ATLAS CDR

Liquid Propulsion Laboratory

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Preface

- LPL currently has a lack of experience designing around and working with cryogenic liquids and cryogenic operations
  - We are looking to the Alumni for help to better understand industry cryogenic design considerations and standards for operations
- Please provide input and ask questions regarding any ConOps or design decisions we address in this CDR, and please provide us with advice regarding anything we did not address, or will likely encounter in the future.

Agenda

1. Introduction & Goals
    a. CDR Entrance and Exit Criterion
    b. Project Planning
2. Feed System
    a. Updated P&ID
    b. CAD Overview
    c. FMEA
3. Feed System Boil-Off and Vent Sizing Calculations
4. Feed System Specifications
    a. Component Specifications
    b. Pressure Drop Calculations
    c. Cost
5. Engine Mount
6. Testing Campaign
7. Summary & Questions

CDR Entrance Criteria

Purpose: Review of Atlas test stand and subsystems design

The following conditions have been met which enable a CDR of the system:
- Feed system P&ID final revision completed and approved
- Feed system lines, pressurant, propellant, and regulator specifications confirmed
- Feed system setup and hot fire ConOps
- Feed system FMEA (Failure Mode and Effects Analysis)
- Feed system final cost
- Complete CAD

CDR Exit Criteria

The following conditions will allow Atlas to exit CDR and enter the manufacturing stage:

- ☐ Determine that a satisfactory basis has been achieved for preceding to a finalized design and test procedures
- ☑️ Confirmation of sufficient funding from department

System Requirements

- Feed System shall be capable of remote safing in the event of a hazard to personnel
- Feed System shall be single fault tolerant against critical hazards during first hot-fire
- Feed System shall be transportable to testing locations
- Feed System components shall be easily accessible for integration, inspection, and calibration once assembled
- Liquid Oxygen flow velocity shall be below *30 m/s* to minimize risk of impact ignition, per NASA Safety Standard for Oxygen and Oxygen System (NASA 1740.15)

System Requirements Cont.

- Feed System shall incorporate independently powered vent valves, per FAR’s REDS Standards
- Feed System shall reuse as many components as possible from the Original Hydra Feed System
- The Feed System shall support the flow and pressure requirements of the Balerion-Dev2 Engine
- The Feed System may support any engine LPL may develop in the future

Project Planning

- Start LOx and Pressurant Side building as soon as CDR is done
  - Aiming to have LOx side built by July 15th
- **DAQ CDR date: July TBD**
- Aiming to have Fuel Side built by August 15th
- Testing Campaign starting on August 16th
- Hot fire by Aerospace Corporation SOW completion date (December)

Atlas
Feed System

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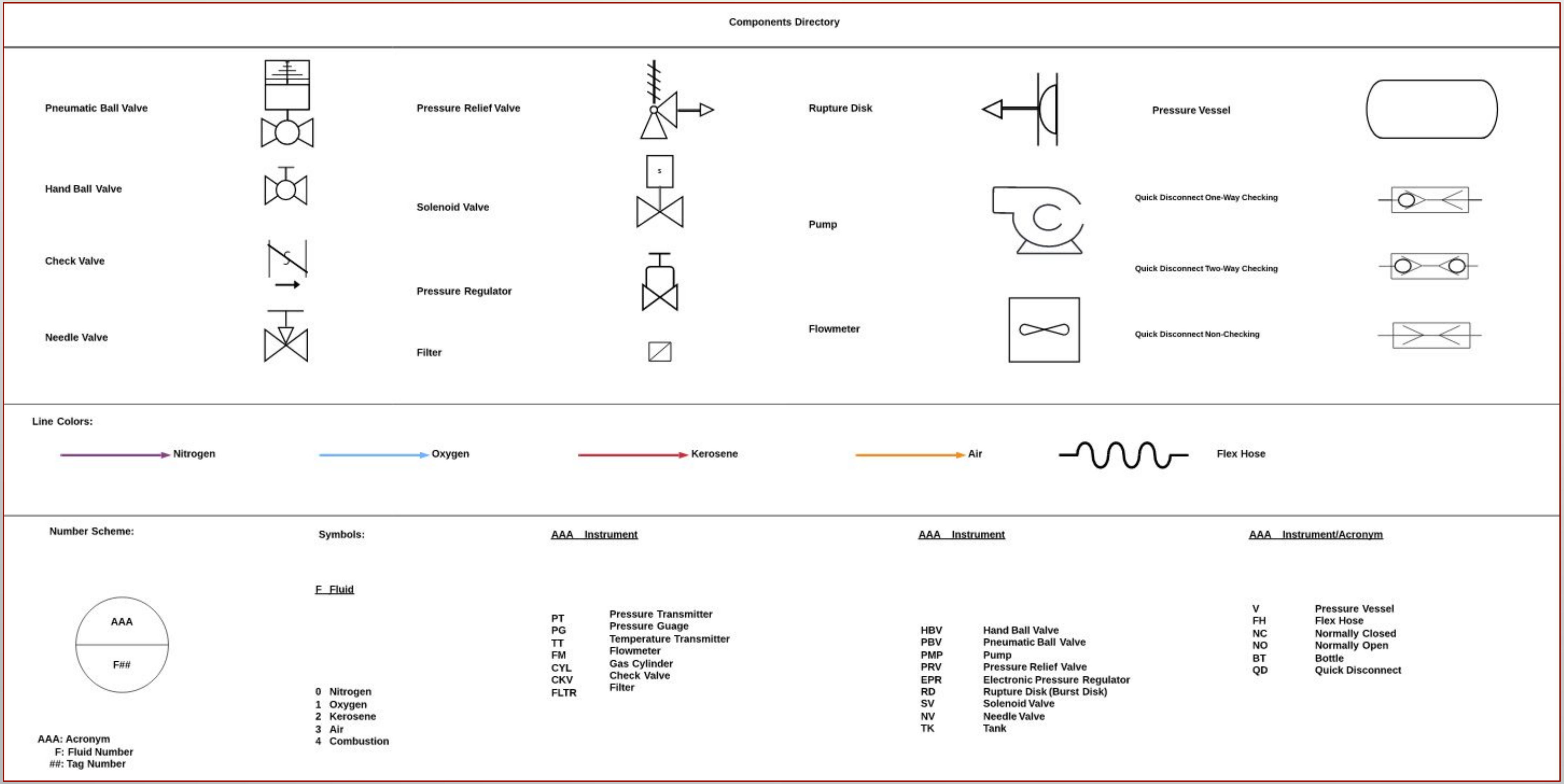
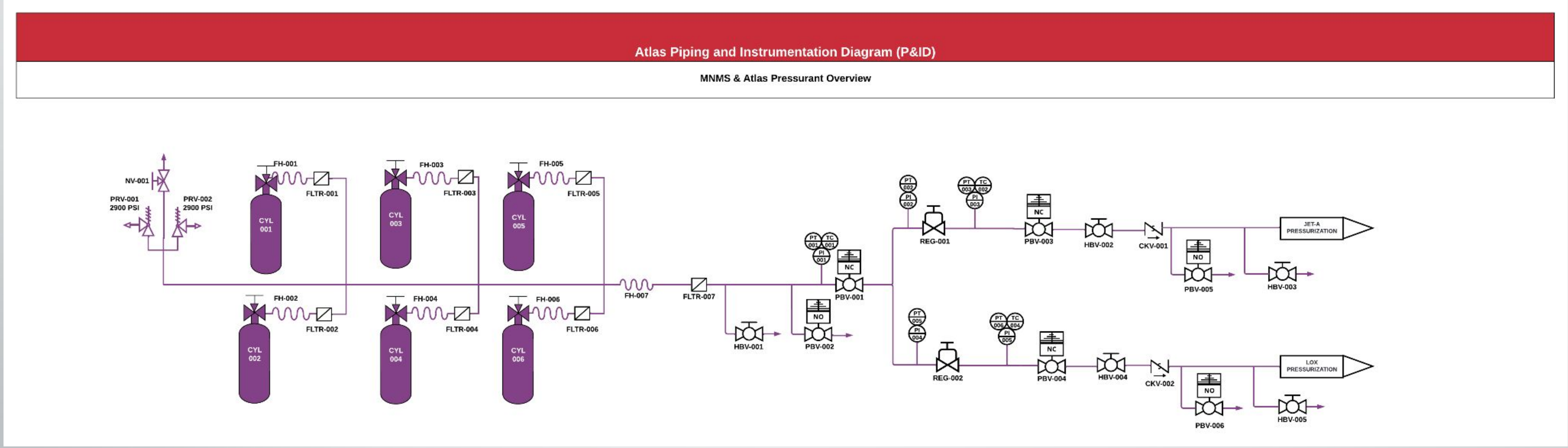
P&ID Component Directory

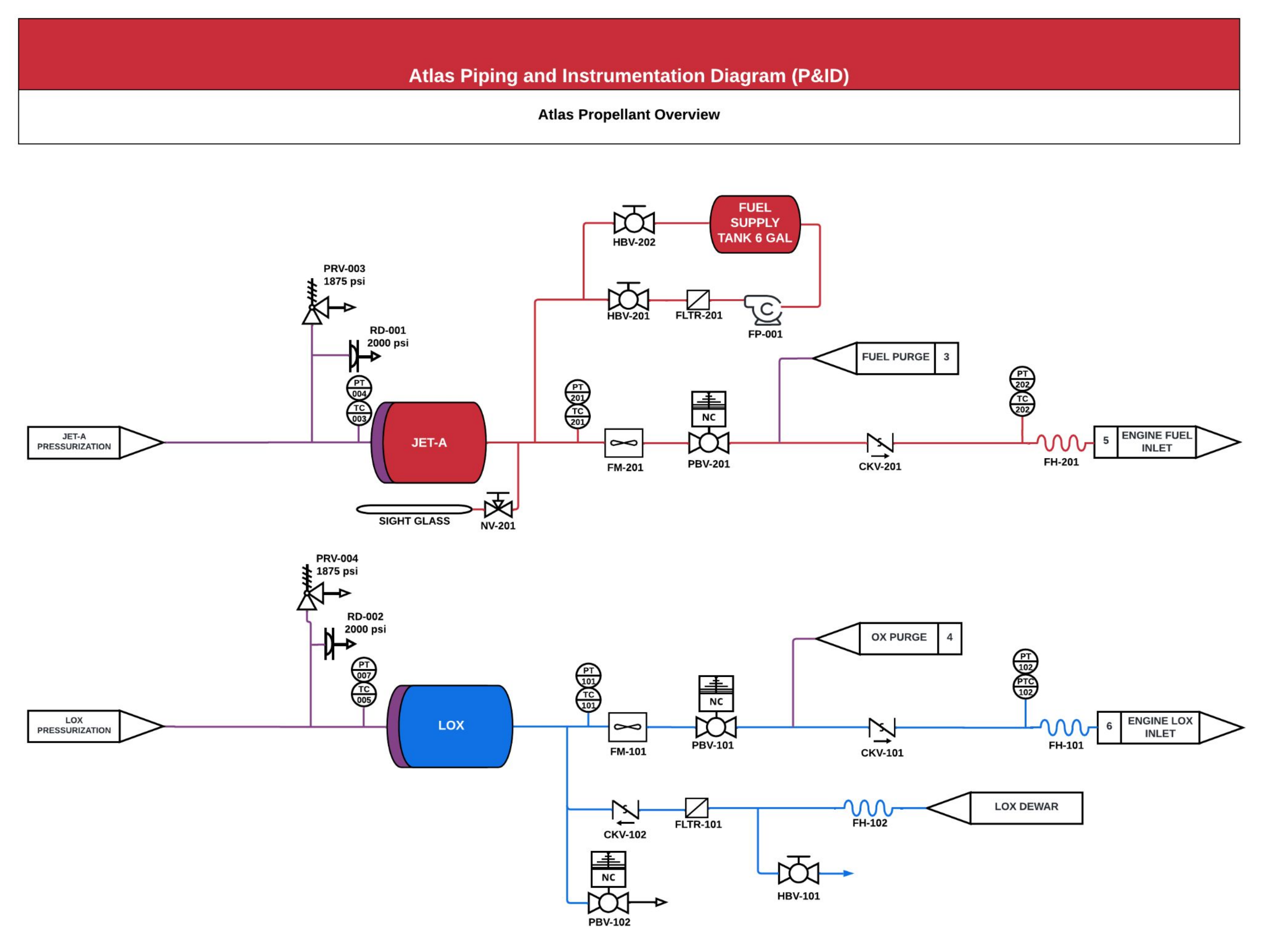


Feed System Overview - Pressurant P&ID



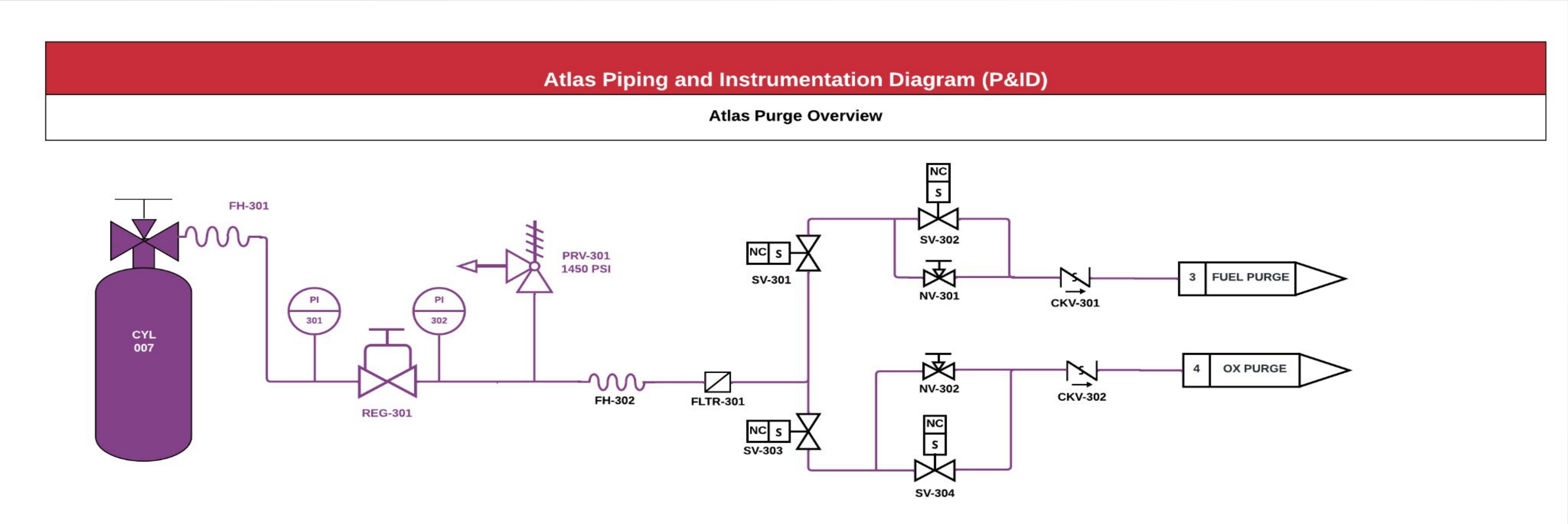
- GN2 Pressurant gas cylinders will be 49L at 2700 psig
  - Port implemented for future remote fill
  - HBV-001, PBV-001 & PBV-002 will be High Pressure Valves
  - PBV-001 will be actuated slowly to reduce water hammer on the regulators
- Filters on all bottles will limit risk of contamination
- HBV-001, HBV-002 & HBV-003 are manually operated in the event the system must be depressed manually (FAR recommendation)

Feed System Overview - Propellants



- Fuel will be filled and drained into a 6 Gal non-pressurized tank
- Fuel tank level will be determined with a sight glass
- LOx filled by dewar and drained into ambient
  - FAR allows for LOx to be drained on ground
- LOx tank level will be determined with a manometer
- Filters downstream of LOx and Fuel inlets to limit risk of contamination

Feed System Overview - Purge



- Will be used for both trickle purge and post-fire purge
  - More about this in ConOps
- CKV-302 will need to be cryo & oxygen rated

CAD Overview

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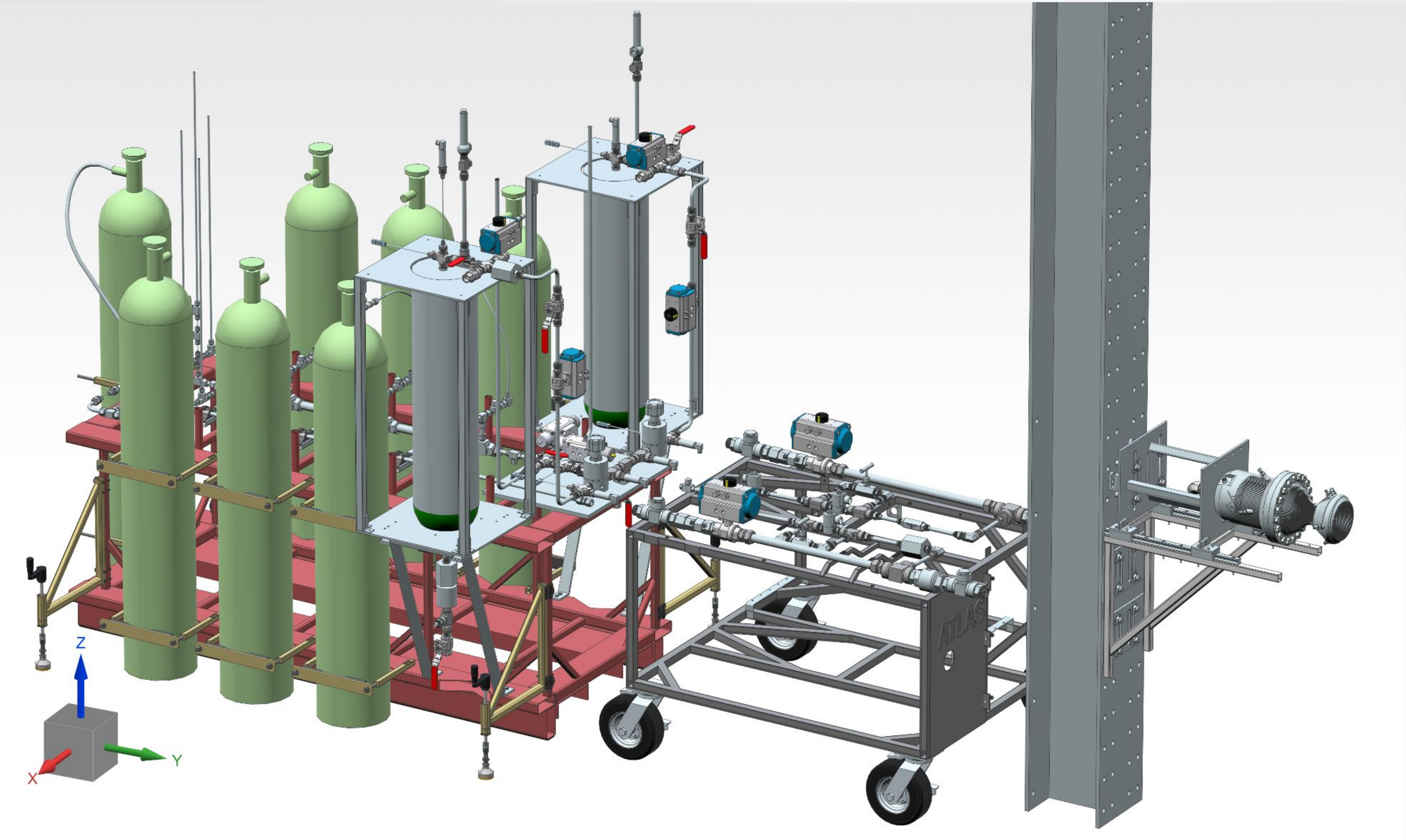

CAD Overview: Atlas

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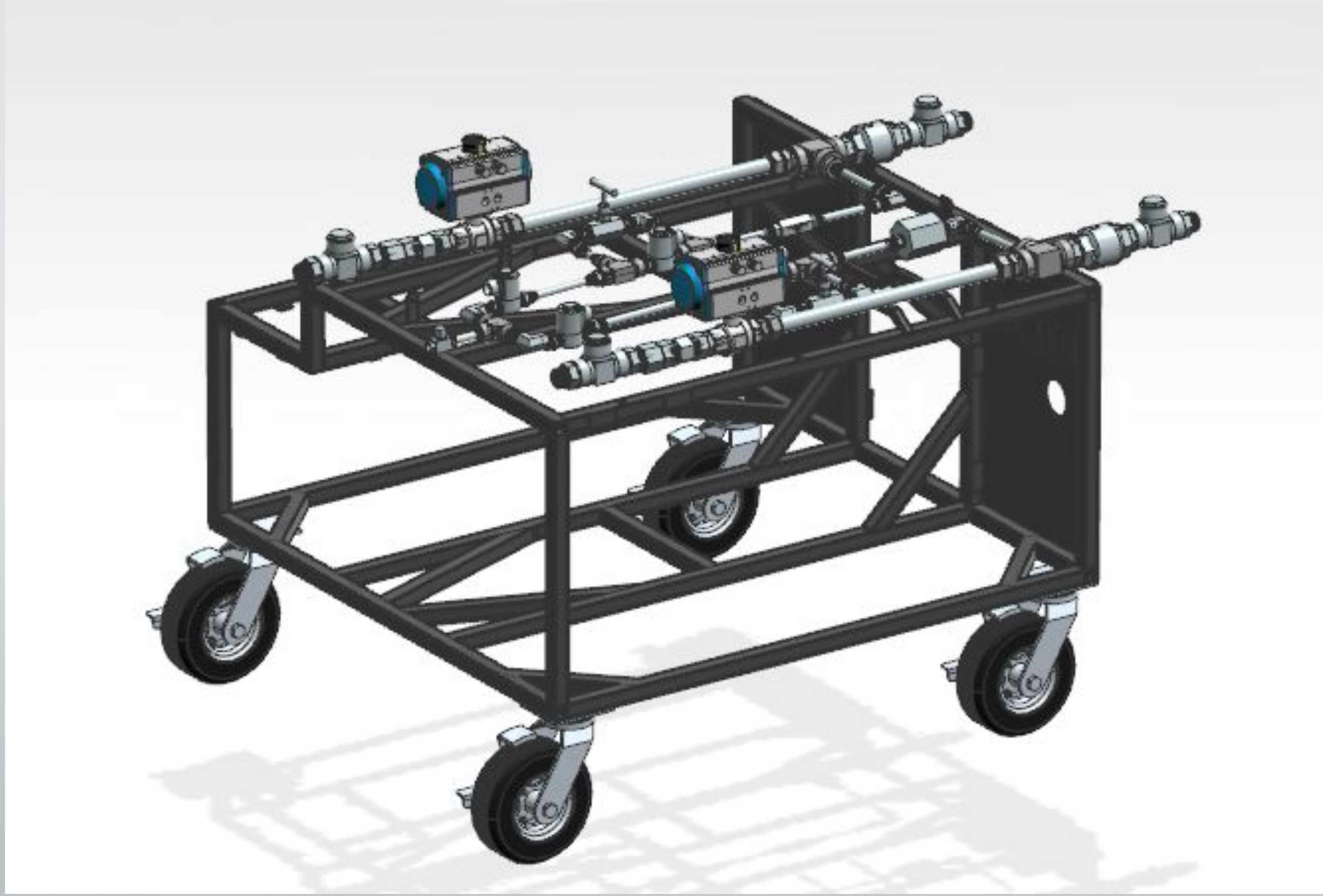
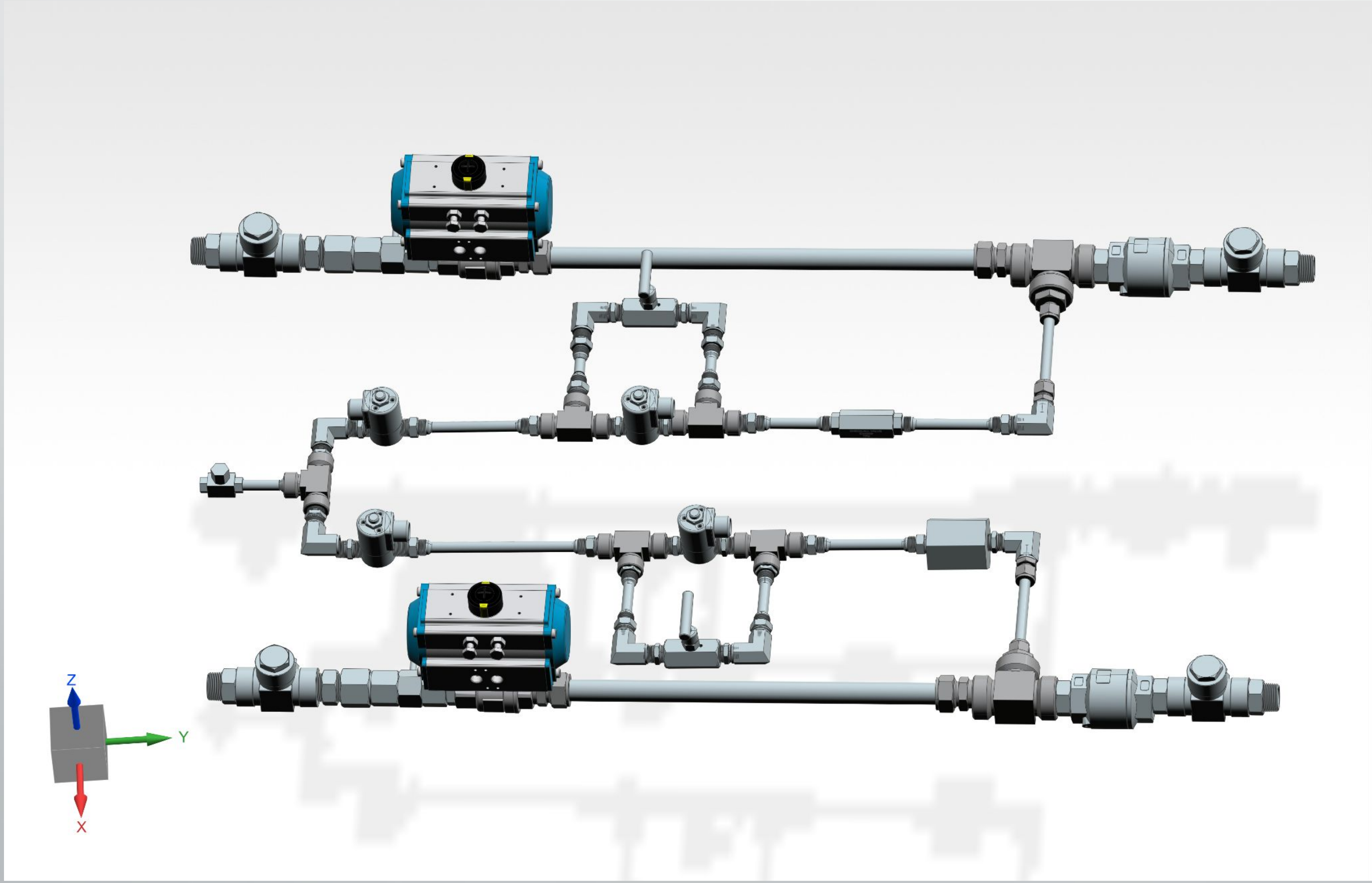


CAD Overview: Fuel, LOx, Purge Lines



CAD Overview: Fuel and LOx Tank Interface

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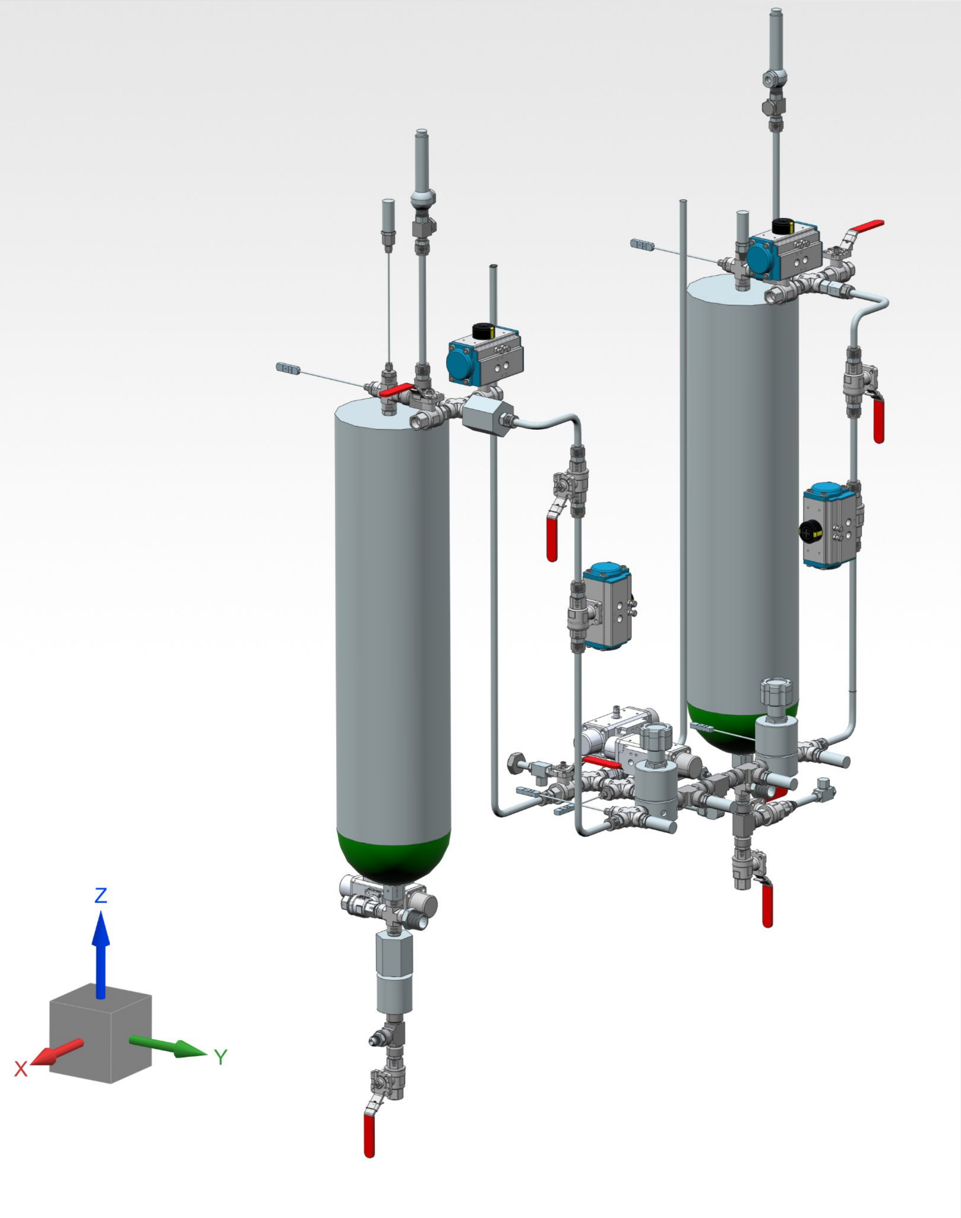

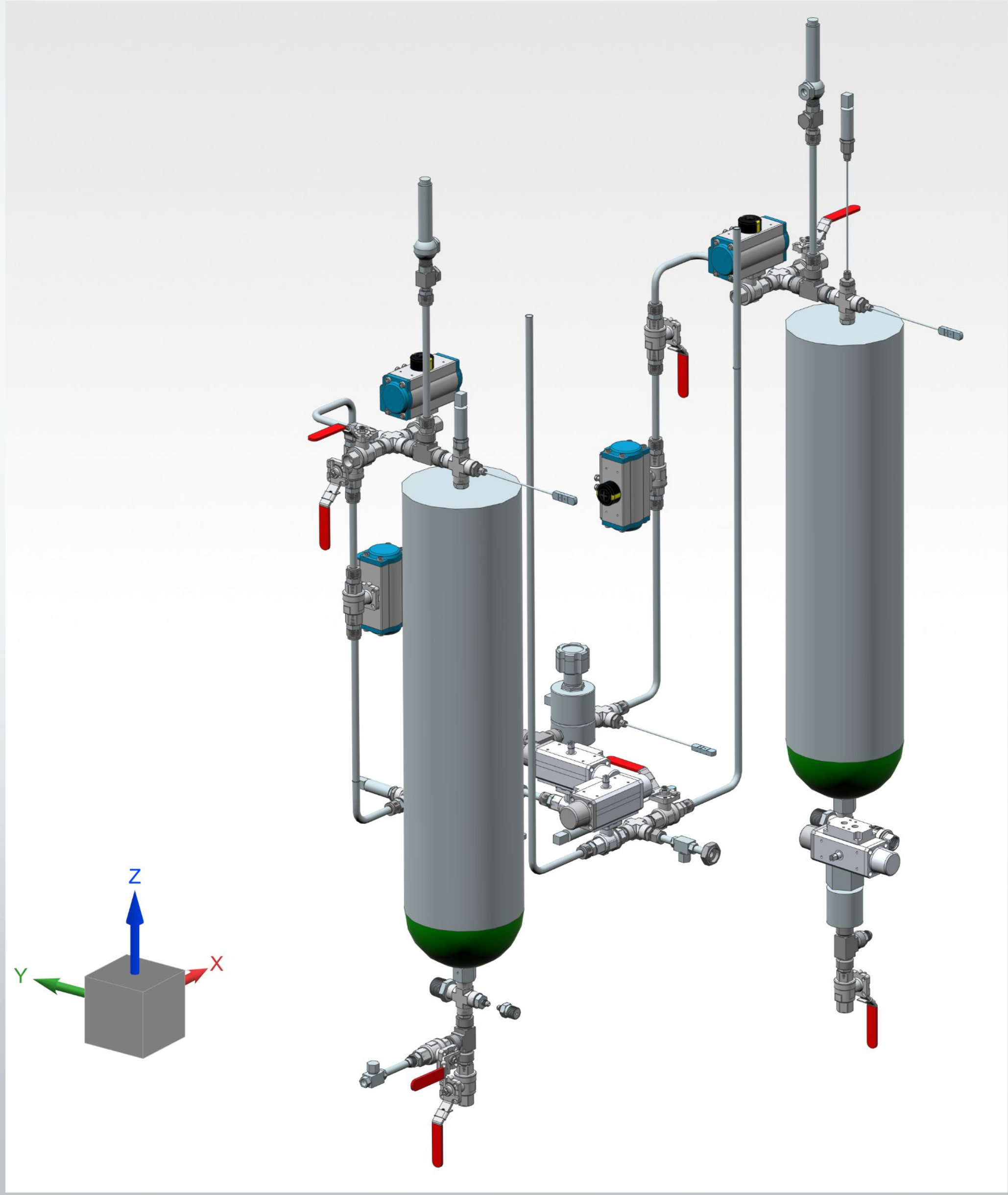

FMEA - Hazard Likelihoods and Severities

Failure Mode Likelihood	Probability Value	Failure Mode Likelihood Criterion
Rare	1	Failure mode not expected to occur, or design controls implemented to eliminate the failure mode. (0-20%)
Unlikely	2	Overall low chance of occuring, or little to no past occurrence of the failure mode. (20-40%)
Possible	3	Overall probability of failure to occur is unlikely, but the failure mode is inherent to the project if not eliminated by design. (40-60%)
Likely	4	History of several occurrences of the failure mode in heritage projects, or failure mode has never occurred, but conditions present for the failure mode to occur. (60-80%)
Very Likely	5	Failure mode is expected to occur, higher than normal chance that controls implemented may not stop the hazard. (80-100%)

Failure Mode Severity	Probability Value	Failure Mode Severity Criterion
Trivial	1	Damage to hardware, facilities, or equipment akin to normal wear and tear, no injury to personnel, project progress not impacted, cost overrun of < $30.
Minor	2	Damage to facilities, equipment, or test stand hardware more than normal wear and tear level, minor injury to personnel, progress slightly impacted but does not impact internal development milestones, cost overrun of < $500.
Moderate	3	Some damage to property or facilities, moderate injury to personnel requiring medical attention, internal schedule slip that does not result in Aerospace Corp. SOW completion date slip, cost overrun of < $1,000.
Critical	4	Risk results in significant injury, significant damage to property, facilities, systems, equipment, test stand hardware, progress temporarily halted, test stand requirement not met, cost overrun of < $10,000.
Catastrophic	5	Risk results in life-threatening injury or death, risk causes loss of multiple major test stand components or facility destruction, results in project failure, cost overrun of > $10,000.

FMEA - Risk Assessment Matrix

Likelihood	Severity				
	Negligible (1)	Minor (2)	Moderate (3)	Major (4)	Catastrophic (5)
Rare	2	3	4	5	6
Unlikely	3	4	5	6	7
Possible	4	5	6	7	8
Likely	5	6	7	8	9
Very Likely	6	7	8	9	10
RIsk Level	**Low (2-4)**	**Medium (5-6)**	**High (7-8)**	**(Critical 9-10)**	

Definitions:

- IRA: Initial Risk Assessment
- PMRA: Post-Mitigation Risk Assessment

Control Categories Implemented:

- Detective : Detective controls are designed to detect errors or irregularities that may have occurred.
- Preventative : Preventive controls are designed to keep errors and irregularities from occurring in the first place.
- Corrective: Corrective controls are designed to correct errors or irregularities that have been detected.

FMEA - Top 5 Failure Modes

Risk Title	IRA	Mitigations	PMRA
High Pressure in LOx Tank	9 Catastrophic Likely	**Preventative:** - 1.5x MEOP (per SMC-s-016) Hydrostatic Test of LOx tank. **Detective:** - PT readings of tank pressure to determine if the system has or will reach the MEOP. **Corrective:** - PRV-004 & PBV-006, HBV-005 & RD-002 rupture to release pressure, no longer able to operate the system unless RD is replaced.	7 Catastrophic Unlikely
High Temperature in LOx Tank	9 Catastrophic Likely	**Preventative:** - Ensure adequate tank insulation using foam then foil. - Wrap Reflective Shielding (foil blanket) around LOx tank to reflect sunlight. - Determine testing day with adequate weather conditions where the temperature does not exceed 100 degrees F. **Detective:** - PT readings of tank pressure to determine if the system has or will reach the MEOP. **Corrective:** - PRV-004 & PBV-006, HBV-005 & RD-002 rupture to release pressure, no longer able to operate the system unless RD is replaced.	7 Catastrophic Unlikely

FMEA - Top 5 Failure Modes

Risk Title	IRA	Mitigations	PMRA
Contamination in LOx Tank	9 Catastrophic Likely	**Preventative:** - Clean tank per the LOx cleaning procedures (per NASA 1740.15). - Purge all lines and tanks before and after testing operations. - Conducted trade study in order to determine the best FLTR based on criteria including MEOP, cost, quality, CV, lab experience, etc.	6 Catastrophic Rare
High Pressure in Kerosene Tank	8 Catastrophic Possible	**Preventative:** -1.5x MEOP (per SMC-s-016) Hydrostatic Test of fuel tank. **Detective:** - PT readings of tank pressure to determine if the system has or will reach the MEOP. **Corrective:** - PBV-005, HBV-003, PRV-003, and RD-001 to release pressure, no longer able to operate the system unless RD is replaced.	6 Catastrophic Rare
PRV-004 on LOx side fails	8 Catastrophic Possible	**Preventative:** - Conducted trade study in order to determine the best PRV based on criteria including MEOP, cost, quality, CV, lab experience, etc. **Corrective:** - Able to vent through RD-002 or HBV-005 as last resort since PBV-006 would have already failed.	6 Major Unlikely

Feed System Boil-Off and Vent Sizing Calculations

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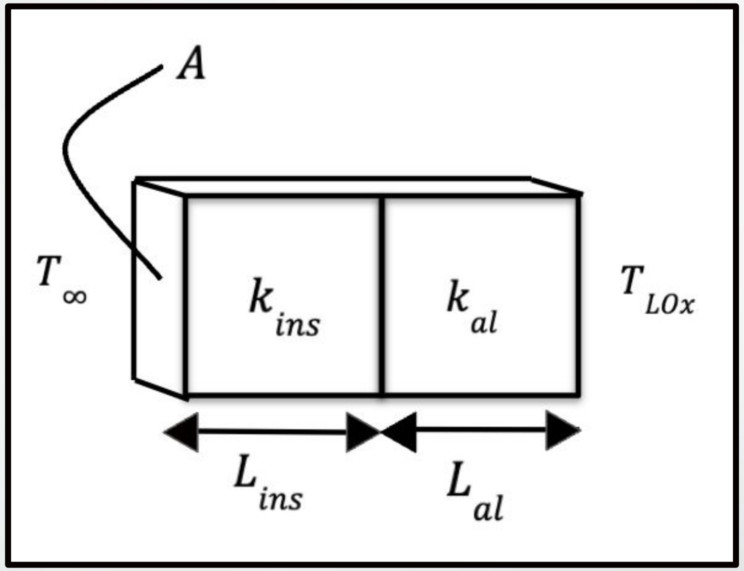
Boil-Off Calculations

Heat Transfer Equation (Two Layers)

$$\dot{Q} = \frac{T_\infty - T_{LOx}}{\frac{L_{al}}{k_{al}\,A} + \frac{L_{ins}}{k_{ins}\,A}}$$



A: Area
k: Thermal Conductivity
L: thickness
ins: foam insulator
al: aluminum tank

Divide Heat Flux by Enthalpy of Vaporization to get boil off mass flow rate →

$$\dot{m} = \frac{\dot{Q}}{\Delta h_{vap}}$$

Boil-Off Calculations

Boundary Conditions:

T_∞ = 180 °F (hot day, direct sunlight)

T_{LOx} = -297.3 °F (boiling temp. Ox)

Aluminum:

k_{al} = 237 [W/(m*K)]
L_{al} = 0.391 [in]

Foam Insulator:

k_{ins} = 0.039 [W/(m*K)]
L_{ins} = 0.25 [in]

Final Value

$$\boxed{\dot{m} = 0.0042\ \frac{kg}{s}}$$

Convert to SCFM

$\rightarrow$

$$\boxed{6.22\ \text{SCFM}}$$

Vent Sizing Calculations

Boil-Off + Fill Rate,
converted from SCFM to GPM

Specific **G**ravity of **cold GOx**

$$\boxed{C_v \geq Q\sqrt{\frac{SG}{\Delta p}}}$$

$$\rightarrow \quad \boxed{C_{v,vent} \geq 6.41}$$

Δp: size vent for steady-state venting at low pressure differential **(1-2 psi)** to prevent high pressure build-up

(C_v of vent must be of at least this value to ensure volumetric flow rate of boil off + fill rate can be sustained)

Feed System Components & Specifications

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Motivation

- We wanted to reuse as many valves, fittings, and components from Hydra as possible.
    - Despite new funding for Atlas, the original objective of recycling as much as possible remains

Check Valve Selection

Feed System Side: Purge, Pressurant
P&ID Reference: CKV 302, CKV 001
Vendor: Check-All
Part Number: SS-8CP2-1
Cv: 4.3
Inlet/Outlet: ½ in. Female NPT
Max Pressure: 3000 psig
***Reusing from Hydra (formerly CVK-003, CVK-002)**

Feed System Side: Purge
P&ID Reference: CKV 301
Vendor: Check-All
Part Number: TFDSSMT1.50SS
Cv: 3.1
Inlet/Outlet: ½ in. Male AN
Max Pressure: 3000 psig
Price: $183.35

Check Valve Selection

Feed System Side: LOx
P&ID Reference: CKV 101
Vendor: Check-All
Part Number: U3HSSTF1.50SS
Cv: 14.6
Inlet/Outlet: 1 in. Female NPT
Max Pressure: 3000 psig
Price: $213.15

Feed System Side: Pressurant, LOx
P&ID Reference: CKV 002, CVK 102
Vendor: Check-All
Part Number: U3DSSTF1.50SS
Cv: 4.3
Inlet/Outlet: ½ in. Female NPT
Max Pressure: 3000 psig
Price: $118.5

***Reusing one check valve from Balerion (CVK 201)**

Solenoid Valve Selection

Feed System Side: Purge

P&ID Reference: SV 303, SV 304

Vendor: GC Valves

Part Number: H401GF24Z1DF5E

Inlet/Outlet: ½ in. Female NPT

Max Pressure: 2200 psig

CV: 1.5

Price: $132.80

***Reusing SV-301 and SV-302 from Hydra**

Needle Valve Selection

Feed System Side: Purge

P&ID Reference: NV 301

Vendor: McMaster

Part Number: 4559K34

Inlet/Outlet: ½ in. Female NPT

Max CV: 0.76

Max Pressure: 6000 psig

Price: $57.95

***Reusing NV-201 and NV-302 from Hydra**

Filter Selection

Feed System Side: Pressurant/Purge

P&ID Reference: FLTR-007,301

Vendor: Swagelok

Part Number: SS-8TF-60

Inlet/Outlet: ½ in. Swagelok Tube Fitting

Filter Size: 60 Micron

Max Pressure: 6000 psig

Price: $182.27

Feed System Side: LOx

P&ID Reference: FLTR-101

Vendor: Chase Filters

Part Number: 23T-8P8P-150ST

Inlet/Outlet: ½ in. Female NPT

Filter Size: 60 Micron

Max Pressure: 6000 psig

Price: $687.00

Flow Meter Selection

Feed System Side: LOx, Fuel

P&ID Reference: FM-101,201

Vendor: Turbine Inc.

Part Number: HA0100-AN-NI

Inlet/Outlet: 1 in. AN

Transmitter: 4-20 mA

Transmitter Part Number: FIC712-2

Flow Rate: 5-60 GPM +/- 0.5% of flow rate

Max Pressure: 2000 psig

Price: $1438

Propellant Tank Selection

Feed System Side/Fluid: Pressurant

Vendor: Tri-Med

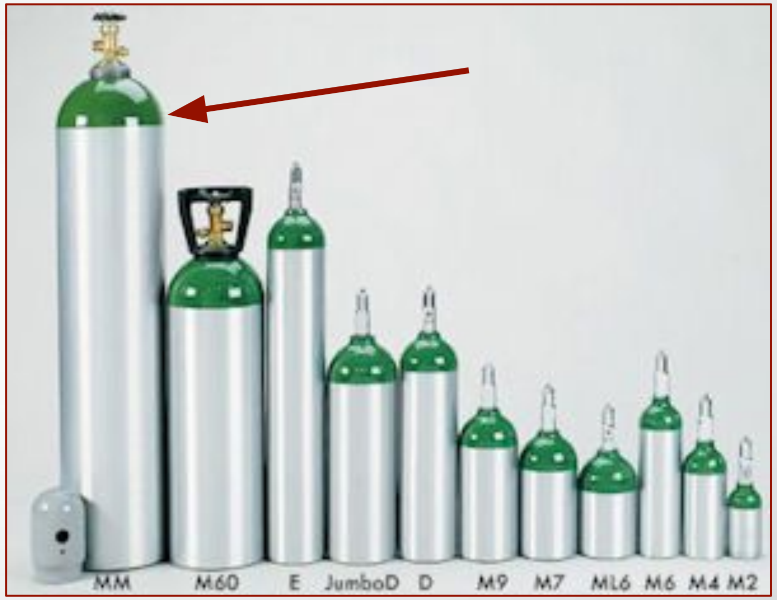
Part Number: CGA540 - SKU 20010

Max Pressure: 2200 psig

Inlet/Outlet: ⅜ in NPT & 1-1/8"-12 UNF

Price: $399.99

***Will be tapping the tank + tank will be heat treated**



Common Oxygen Cylinder / Tank Size Chart:

	LITERS	PSI	HT	DIAM	LBS.
M2	40	2200	9.0	2.5	.74
M4 = A	113	2200	12.0	3.2	1.6
M6 = B	165	2200	15.0	3.2	2.8
ML6	165	2200	10.68	4.38	3.4
M9 = C	255	2000	14.1	4.38	3.7
D	425	2000	20.0	4.38	5.3
Jumbo D	640	2000	20.0	5.25	8.1
E	680	2000	29.0	4.38	7.9
M60	1738	2200	23.0	7.25	21.7
MM	3455	2200	35.75	8.0	38.6
H (K)	7842	2000	55.0	9.0	120

Fuel Supply Tank Selection

Feed System Side: Fuel

Vendor: Scepter

Part Number: 08669

Capacity: 12 Gallons

Inlet/Outlet: ¼ in. NPT Pick-Up

Material: Polyethylene

Price: $95.00

Fuel Pump Selection

Feed System Side: Fuel

P&ID Reference: FP-001

Vendor: Grainger

Part Number: 38NH83

Inlet/Outlet: ½ in. NPT

GPM: 10 GPM

Rated Fluid: Liquid Fuels (i.e Kerosene, gasoline, diesel)

Discharge Head: 36 ft.

Price: $182.04

High Pressure Ball Valve Selection

Feed System Side: Pressurant

Hand Ball Valve

P&ID Reference: HBV-001

Part Number: CHPFNGSFM

Inlet/Outlet: ½ in. Female NPT

Vendor: Assured Automation

Cv: 28

Max Pressure: 3000 psig

Price: $245.00

Pneumatic Ball Valves

P&ID Reference: PBV-001,002

Part Number: CRS329HP-½

Inlet/Outlet: ½ in. Female NPT

Vendor: CR-TEC

Cv: 19

Max Pressure: 3000 psig

Price: $425.00

Ball Valve Selection

Feed System Side: Pressurant/Fuel

<u>Inlet/Outlet:</u> <u>½ in. Female NPT</u>
Vendor: Assured Automation
Cv: 28
Max Pressure: 2000 psig

Hand Ball Valves
P&ID Reference: HBV-002,003,004,201
Part Number: C26NRXM
Price: $120.00
***Reusing 1 Handball Valve from Hydra (HBV-002)**

Pneumatic Ball Valves
P&ID Reference: PBV-003,004,005
Part Number: C26NRXC8SCC3F/C26NRXC8SOC3F
Pneumatic Actuator: C Series Dual Rack-n-Pinion
Supply Air Pressure: 80 Psig
Price: $454.00
***Reusing 2 Pneumatic Ball Valves from Hydra (PBV-003,004)**

<u>Inlet/Outlet:</u> <u>1 in. Female NPT</u>
Vendor: Assured Automation
Cv: 87
Max Pressure: 2000 psi

Pneumatic Ball Valves
P&ID Reference: PBV-201
Part Number: E26NRXC8SCC3F
Pneumatic Actuator: C Series Dual Rack-n-Pinion
Supply Air Pressure: 80 Psig
Max Pressure: 2000 psig
Price: $598.00
***Reusing Pneumatic Ball Valve from Hydra**

Cryogenic Ball Valve Selection

Feed System Side: Pressurant/Ox
Inlet/Outlet: ½ in. Female NPT
Vendor: Assured Automation
Cv: 18
Max Pressure: 3000 psig

Hand Ball Valves
P&ID Reference: HBV-005,101
Part Number: HPF51SS-1-FGF-L-215
Price: $609.20

Pneumatic Ball Valves
P&ID Reference: PBV-006,102
Part Number: HPF51SS-1-FGF-G-15
Pneumatic Actuator: C Series Dual Rack-n-Pinion
Supply Air Pressure: 80 Psig
Price: $1032.00

Inlet/Outlet: 1 in. Female NPT
Vendor: Assured Automation
Cv: 72
Max Pressure: 3000 psig

Pneumatic Ball Valves
P&ID Reference: PBV-101
Part Number: HPF51SS-1-FGF-G-25
Pneumatic Actuator: C Series Dual Rack-n-Pinion
Supply Air Pressure: 80 Psig
Price: $1231.00

PRV Orifice Sizing

The following equations was used to size the orifice:

Set pressure: 1889.7 psia

$$A = \frac{W\sqrt{TZ}}{CKP_1K_b\sqrt{M}}$$

Discharge Coefficient (K) = .75

Molecular Weight = 28 kg/kmol

Specific Heat Ratio = 1.4

T = 316.5 K (110 °F)

W = 4859 (lbs/h)

Nozzle Constant (C, function of γ) = 356

This provided an orifice sizing of: **0.2352 inches**.

PRV Selection

P&ID Reference: PRV-003,004

Part Number: PRVN4F-02-2-VV

Inlet/Outlet: ½ in. Female NPT

Vendor: Swagelok

Cv: 4.36

Max Pressure: 6000 psig

Orifice Diameter: 0.45 in

Price: $300

Rupture Disk Selection

P&ID Reference: RD-001,002

Part Number: NSP-2002-2

Inlet/Outlet: ¼ in. Female NPT

Vendor: NLB Corp.

Set Pressure: 2000 psig

Diameter: 0.25 in

Price: $50.20

→ Re-use existing Swagelok disk housing from Hydra Dev-1, swap-in new disk with correct set pressure

Regulator Selection

Feed System Side: Pressurant

P&ID Reference: REG-001 & REG-002

Vendor: Swagelok

Part Number: RSHN4-02-VVK-GN2

Cv: 1.84

Inlet/Outlet: ½ in. Female NPT

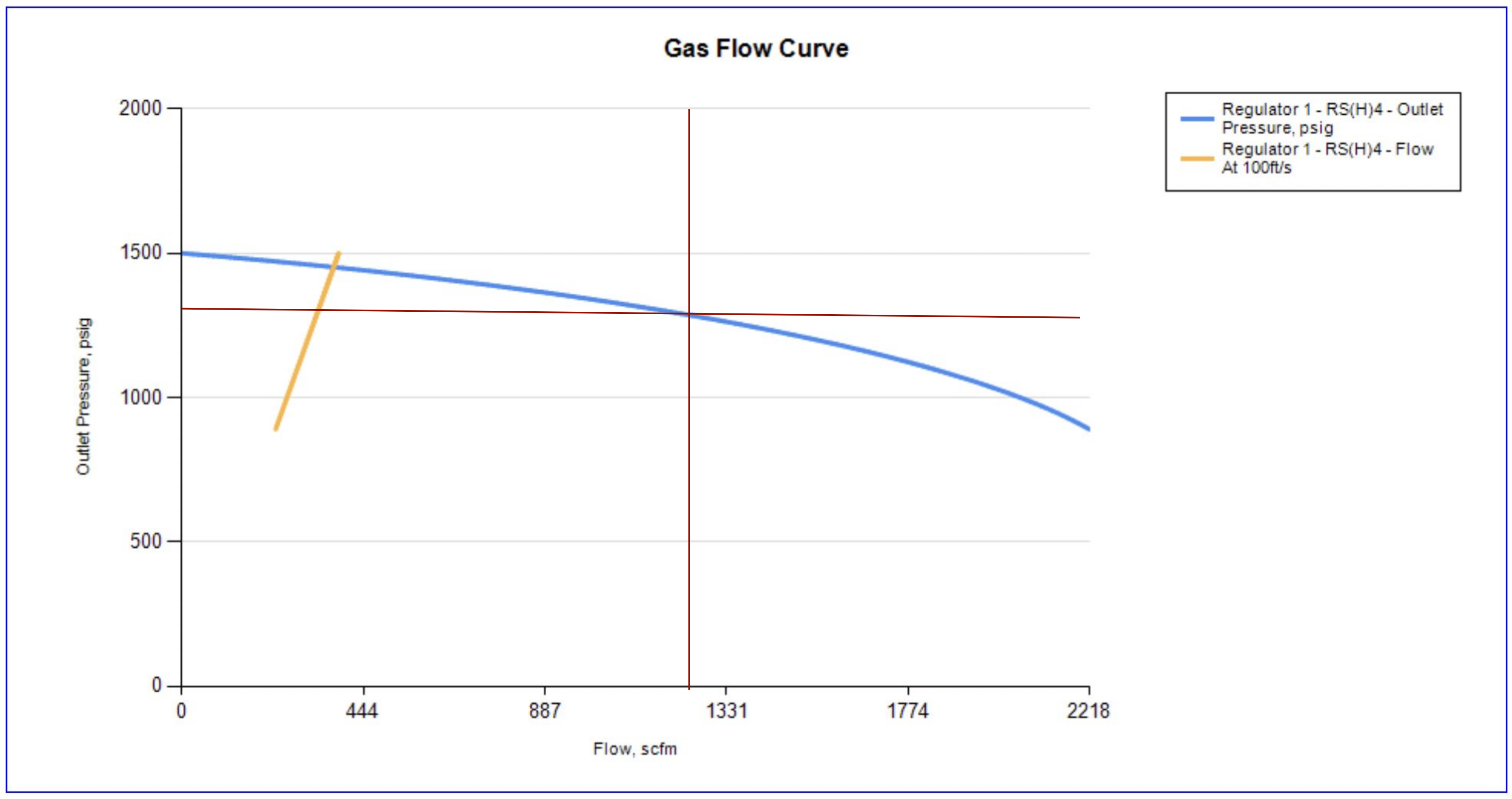
Max Inlet Pressure: 5800 psig

Pressure Control Range: 0 - 2175 psig

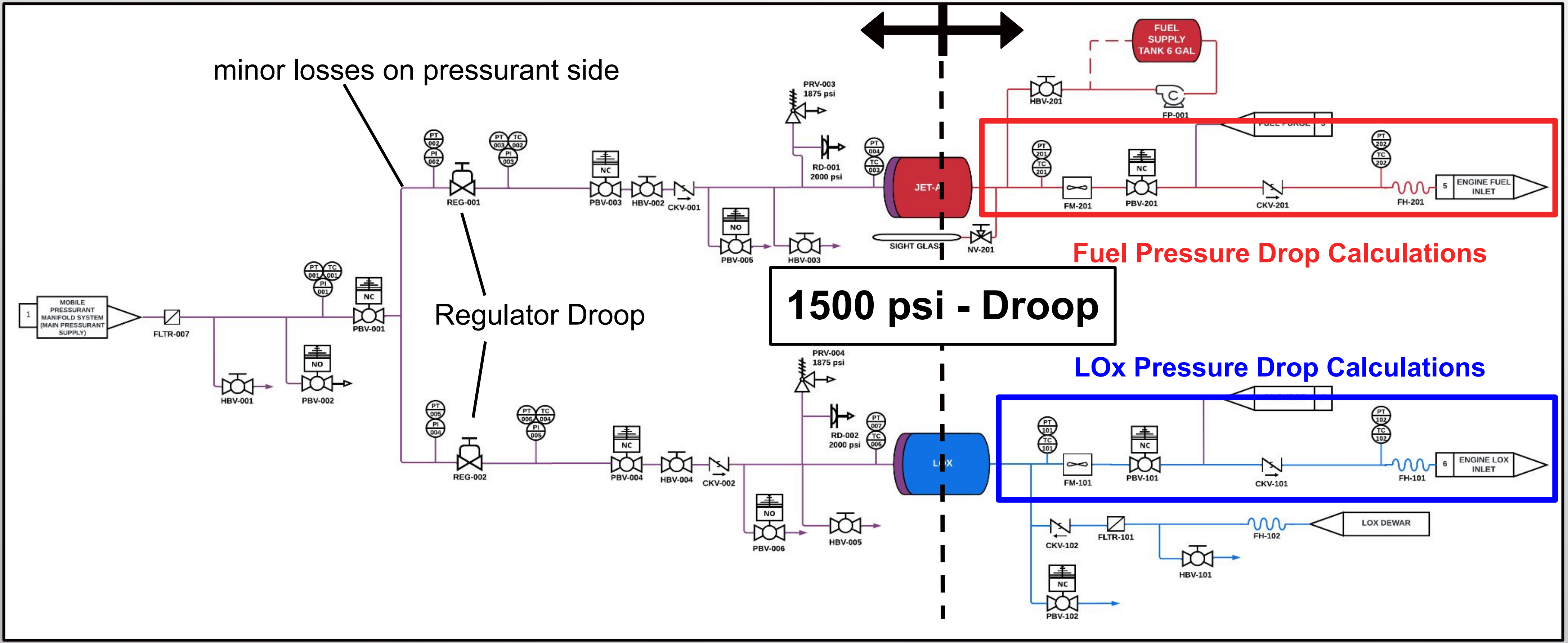
Price: $2148.21

Droop

Droop: A decrease in outlet pressure caused by an increase in flow rate to a pressure reducing regulator.



Pressure Drop



Inlet Pressures

Pressure Drop - LOx

→ **1249 psi**

Pressure Drop - Fuel

→ **1262 psi**

Instrumentation

Pressure Transducers

- PT's on cryo lines will have a stand-off to avoid the need for cryo rated PT's

P&ID Reference: PRV 001, 002, 003, 004, 005, 006, 007, 101,102, 201, 202, 401

Part Number: PX359

Inlet/Outlet: ¼ in. Male NPT

Vendor: Omega

Max Pressure: 1000 psia

Price: $371.01

Thermocouples

- T-type TCs for all cryo wetted components and K-type for the rest

P&ID Reference: TC 001, 002, 003, 004, 005, 101, 102, 201, 202

Part Number: TQSS

Inlet/Outlet: ¼ in. Male NPT

Vendor: Omega

Max Temperature: 1150 Celsius

Price: $50

Feed System Cost

Component Cost Before Savings	$28,787.41
Component Cost After Savings	**$27,289.01**
Component Savings	$1,498.40
Fitting Cost Before Savings	$5,614.51
Fitting Cost After Savings	**$5,232.88**
Fitting Savings	$381.63
Total Cost	**$32,521.89**

*Potential Savings from PTs: $4452.12

Tank Support Structure

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Tank Structure

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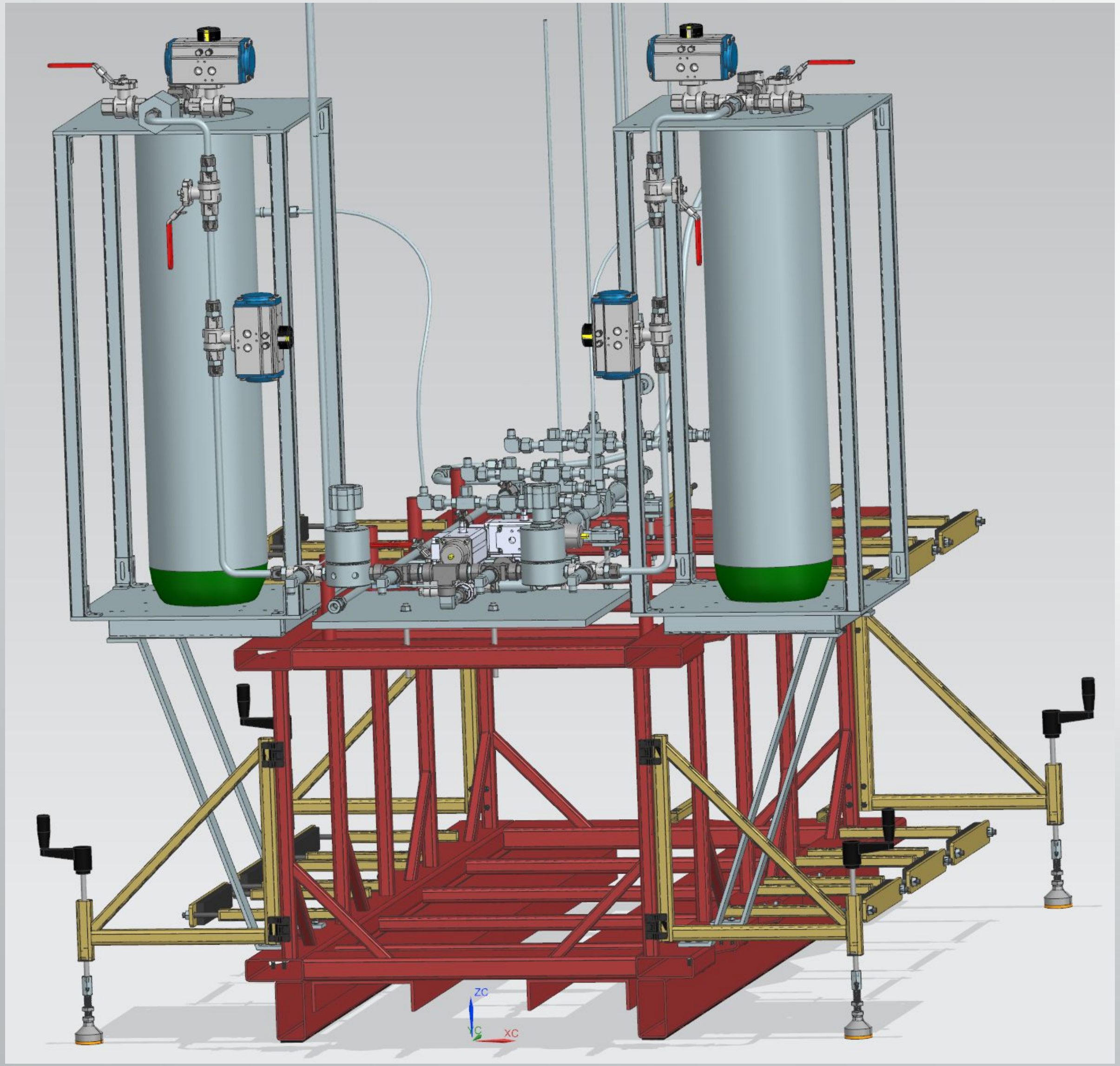
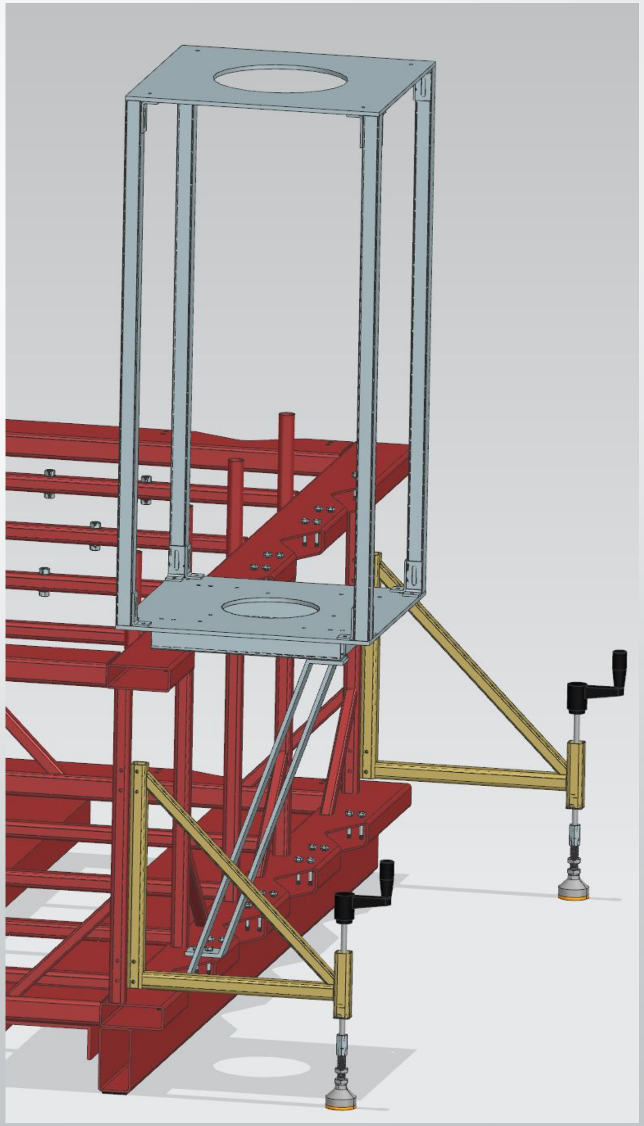
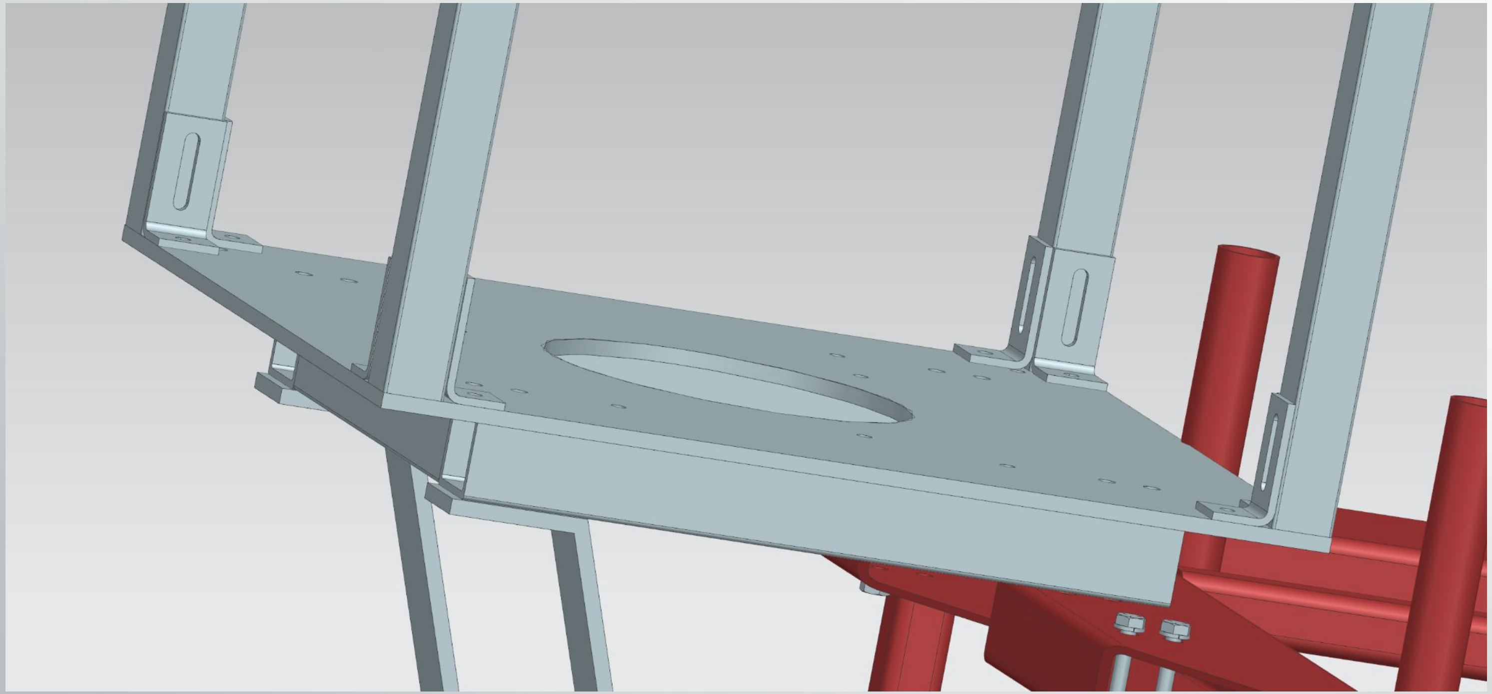
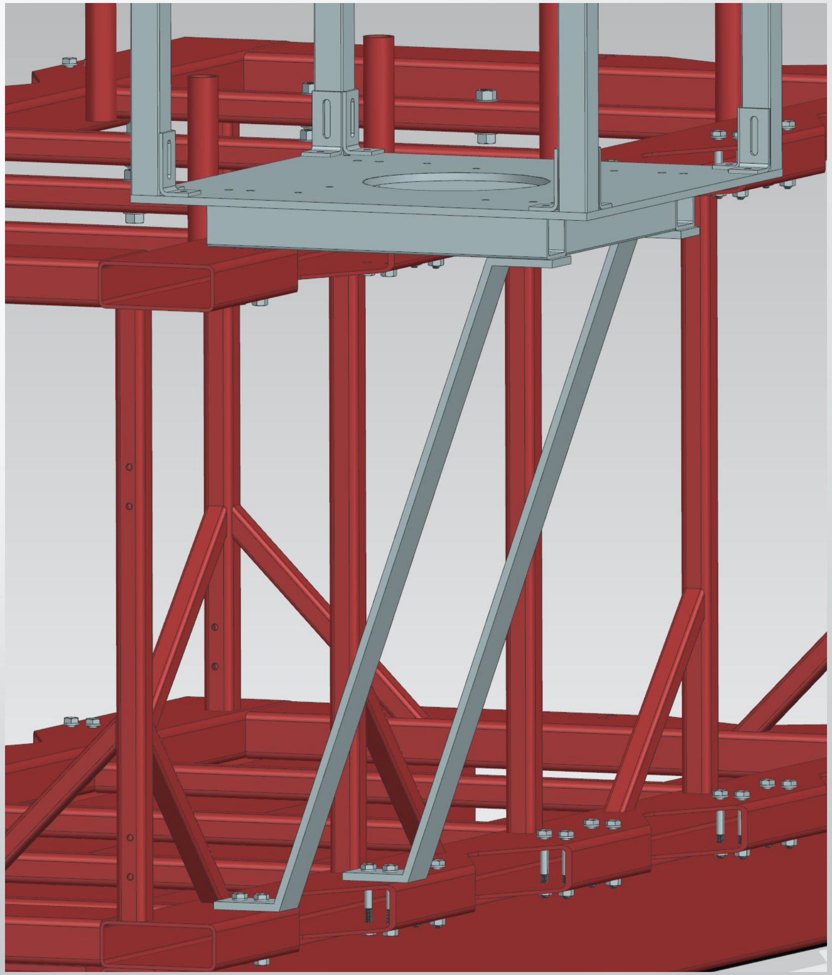


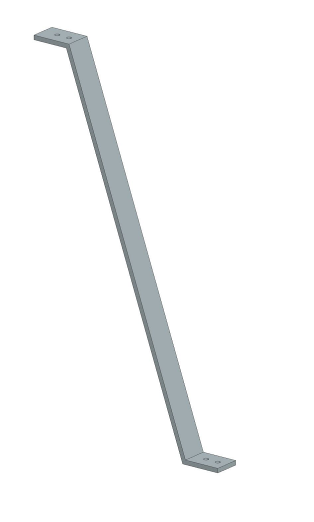


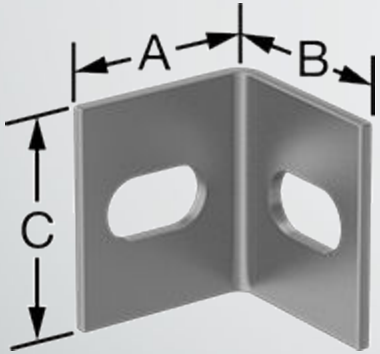
Tank Structure

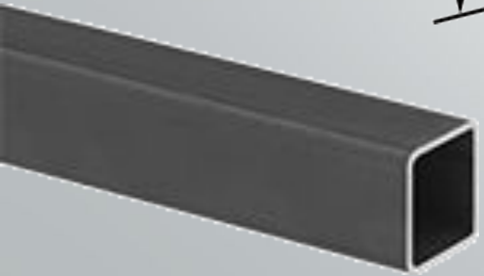




Tank Structure







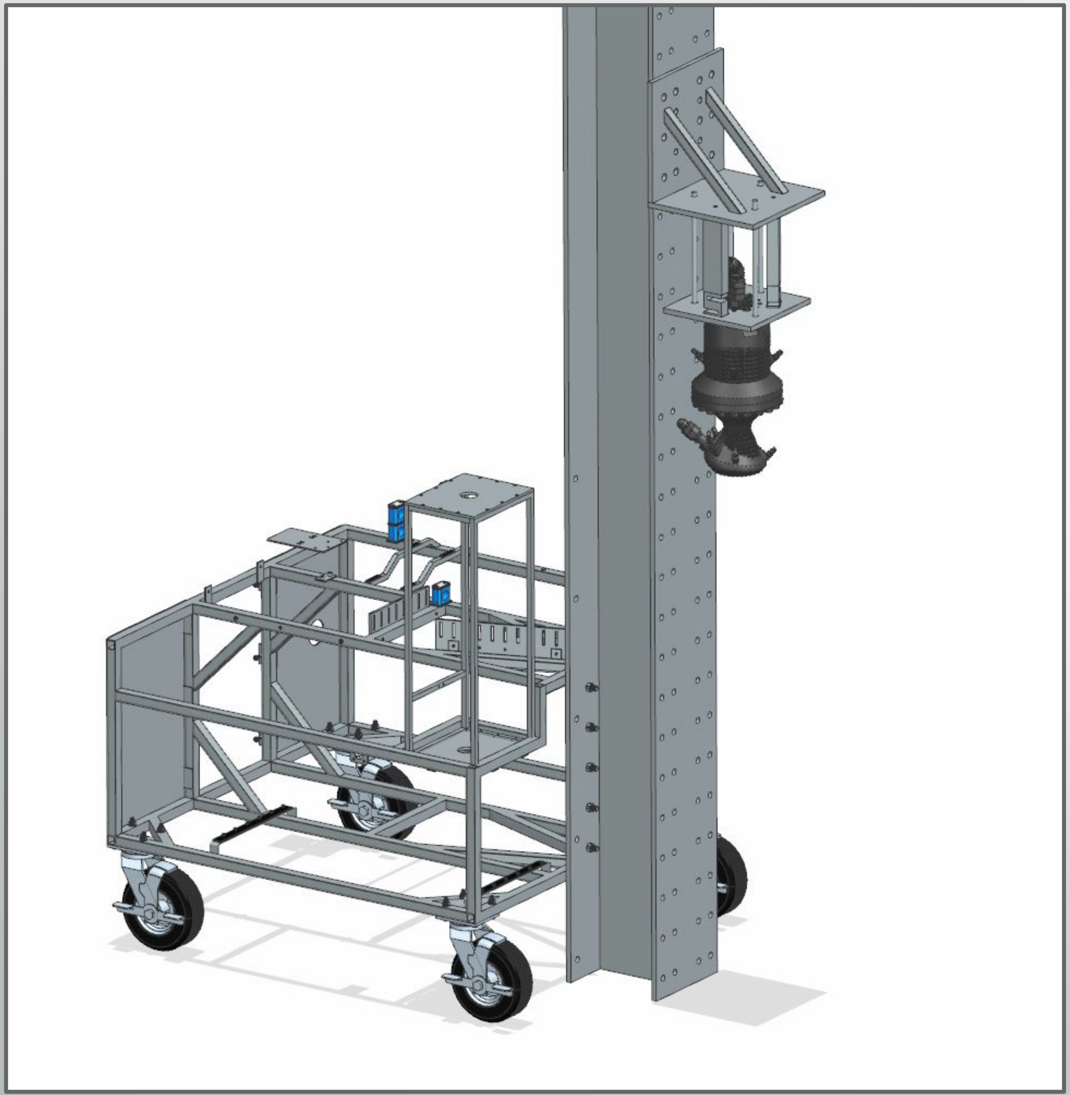
Component	Vendor	Amount	Price/Unit	Total Price
Square Tubing 3 ft (Vertical Column)	McMaster	4	$7.69	$30.76
Angle Brackets	McMaster	16	$9.01	$144.16
Steel Plates	McMaster	2	$67.70	$135.40
Square Tubing (Tank Platform)	McMaster	1	$7.69	$7.69
Steel Bar (Truss)	McMaster	2	$33.72	$67.44
Bolts	McMaster	48	$13.86 (50 pc.)	$13.86
Nut	McMaster	48	$8.95 (100 pc.)	$8.95
Total (excluding machining costs)				**$408.26**

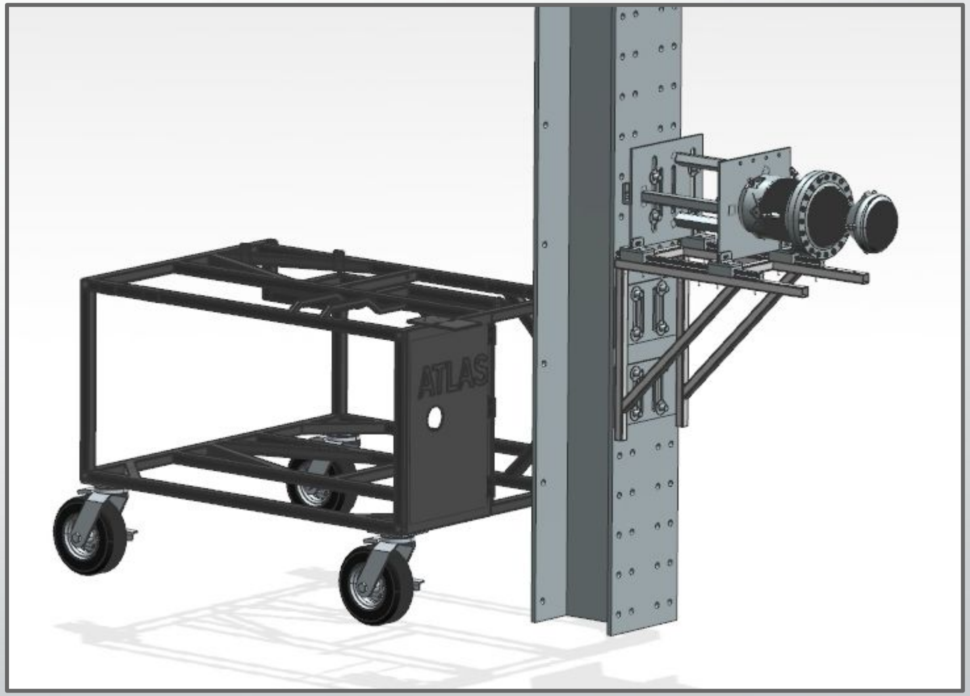
Engine Mount

Liquid Propulsion Laboratory

USC Viterbi
School of Engineering

New Horizontal Engine Mount

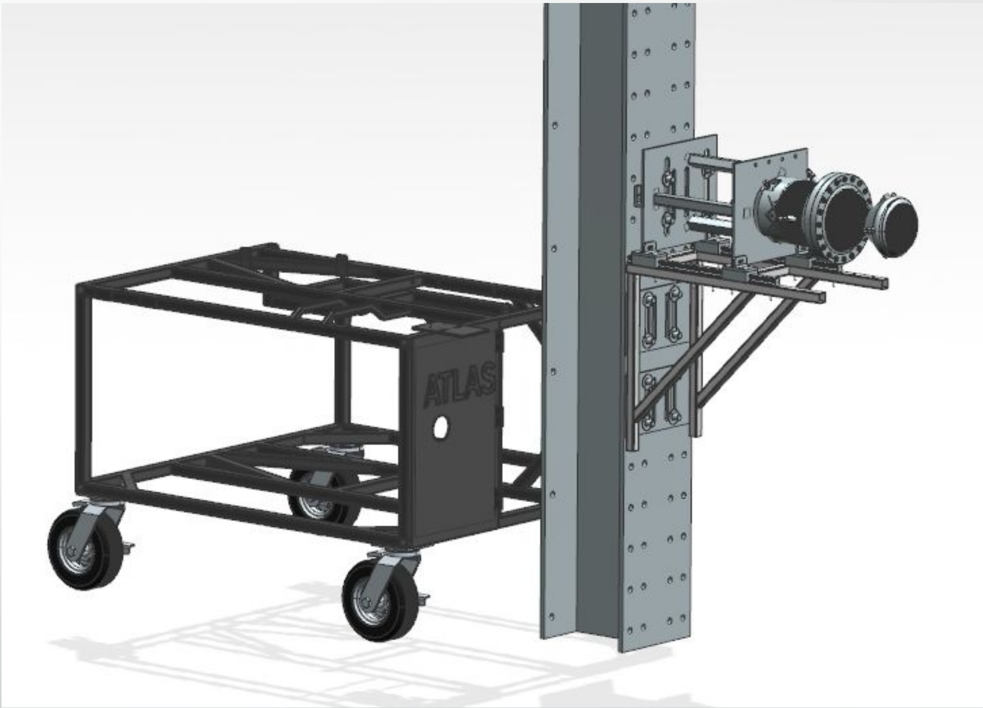




Motivation

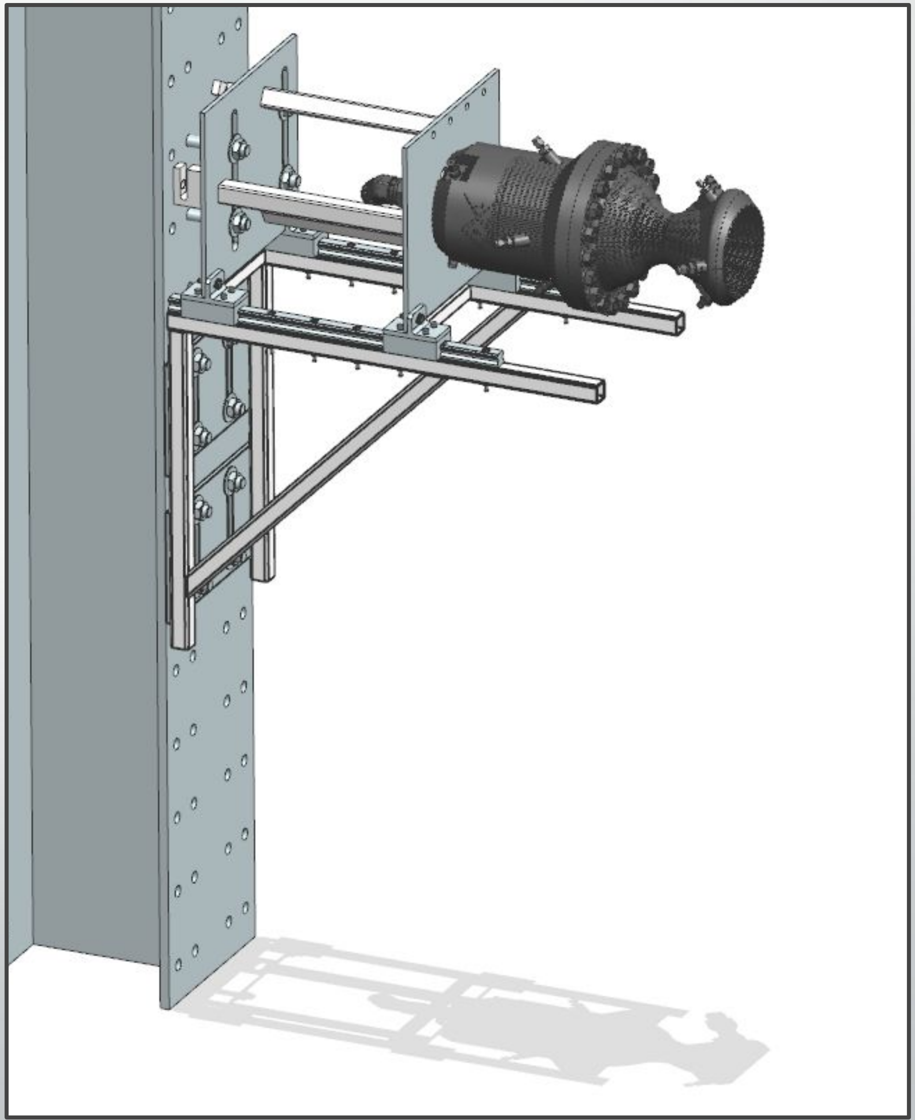
- Reduces complexity of feed system
  - Previously needed to bring both main lines, both purge lines, pneumatic lines, and DAQ wiring 6-8 ft up to Balerion
- Eliminates need for flame diverter reduces size of blast shield

- Why did we have vertical in the first place?
  - Based on Balerion history wanted to minimize chance of a hard start
    - No longer pre-chilling

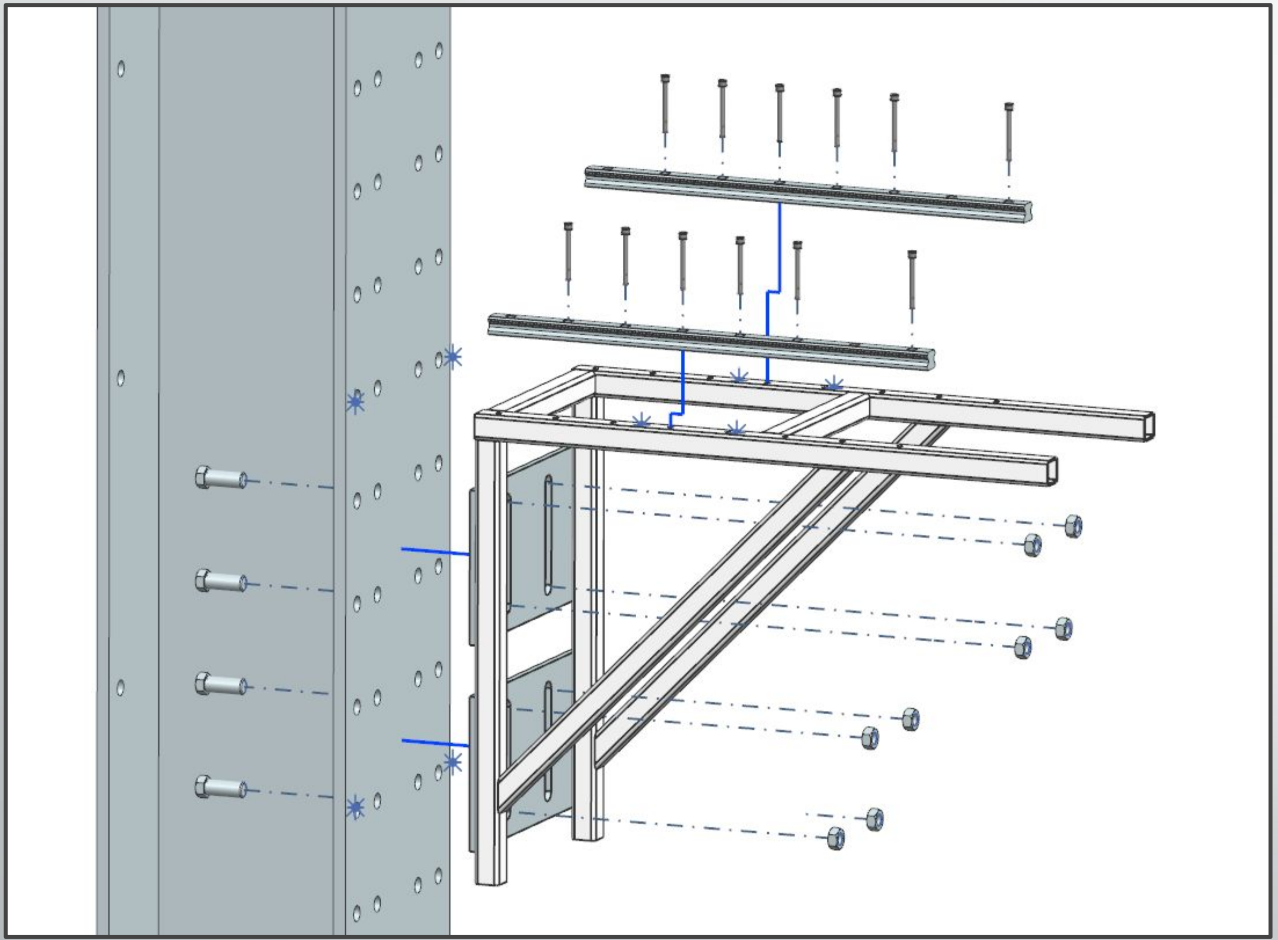


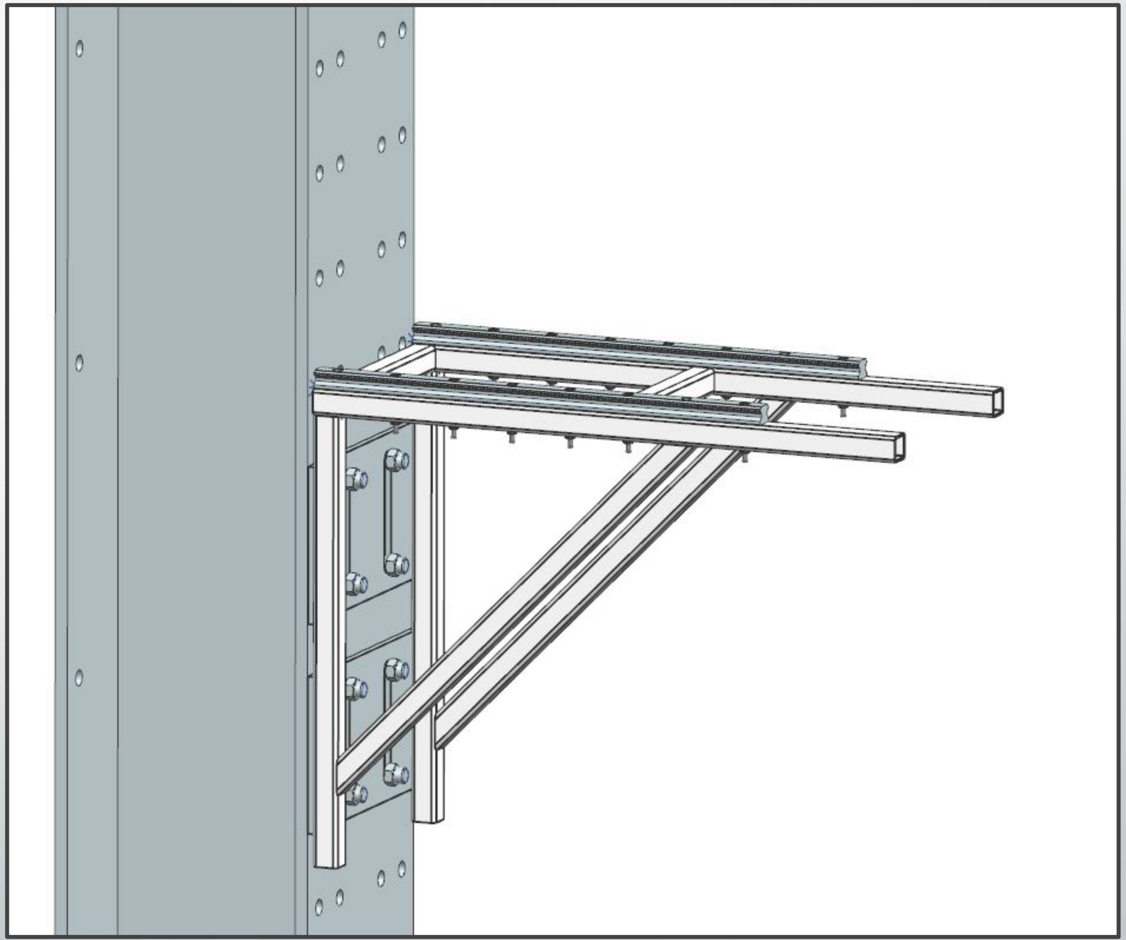
Requirements

- Engine Mount shall…
  - Interface with FAR’s Extra Large I-Beam
  - Interface with Balerion engine
  - Create even preload for load cells
  - Be liftable by 1-2 People
  - Withstand Balerion’s Max Thrust (with 2.25 FOS)

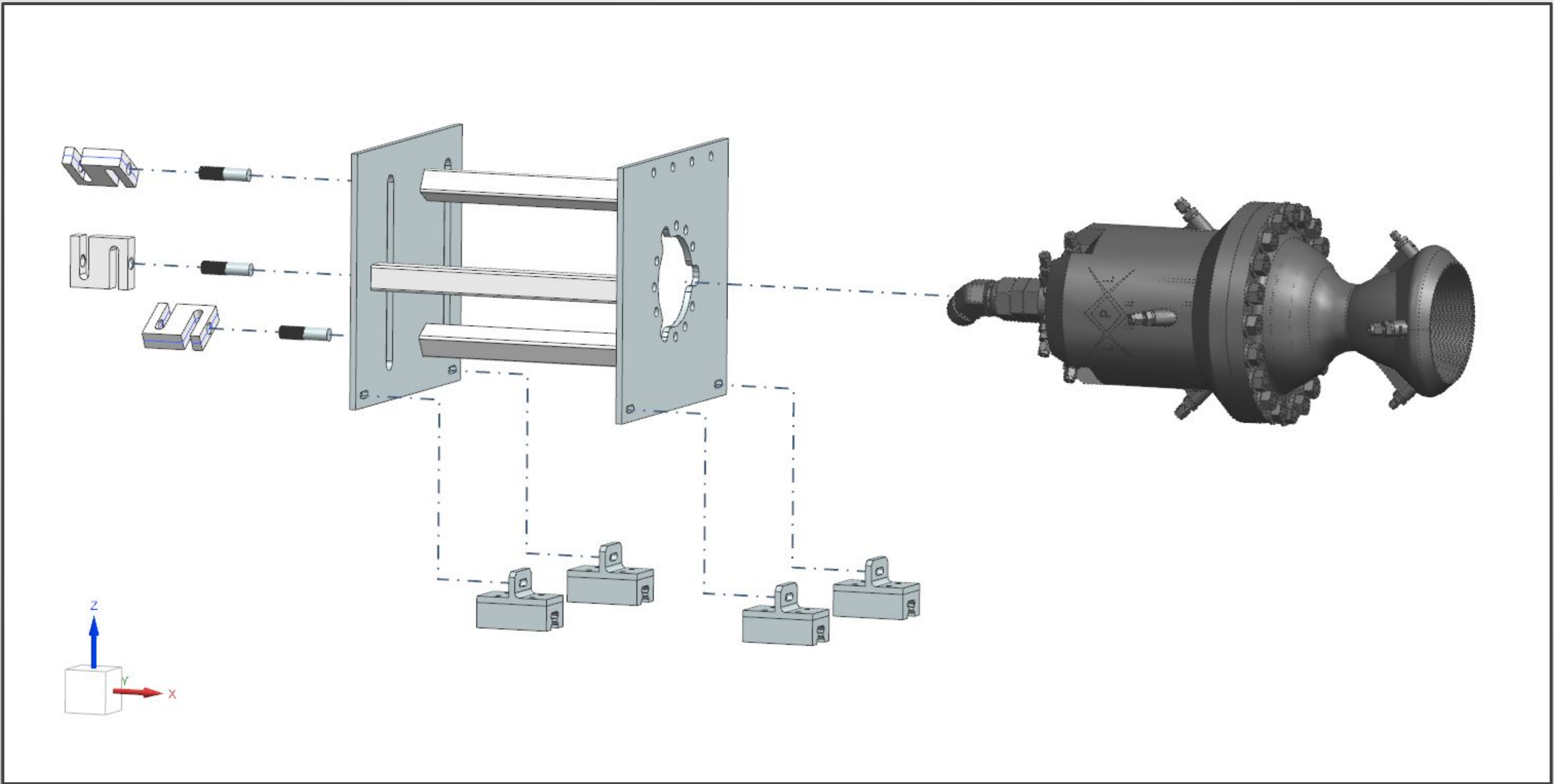


Design Overview - Rail Platform

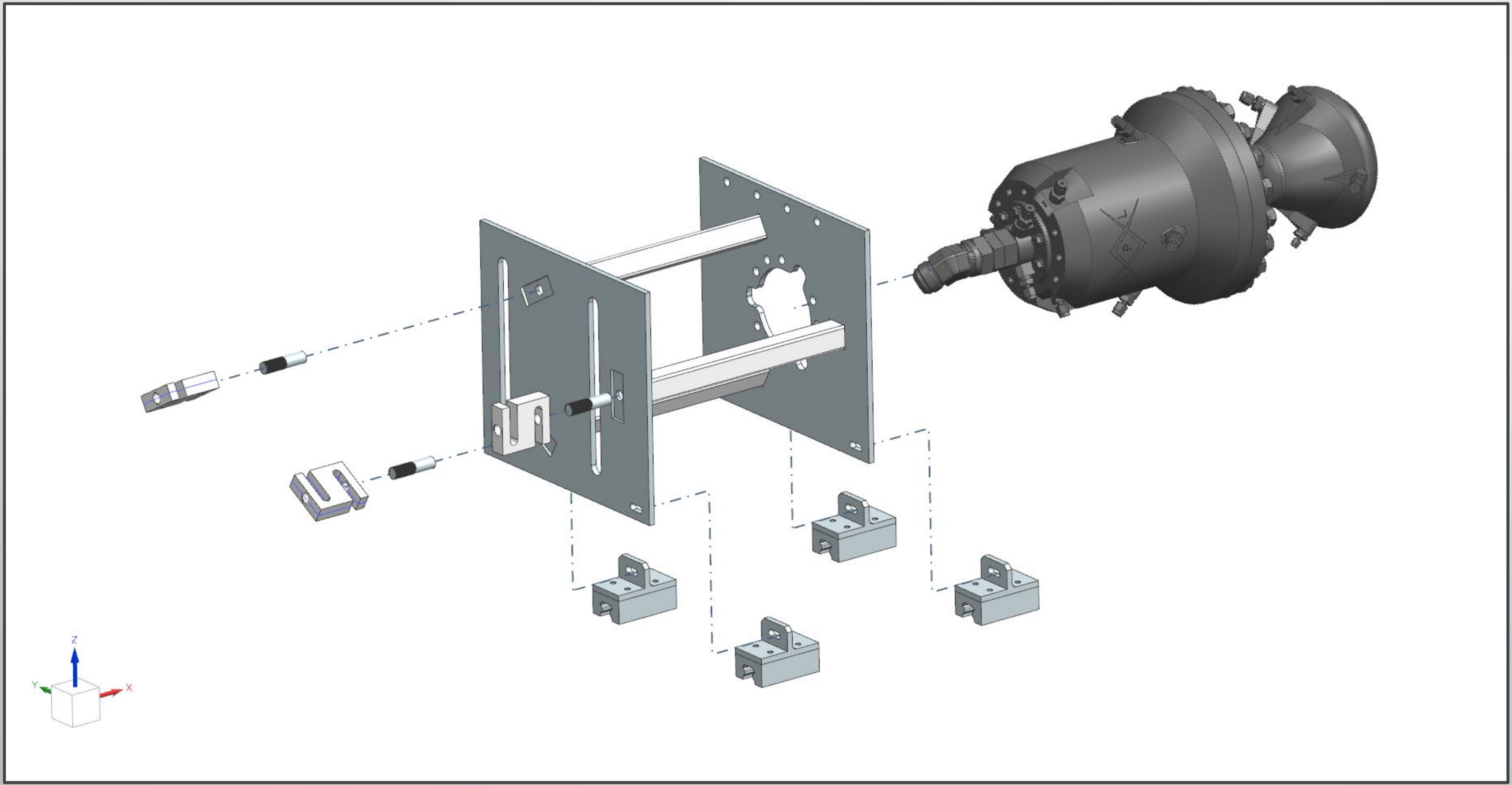




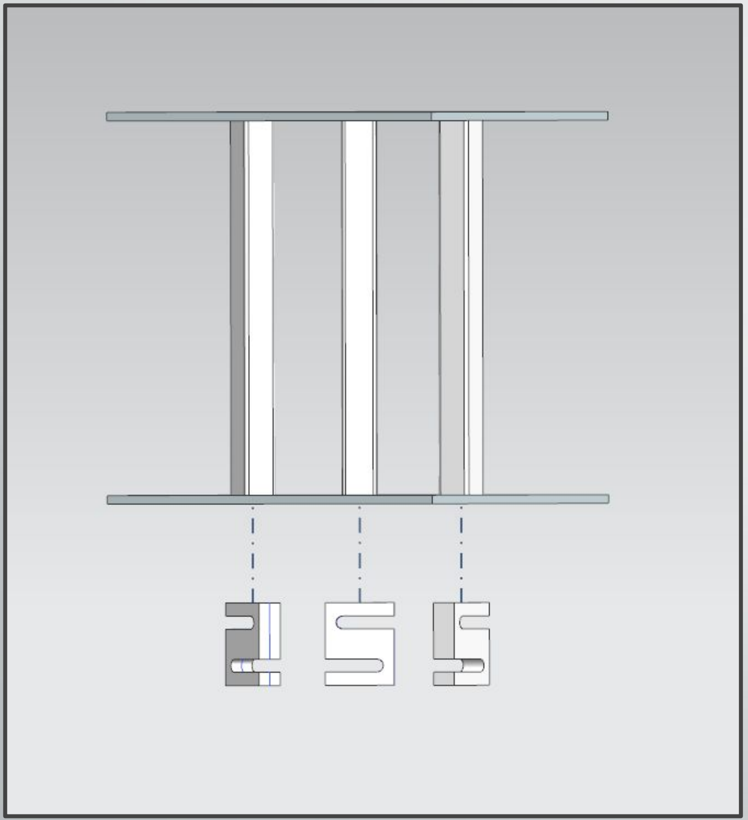
Design Overview - Milk Stool

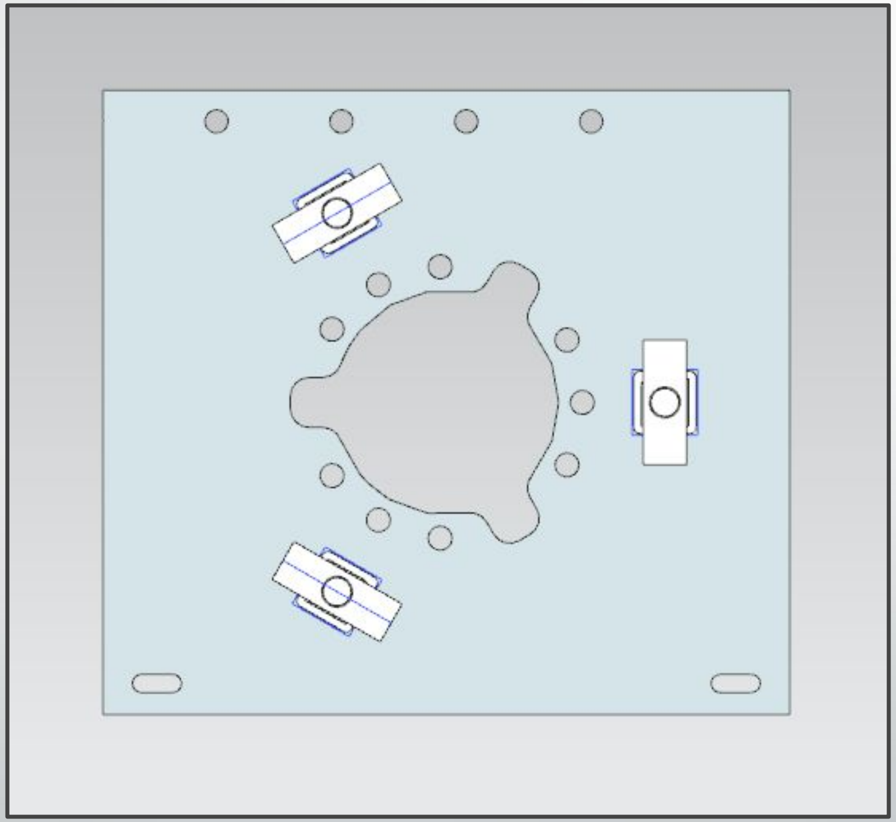


Design Overview - Milk Stool



Design Overview - Load Cells

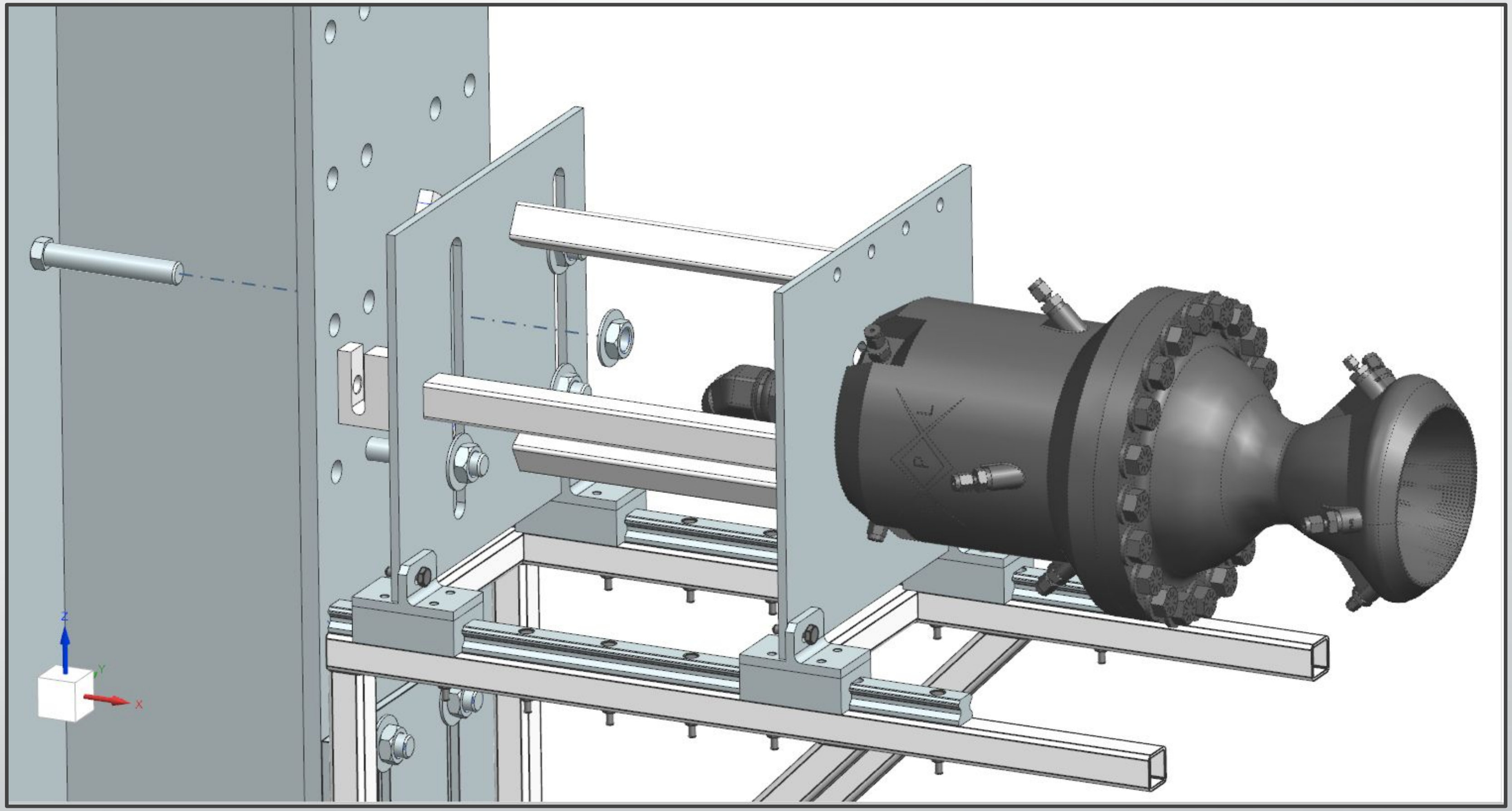




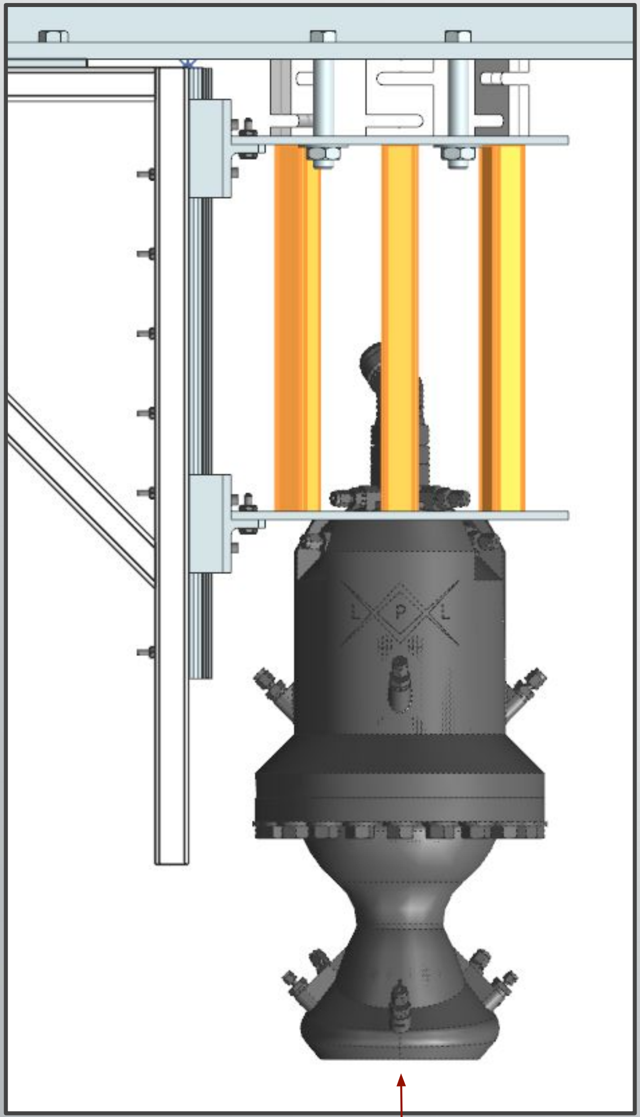
- Redundancy
- Off-axis loading measurement
- Parallel arrangement reduces cost as cells experience ⅓ of thrust, lowering load rating

Design Overview - Interface

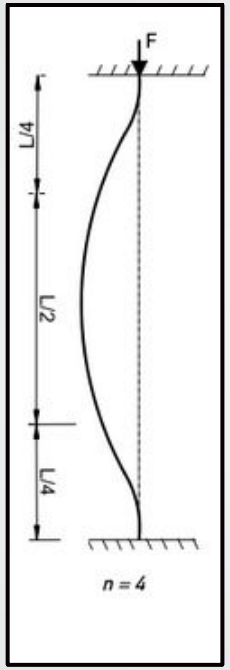
- Ball bearing carriages allow for untampered measurement of thrust (mitigates friction)
- Slots allow for vertical misalignments
- Use of UNF bolts to prevent loosening during engine fire

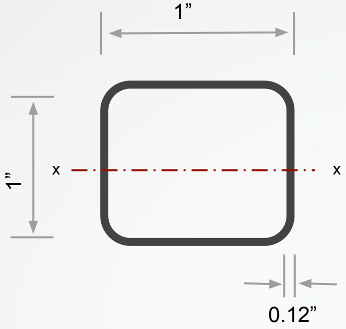


Structural Analysis - Hand Calcs



2250*2 lbf





$n = 4$

$E_{A36} = 29{,}000$ ksi

$L = 11$ in

$F_m = 1500$ lbf

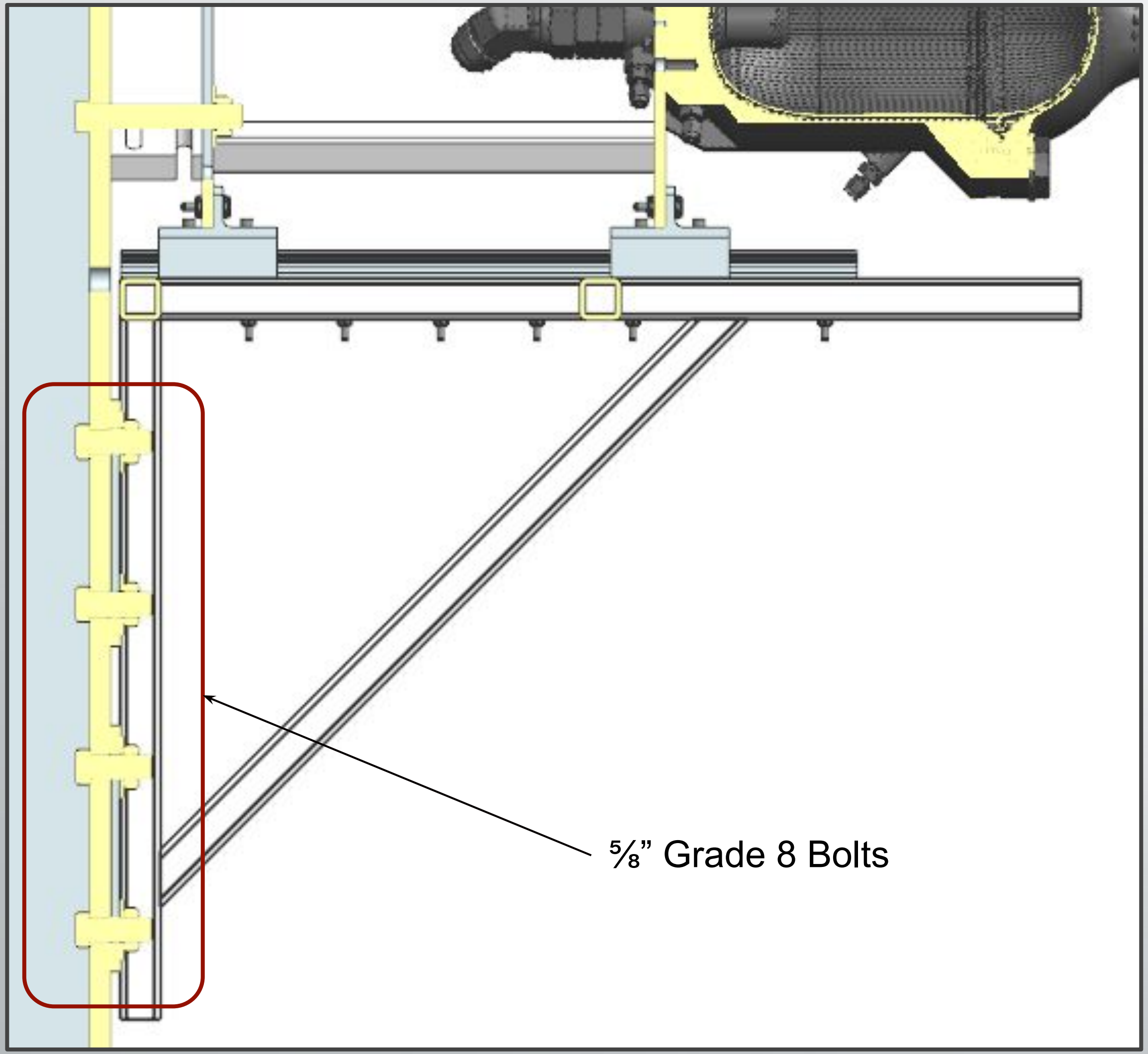
$I_{xx} = bh^3/12 = (1^4 - 0.76^4)/12 = 0.055 \text{ in}^4$

$F_{crit} = n\,\pi^2 E_{A36} I_{xx} / L^2 = 1577$ kip

$SF_{buckling,xx} = F_{crit,xx} / F_m = 346$

Each column can support x346 its expected load before buckling occurs

Structural Analysis - Hand Calcs



$\sigma_{y,\ grade\ 8\ steel}$ = 150 kip

Tensile Stress Area = 0.226 in^2

$\mu_{static,\ steel\text{-}steel}$ ≈ 0.7

K = 0.2

Preload Force = (75%) * $\sigma_{y,\ grade\ 8\ steel}$ * (Tensile Stress Area)

= (0.75) * (150 kip) * (0.226 in^2)

= **25,430 lbf**

Installation Torque = K * (⅝" nominal diameter) * (Preload Force)

= (0.2) * (0.625 in) * (25,430 lbf)

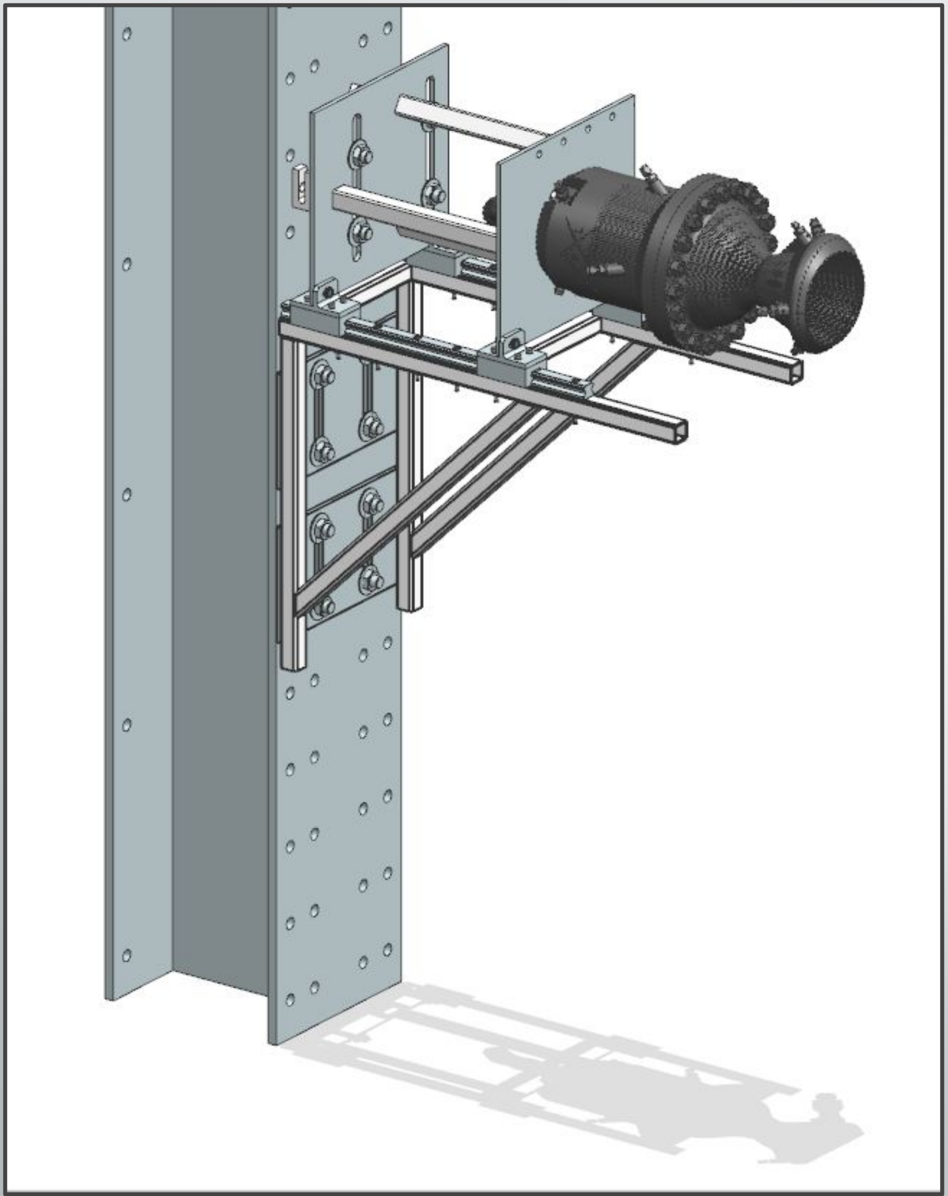
= **2,543 in-lbf**

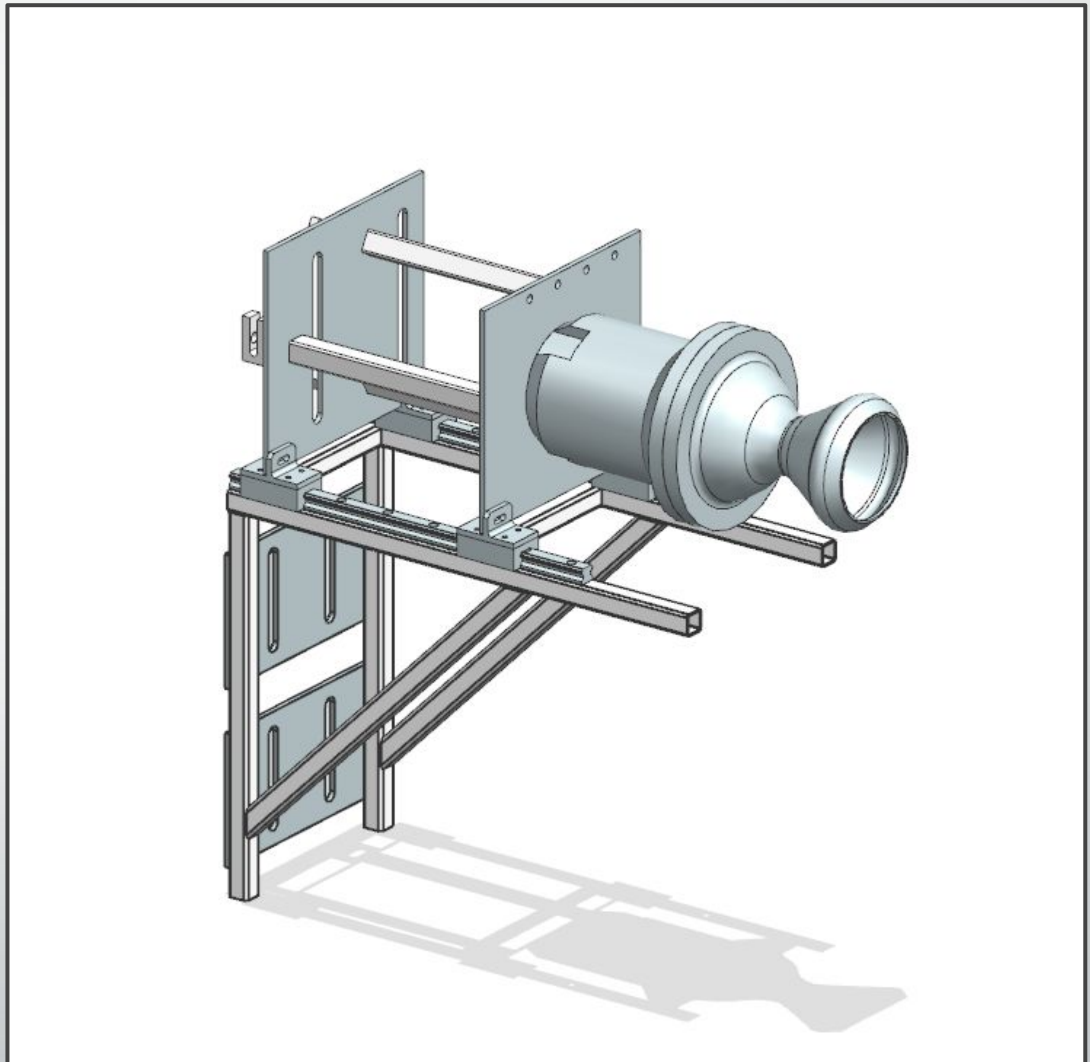
Clamping Friction = (# of bolts) * (Preload Force) * $\mu_{static,\ steel\text{-}steel}$

= (8) * (25,430) * (.7)

= **142.4 kip**

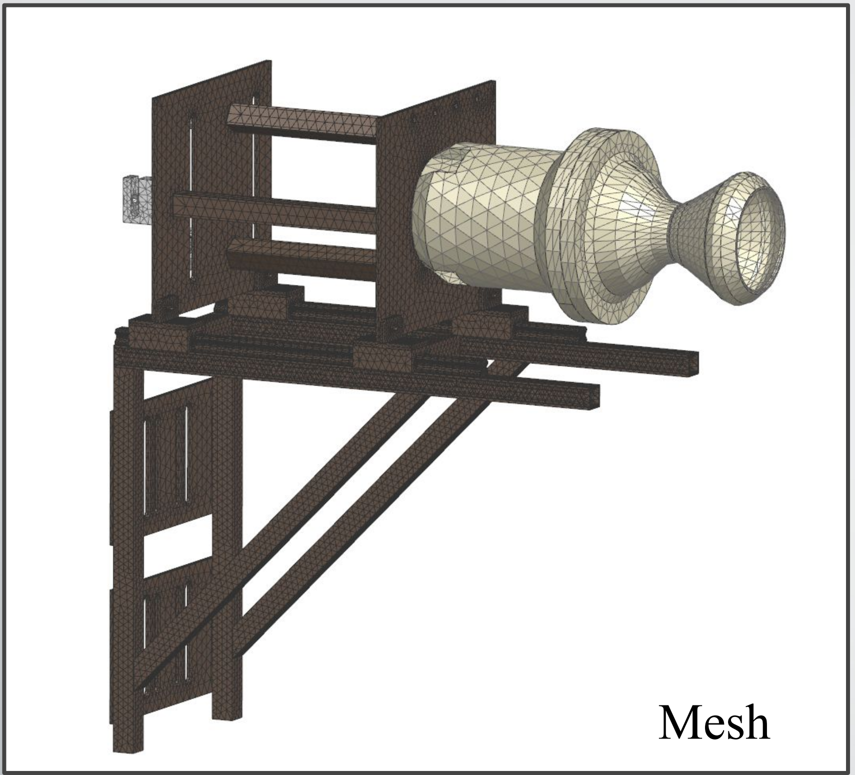
Structural Analysis - FEA

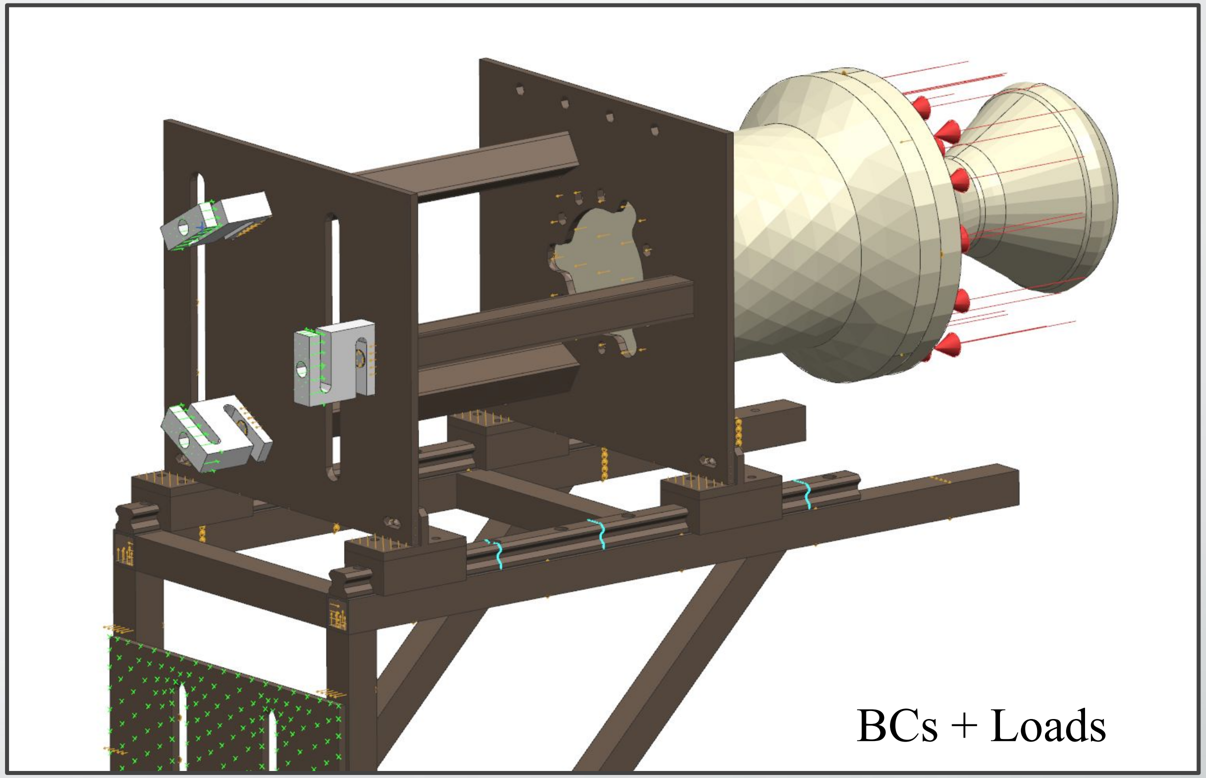




Simplified Model

Structural Analysis - FEA

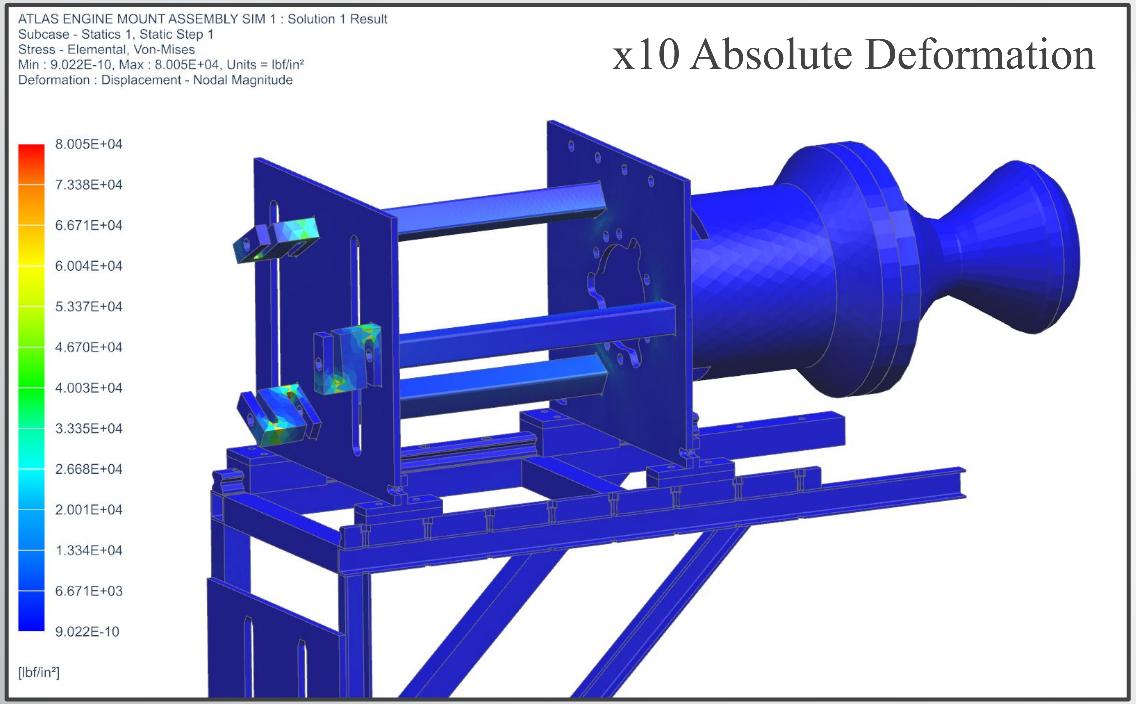

Mesh


BCs + Loads

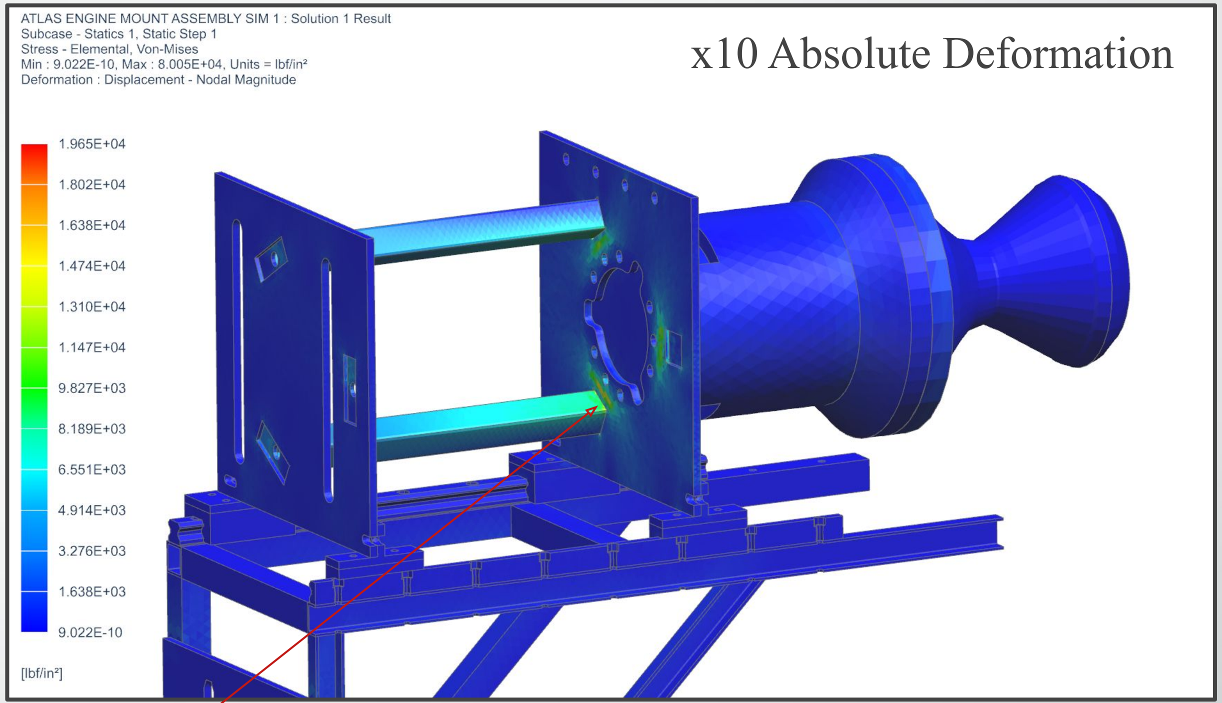
- A36 Steel
- 310 Stainless steel
- Inconel 718 aged

- Fixed BC
- Simply Supported BC
- Thrust: 2250 lbf x 2 = 4500 lbf
- Glue contact

Structural Analysis - FEA



VMSTRESS 1



VMSTRESS 2

~ 14000 psi

*contour rescaled after hiding load cells

$\sigma_{y,\,A36} = 36{,}300$ psi

$\boxed{SF_{min} \approx 2.6}$

Material Costs

Part	Description	Individual Cost [$]	Quantity	Total Cost [$]	Part Number	Manufacturer
Steel Square Cross Sectional Tubing	1" x 0.12" Carbon Steel Square Tube A500/A513 Hot Rolled, 6ft	32.95	2	65.9	10305	Online Metals
Steel Guide Rails	20 mm Wide Guide Rail for Ball Bearing Carriage, Rail Length 280mm	109	2	218	6709K63	McMaster
Steel Carriages	Ball Bearing Carriage for 20 mm Wide Rail	127	4	508	6709K18	McMaster
Engine Mount Plate	1/4 inch THICK A36 Steel Plate 1ftx4ft	96.76	1	96.76	P112	Metals Depot
Steel Rectangular Bar Stock	1in x 2in. Hot Rolled A-36 Steel Rectangle 4ft	51.96	1	51.96	P1112	Metals Depot
S-Beam Load Cell	High Accuracy, Stainless Steel, S-Beam Load Cell	122.1	3	366.3	LC103B-1K	ATO
M8 hex nut	x50 Zinc Yellow-Chromate Plated Steel Hex NutMedium-Strength, Class 8, M8 x 1.25 mm Thread	5.93	1	5.93	97700A160	McMaster
M8 25mm Steel Socket Head Screw	x50 Alloy Steel Socket Head ScrewBlack-Oxide, M8 x 1.25 mm Thread, 25 mm Long	12.67	1	12.67	91290A432	McMaster
M8 1mm Steel Socket Head Screw	x10 Fine-Thread Alloy Steel Socket Head Screw M8 x 1 mm Thread, 16 mm Long	8.33	1	8.33	96144A216	MCMaster
1/2"-20 UNF Flat Head Screw	x5 Zinc-Plated Alloy Steel Hex Drive Flat Head Screw1/2"-20 Thread Size, 1" Long	7.41	2	14.82	91263A795	MCMaster
5/8"-11 UNC Steel Hex Bolt	x5 High-Strength Grade 8 Steel Hex Head ScrewZinc-Aluminum Coated, 5/8"-11 Thread Size, 1-1/2" L	9.39	1	9.39	91286A397	MCMaster
5/8" Steel Hex Nut	x25 Medium-Strength Steel Hex NutGrade 5, Zinc-Plated, 5/8"-11 Thread Size	14.26	1	14.26	95462A533	MCMaster
5/8" Steel Washer	x10 316 Stainless Steel Washerfor 5/8" Screw Size, 0.688" ID, 1.5" OD	8.2	1	8.2	90107A035	McMaster
1/2"-20 UNF Threaded Stud	x1 Grade B7 Medium-Strength Steel Threaded Rod1/2"-20 Thread Size, 1" Longx	2.41	4	9.64	98750A478	McMaster
				1390.16		

Load Cells

OMEGA

- Specified Load: 2000 lbf (8900 N)
- Safe Overload: 150%
- Width: 27.94 mm
- Length: 50.8 mm
- Input Impedance: 430 +/- 50 Ohms
- Output Impedance: 351 +/- 2 Ohms
- Operating Temp: -35 to 65 Degrees Celsius
- Price: **$282.49**

ATO

- Specified Load: 2200 lbf (9800 N)
- Safe Overload: 150%
- Width: 25.4 mm
- Length: 51 mm
- Input Impedance: 380 +/- 10 Ohms
- Output Impedance: 350 +/- 3 Ohms
- Operating Temp: -20 to 65 Degrees Celsius
- Price: **$122.10**

Testing Campaign

Liquid Propulsion Laboratory

Proof Test

This will be done by subjecting the individual sections to 1.5x maximum expected operating pressure (MEOP), using a manual lever-pump (water is used instead of a compressible fluid as a safety precaution). This type of testing screens for acceptable workmanship and manufacturing defects.

Proof pressure:

2200 psi for downstream of regulator pressurant lines, main lines and tanks

4050 psi for upstream of regulator pressurant lines

*Ox Side lines have to be Ox cleaned after proof testing

Leak Test

This leak test is designed to identify potential leaks from the fittings of the systems. The test will use Snoop Liquid Leak Detector to identify leaks in the fittings and lines, applied at intervals of 2, 4 and 5 minutes after initiating the test at a certain pressure. The test will look for the presence of leaks at 50 psi, 100 psi, 200 psi and 375 psi.

Class I - Small, uniform (approximately 1/16 inch diameter) long persisting bubbles.

Class II - Mixture of random size bubbles, moderately persistent.

Class III - Large, fast forming bubbles of short persistence, most break as next one starts.

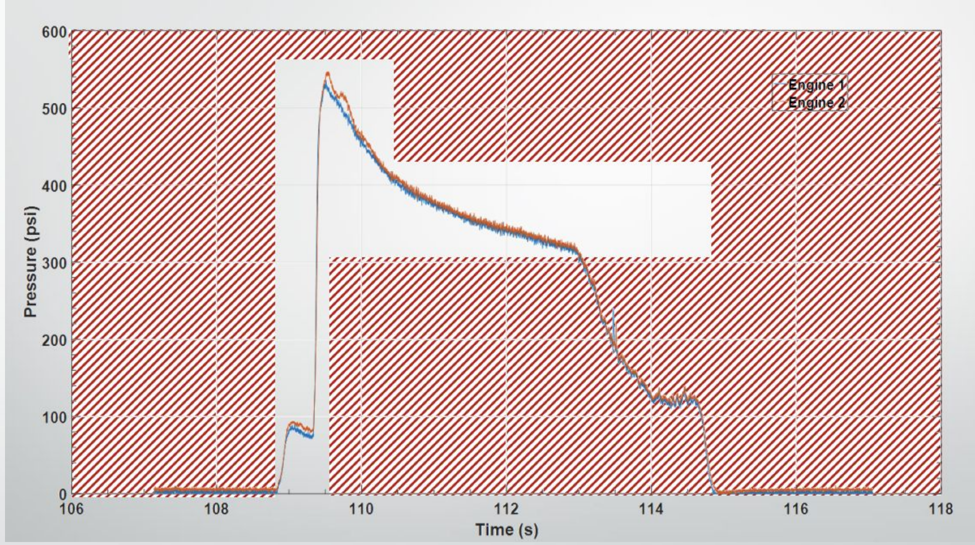
Testing Campaign

- Qualifying the Test Stand
  - Hydrostatically proof test of all lines
  - Proof test of propellant tanks
  - Leak test of system
- Flow Tests
  - Fuel Side Cold Flow
  - LOx Side Cold Flow

Cold Flows

This will be done in order to characterize flow rate, droop, and pressure drop through the system. This is a high pressure test flow where we will emulate hot fire procedures. This test also serves to prepare TCs and TDs for actual hot fire.

Data from Cold Flows will be used to create abort gates.



Water will be used for Fuel Side Cold Flow

Cryogenic Nitrogen will be used for Ox Side Cold Flow

We will machine an orifice with a specific Cv to simulate chamber pressure at the end of our system

*Previously used WFTS to “tune” a Needle valve, however we learned from Hodor that that method was prone to errors due to issues with WFTS load cells

Conclusions

Liquid Propulsion Laboratory

Machining Costs

Part	Machining Needed	Cost
Tank Support Structure	Water Jetting, Welding	~$150/hr
Engine Mount	Water Jetting, Welding	~$150/hr
Orifice	Water Jetting	$0
Tanks	Heat Treating, hole tapping	~$400

Overall Cost Breakdown

Feed System Cost	$32,521.89
Tank Support Structure Cost	$408.26
Machining Costs	$2000
Mount Structure Cost	$1390
Allocated DAQ Cost	$5000
Total Cost w/ 15% margin	$47,518.17

Question/Comments?