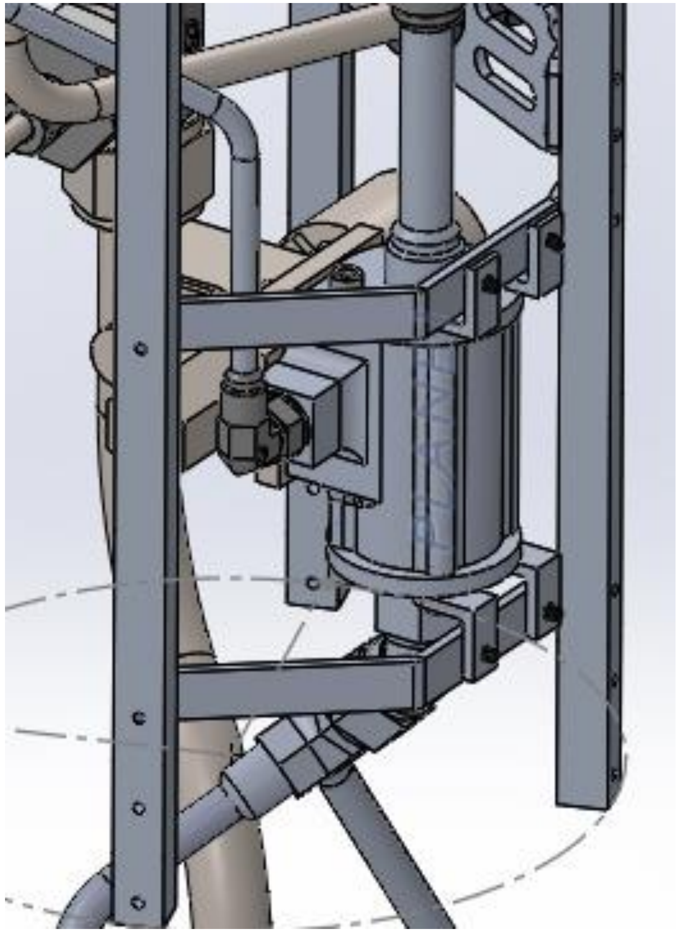




FMV Mount

- Keeps FMV rigid
- Mounts FMV at appropriate angle for new engine clocking
- Bent 1/8" aluminum
- Slots allow for some slop

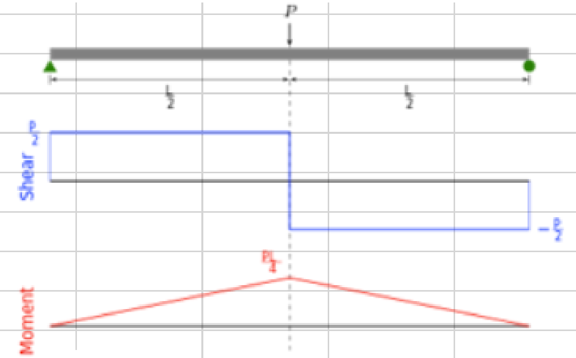




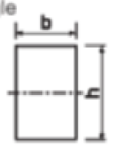
OQD Mount

- Mounts to stringers
- Holds OQD male end rigid, resisting loads during attach/detach
- 1/8" bent aluminum
- Slots are for mass saving

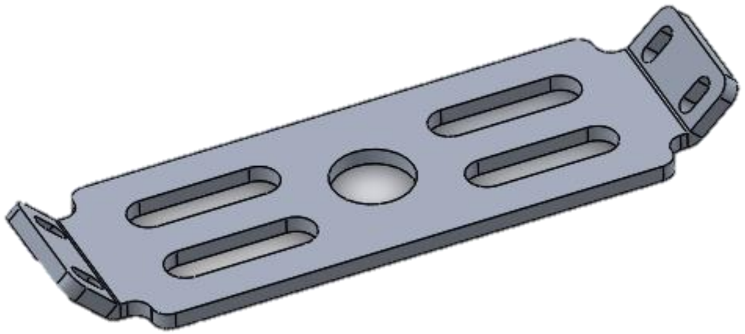
Bending Analysis			
Variable	Value	Unit	Notes
Estaimted Load	20	lb	From QD tests
Beam Length	4.14	in	From CAD
Max Moment	20.7	in-lb	PL/4
Plate thickness	0.125	in	CAD
Plate min width	0.9	in	CAD
Area Moment of Inertia	0.000146	in^4	bh^3/12
Max Bending Stress	8832	psi	My/I
Aluminum 6061 Yield Strength	35000	psi	link
FOS in Bending Failure	**3.962862**	-	



$$\sigma_b = \frac{My}{I}$$

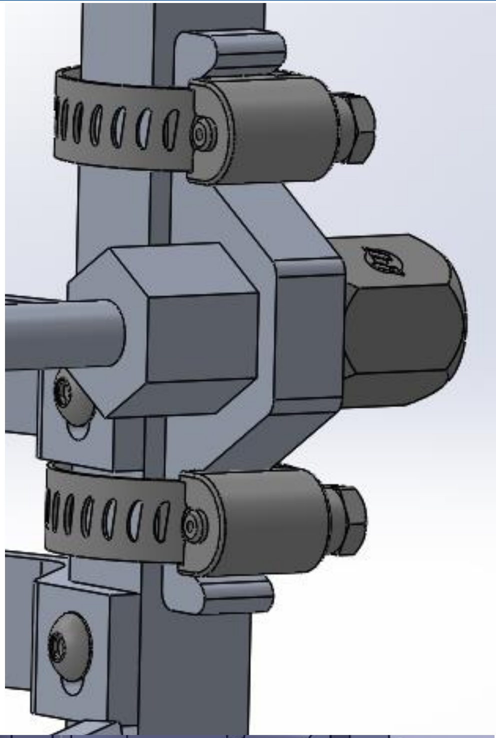


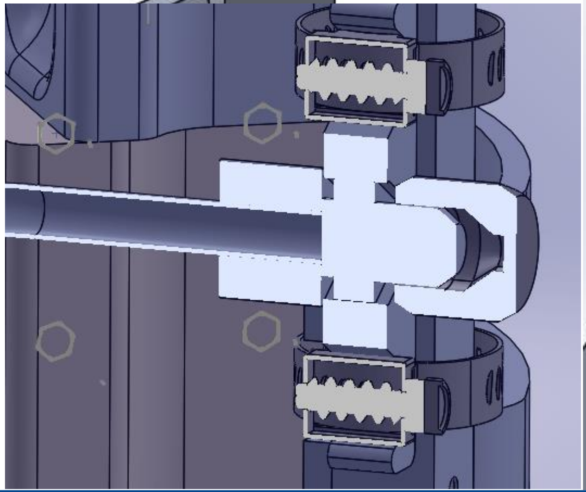
$$I = \frac{bh^3}{12}$$

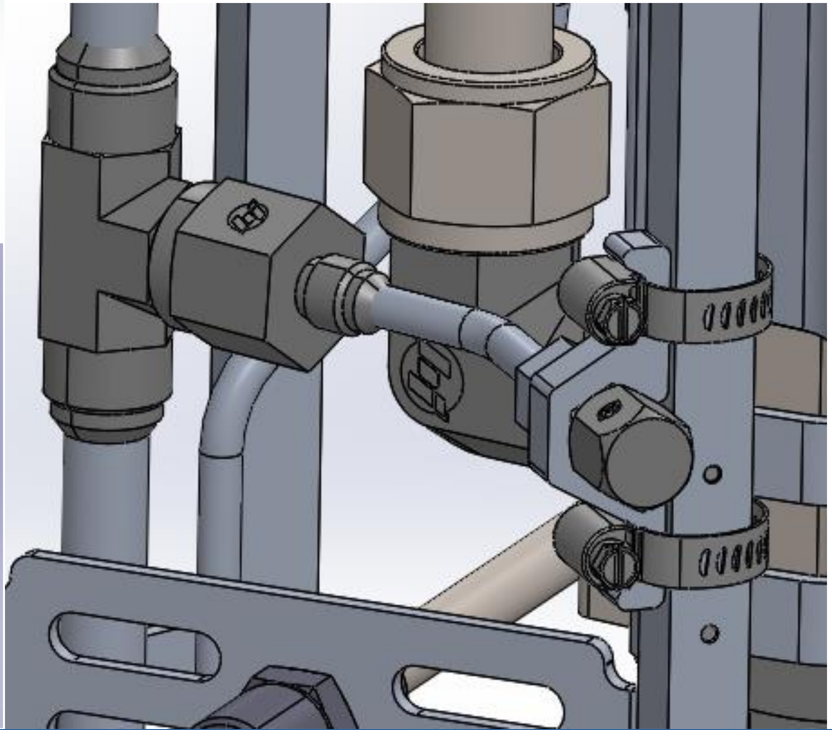


Fuel Fill Port

- Access point for filling kerosene
- Waterjet piece has hex cutout for union fitting to resist torque from wrench
- Cap sticks out of airframe for loosening and tightening with clamshell on
- Hose clamps mount this piece to a stringer

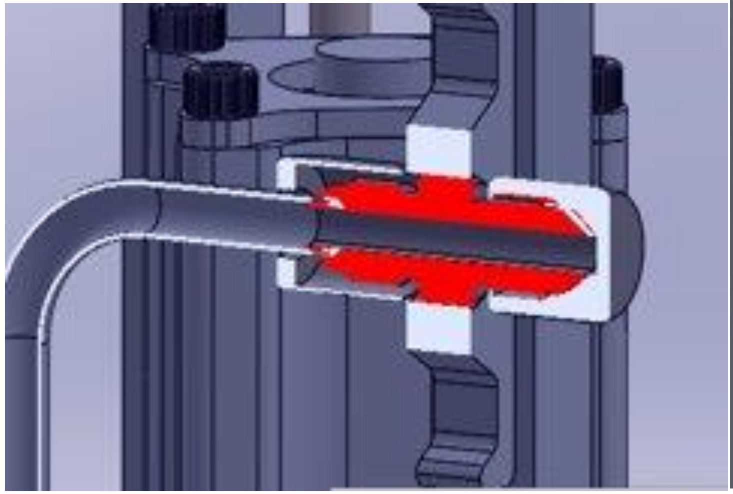


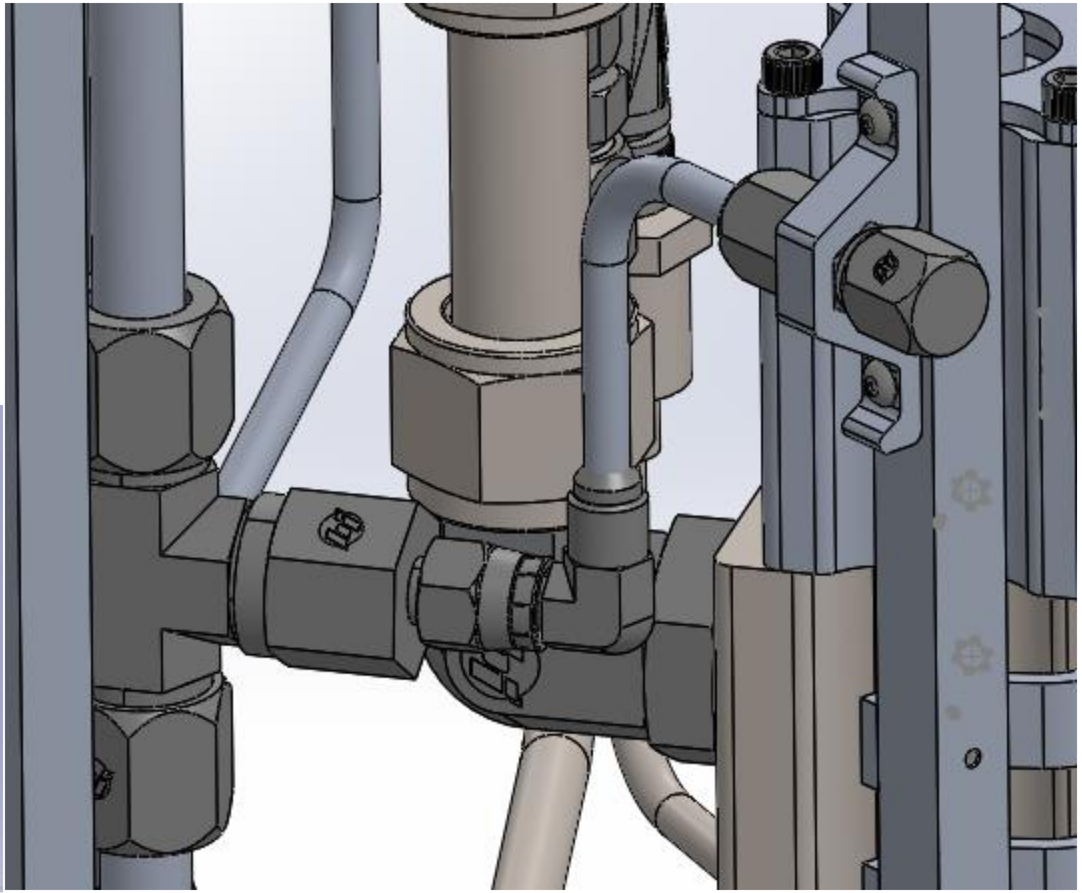




Fuel Fill Port Option Two

- Use 6-32 bolts threaded into stringer instead of hose clamps
- Higher up to avoid hole concentrations in stringer



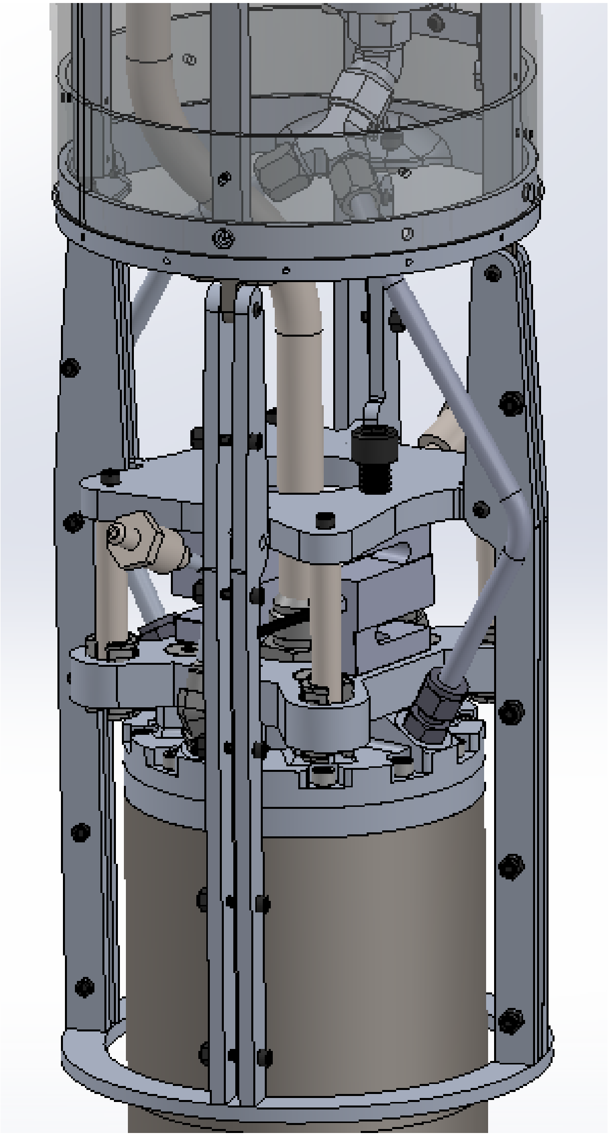


Engine Section

Overview

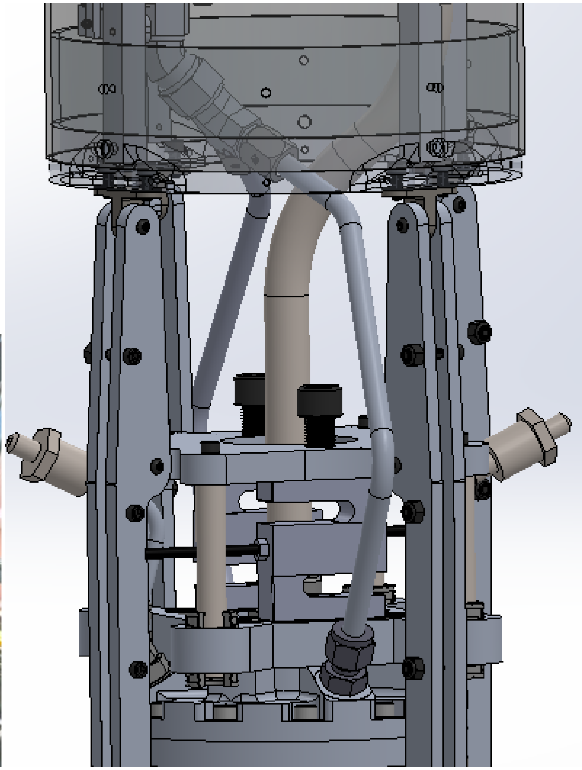
- Fuel Injector Plumbing
- LOX Injector Plumbing
- Load Cell Structure

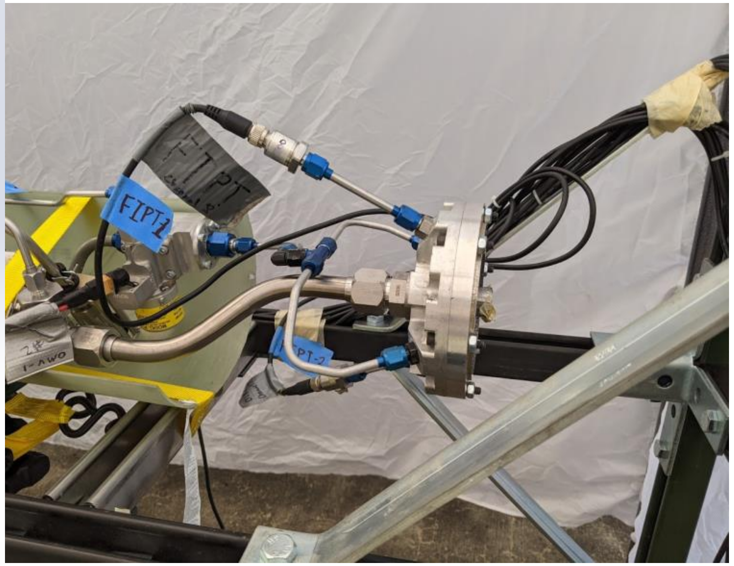
- Engine Section Variations
  - Heat Sink Static Fire
  - Regen Static Fire
  - Launch



Fuel Injector Plumbing

- 3/8 tubing now used
  - Less of a pressure drop
- Trickly bends for fuel lines
  - May require multiple attempts
- LOX line has been extended for load cell use

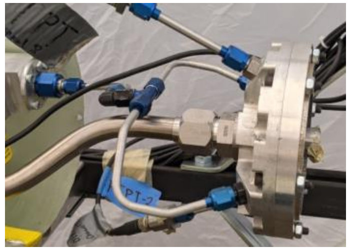




Fuel Pressure Drop

Pressure Drop Calculations

- Water Flows
  - 350 PSI Fuel Tank (FTPT)
  - 50 PSI Injector (FIPT)
  - 300 PSI Total DP
  - 160 PSI DP from Inj Lines + Long Line
  - 190 PSI DP from Top of Tank to FMV
  - Assuming Diffuser/Baffles is causing remaining DP
- New Geometry (3/8, less bends, Y-fitting)
  - ~80 PSI DP
  - Decrease DP by 80 PSI
    - *130 PSI Inj
  - Target Inj: 365 PSI
  - Increase Fuel Tank To *635 PSI
    - 365 + 190 + 80 = 635
- Fuel Tank
  - 390 PSI MEOP, 3.6 FOS based on stress analysis
  - Proof tested to 700 PSI, 1.8 FOS



Old Geometry (1/4)

Downstream of	Upstream of	Total Pressure Drop
Fuel Tank	Injector (1)	158.2621432
1/4" Lines	Injector (2)	166.6457937
3/8" Lines	1	129.7339438
	2	131.1578649
1/2" Lines	1	125.409788
	2	125.769641

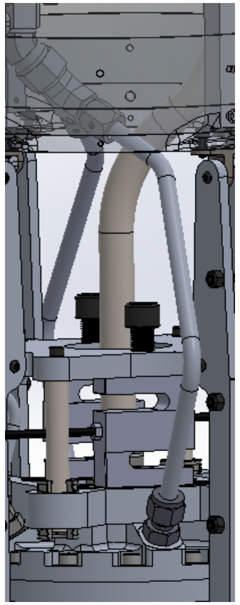
New Geometry (Kerosene)

3/8" Lines	1	73.49106302
	2	73.49106302

New Geometry (Water)

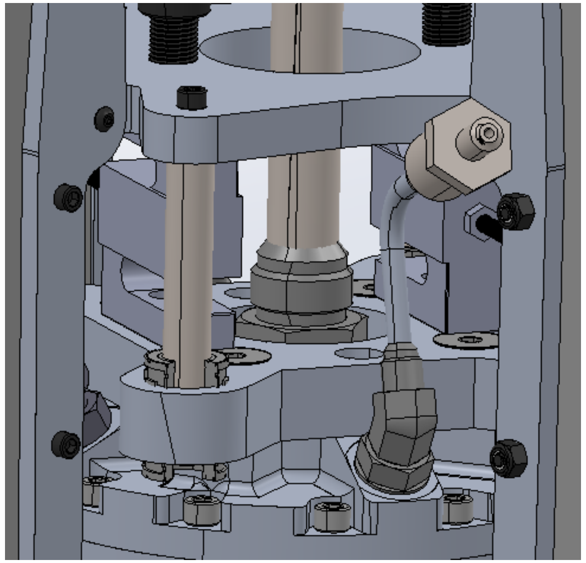
3/8" Lines	1	90.69942771
	2	90.69942771

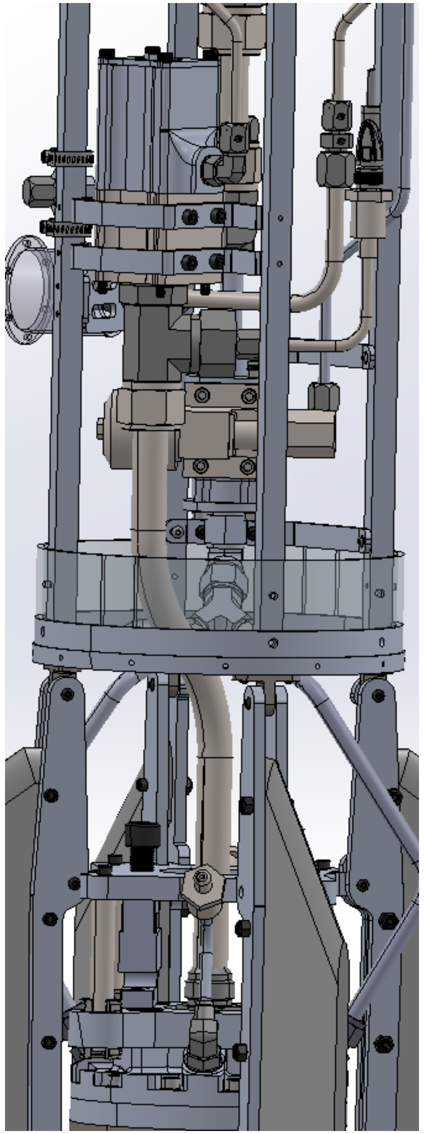
SF Config



LOX Injector Plumbing

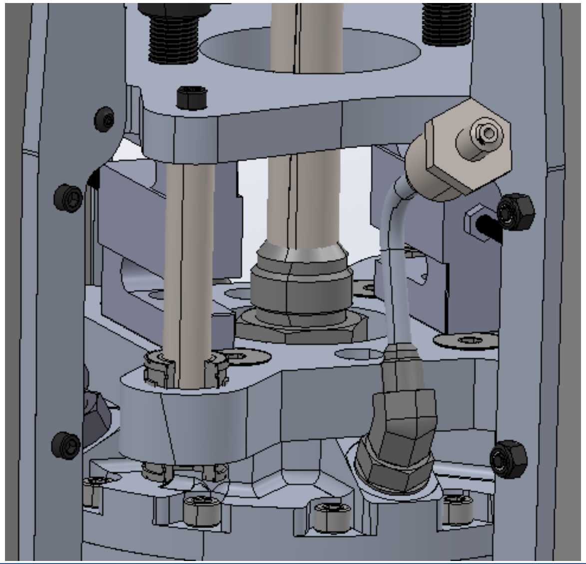
- Same as before
- Longer for Static Fire
- Barely enough clearance to tighten lower B Nut with custom wrenches

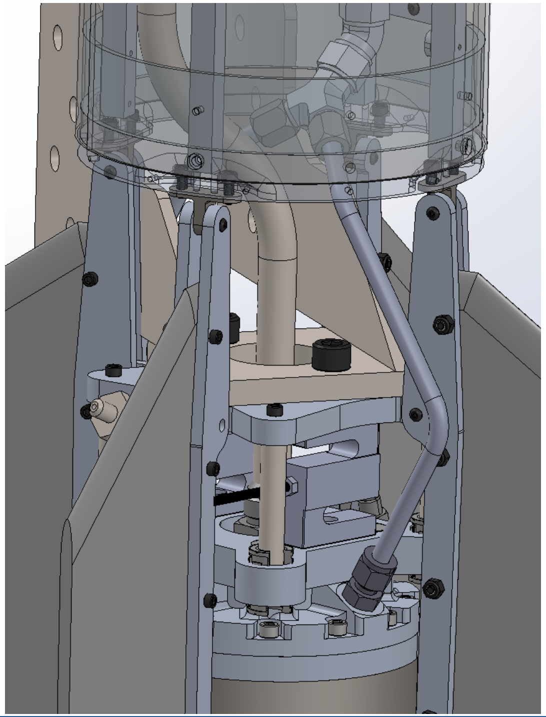




Load Cell and Holddowns Issue

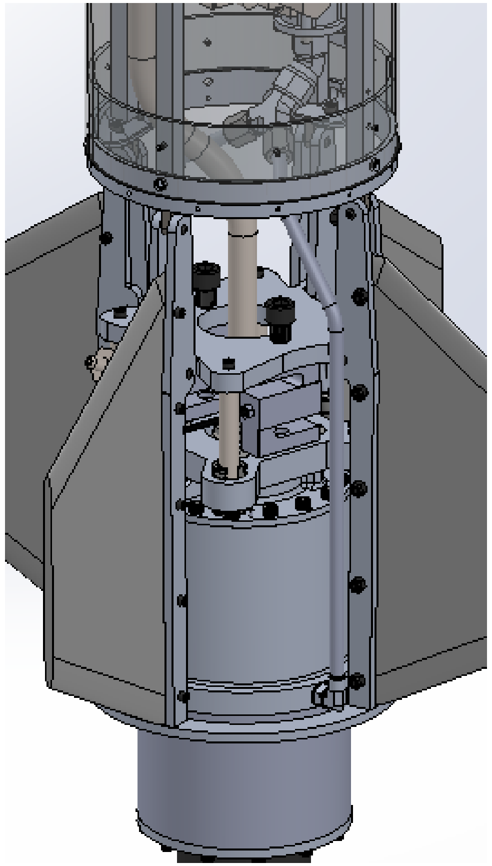
- Mating Booster to LCH Rail requires undoing LOX & Fuel Injector Lines, Thrust Structure, and Load Cell Str to attach Holddowns
- Then using custom wrenches to attach LOX Line



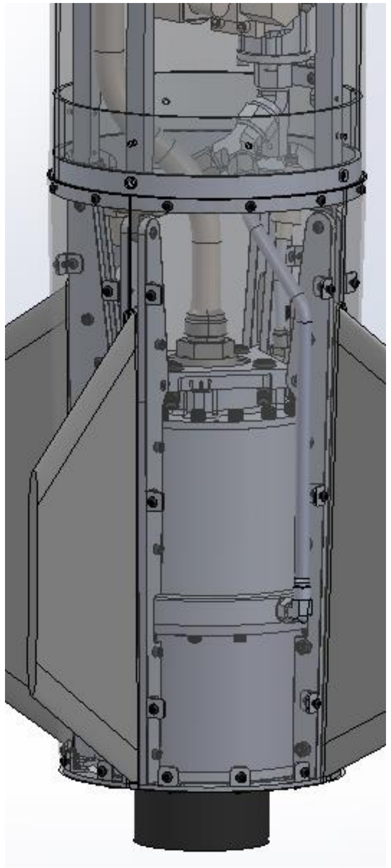


Additional Engine Configurations

Regen Static Fire



Flight



- Engine interface plate needs to be redesigned to account for engine rotation
- Airframe needs to be slotted for fuel line
- Flight Fuel Injector Lines protrude airframe

Subscale Mass & Length

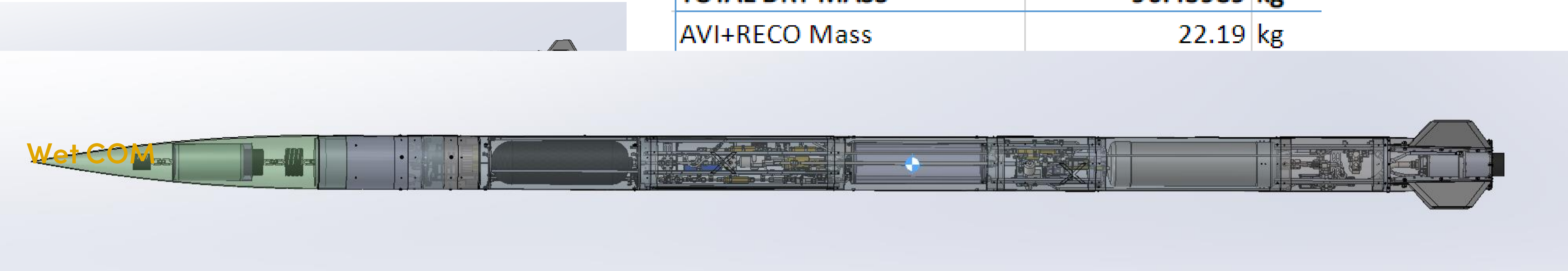
- Old Wet Mass: 107.6 kg
- New Dry Mass: 96.44 kg
- New Wet Mass: 112.77 kg (5.17 kg increase)
- Old Length: 213.8 in
- New Length: 214.9 in (1.1 in increase)

Mass	Value	Unit
Pressurant	9.519274376	kg
IT1	11.679443	kg
Fuel	8.299319728	kg
IT2	8.171596392	kg
LOX	14.92063492	kg
IT3	8.580498866	kg
Engine	11.90022676	kg

Mass	Value	Unit
TOTAL DRY MASS	**96.43989**	**kg**
AVI+RECO Mass	22.19	kg

Dry COM

Wet COM



Assembly Procedures

Booster Edition

- Assembly Nodes
  - Individual Node Assembly Procs
  - Node Connection Procs

Assembly Procedures

Booster Edition

- Work In Progress
- Outline
  - Assembly/Node Rules
  - Node by Node Definition (Including STR, FFS, AVI Components)
    - Node Assembly Procs
  - Node Connection Procs

- Assembly Procedures

Questions?

In Memory of Simon Pahlsmeyer