Hydra-Dev2 (Atlas) PDR

Liquid Propulsion Laboratory

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USC Viterbi School of Engineering

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 PDR, and please provide us with advice regarding anything we did not address, or will likely encounter in the future.

Agenda

1. Introduction & Goals
    a. PDR Entrance and Exit Criterion
    b. Balerion-Dev2 Hotfire Campaign
    c. Aerospace Corporation SoW
    d. Previous Student Cryogenic Liquid Projects
    e. Project Goals
    f. Planning
2. Hydra-Dev2 Design
    a. Requirements
    b. Project Structure
    c. System Overview
    d. Interfaces
    e. Schedule
3. Feed System
    a. Changes to Feed System
    b. LOx Side
    c. Fuel Side
    d. MOMS/Pressurant
4. DAQ & Instrumentation
5. Engine Mount
6. Summary & Questions

PDR Entrance Criteria

Purpose: Alumni review of Hydra-Dev2 test stand and subsystems design

The following conditions have been met which enable a PDR of the system:

- Feed system P&ID internally reviewed and approved
- Feed system lines, pressurant, propellant, and regulator trade study
- Feed system ConOps
- Feed system FMEA (Failure Mode and Effects Analysis)
- Feed system planning and scheduling
- Instrumentation, data acquisition and controls high level design
- Balerion engine mount design
- Cost estimation

PDR Exit Criteria

The following conditions will allow Hydra Dev2 to exit PDR and enter the CDR design stage:

- Completion of Delta PDR which will acknowledge all feedback received from alumni and resulting design changes
- Alumni determine a satisfactory basis for preceding to finalized design and test procedures has been achieved
- Confirmation of sufficient funding from department

Balerion-Dev2 Hotfire Campaign

Summary:

- September 2022: Completed Particle Shedding Research w/ Aerospace Corp
- October 2022: Began Engine Qualification
  - Completed: Chamber & Nozzle proof
  - Completed: Center Annulus and Fuel Inlet Leak Test
  - Ongoing: WFTS pintle & fuel side flows
  - Ongoing: C-Seal Delivery
  - Next: Cold Flows

UCSD:

- We were forced to leave them as a test stand provider due to budgeting
- Quoted us a hotfire cost way outside our price range

"Perhaps it is time to fundraise for our own system" - Dan Erwin

Funding & Aerospace Corp.

Received Funding:
- $10k - General Electric
  - For Balerion Design

Statements of Work:
- $10k - Aerospace Corporation
  - Must Hotfire Balerion-Dev2
  - Must participate in bi-weekly meetings
  - Must present Final Data Report (FDR) after Hotfire

USC Astro Department & Viterbi:
- Leads had a meeting with the Dean Tuesday the 21st about funding

LPL and Previous Cryo Test Stands

While LPL has never designed and operated a Cryo Test Stand, we have several resources to pull from for design:

UCSD’s Colossus:

- Extensive documentation & procedures to reference
- Has been successfully tested (not w/ Balerion)

LPL/Pangea Aerospace CryTOS:

- Extensive documentation & procedures to reference
- Similar system to Hydra-Dev2

Hodor:

- Current lab design, test & build experience

Project Goals

Qualitative:

- Cement LPL's future in developing cryogenic engines
- Continue to solidify our industry connections and create new ones
- Provide LPL members with valuable, industry level experience
- Bring notoriety and pedigree to the LPL team

Quantitative:

- Design a cryogenic test stand capable of facilitating the hot fire of Balerion-Dev2 and future (larger) engine developments
- Build as cost effectively as possible
- Integrate lessons learned into decisions
- Hot fire by September 2023 (Aerospace Corp SOW completion date)

Motivation

- Why is this good for LPL and members?
  - Provide LPL members a platform to conduct research on cryogenic liquid rocket engines
  - Provide LPL members a platform to gain cryogenic liquid rocket engine test experience
  - Allows LPL members to gain experience in cryogenic feed system development and test operations
  - Iterating on existing infrastructure (Hydra)
- Why is this good for USC?
  - Raises USC's profile as a top engineering and rocket engineering school, thereby attracting top students and industry members who are interested in space engineering
  - Gives students real-world, hands-on skills with cryogenic engines
  - Attracts corporate sponsorships and research opportunities

Planning

Two Phase Plan

6 Months

-Design, manufacture and test engine/feed system

Result

Static fire of Balerion with Hydra-Dev2 System

Phase 1

6 - 9 Months

-Upgrade and refine components around feed system

Result

Provide LPL with infrastructure to facilitate a wide range of engine dev. projects

Phase 2

Today's Focus

Flabob Airport Testing Location

- New Testing Location: Flabob Airport in Riverside, CA
  - Recommended by FAR for cold flow testing and all non-hotfire testing
  - Available for pressurized cryogenic operations
  - I-beam interface similar to FAR
  - 1 hour drive from LPL, versus 2.5 hours for FAR

Project Planning

- LPL Leads met with the Dean on 02/21 to discuss project funding
  - Funding has not been received yet by LPL
- Project Goals (independent on when funding is received)
  - Delta PDR by end of March
  - CDR by the end of April
- Hot fire by Aerospace Corporation SOW completion date
  - No cost extension possible, but not preferable

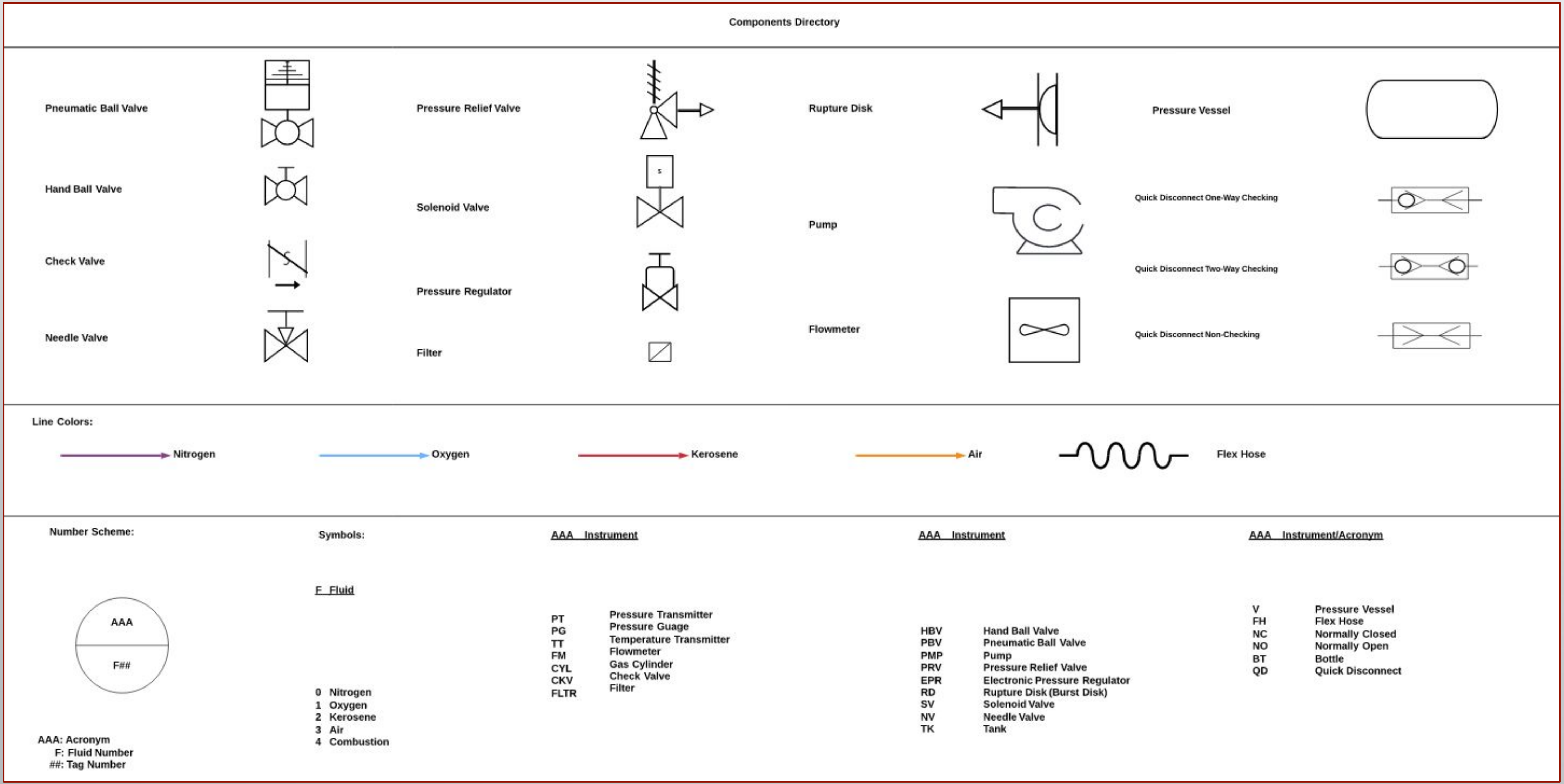
Atlas/Hydra-Dev2 Feed System

Liquid Propulsion Laboratory

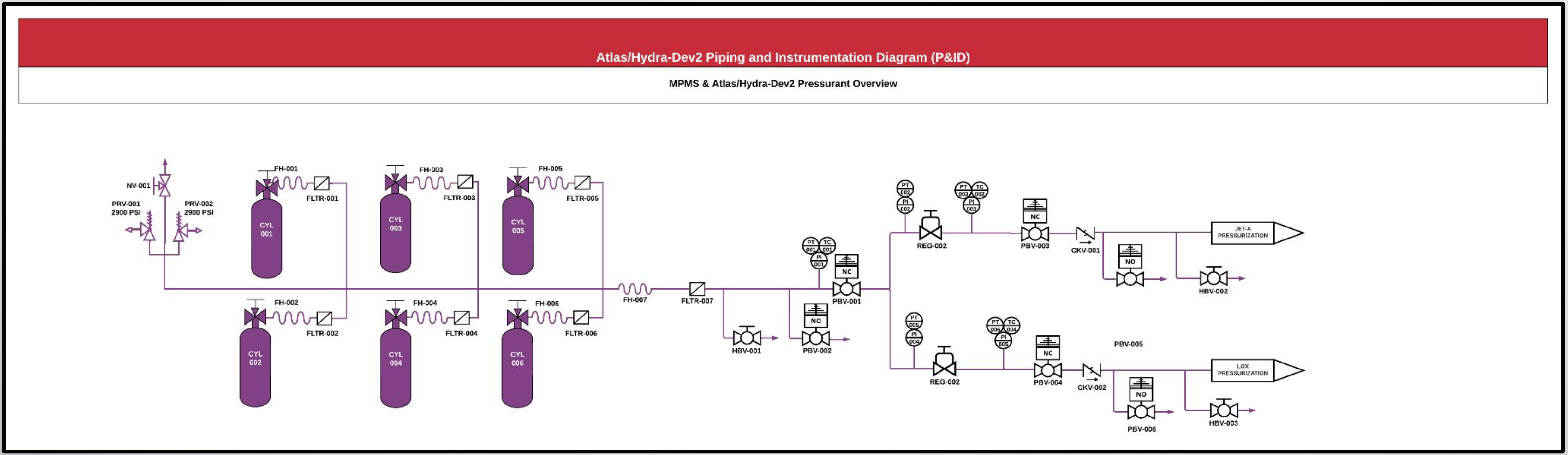
L1 Design & Build Requirements

- 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)
- 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

P&ID Component Directory

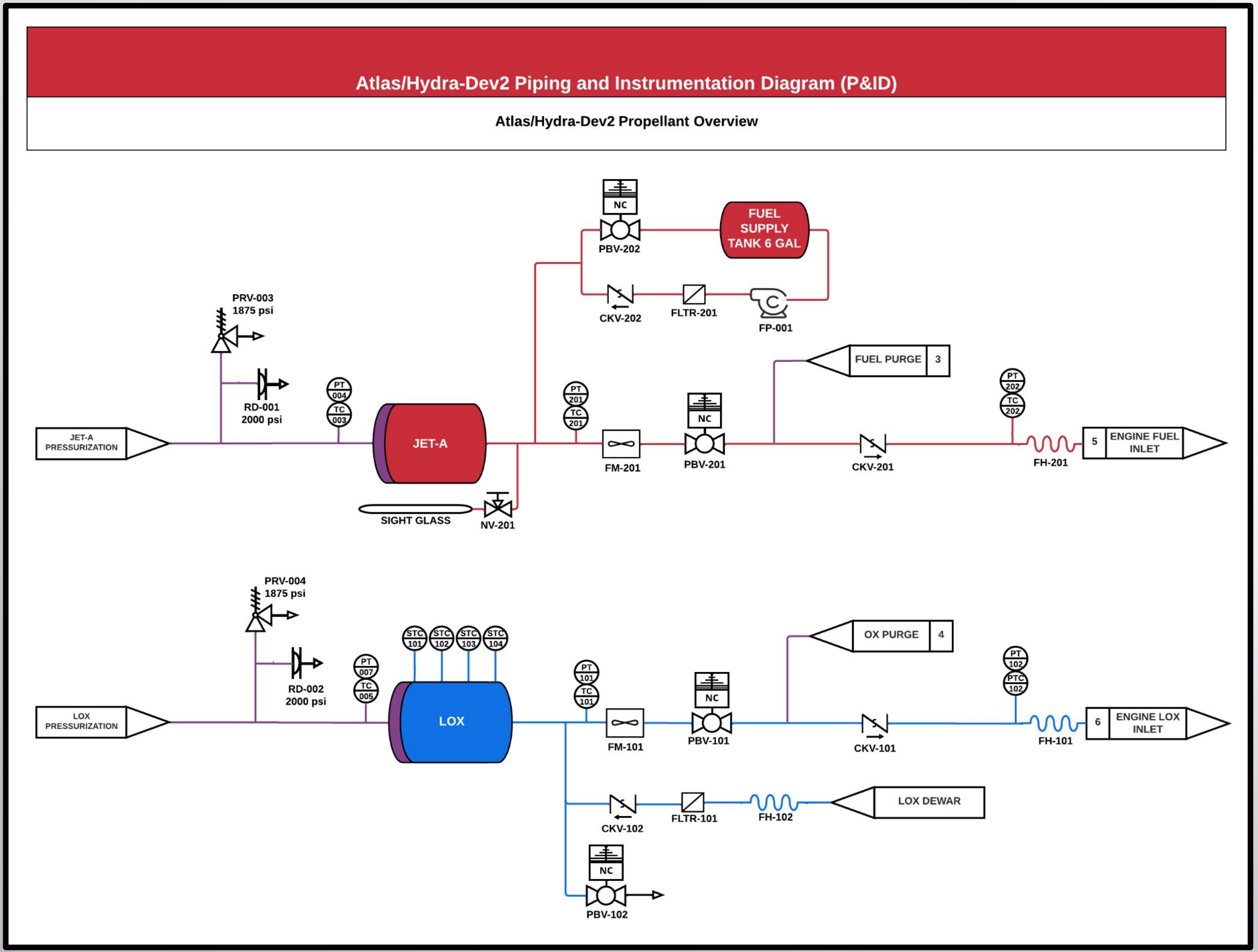


Feed System Overview - Pressurant P&ID



- GN2Pressurant 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)

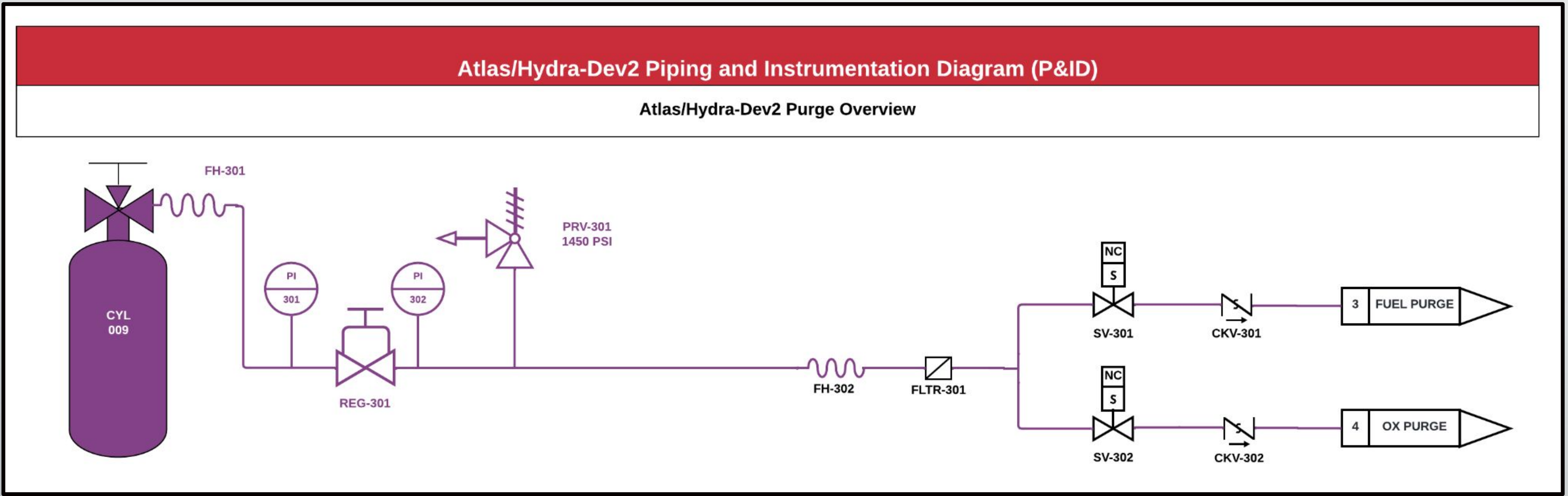
Feed System Overview - Propellants



- Fuel will be filled and drained into a 6 Gal non-pressurized tank
- Fuel tank level will be determined with a sight glass

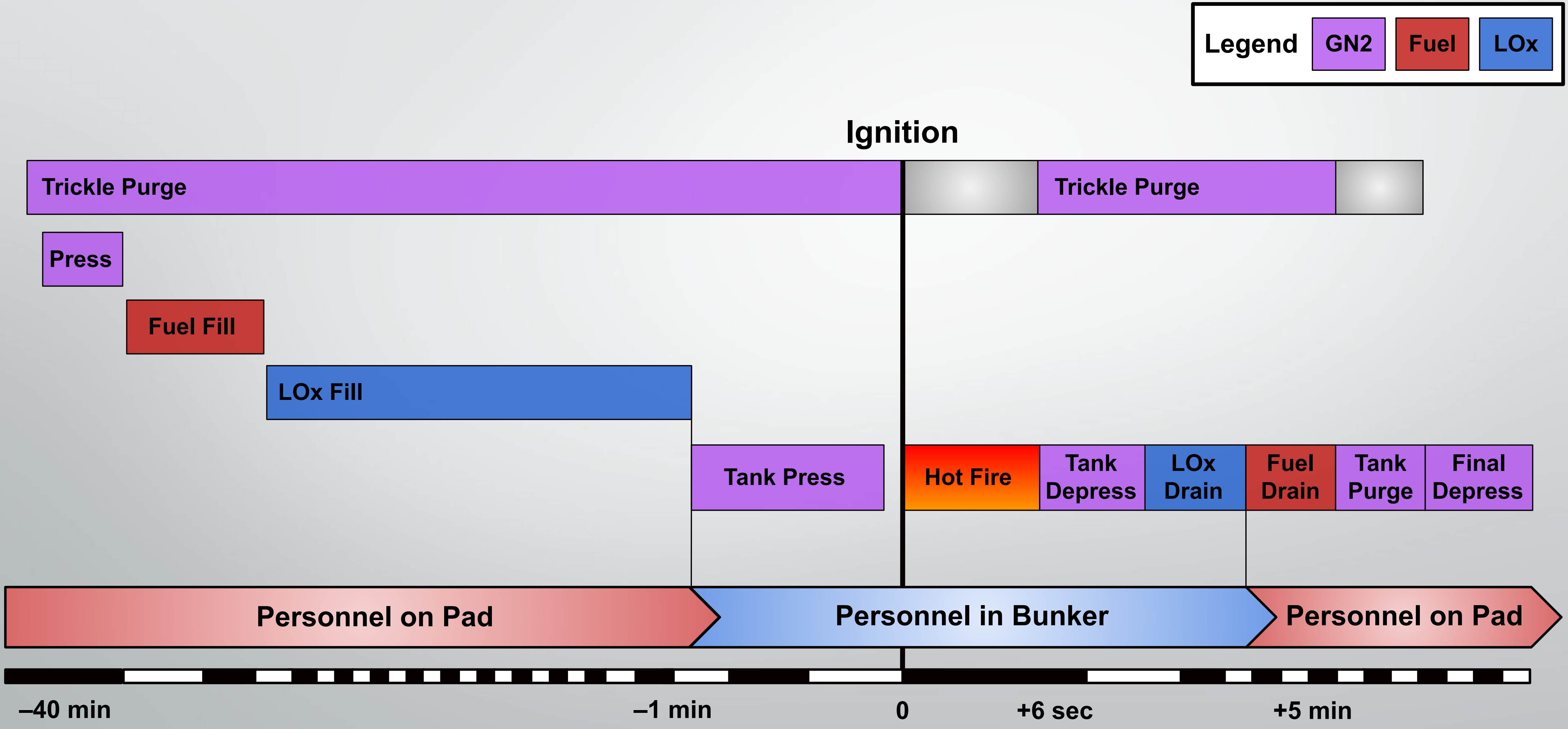
- LOx will filled by dewar and drained into ambient
  - FAR allows for LOx to be drained on ground
- LOx tank level may be determined by surface TCs
  - Trade study in coming slides
- Filters downstream of LOx and Fuel inlets to limit risk of contamination

Feed System Overview - Purge

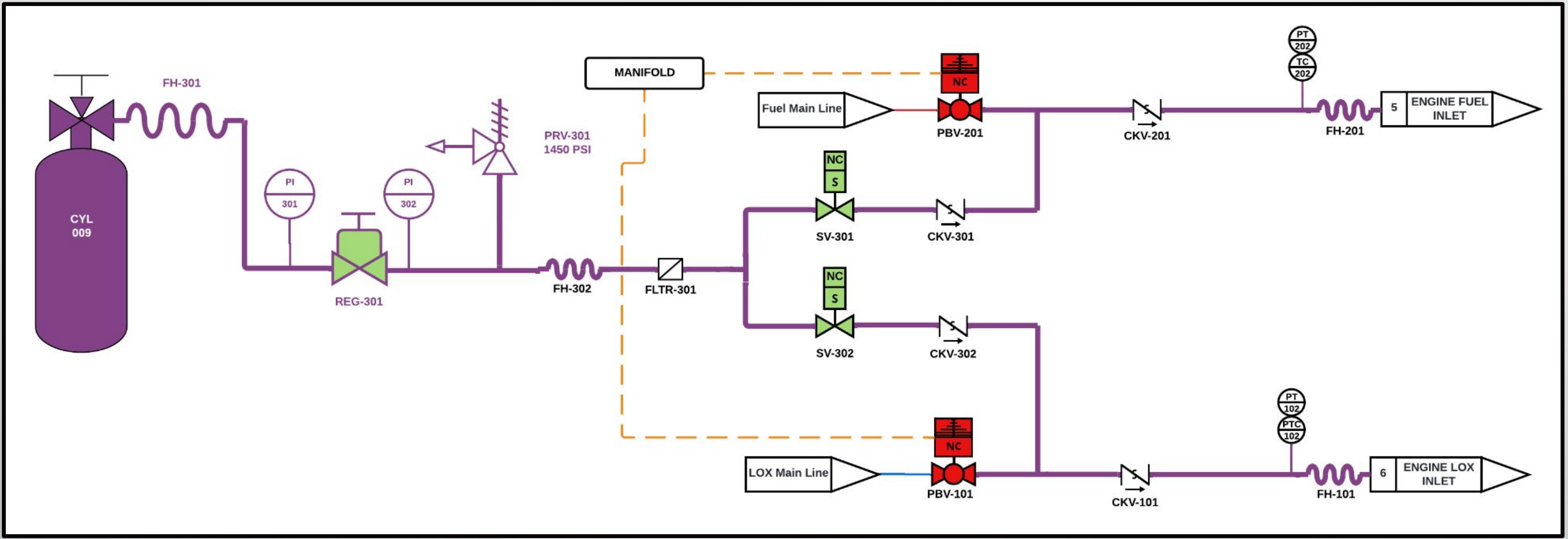


- Will be used for both trickle purge and post-fire purge
  - More about this in ConOps
- CKV-302 will need to be cryo & oxygen rated

ConOps Overview

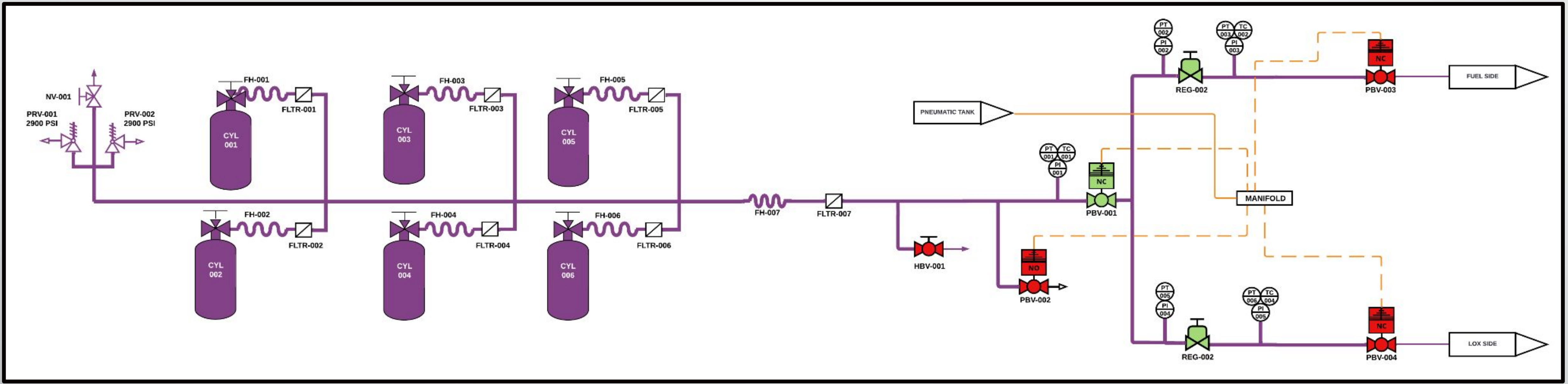


ConOps - GN2 Trickle Purge



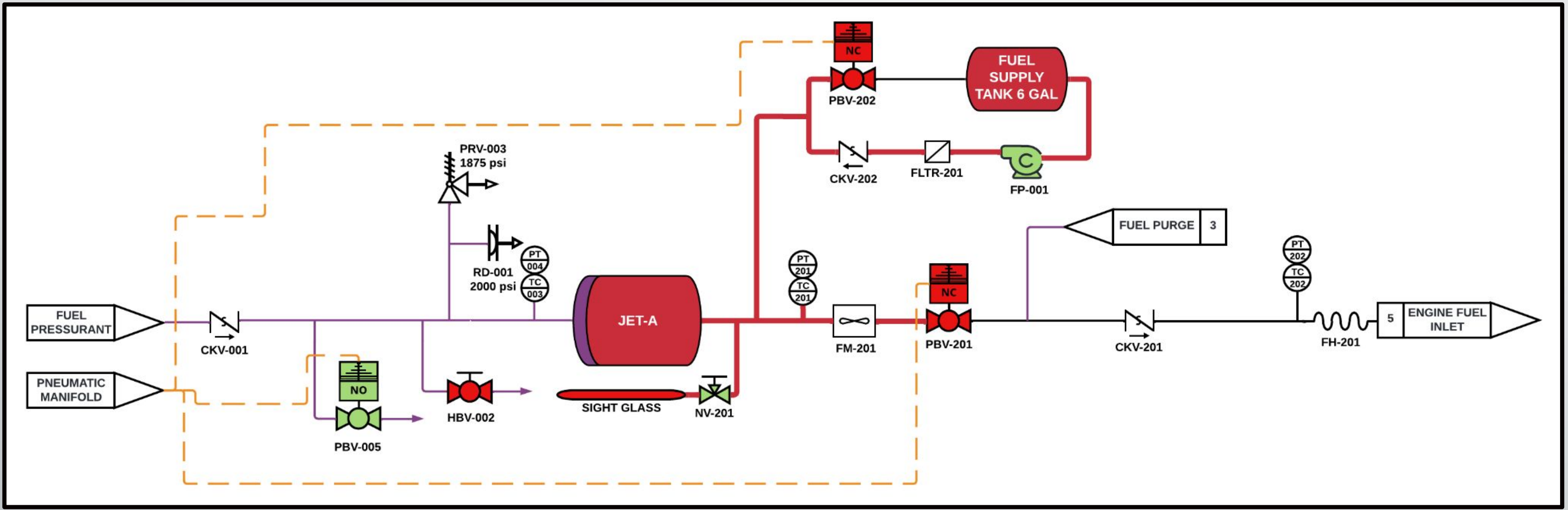
- Open N2 bottle valve
- Set regulator to purge pressure
- Open solenoid valves
  - Actuate valves in short bursts at high pressure (~150 psi), final continuous purge before hot fire

ConOps - GN2 Pressurization



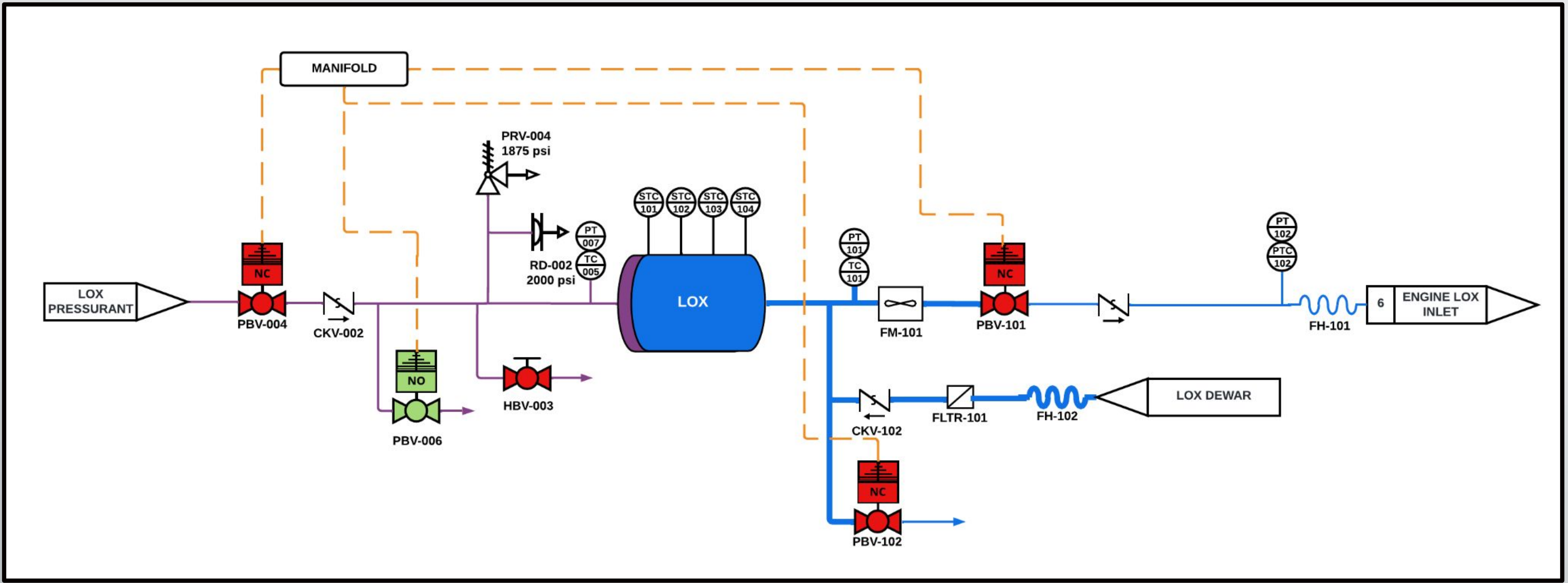
- Close vent valve PBV-002
- Open N2 bottle valves & pressurize up to pressurant isolation valve
- Open pressurant isolation valve
- Increase regulator pressure to desired tank pressures

ConOps - Fuel Fill



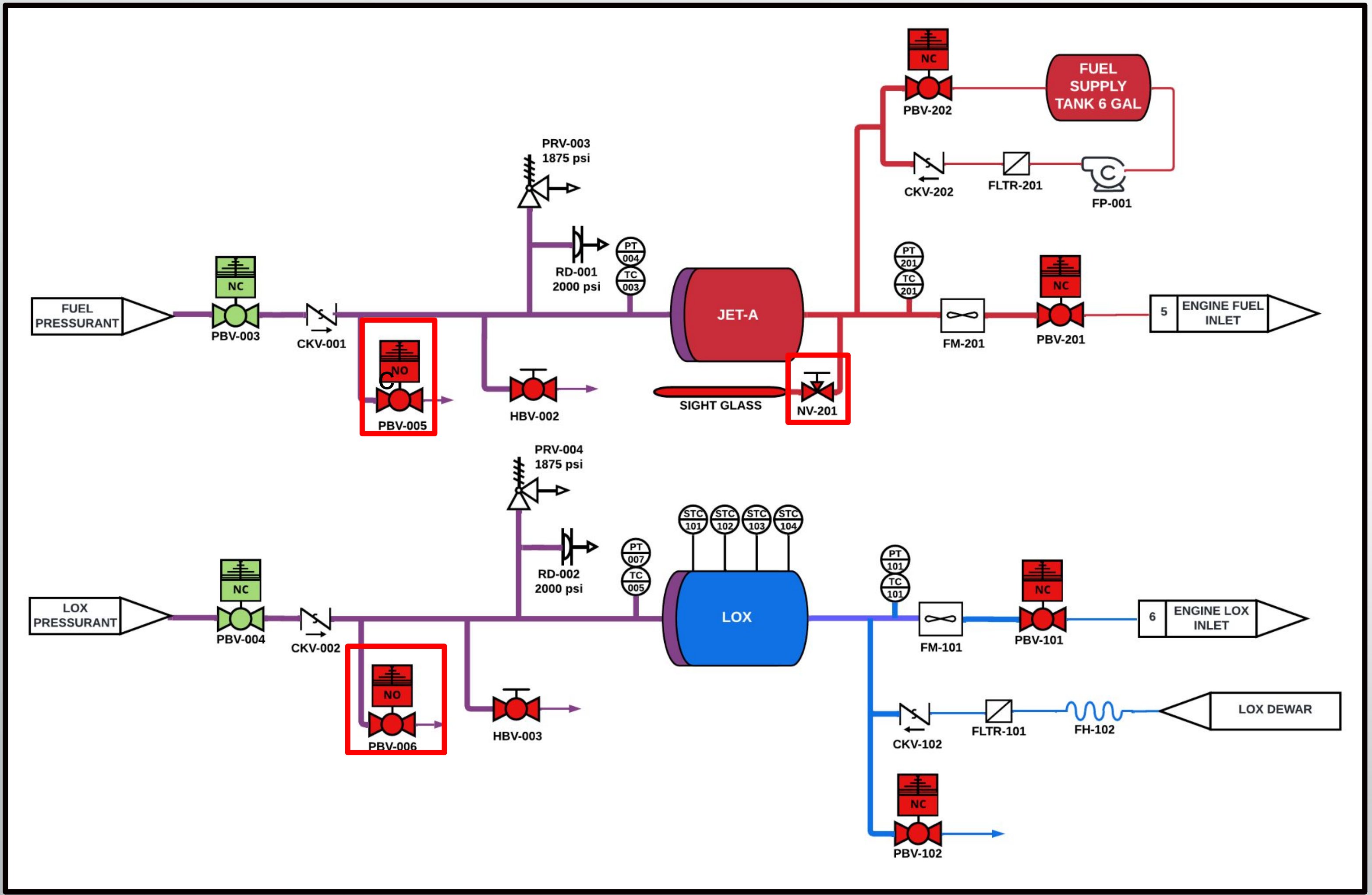
- Open sight glass needle valve NV-201
- Turn on fuel pump & closely monitor sight glass
- Turn off fuel pump when final fill level is reached
- Close sight glass needle valve NV-201

ConOps - LOx Fill



- Ensure LOx vent valve is open before turning on LOx dewar
- Open dewar and monitor LOx fill stand (TC’s or alternate method, see trade study [slide 41])
- When final fill level is reached, close dewar and bring personnel to safe location before pressurizing

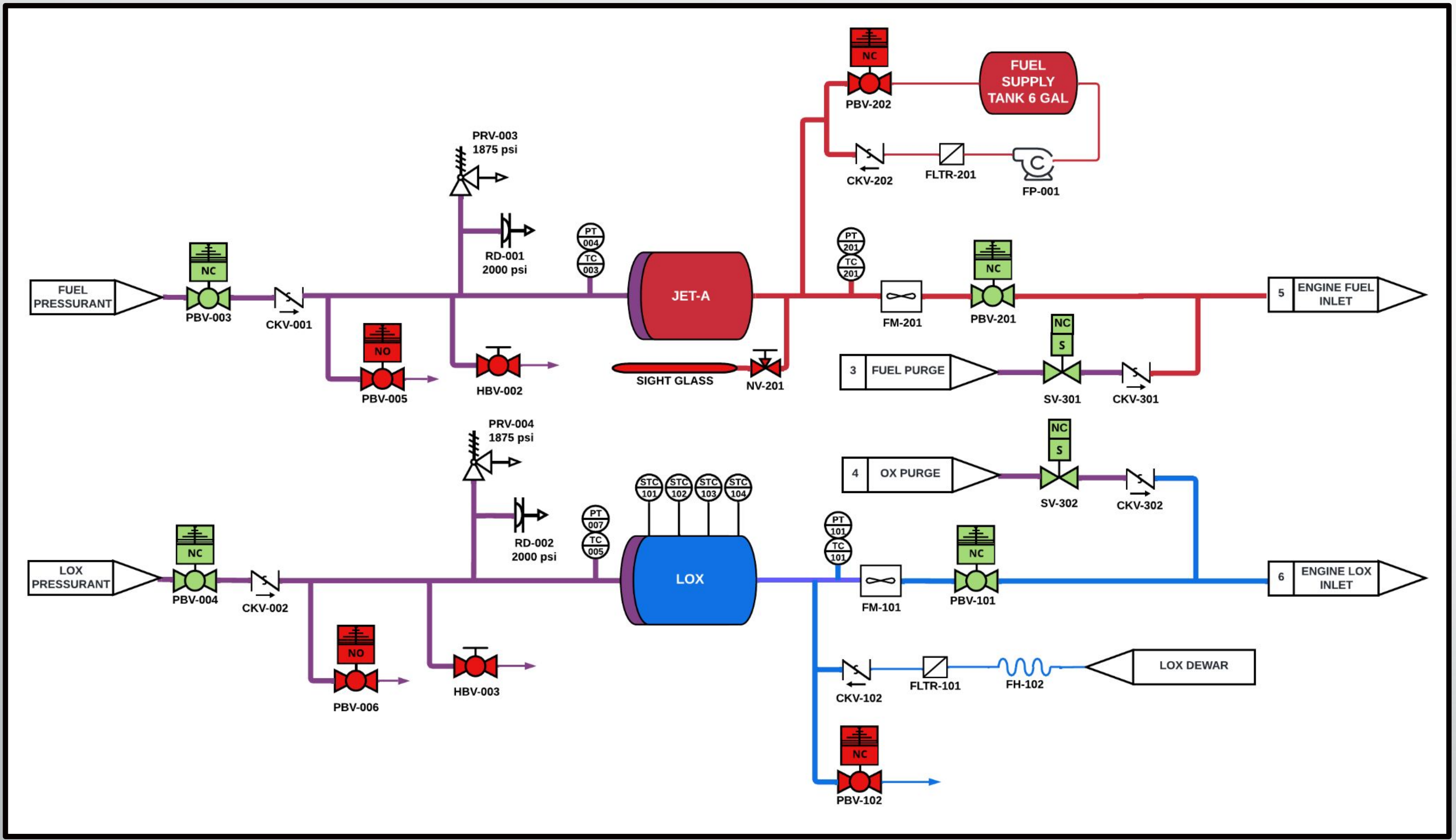
ConOps - Fuel & LOx Tank Press



Bring all personnel to safe location

- Close tank vent valves
- Open fuel and LOx pressurant isolation valves

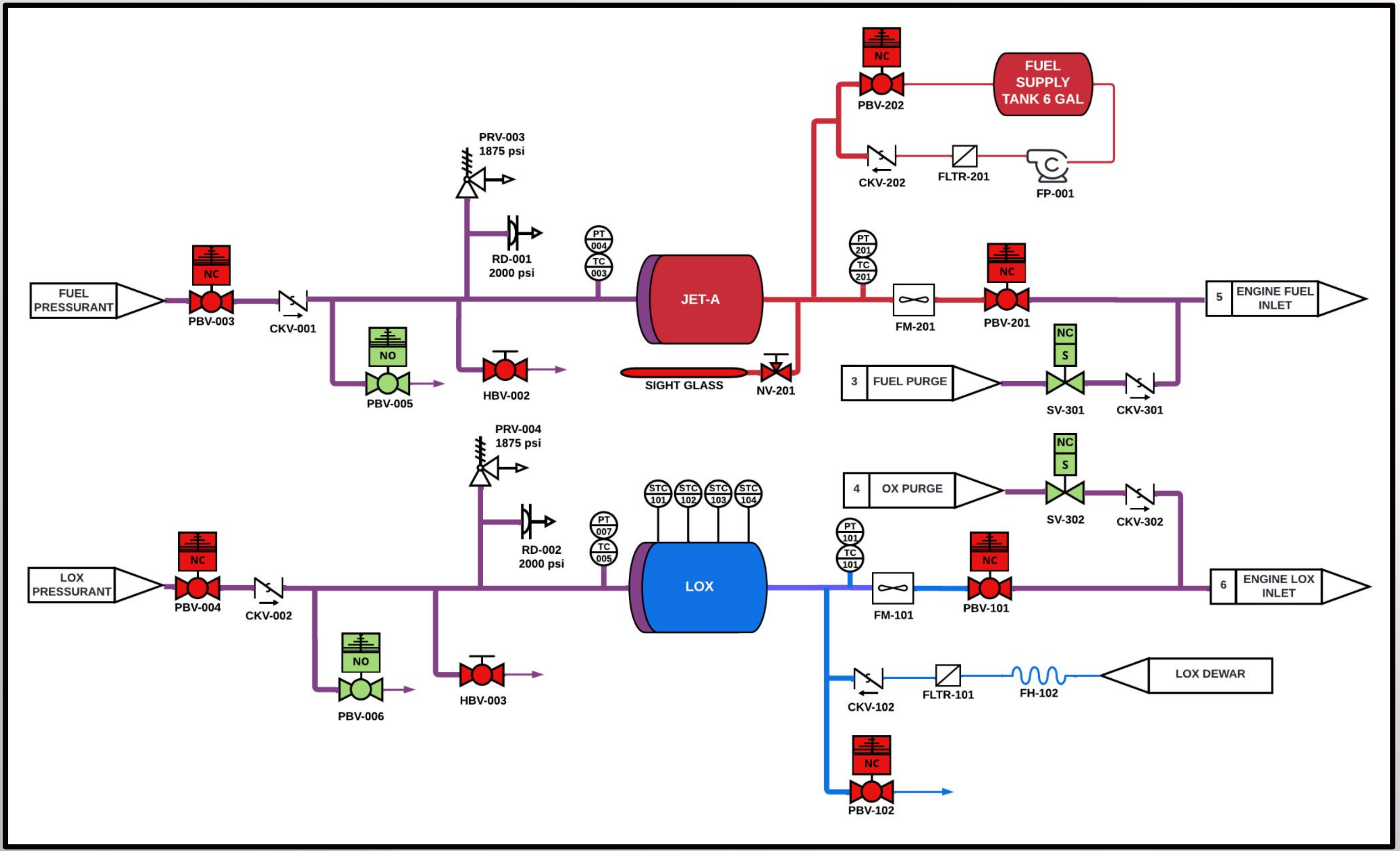
ConOps - Hot Fire



Hot Fire Sequence

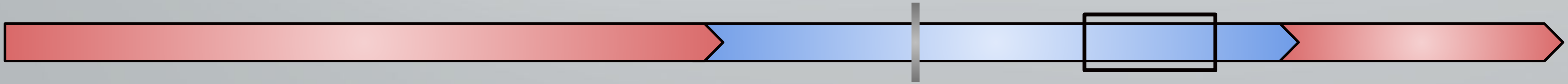
- Final continuous purge
  - Purge paused during fire by back pressure on check valve
- Igniter → LOx valve → fuel valve
  - ➔ Final sequence and delays to be determined in timing test

ConOps - Shut Off & Tank Depress

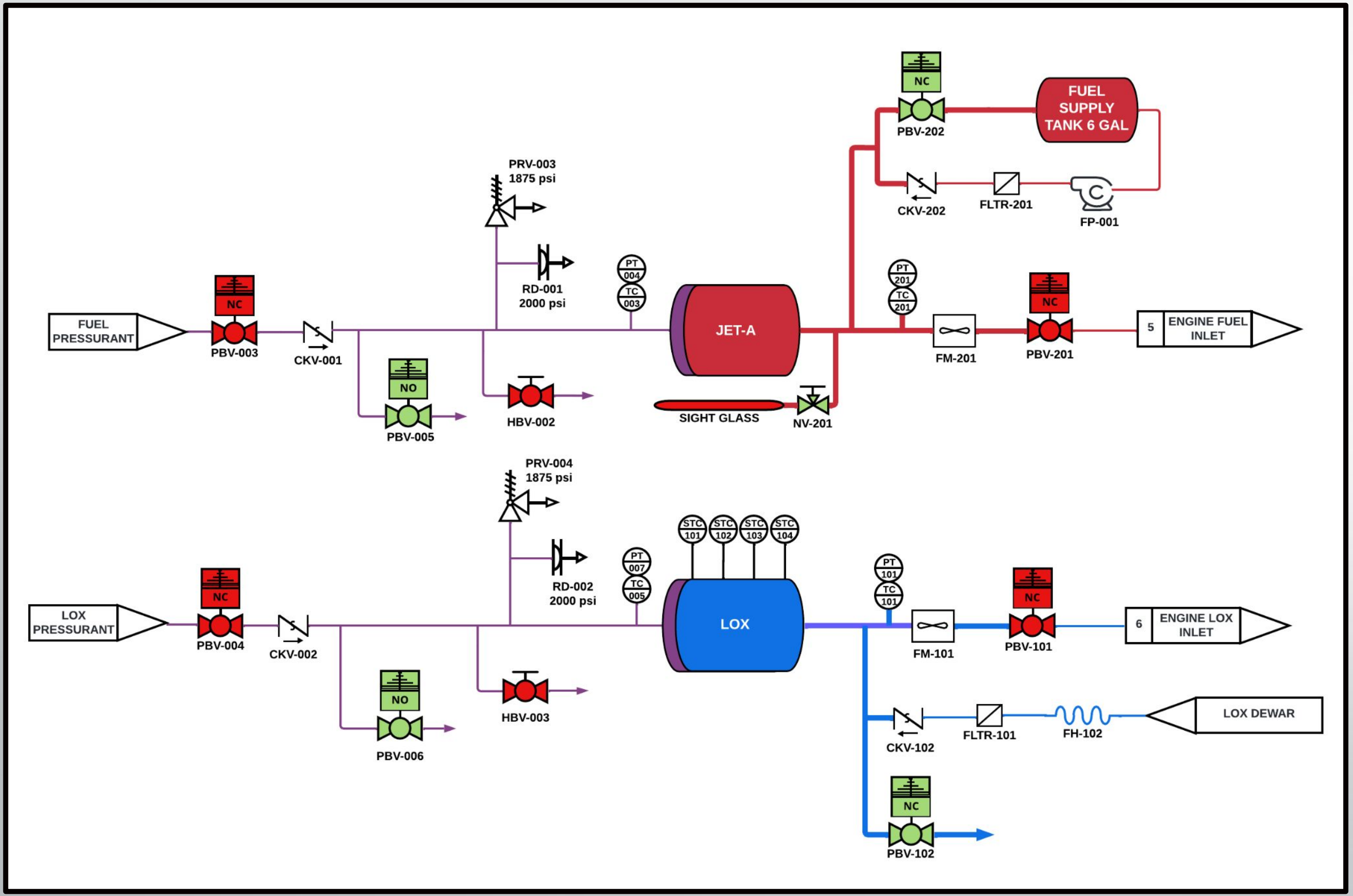


Shut-Off Sequence

- Close fuel valve and LOx valve simultaneously
  → Trickle purge resumes
- Close fuel and LOx pressurant isolation valves
- Vent LOx and fuel tank to atmosphere



ConOps - Drain



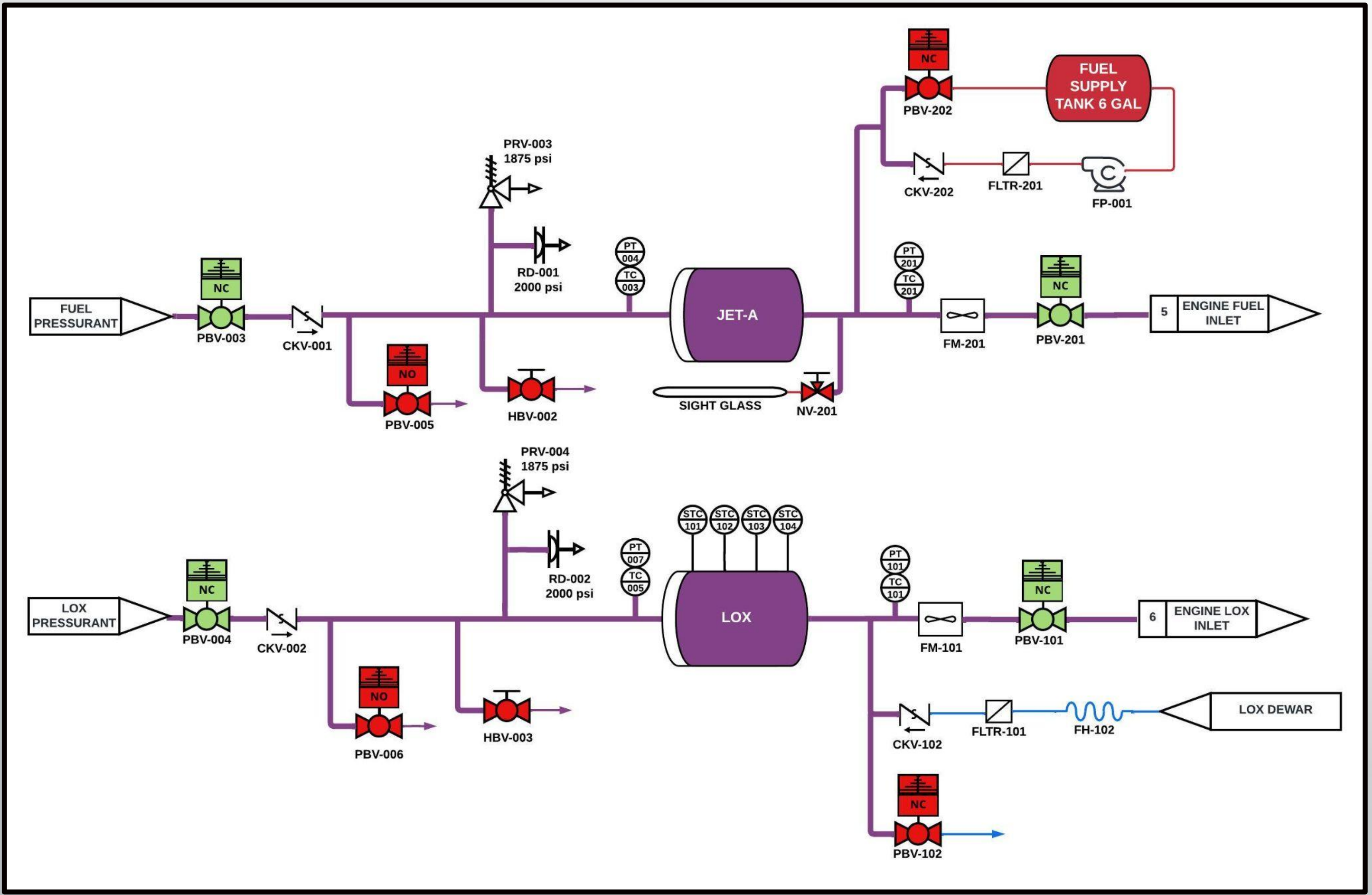
Drain LOx [Remote]

- Open LOx valve & fully drain

Drain fuel [On-site]

- Open sight glass needle valve
- Open fuel drain valve

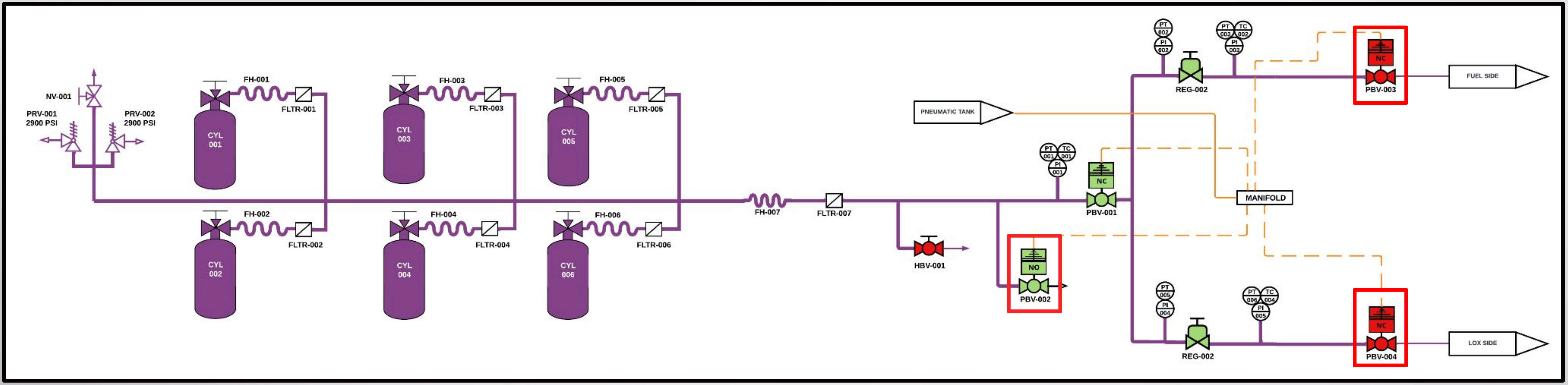
ConOps - Tank Purge



Tank purge

- Close both vent valves & both drain valves
- Close sight glass needle valve
- Open main LOx and fuel valves
- Open fuel and LOx pressurant isolation valves

ConOps - Final Depress



- Close fuel and LOx pressurant isolation valves
    - Downstream pressure will already be vented
- Close N2 bottles
- Open PBV-002 pressurant vent valve

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 (D): Detective controls are designed to detect errors or irregularities that may have occurred.
- Preventative (P): Preventive controls are designed to keep errors and irregularities from occurring in the first place.
- Corrective (C): 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	1) PRV-004 and RD-002 - P 2) PT readings of tank pressure - D	7
High Temperature in LOx Tank	9	1) Pick Test Day that falls within test conditions - P 2) Insulation - P 3) Reflective Shielding around LOx tank - P	7
Contamination in LOx Tank	9	1) Inspection - P 2) Oxygen Cleaning per NASA 1740.15 - P	6
High Pressure in Kerosene Tank	8	1) Pick Test Day that falls within test conditions - P 2) PRV-003 and RD-001 - P 3) PT readings of tank pressure - D	4
PRV-004 on LOx side fails	8	1) Component Selection - P 2) RD-002 - P	6

Propellant Lines Functional Requirements

Initial LOx & Fuel Lines:

- Want to size to ~3 times Balerion
  - LOx: 7 kg/s
  - Fuel: 5 kg/s

Initial Pressure Requirements:

- Want to size to accommodate inlets of Balerion
  - Balerion's max inlet: ~1100 psi
  - Feed System MEOP: ~1500 psi

Trade Study - Pressurization System

Pressurization System	Pros	Cons
Pressure-Fed	- Lab Experience - Lower Cost - Simple & Reliable	- Increases overall system weight
Electric Pump-Fed	- Reduces overall system weight - Lower Tank Pressure - Higher Performance	- Complexity (would require significant development time) - Expensive - Long Lead Time

Design Decision: Given the lab experience with pressure-fed systems, ability to get COTs parts, and space limitations a pressure-fed system will be used

Trade Study - Pressurant

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- Nitrogen Solubility in LOx
  - Worse at higher pressures
  - Pressurization time is relatively short
  - Research papers show ~20% mole fraction of N2 into thin top layer takes 2 hours
- Joule-Thomson Effect - High to Low Pressure
  - Nitrogen will be cooled
  - Helium will be heated
    - Short burn duration
    - Verify with analysis

Pressurant	Molecular Mass	Tank Volume	Cost
Helium	4.0g/mol	6	$$$
Nitrogen	28.01g/mol	6	$

Design Decision: Nitrogen is cheaper, leaks less and has lab heritage

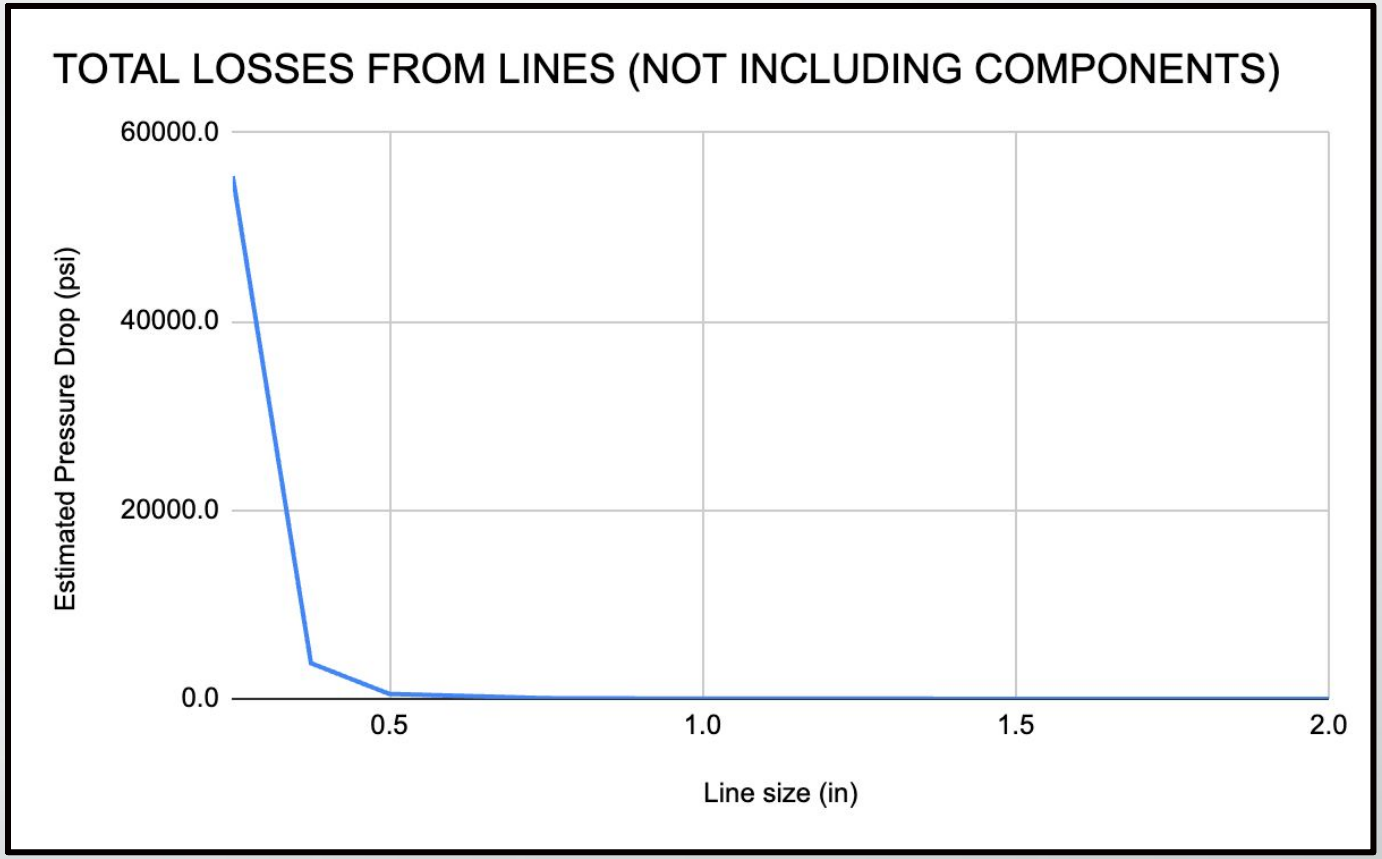
Trade Study - Propellant Lines

Lines Sizes	Pros	Cons
¾”	- Component Cost - Fitting Options - Assembly	- Pressure Drop
1”	- Flow Rate - Current Ox Lines - Large margin for future engine development	- Increased Torque Required for Assembly - Integration - LPL does not have infrastructure to bend or flare 1” lines

Decision: Current 1” Ox lines become the new Fuel lines. Investigate ΔP for NEW LOx line sizes

Fuel Line Sizing

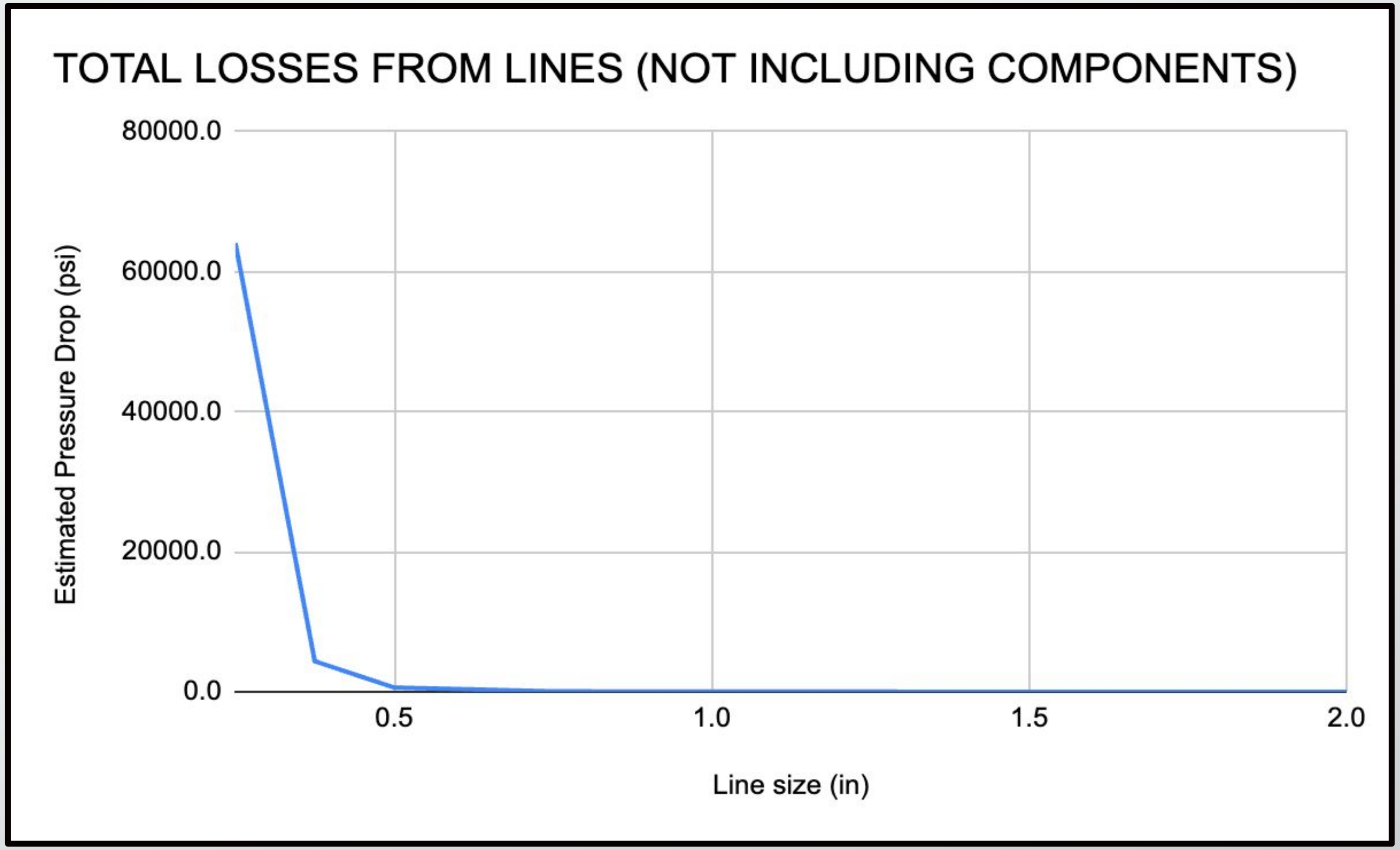
Line Size	$\Delta P_{oxidizer}$ (psia/ft)	Approx length LOx (ft)	Total Line Loss (psia)
¼” x 0.028”	55413.9	10	110827.8
⅜” x 0.028”	3770.8		37708
½” x 0.035”	517.1		5171
¾” x 0.065”	64.8		648
1” x 0.083”	9.65		96.5
1.5” x 0.095”	0.82440		8.244
2” x 0.109”	0.16283		1.6283



- **Decision:** 1” x 0.083” for fuel lines
  - 1” line is readily available
  - Not near flow capacity so can facilitate larger engines
  - Can use Swagelok & NPT

LOx Line Sizing

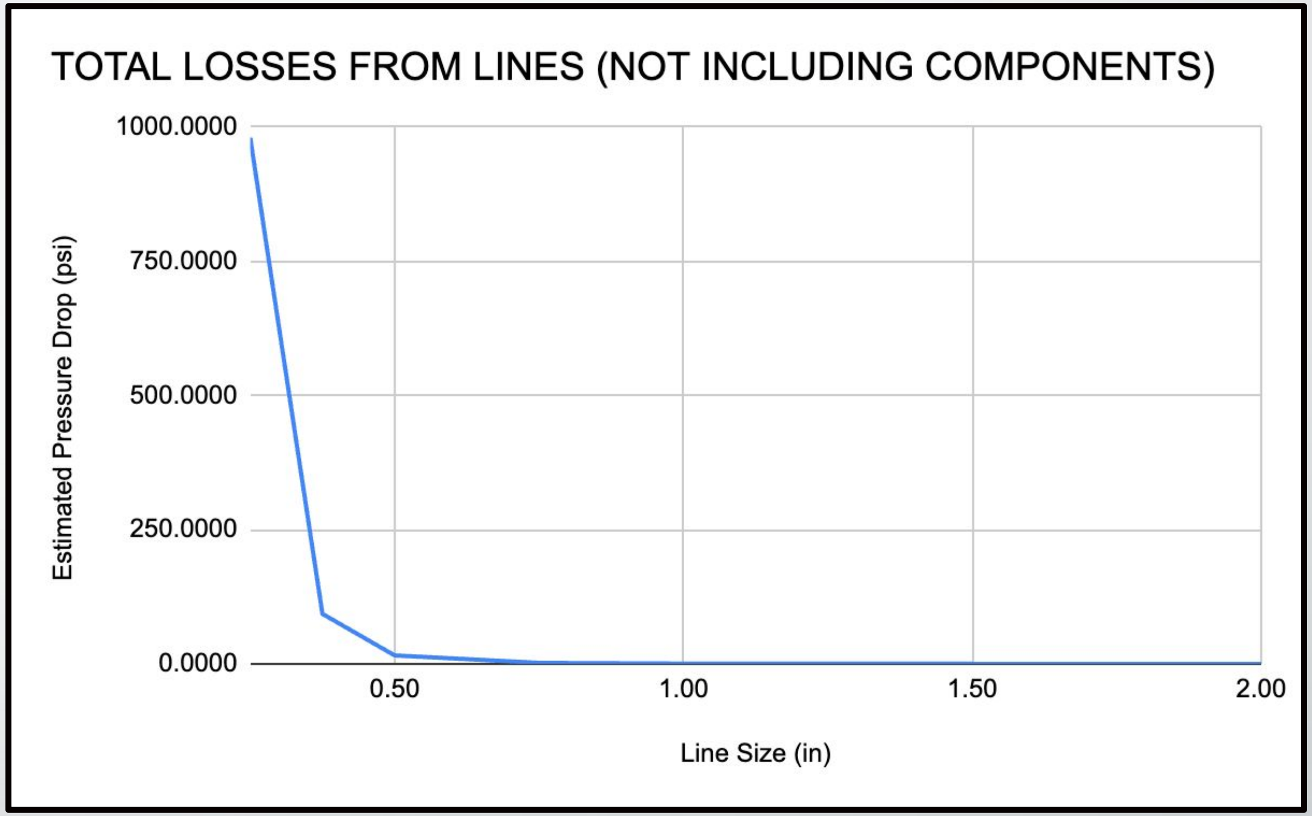
Line Size	$\Delta P_{oxidizer}$ (psia/ft)	Approx length LOx (ft)	Total Line Loss (psia)
¼" x 0.028"	65208		652080
⅜" x 0.028"	4431.97		44319.8.9
½" x 0.035"	606.24		6062.2
¾" x 0.065"	75.50	10	755
1" x 0.083"	14.27		142.7
1.5" x 0.095"	1.167		11.67
2" x 0.109"	0.217		2.17



- **Decision:** 1" x 0.083" for LOx lines
  - 1" line is readily available
  - Not near flow capacity so can facilitate larger engines
  - Can use Swagelok & NPT
  - v = 17.4 m/s < 30 m/s threshold

Pressurant Line Sizing

Line Size	ΔP_{both} *(psi/ft)*	Approx length (fuel or LOx) (ft)
¼” x 0.028”	103.1020	4
⅜” x 0.035”	9.8929	
½” x 0.035”	1.6911	
¾” x 0.049”	0.20315	



- **Decision:** ½” x 0.035” for pressurant lines
  - ½” line is readily available
  - Not near flow capacity so can facilitate larger engines
  - Can use Swagelok, AN & NPT

Trade Study - Regulator

Regulator Type	Pros	Cons
Spring Loaded	- Relatively cost-effective - Easy to work with	- Droop (~300 psi @ 1600 SCFM) - SPE
Dome Loaded	- Minimal droop	- Price - New System - SPE - Limited Pressure Inlet
Electronic Pressure Reg	- Non Existent Droop	- Difficult to tune PID - Price - Requires consistent pneumatic supply (ER5000)

Trade Study - Regulator

What size regulator will we need to maintain tank pressure at the mass flow rate of GN2 we desire?

All Regulators are sized in their volumetric flow rate @ STP so we need the max SCFMs for our system

$$\dot{m}_g = \frac{P_T \dot{m}_l}{R_g T \rho_l}$$

$$SCFM = \frac{2119 \cdot \dot{m}_g}{\rho_{STP}}$$

Process:

1. Can assume Volume flow rate in equals Volume flow rate out for each tank
2. Rearrange this to get mass flow rate of gas @ tank pressure
3. Convert this into SCFMs

Max SCFMs of Nitrogen			
Max Propellant Flow Rate	LOx	7.0 kg/s →	1617 SCFM of GN2
	Jet-a	5.0 kg/s →	1543 SCFM of GN2

Yields about 5 Gal of each propellant for a 3 second hotfire

Pressurant Volume Sizing

Approximately how many k-bottles will we need to press the tanks through the hotfire?

Inputs & Constants	
Tank Volume	6 Gallons
Tank MEOP	1500 psi
GN2 density @ Tank Pressure	116.9 kg/m^3

Process:

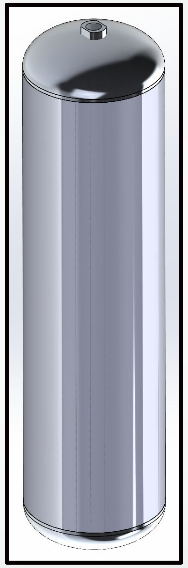
1. Find mass needed to fill each tank (end of hot fitre): 2.66 kg $m_f = \rho V$
2. Multiply Cryo side by a FoS of 1.35 for cryogenic collapse
3. Find density in k-bottles (2750 psig and 49L): 214.4 kg/m^3 $\rho = \frac{P}{RT}$
4. Find mass in a full k-bottle: 10.5 kg
5. Find mass left in k-bottle when pressure equals tank pressure (times 1.1 to not equal final pressure exactly), 1650 psig: 6.3 kg
6. Find the change in mass in each k-bottle when going from full to tank pressure: 4.2 kg
7. Find number of k-bottles needed: 0.85 for LOx and 0.63 for Jet-a $n_b = \frac{\Delta m_b}{m_f}$
8. Add and round up: 1.49 → 2 k-bottles

Propellant Tank Selection

<u>Tank Options</u>

1. **Custom Tanks**
   a. COPV - **NOT VIABLE**
      i. **Expensive**
   b. Pipe Tank - **NOT VIABLE**
      i. Extruded pipe body + welded end caps
      ii. Hydrostatic testing to 1.5x MEOP
      iii. Long Lead times
2. **Tank Refurbishment/ Retrofitting**
   a. Fire extinguisher - **NOT VIABLE**
      i. Standard tank size 2.5 gallons, **too small**
   b. Scuba Tank
      i. Only need to add ports (looking for machine shop)
      ii. Rated to 3,000 PSI
      iii. Must be aluminum, (Chromoly Material - no data for LOx cryo compatibility)
   c. Medical Oxygen Cylinder
      i. Good size choices
      ii. Only need to add ports (looking for machine shop)
      iii. 6061 Aluminum material
      iv. 2,000+ PSI DOT rating (Minimum Burst Factor: 3.4)


Oxygen Cylinder


Pipe Tank

Fire Extinguisher Tank


Custom COPV

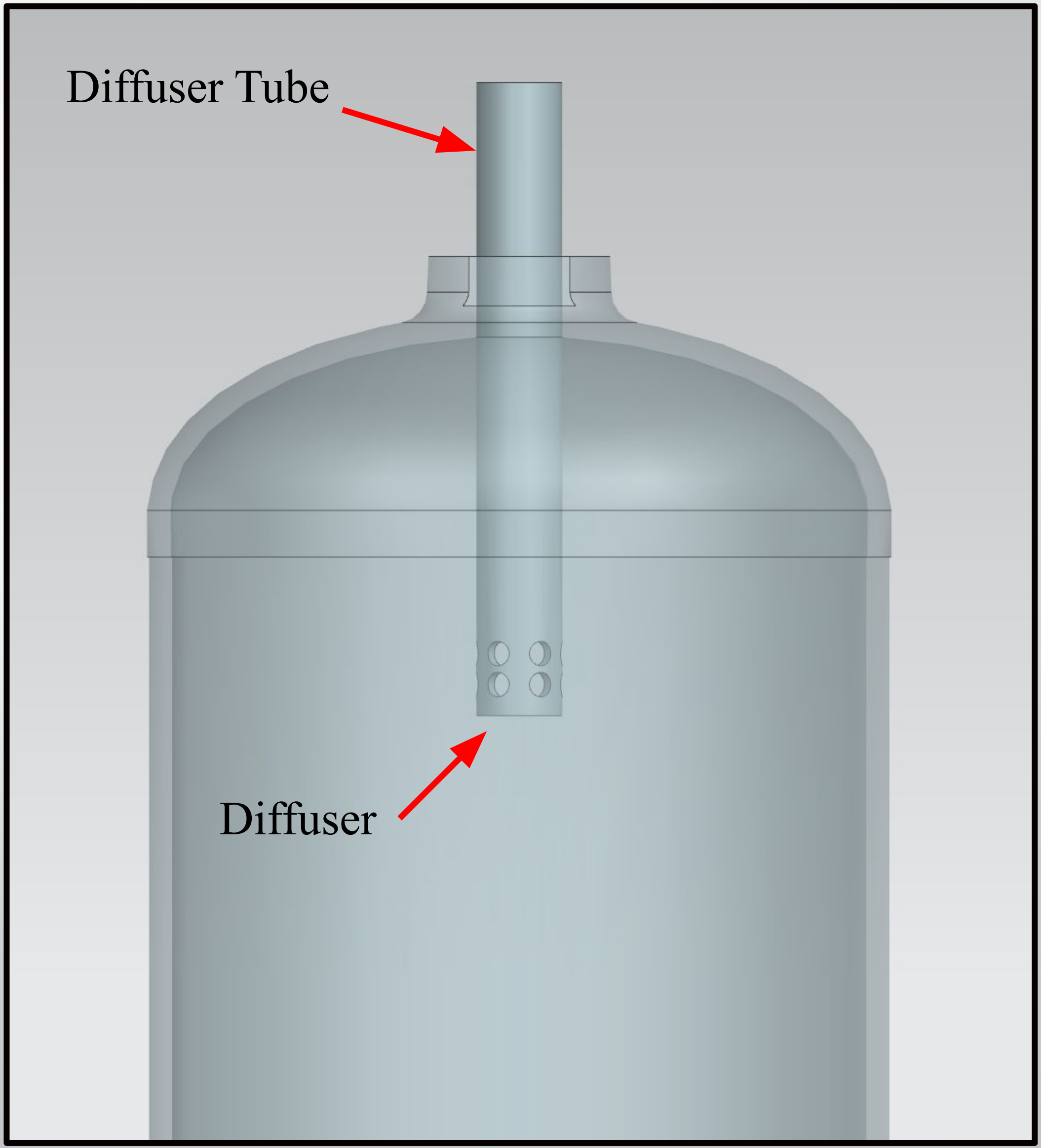

Scuba Tank

Trade Study - LOx Tank Fill Level

Tank Fill Level Methods	Pros	Cons
Overflow Spout	- Simple - Visual verification of fill level	- Wasted LOx - Possible FOD - Cryo valve required
Load Cells	- Most Accurate - No modifications to tank	- Price (3 Load Cells)
Thermocouple Metering (Surface)	- Currently on-hand in lab (15+)	- May fall off due to Thermal Shrinkage - Boil off will also be cold - Dependent on fast thermal transfer
Thermocouples Metering (Probe)	- Fill level evident when probe is wetted	- May require a heated tip - Requires additional machining and welding - Boil off will also be cold
TC Fitting Fill	- Reliable - Price	- No literature - Additional machining required

TC Fitting Fill Explanation

- Have a diffuser tube go into the tank with the bottom plugged
- During fill, the LOx will go up to the top of the diffuser then through the Diffuser Tube rather than compress the gas in the cavity above
  - The diffuser minimizes frothing during pressurization
- Allows for a guaranteed fill level
  - No concerns for BLEVE due to any pressurization of the cavity having gas move through the diffusers and out to atmosphere through the open vent upstream
  - Size the diffuser to have more open area than the ½ tube (standard 0.7 Cd flat edged orifice
- Guarantees fill level
- Upstream have a bored TC into the line, can guarantee when the line is wetted, stop fill when that mark is hit



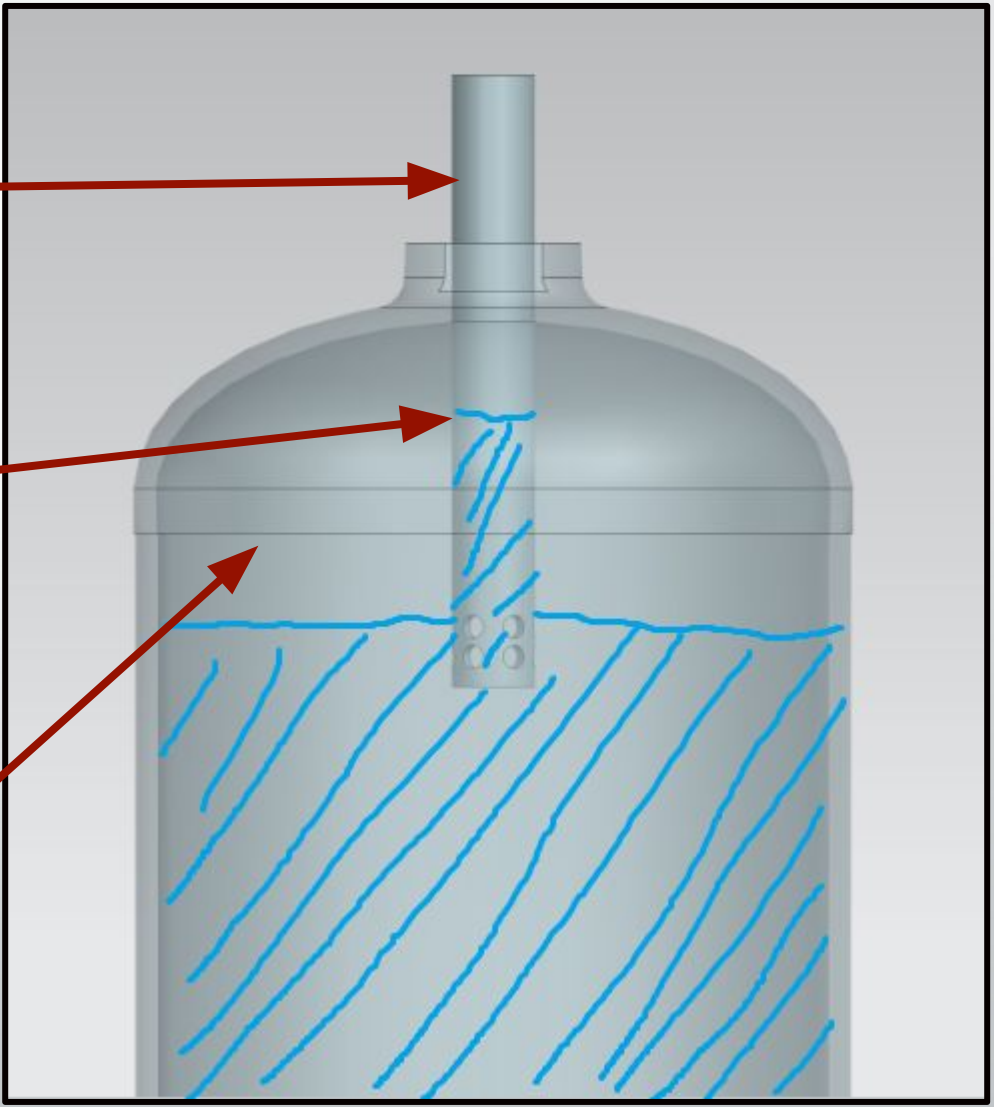
TC Fitting Fill Explanation

- Any buildup of Lox in the Diffuser Tube volume will likely boil off before pressurization
  - Will account for the added LOx between the line and TC when sizing the depth of the tube
- Allows for reliable fill levels at low expense and high reliability

Tap a TC into the line to know when wetted

Fills only through the tube

Any pressure increase in the cavity greater than a few psi will move through the LOx out of the vent upstream



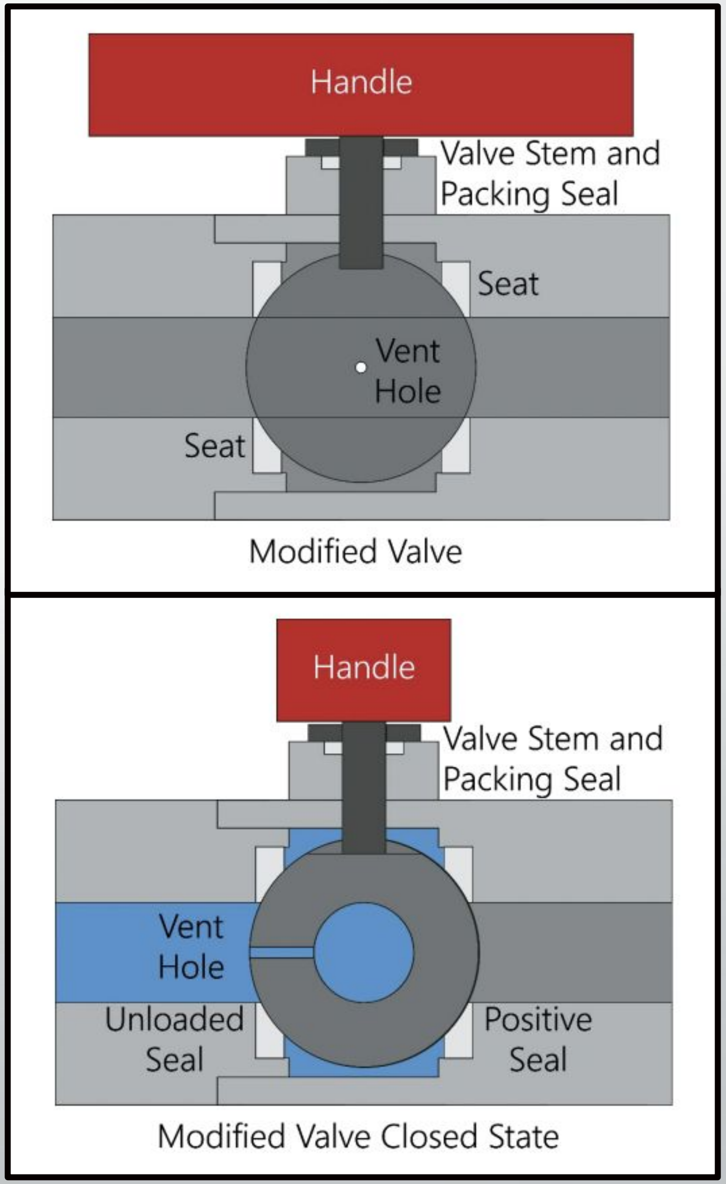
Build Plan

- Stainless Steel 316 tubing for feed system
- 1.5x MEOP (per ASME Section VIII) Hydrostatic Test tubing and tanks
- Ox cleaning oxygen lines, fittings, components, etc (per NASA 1740.15)
  - Adapting non-cyro Ox rated ball valves for LOx
- Leak testing with snoop to identify any leaks in system
- Will minimize the use of NPT fittings in feed system
  - Will use AN, SAE, JIC or Swagelok fittings where possible

Porting Non-Cryo Ball Valves

- Non-cryo ball valves lead to trapped LOx in the bore which can result in BLEVE.
- Cryo ball valves are significantly more expensive than non-cryo ball valves.
- To save on cost, non-cryo ball valves can be modified to accommodate cryogenic fluids.
- Modification procedure:
  - 1) Disassemble ball valve
  - 3) Drill vent in ball (~1/8" diameter)
  - 4) Clean components for oxygen service
  - 5) Reassemble valve with PTFE seals
  - 6) Repack valve stem with PTFE
  - 7) Store in clean bag until installed

Resource: [FAR Liquid Rocketry Symposium]()



Instrumentation

Pressure Transducers

- Measure pressure of pressurant, fuel & LOx throughout the feed system and the engine
- PT’s on cryo lines will have a stand-off to avoid the need for cryo rated PT’s

Thermocouples

- Measure pressurant, fuel, LOx throughout the feed system and the engine
- T-type TCs for all cryo wetted components and K-type for the rest

Load Cells

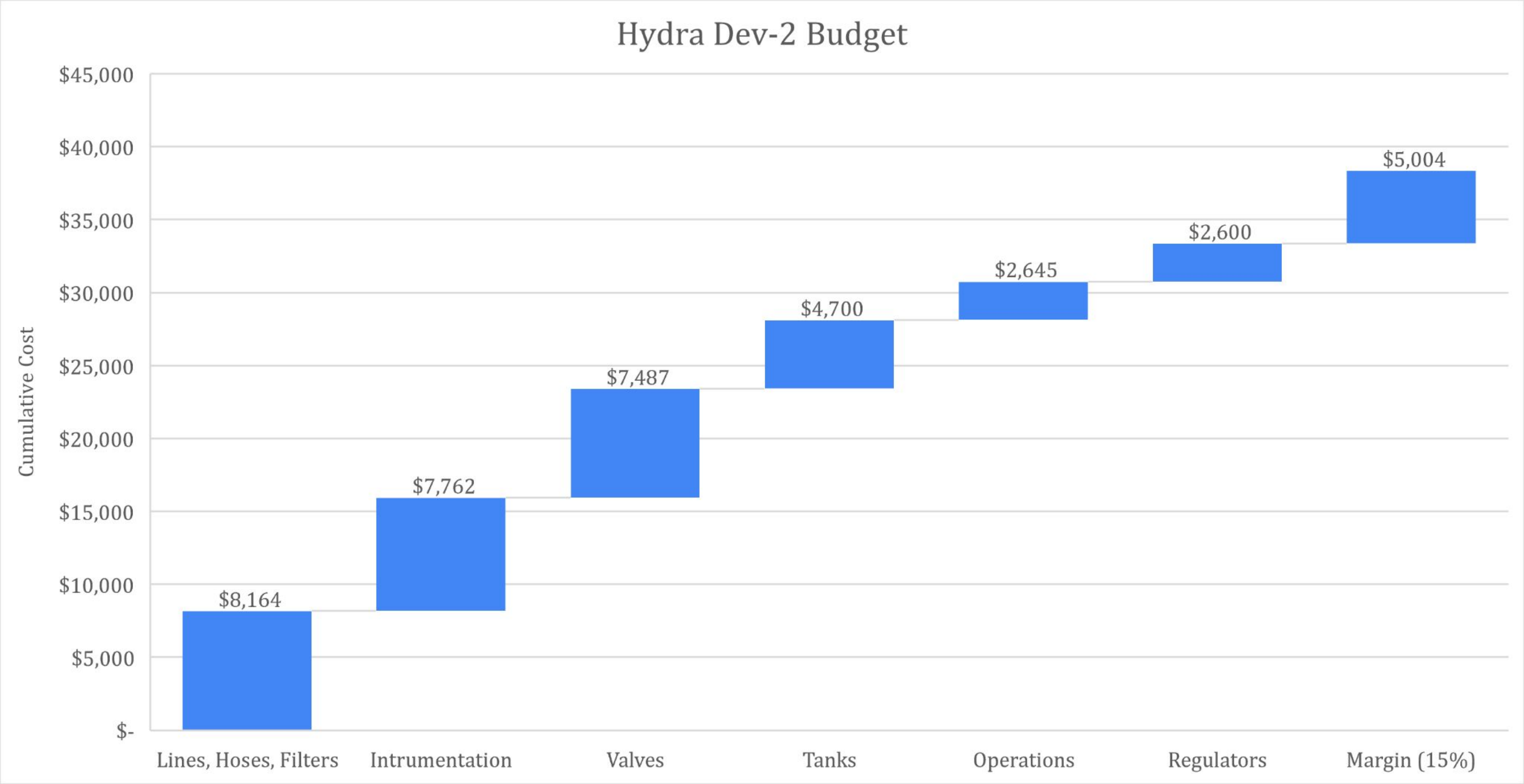
- Tank Fill Level
- Thrust Measurements

Strain Gauges

- Measure strain on the Engine

Preliminary Feed System Cost (w/ Margin)

- Savings (Reused Components): $13,274
- Total + Savings : $33,358
- Total + Savings + 15% Margin: $38,362



Feed System Schedule

- CDR by the end of April
  - Finalized feed system design and component spec.
  - Tank interfaces CAD, and drawings completed for any machining required
  - Full feed system assembly CAD
  - SOPs internally reviewed and approved (including abort procedures)
  - Flow meter trade study and component spec.
- Long lead components (valves and tanks) ordered as soon as funding is acquired

Path to CDR - Feed System

<u>Feed System Action Items</u>

- Spec Regulator
- Spec Relief Valve
- Order Long Leads
  - Registering new vendors can take a while
  - Large orders take time to get approval
- Purchasing and Machining of Propellant Tanks
- Continue looking into cryo flow meters at a cheaper cost

DAQ & Controls

Liquid Propulsion Laboratory

L1 Design Requirements

- DAQ system shall be capable of acquiring data from instrumentation
- DAQ system shall be capable of recording instrumentation data to a file on storage device
- DAQ system shall be capable of polling data at desired rate and accuracy
- DAQ system shall be capable of automated ignition sequence
- DAQ system shall be capable of 15 - 20 minutes of uninterruptible power
- DAQ system shall be capable of fail safing to a safe state in the event of communication loss
- DAQ system shall include automatic abort procedures if redlines are met
- DAQ system shall require a physical “key” for power lock out at test stand and control room

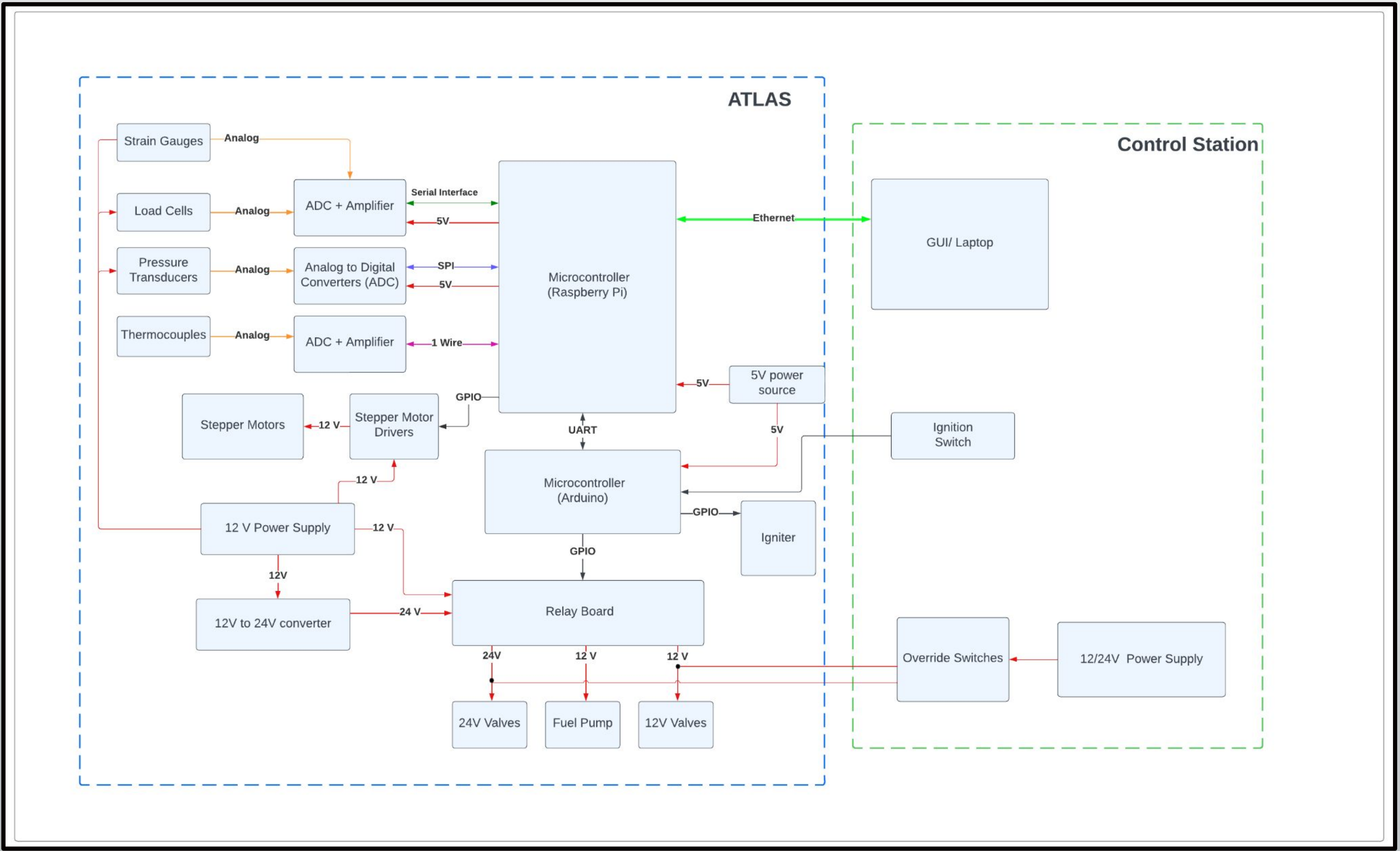
DAQ System Overview

- **Ground Station System**
  - Backend code written in Python 3
  - Graphical User Interface written in QML
  - Communicates with DAQ system over a TCP socket via Ethernet
  - Physical Ignition switch
    - Long wire cable to the DAQ system to initiate ignition sequence
  - Dual Safing Key system to prevent inadvertent hazardous commands
    - One to disable power to the Main Valves and one to disable power to ignition switch.
  - Override Switches to control critical valves in case of communication loss.

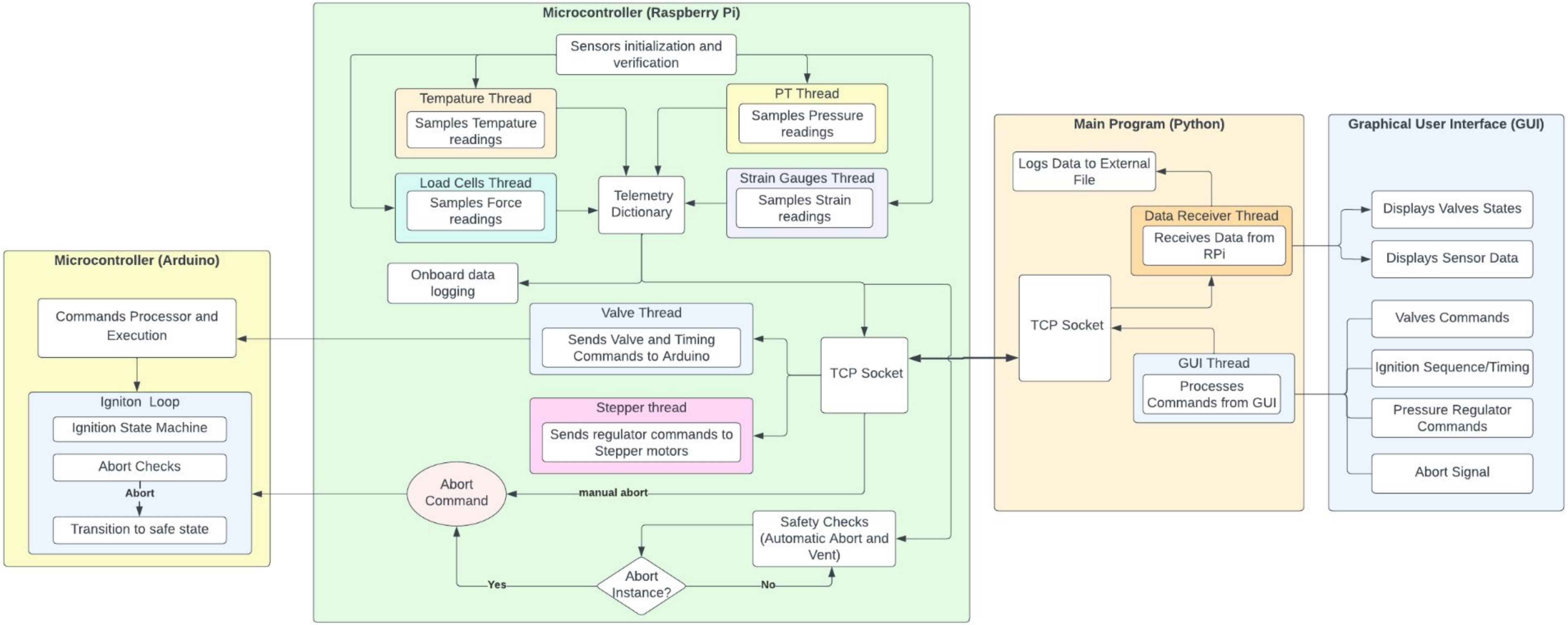
DAQ System Overview

- **DAQ System**
  - Python running on a Raspberry Pi 3
  - Pressure Transducers are read by 10 bit ADC and sampled at 1kHz with 0.25% accuracy.
  - K and T types thermocouples are read by 14 Bit ADC with 0.375s sampling time and accuracy of ±1C^{o} or ±0.75% (K Type) and ±2.2C or 0.75% (T Type).
  - Load cells and strain gauges are read by 24 Bit ADC
  - Solenoids are controlled by an Arduino and switching relays
    - Communication between Raspberry Pi and Arduino is through UART
    - Arduino is used to allow for expanded GPIO pins and reliable timing for critical functionality including the launch sequence
  - Pressure regulators are remotely controlled by stepper motors, which receives commands from Raspberry Pi.

High Level Hardware Architecture

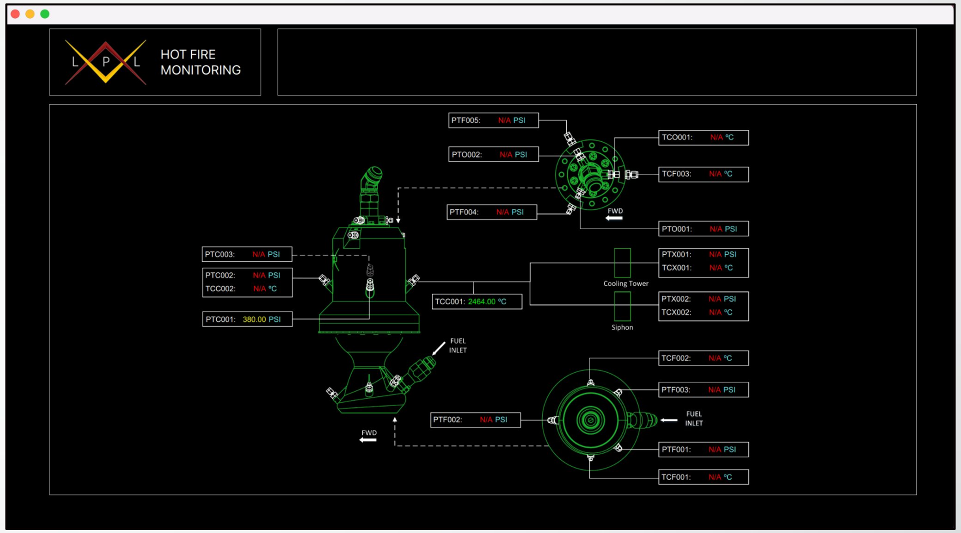


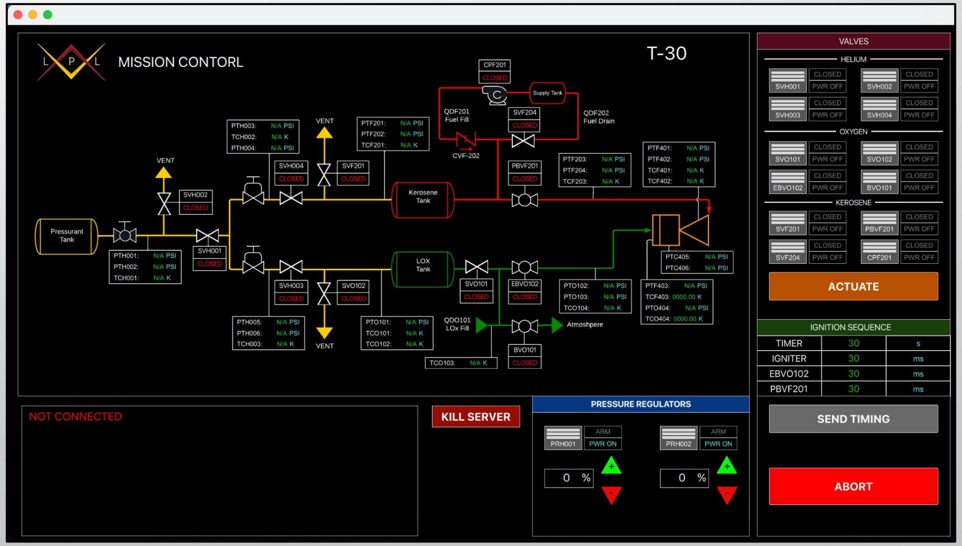
High Level Software Architecture



Graphical User Interface

- Display engine data during firing (thrust, strain, pressure, temperature)
- Display feed system data (tank level, pressure, temperature)
- Open/close valves
- Remotely control pressure regulators
- Modify and initiate Ignition Sequence
- Abort Countdown





Path to CDR - DAQ

- Transferring out current DAQ setup into a server rack
- Design high density harnessing to allow for the increased numbers of sensors and valves
- Create a more flexible GUI
- Develop wiring diagrams
- Design new PCBs to allow for a cleaner DAQ system
- Design a connectors interface to the DAQ box
- Integrate and test load cells and strain gauges

Engine Mount

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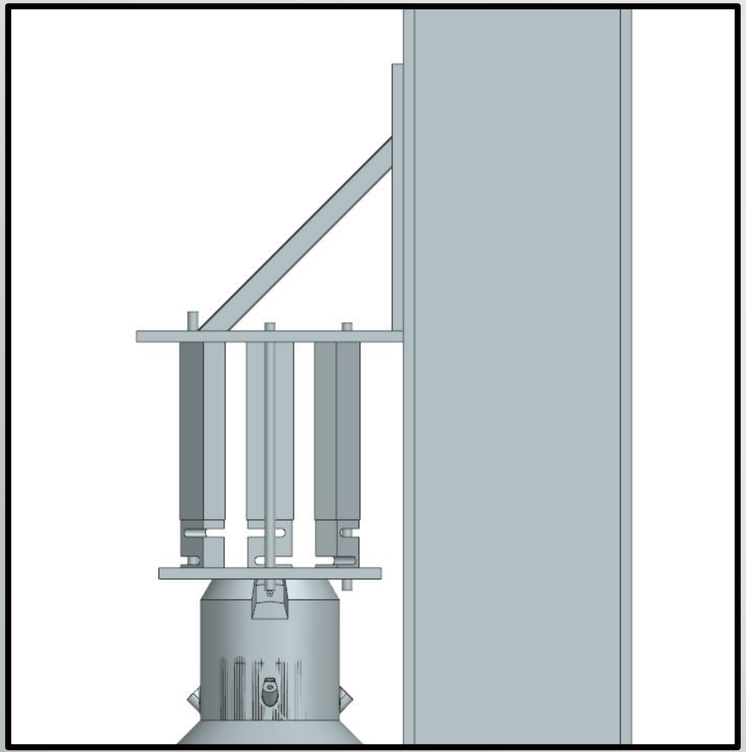
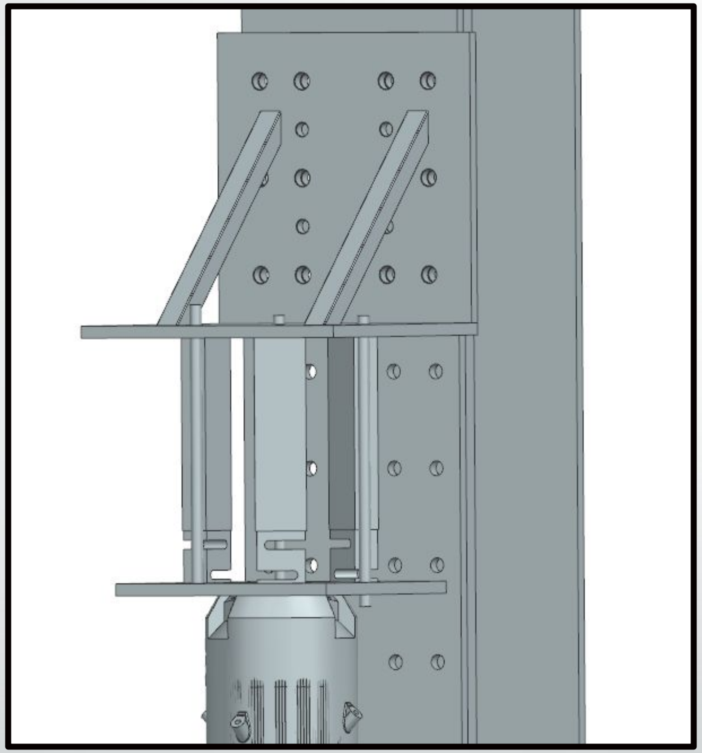
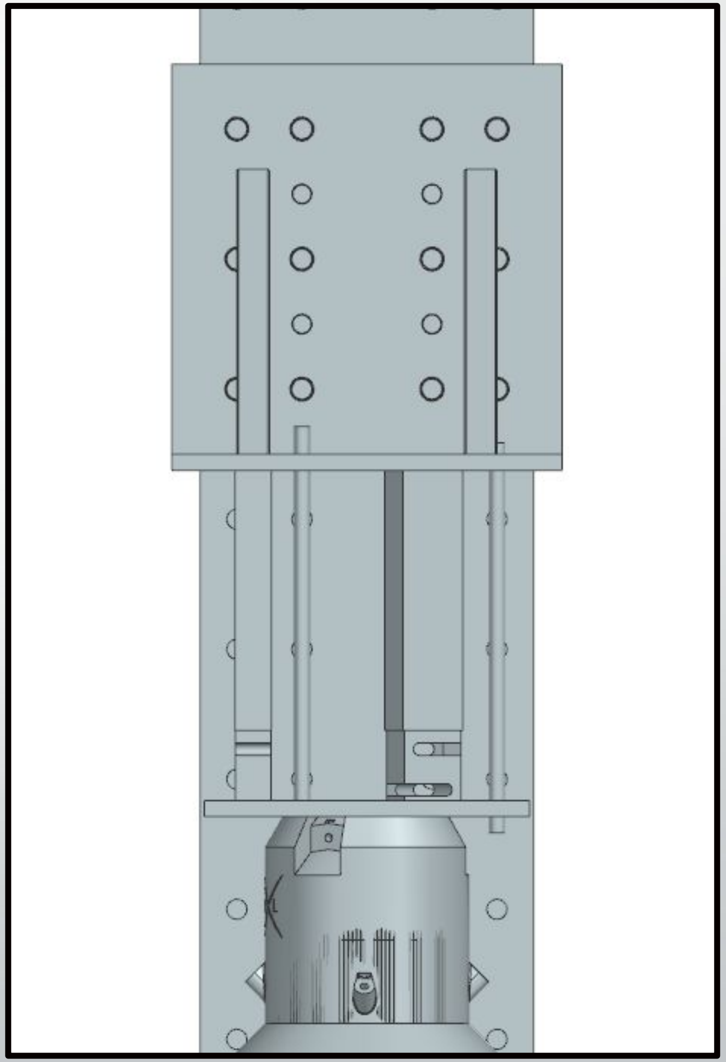
Requirements

- Engine Mount shall Interface with FAR’s Extra Large I-Beam & FAR’s Large I-Beam
- Engine Mount shall Interface with Balerion’s Chamber Interface
- Engine Mount shall have ability to Preload Load cells
- Engine Mount shall be liftable by 1-2 People
- Engine Mount shall withstand Balerion’s Max Thrust (with 2.25 FOS)

Preliminary CAD

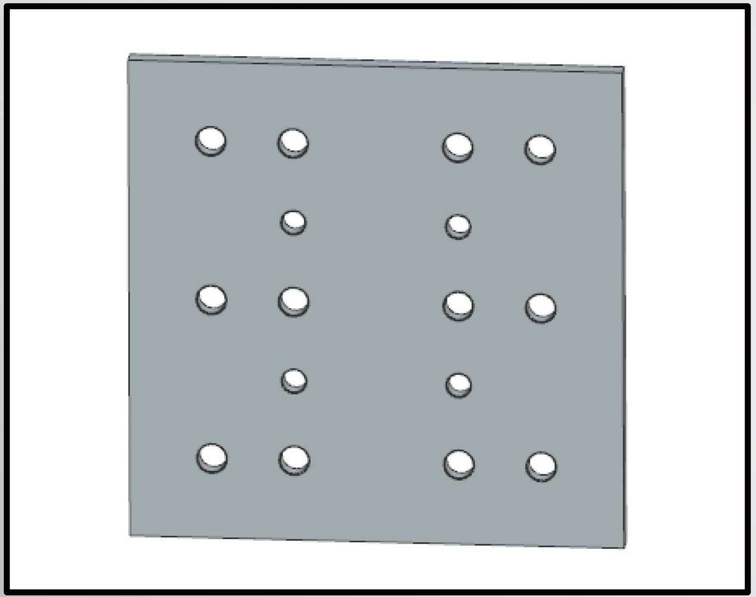




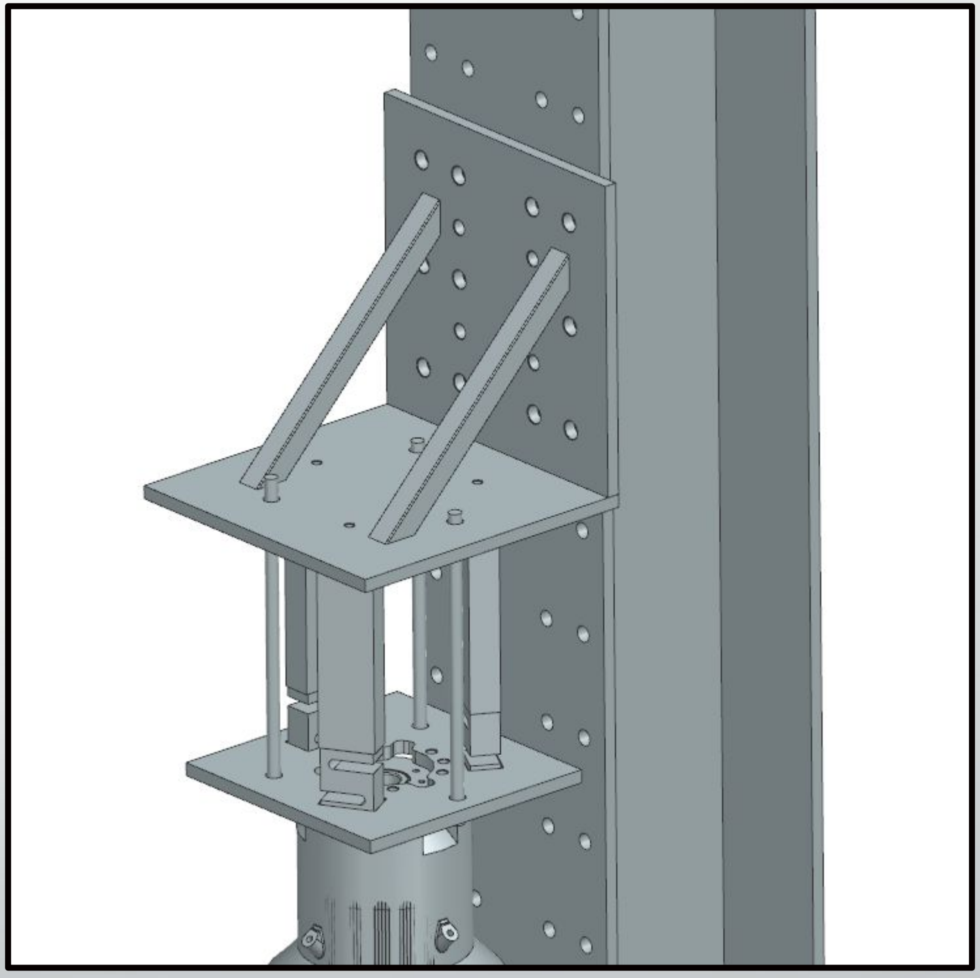


- Design to be updated
- Load cells still need to be spec’d

Engine to I-Beam Interface

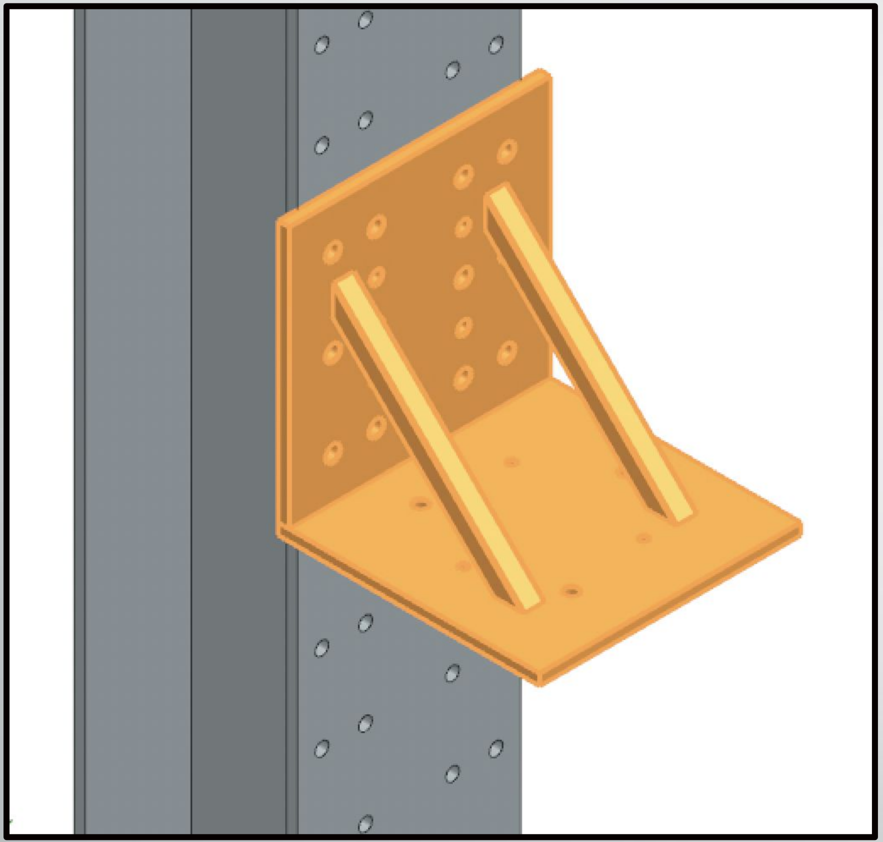


I-Beam Hole Pattern

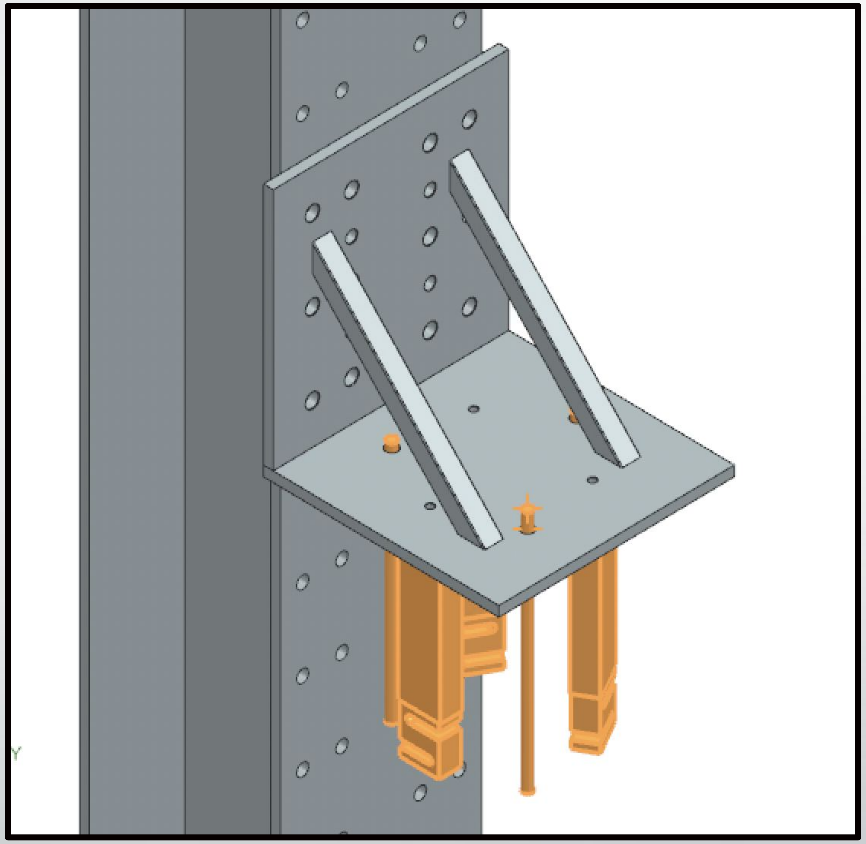


*The engine mount can interface with both the XL I-Beam at FAR and the Large I-Beam at Flabob

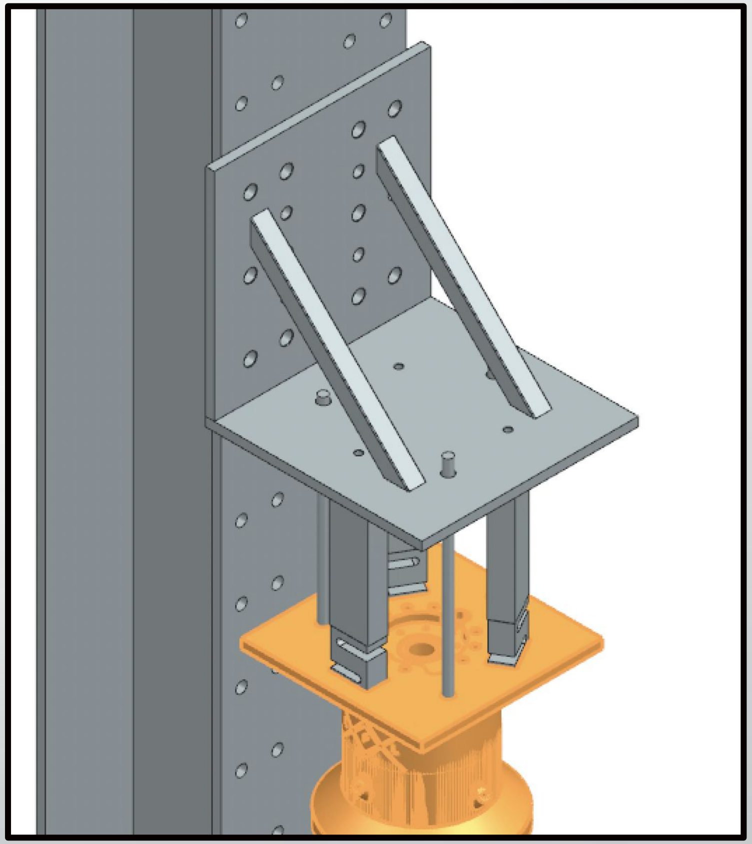
Order of Construction



1. Plates are attached to I-beam



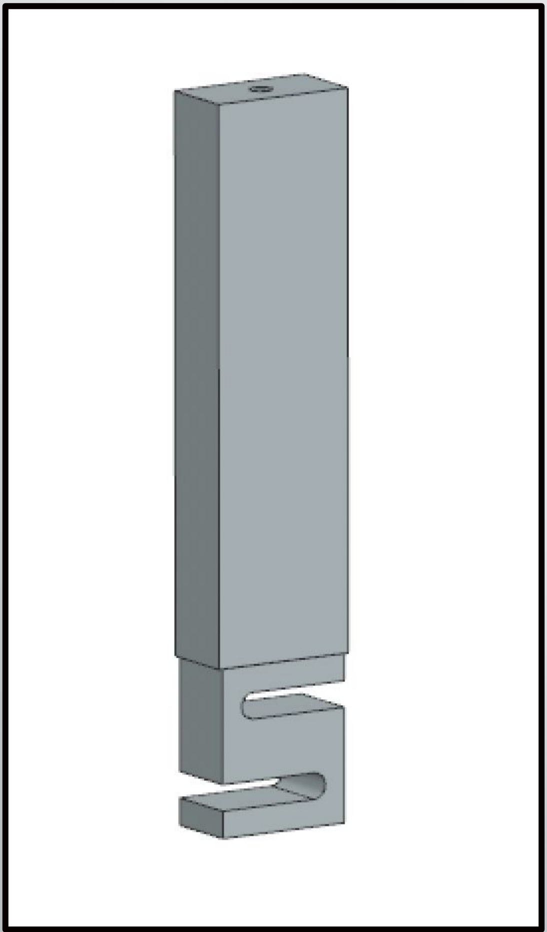
2. Tension rods and load cells are secured



3. Balerion is attached

*Fasteners not shown

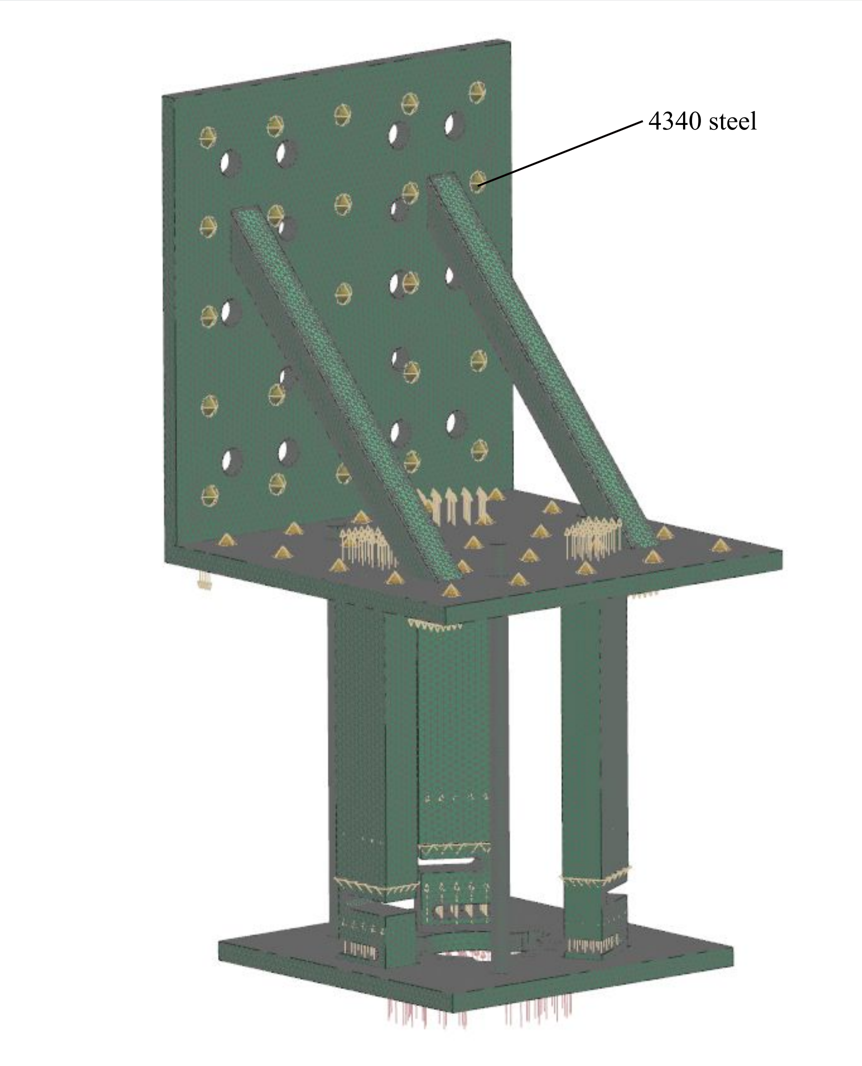
Load Cell Procedure



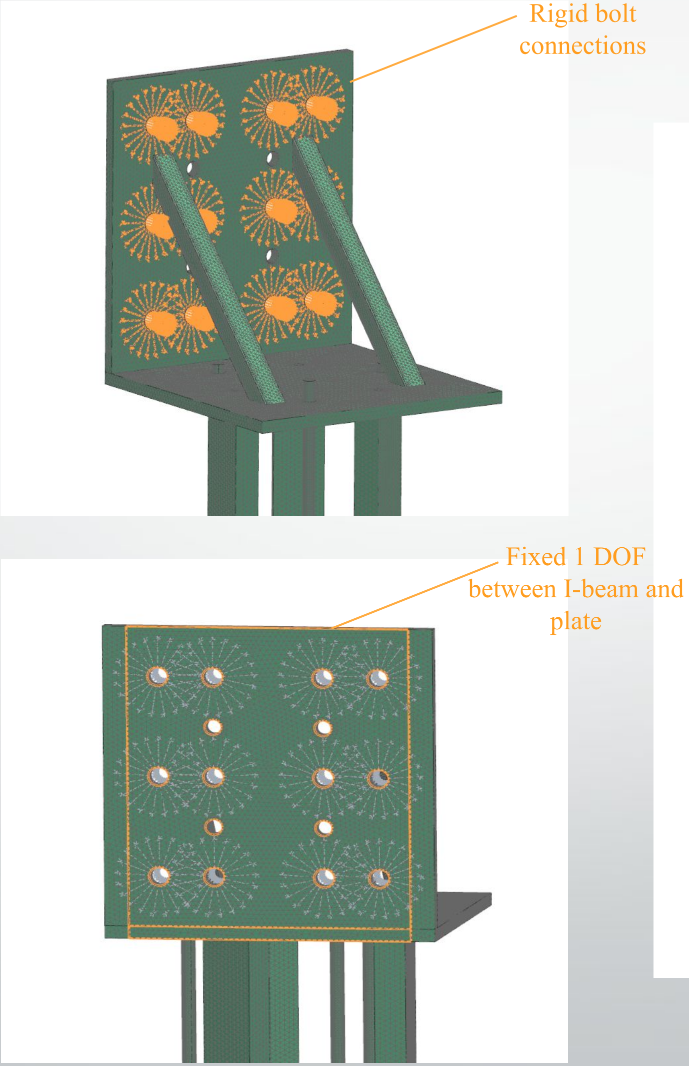
- Verify load cells are functioning as intended
- Attach load cell to load cell support with a pre threaded rod
- Load cells with supports attached to top and bottom plate using bolts

This allows for interchangeability in the event of load cell failure or different spacing requirements

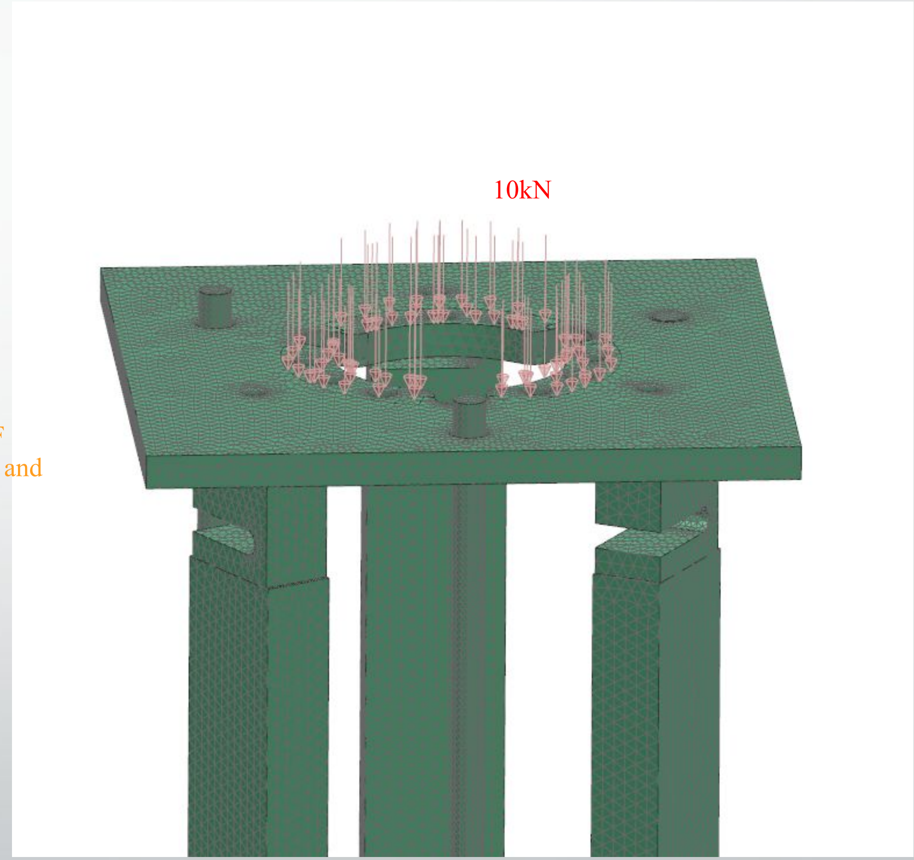
Balerion Test Mount V1 - Structural Analysis



Mesh

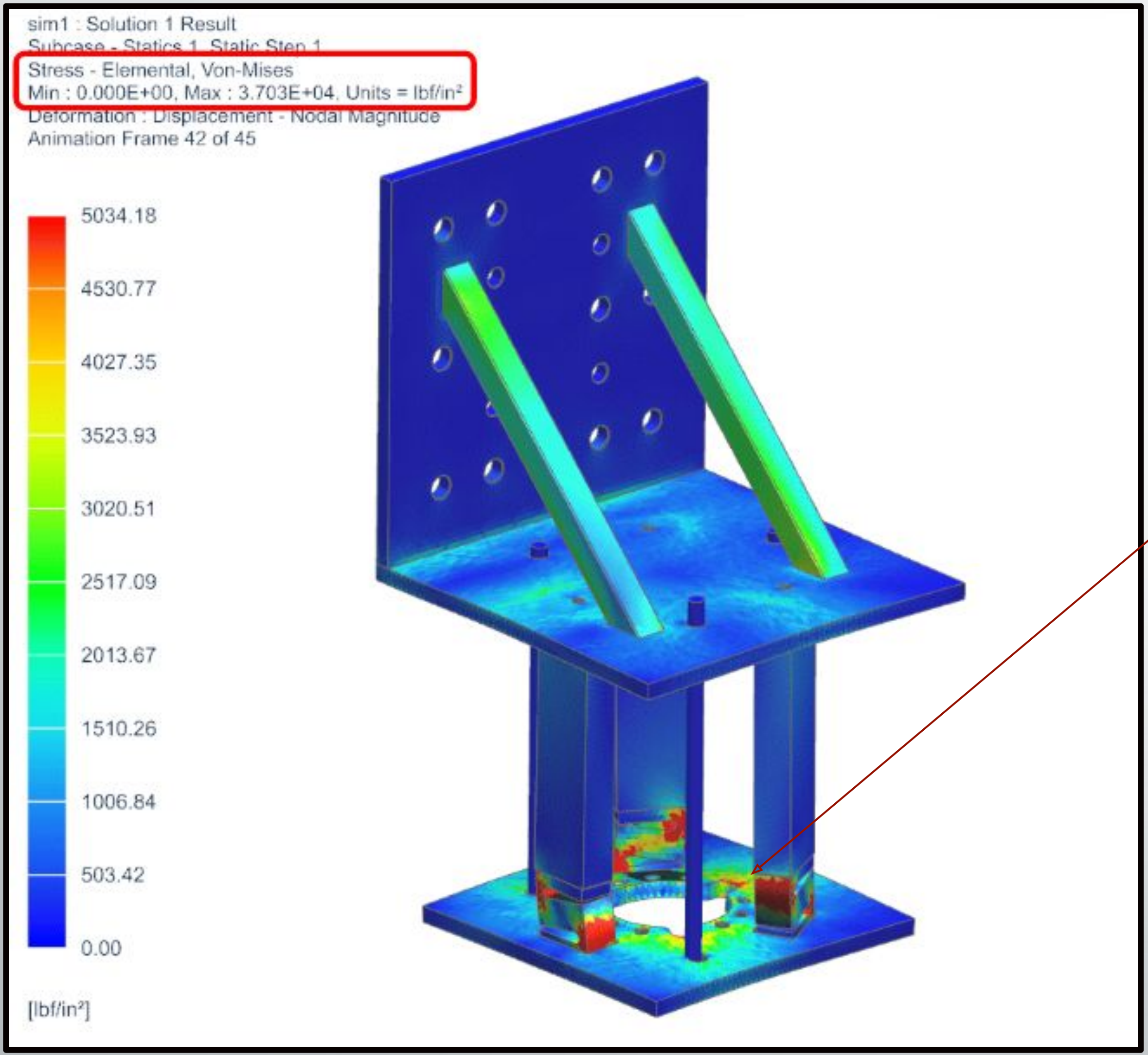


BCs



Load

Balerion Test Mount V1 - Structural Analysis



Von Mises Stress

Material: 4340 steel

Yield Strength: 68200 [psi]

SF_min: ~12 (w/ 10 kN)

Path to CDR - Vertical Test Stand

Vertical Test Stand Action Items

- Update FEM
  - Apply more accurate material selections
  - Determine whether ¼” or ½” steel is necessary
  - Convergence study
- Design & Spec load cells & tension rods in detail

Cost Estimate

2x 1” Steel 4043 square tubes (.12” thickness): ~$6 each

2 (12”x 12”, ¼” thick) steel plates: ~$45 each

Welding: ~ $100

Water Jetting: ~ free if done with USC Makerspace

Total: $202

Conclusions

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System Summary

- Redesign Hydra to accommodate LOx
- Reduce build cost by repurposing components
- Increase fuel and LOx line sizes to 1”
- Accommodate mass flow rates of 7 kg/s and 5 kg/s for LOx and fuel, respectively
- New fuel and LOx tanks to accommodate 1500 psi MEOP tank pressure
- Custom DAQ system to support system
- Engine mount is independent of feed system and can accommodate Balerion, with the capability for future engines

Question/Comments?