Water Flow Campaign Test Readiness Review

By: Ethan Heyns

Overview

Purpose

The Water Flow Campaign is a series of tests to prove the functionality of the Flight Feed System (FFS). Using water in place of propellants, flows can be done safely while still providing useful data and scenarios to solve problems.

General Testing Goals:

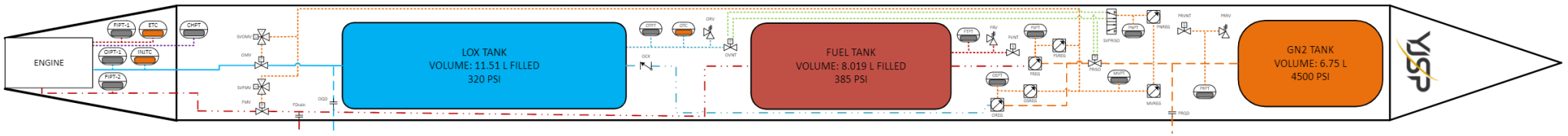
- Prove Intended Functionality
- Tune System
- Test the accuracy of our prior calculations with actual data

Overview

FFS Description

The Flight Feed System is a pressure regulated feed system designed to use gaseous nitrogen (GN2) to deliver liquid propellants (LOX and Jet-A) to an engine at a desired mass flow rate and pressure. The system uses an array of pressure regulators to pressurize the propellant tanks at desired operating pressures. Once pressurized, actuating the Fuel (FMV) and Oxygen (OMV) main valves delivers these propellants to the engine.

Plumbing & Instrumentation Diagram (P&ID)



Top Level Objectives

Data Acquisition

- Obtain flight like pressures in both the LOX injector (308 PSI) and fuel injector (365 PSI).
- Determine the pressure differential from the tank pressures to the injector pressures. We expect the LOX tank to be at 320 PSI (12 PSI dP) and the Fuel tank to be at 385 PSI (20 PSI dP).
- Quantify our mass flows for both fuel and LOX, which are expected to be 0.53 kg/s for fuel and 0.955 kg/s for LOX.
- Determine the delay between fuel and LOX entering the injector to find the exact valve timing to mitigate the delay. Using an auto-sequence we will find the optimal valve timing.
- Verify ability to control system accurately using our custom-made Master Computer Flight Software (MCFS) along with our ground electronics systems including the Data Acquisition Device (DAQ) and Engine Controller (EC) to record pressure transducer and thermocouple data and actuate solenoid valves.
- Verify that the pressurant in the COPV with an initial pressure of 4500 PSI should be sufficient to supply engine with propellant for 11 second burn time and purge for at least 3 seconds.

Tests

Overview

- System Checks: 1000 PSI Leak Check
  - Run Ground Electronics and MCFS, Find Leaks, Set Regulators
- Short Water Flows: 2000 PSI, 3 Second Flows
  - Injector Pressures, Valve Timing, Adjust Regulators
- Long Water Flows: 2000 PSI, 11 Second Flows
  - Mass Flow, Reconfirm Prior Results, LFS Fuel Fill Precision
- COPV Fill Test: 4500 PSI
  - High Pressure Leak Test, Fill and Vent Times, Orifice Sizing, Hysteresis
- Full Water Flows: 4500 PSI and 11 Second Flows
  - Reconfirm Prior Results, Remaining COPV Volume, Purge

Schedule

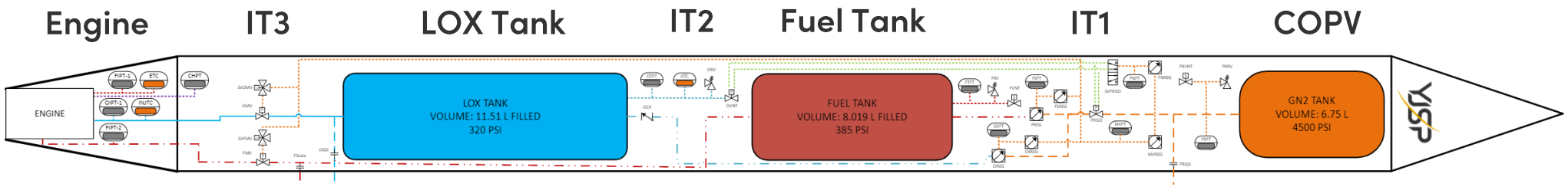
SUN	MON	TUE	WED	THU	FRI	SAT
30	31	Jun 1	2	3	4	5
System Checks				Short Water Flows		
6	7	8	9	10	11	12
	Data Review			Long Water Flows		
13	14	15	16	17	18	19
	Data Review				COPV Fill Test	
20	21	22	23	24	25	26
	Data Review			Full Water Flows		

- Overview
- **FFS**
- Support Systems
- Configuration
- Data Acquisition
- Test Objectives
- Risk Avoidance
- Procedures
- Contingency Plan

Flight Feed System

Overview

- **Fluid Storage**
  - COPV, Fuel and LOX Tanks
- **Intertanks**
  - IT1 – High Pressure, Pneumatics, Fuel Tank Components
  - IT2 – LOX Tank Components
  - IT3 – Main Valves, Fill Ports, Engine Feed

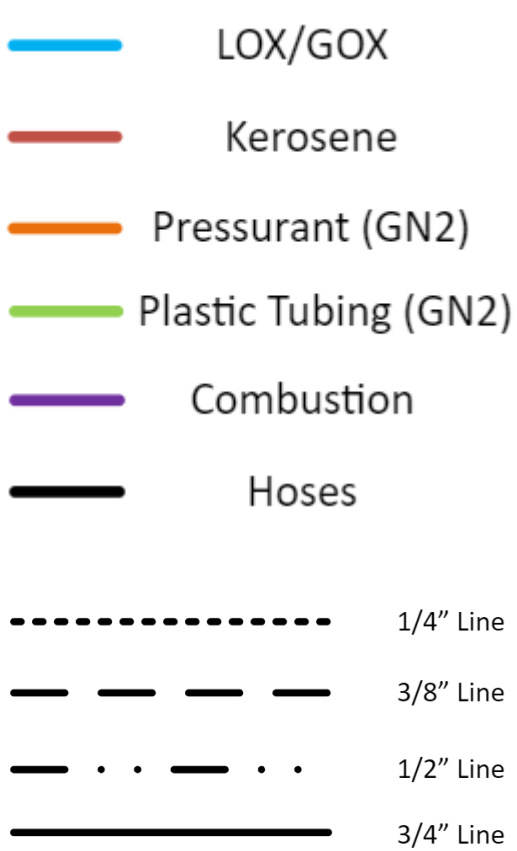


Naming Scheme

Flight Feed System

- PR: Pressurant
- PN: Pneumatics
- F: Fuel
- O: Oxygen

- G: Ground
- Everything else is flight



COPV – Composite Overwrapped Pressure Vessel

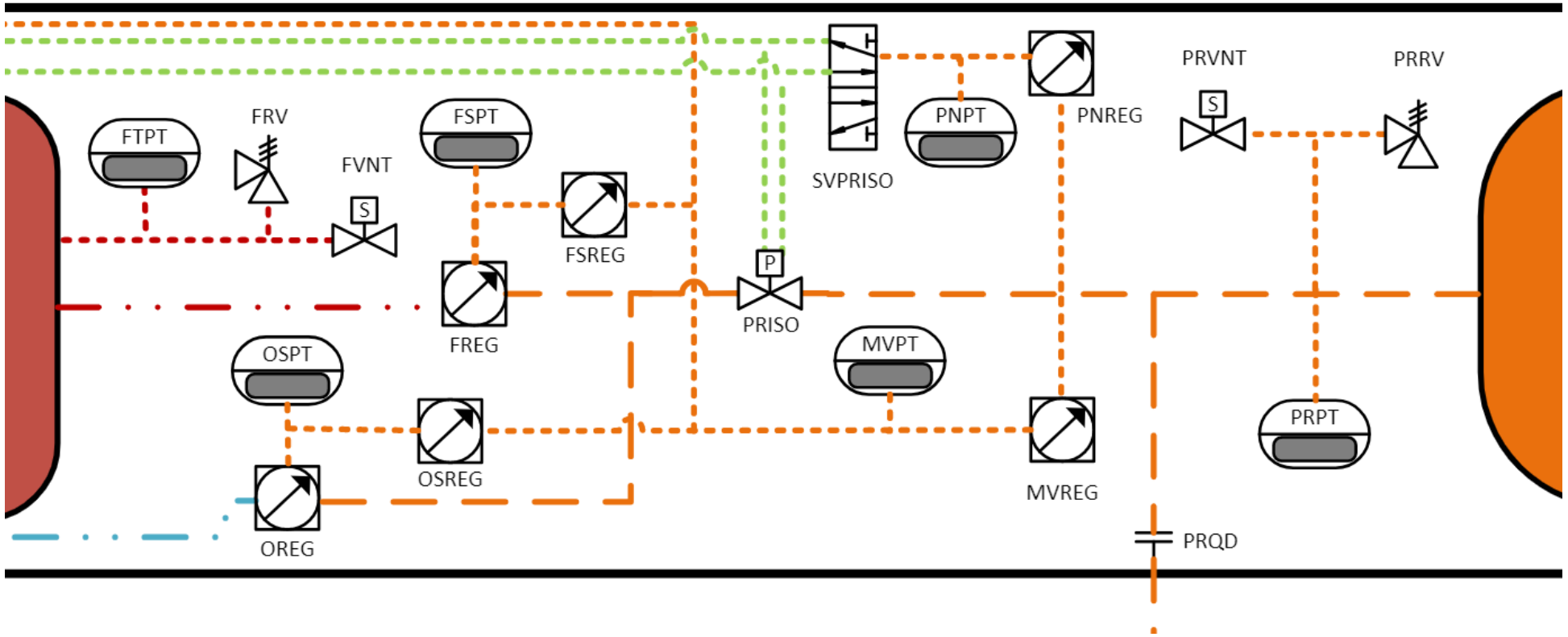
GN2, 4500 PSI

- Type 3 Pressure Vessel: Aluminum Liner, Carbon Fiber and Fiber Glass Composite
- 6.75 L, 15 year service life, DOT Specification
- Operating Pressure: 4500 PSI
- Proof Pressure: 7500 PSI, 1.67 FOS
- Burst Pressure: 15300 PSI, 3.4 FOS
- Hydrostatic Tested to 5000 PSI
- Proof Tested to 7500 PSI within the last 5 years (9/14/17)

IT1

Intertank 1

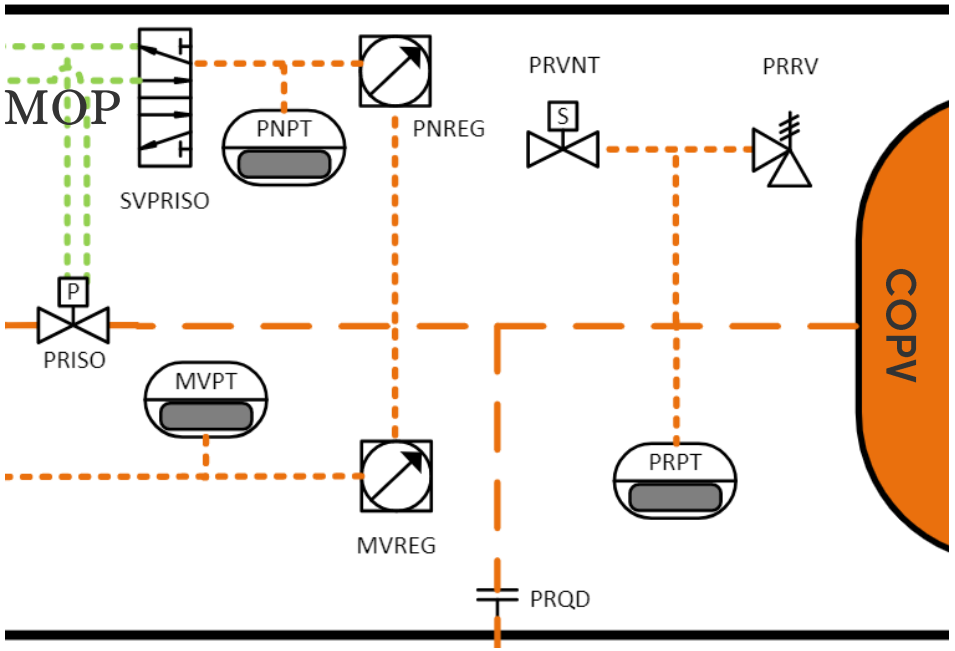
- Line Sizing: FOS of at least 4 for all lines. Stainless Steel for Pressurant and LOX Sections, Aluminum for Fuel Section



High Pressure Section

Intertank 1 Components

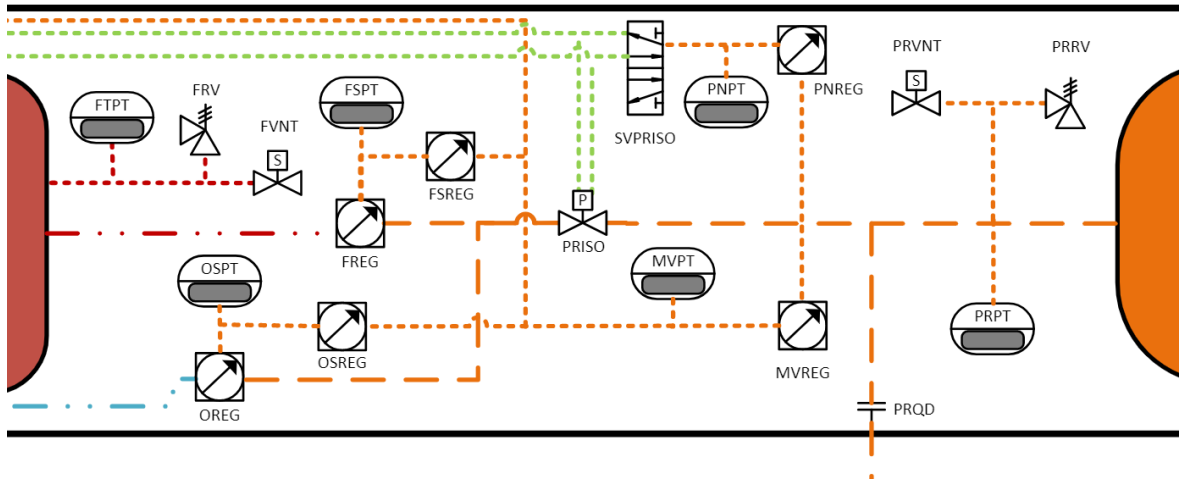
- **PRVNT**
  - 2 way solenoid, NC, 5000 PSI MOP
- **PRRV**
  - Relief Valve, 4750 PSI, 6000 PSI MOP
- **PRPT**
  - 5000 PSI Pressure Transducer
- **PRISO**
  - Pneumatically Actuated Ball Valve, 6000 PSI MOP



Regulators

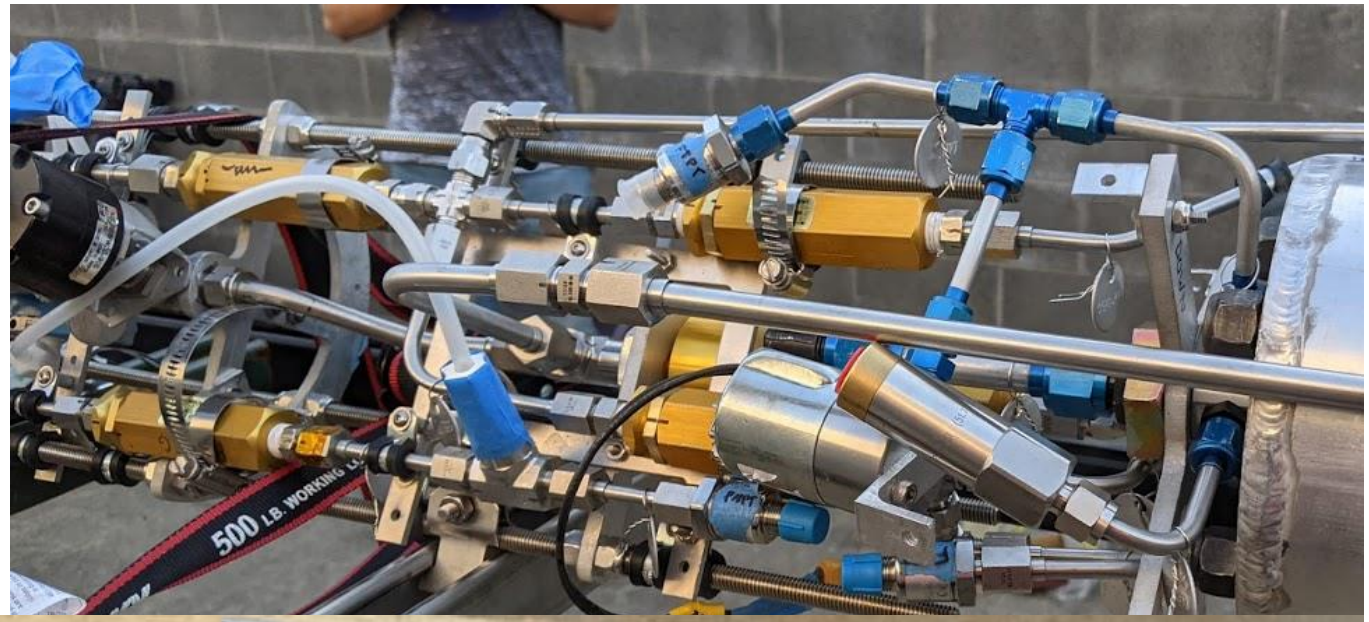
Intertank 1

- Hand Loaded – 6000 PSI MOP
  - PNREG – 70-90 PSI
  - MVREG – 500 PSI
  - FSREG – Depends on FREG
  - OSREG – Depends on OREG
- Dome Loaded – 6000 PSI MOP
  - FREG – 385 PSI
  - OREG – 320 PSI
- Each Reg has its own PT



IT1

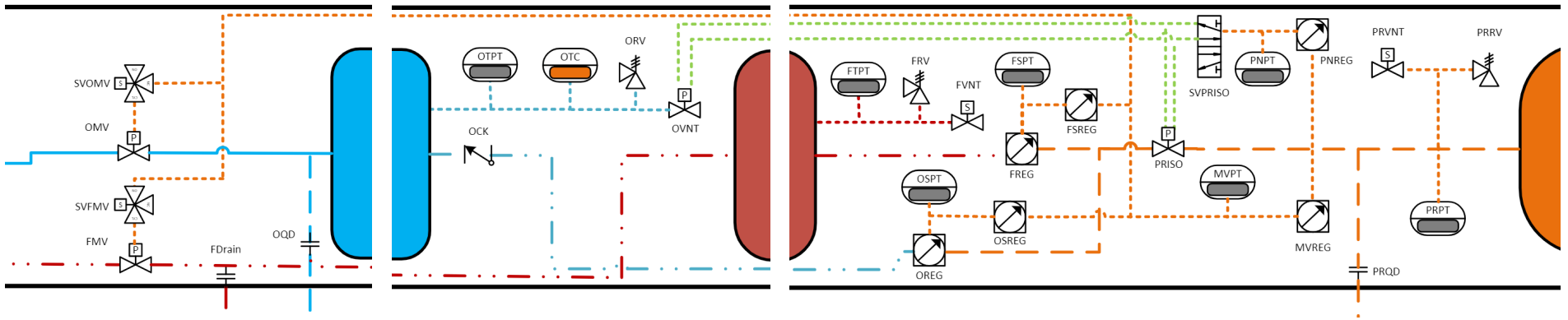
Intertank 1



Low Pressure

Pneumatics

- **PNREG: 70-90 PSI**
  - SVPRISO - 5/2 way solenoid, 145 PSI MOP
  - PRISO/OVNT - Inversely actuated by SVPRISO
- **MVREG: 500 PSI**
  - SVOMV – 3/2 way solenoid, 6000 PSI MOP
  - SVFMV – 3/2 way solenoid, 6000 PSI MOP



Propellant Tanks

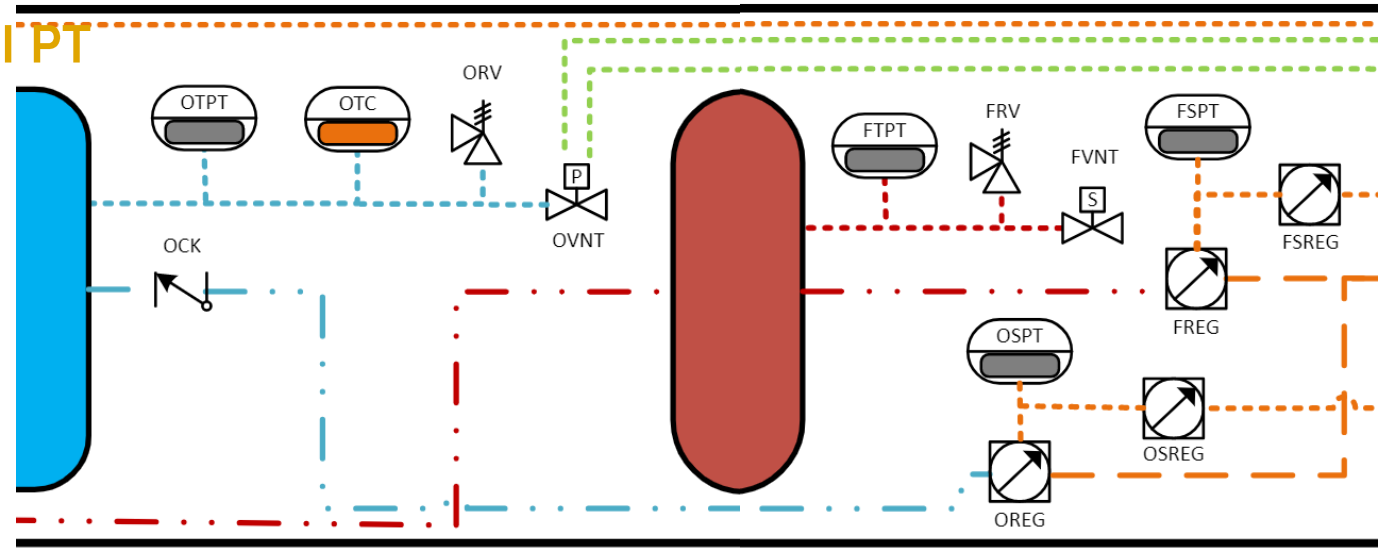
Jet-A and LOX

- **Fuel Tank**
  - Aluminum
  - Welded, Rods
  - 390 PSI MEOP, 3.6 FOS based on stress analysis
  - Proof tested to 700 PSI, 1.8 FOS
- **LOX Tank**
  - Stainless Steel
  - Welded
  - 325 PSI MEOP, 4.1 FOS based on stress analysis
  - Hydrostatic Proof Tested to 600 PSI, 1.8 FOS

Tank Components

LOX & Fuel

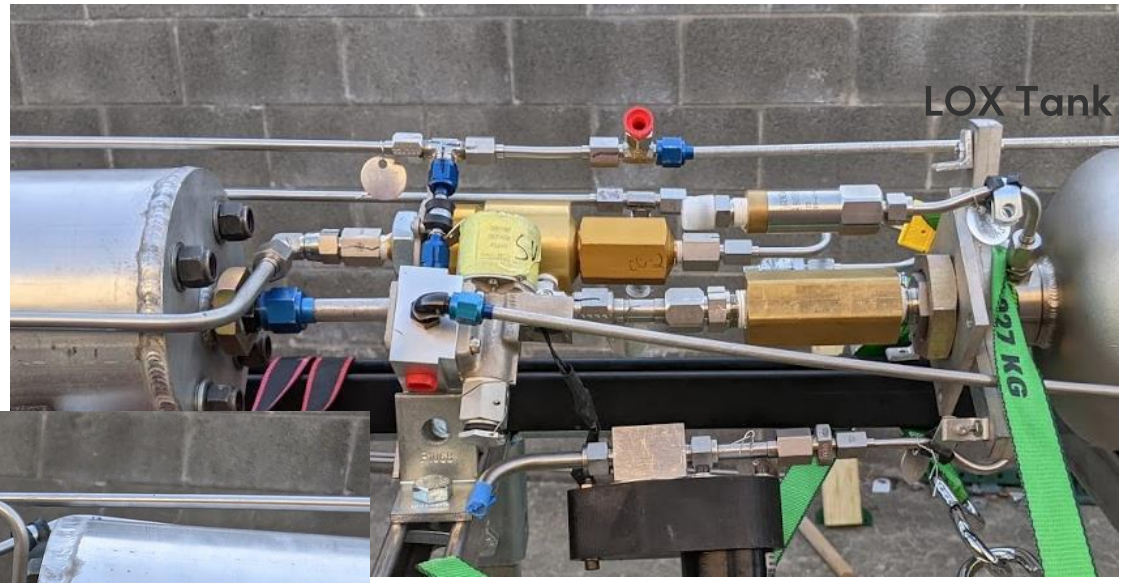
- OVNT – Pneumatically actuated ball valve, 2500 PSI MOP
- ORV – Relief Valve, 600 PSI
- OCK – Check Valve
- OTPT – 1000 PSI PT
- OTC – In Line
- FVNT – 2 way solenoid, 2000 PSI MOP
- FRV – Relief Valve, 600 PSI
- FTPT – 1000 PSI PT



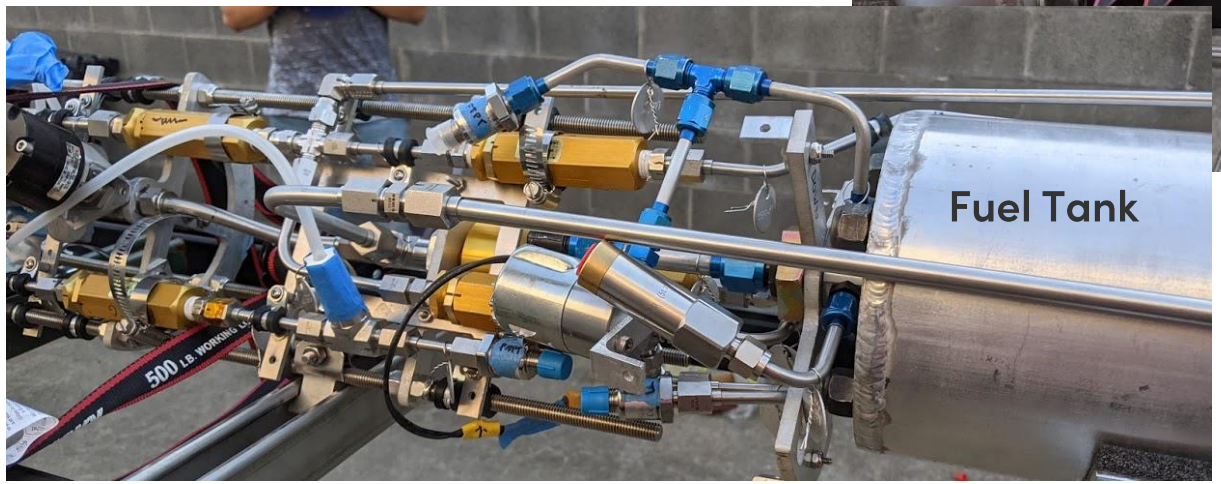
Tank Components

IT1 & IT2

IT2



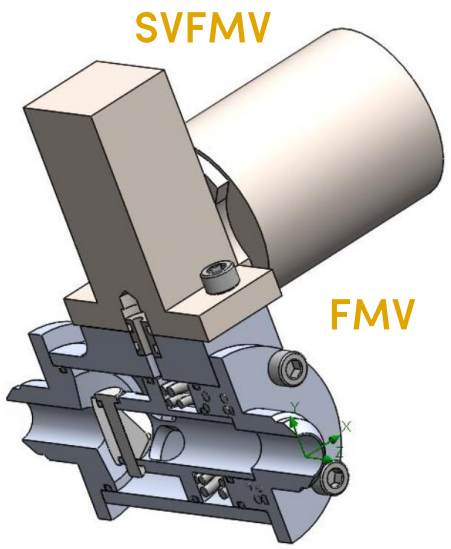
IT1

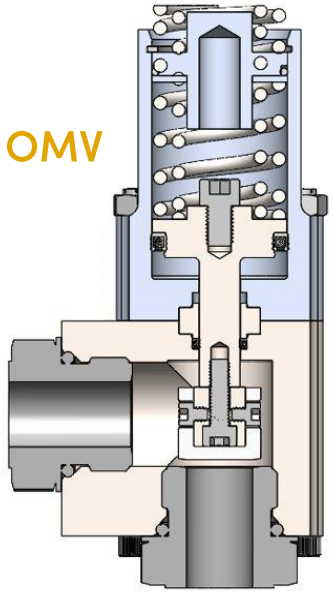


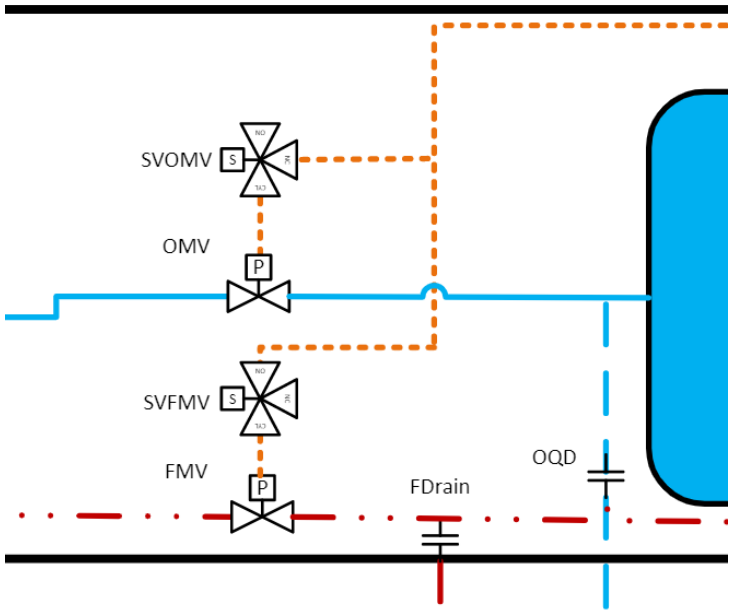
Main Valves

Intertank 3

- Built In-house, Pneumatically Actuated
- FMV – Fuel Main Valve, NC, Opens with tank pressure
- OMV – Oxygen Main Valve, NC

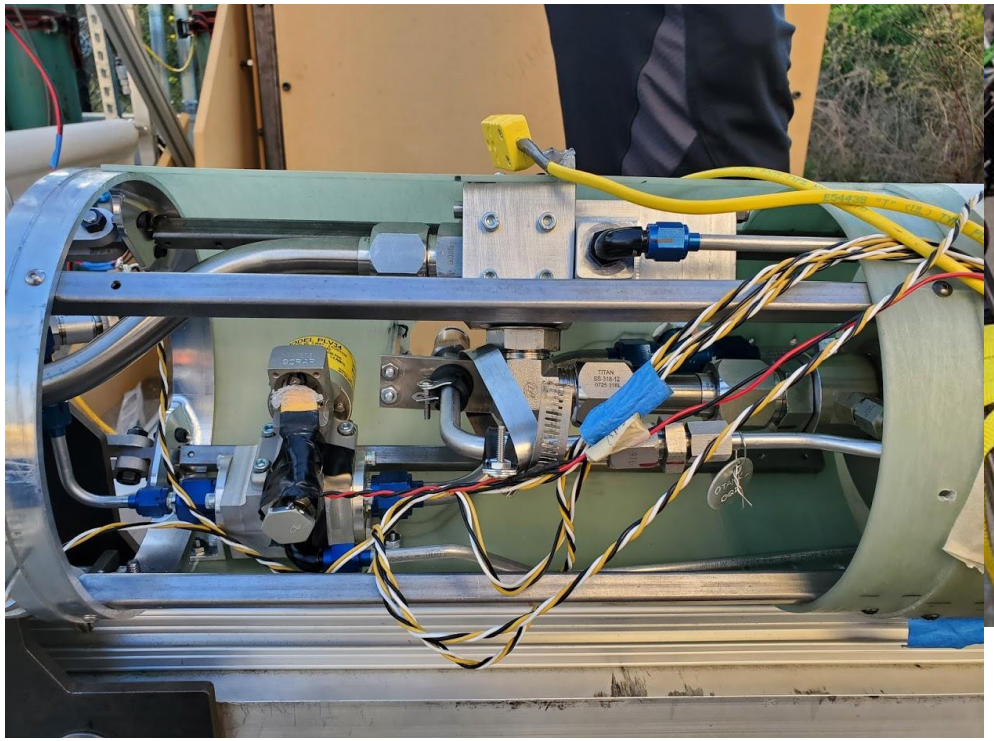


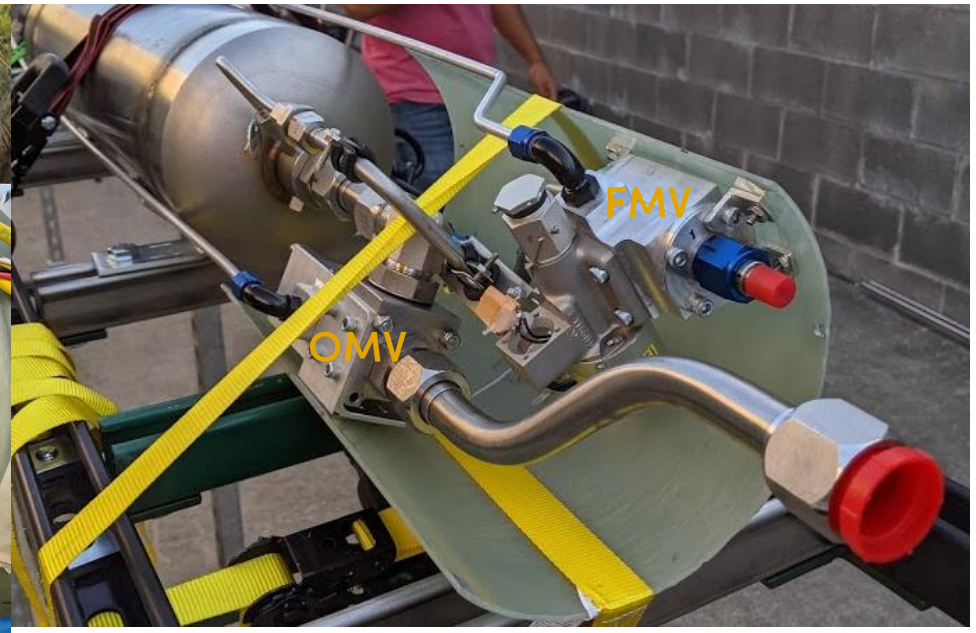




IT3

Intertank 3

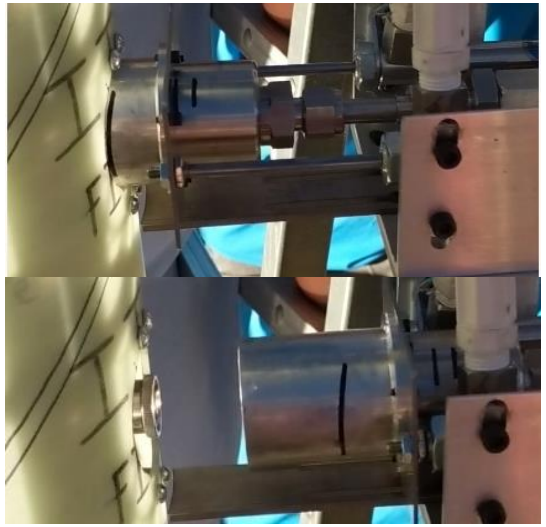


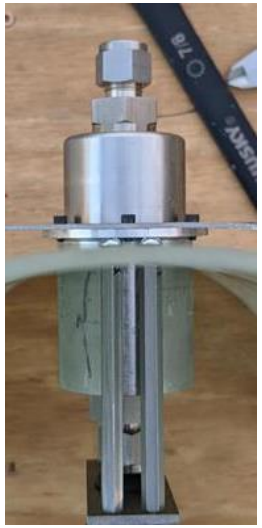


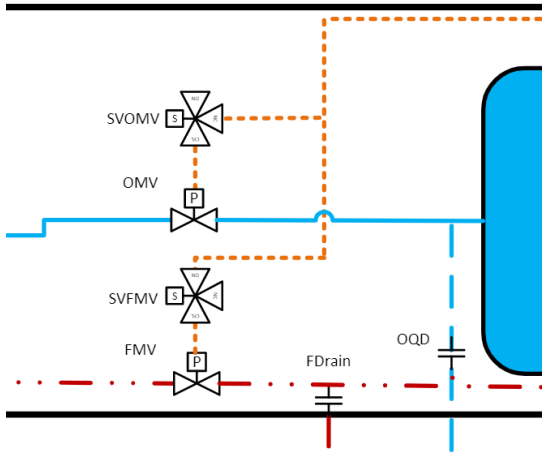
Fill Ports and Quick Disconnects

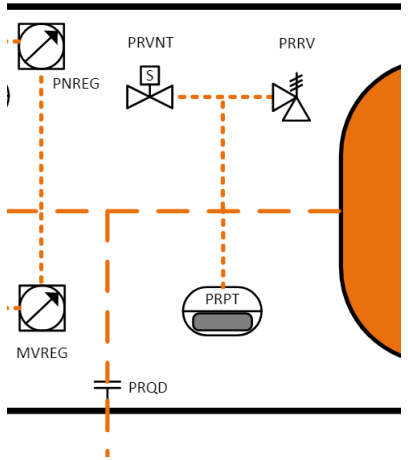
IT1 & IT3

- PRQD – 10000 PSI MOP
- OQD – Cryo rated, 1000 PSI MOP
- Fuel Fill / Drain – Plugged for manual fill/drain





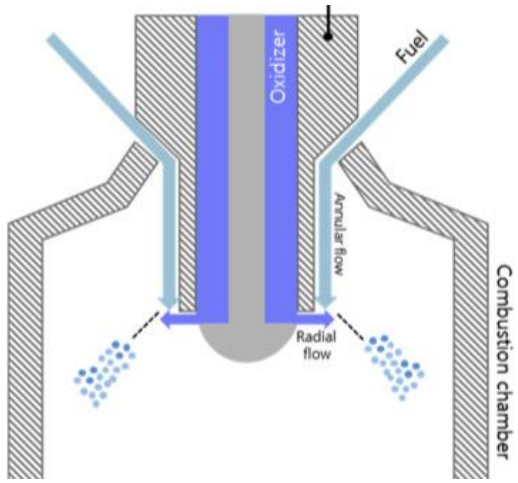


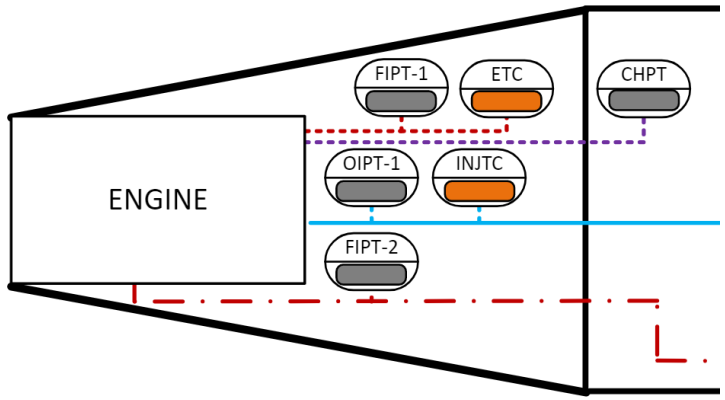


Pintle Injector

Engine

- LOX – Radial
- Fuel – Axial
- Injector pressures are read via FIPT-1&2 and OIPT





Fire/Flow Sequence

Complete System Functionality

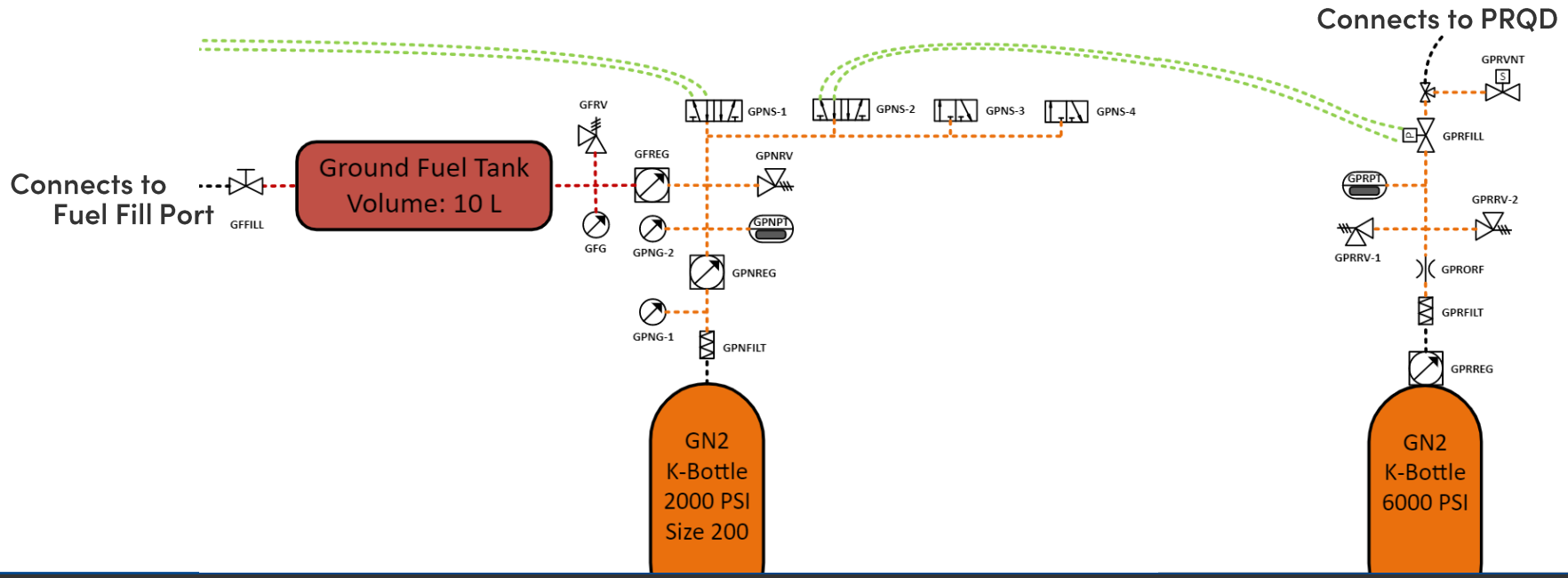
- Filled Tanks and COPV
- PRISO Opens, Tanks are Pressurized
- FMV and OMV Open, Fire/Flow

Current System State											
	Filling	Pressurizing Tanks Top Off COPV	Go-No-Go	QD Disconnect	LOX Lead *Valve Timing	Ignition	Burn Duration	End Burn Purge Fuel	Vent LOX	Vent System Confirm Ambient Pressure	LOX Boiloff
Valve State											
PRVNT	Closed										
FVNT	Closed										
SVPRISO	Closed										
PRISO	Closed										
OVNT	Open										
SVOMV	Closed										
OMV	Closed										
SVFMV	Closed										
FMV	Closed										
Ignitor	Off										

Launch Feed System

Supporting Systems

The Launch Feed System (LFS) is a pressure fed system designed to supply the FFS with propellant and pressurant during fill procedure. LFS has the capability to regulate 6000 PSI K-Bottles to 4500 PSI which is the operating pressure for FFS. LFS also has remote control over their pressurant fill and vent valves for safe actuation from a distance. LFS can also fill fuel, or in our case water, using a low-pressure system to overcome gravity head.



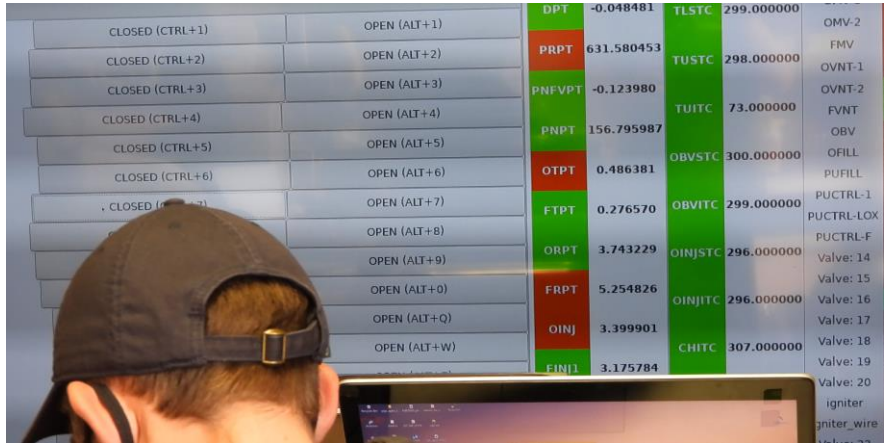
Ground Electronics and MCFS

Supporting Systems

Avionics systems designed to control the flight and ground systems along with collecting sensor data. Ground electronics are composed of a ground Data Acquisition device (DAQ) and ground Engine Controller (EC) and the Master Computer Flight Software (MCFS). The DAQ is used to collect and store sensor data within the combined ground and flight feed systems. The EC works to actuate electronic components, chiefly solenoids and motors. An operator can send electronic signals through the EC and read/collect data from the DAQ using the MCFS on their laptop to operate LFS and FFS completely remotely.

EC DAQ

MCFS



Overview
FFS
Support Systems
Configuration
Data Acquisition
Test Objectives
Risk Avoidance
Procedures
Contingency Plan

Test Config

Test Site

FFS + LFS

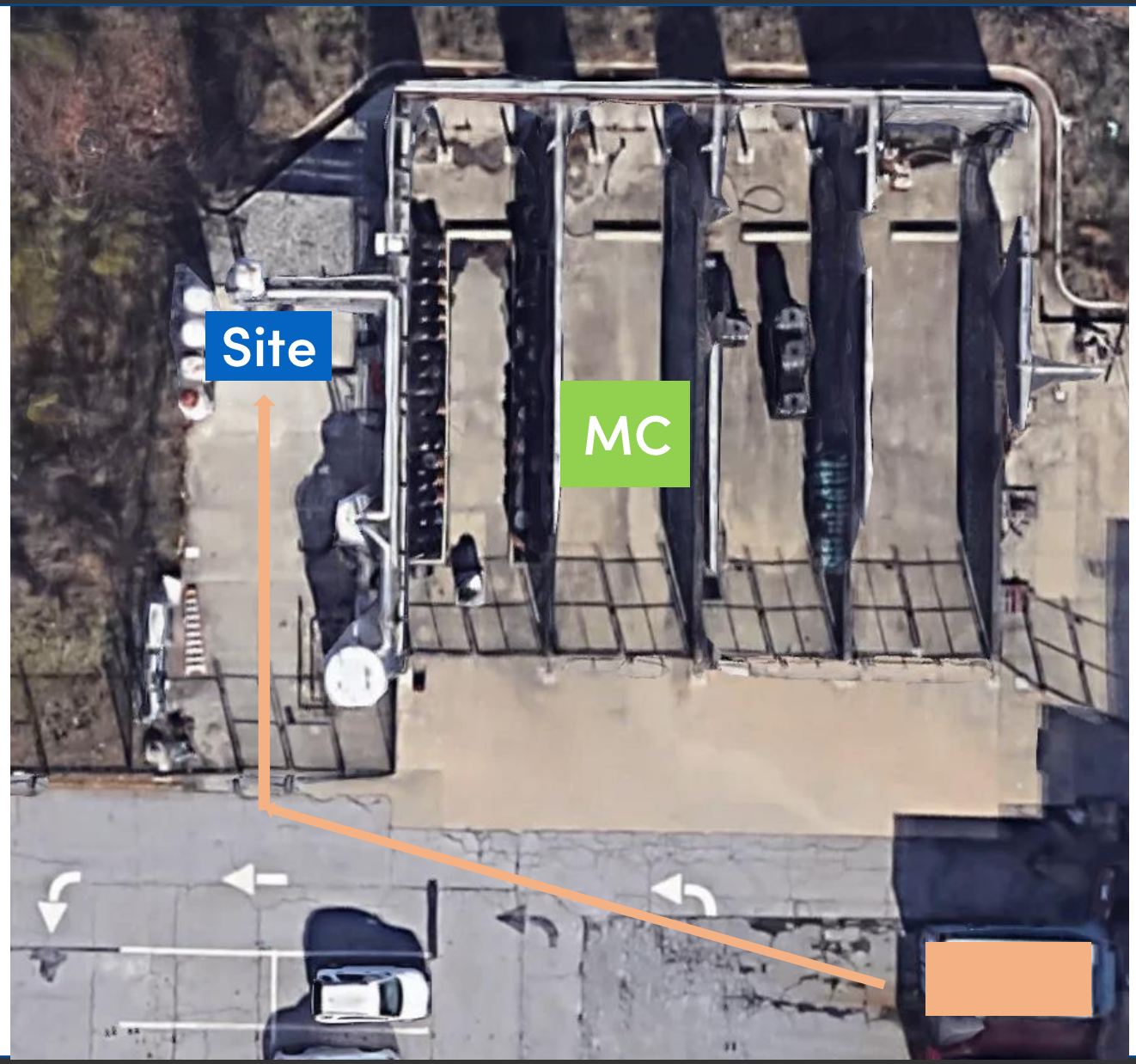
Ground DAQ + EC

Mission Control

MCFS

Shipping Container

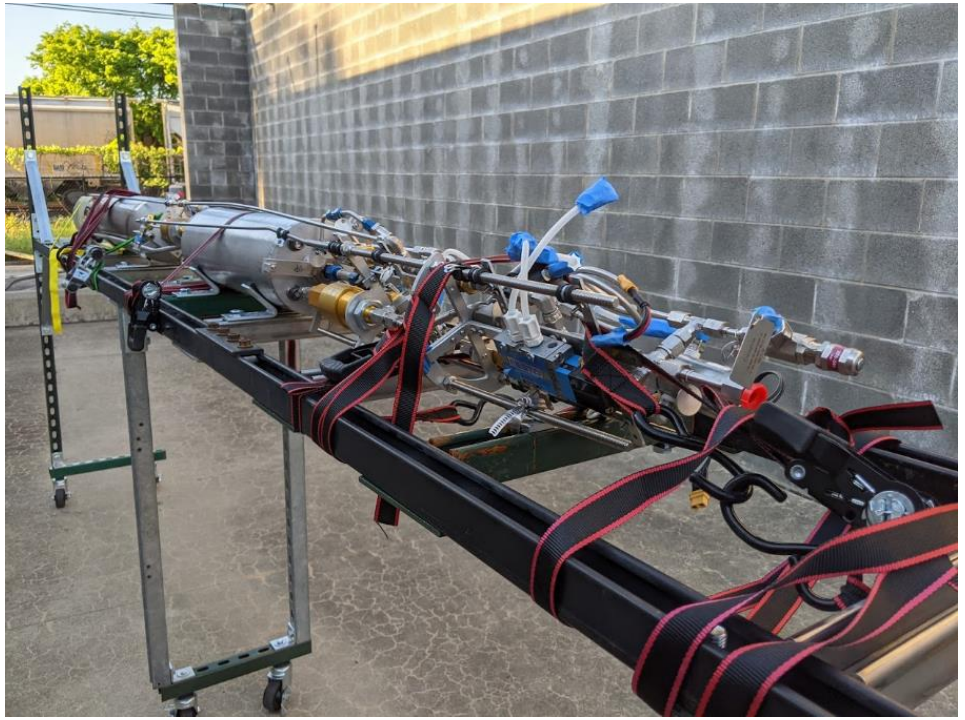
FFS Storage



Test Configuration

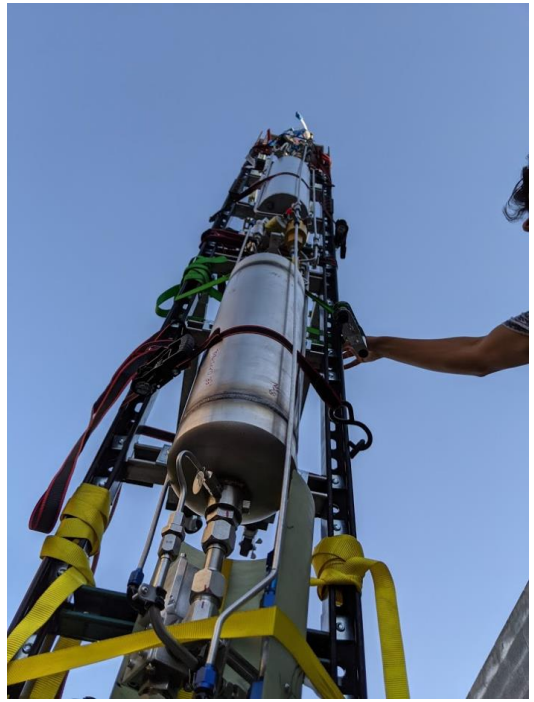
Naked

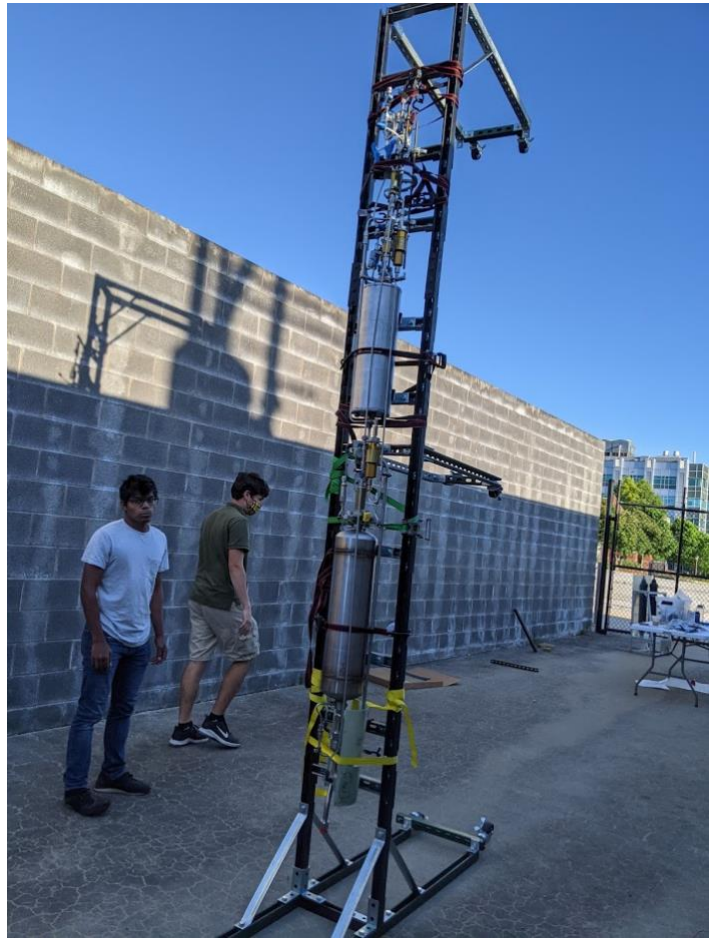
- Everything is accessible
- Easy to transport
- FFS is secured via ratchet straps, hose clamps, and brackets to the integration table / vertical stand



Vertical Stand

- Switches between horizontal and vertical
- Need 6 people minimum to go vertical





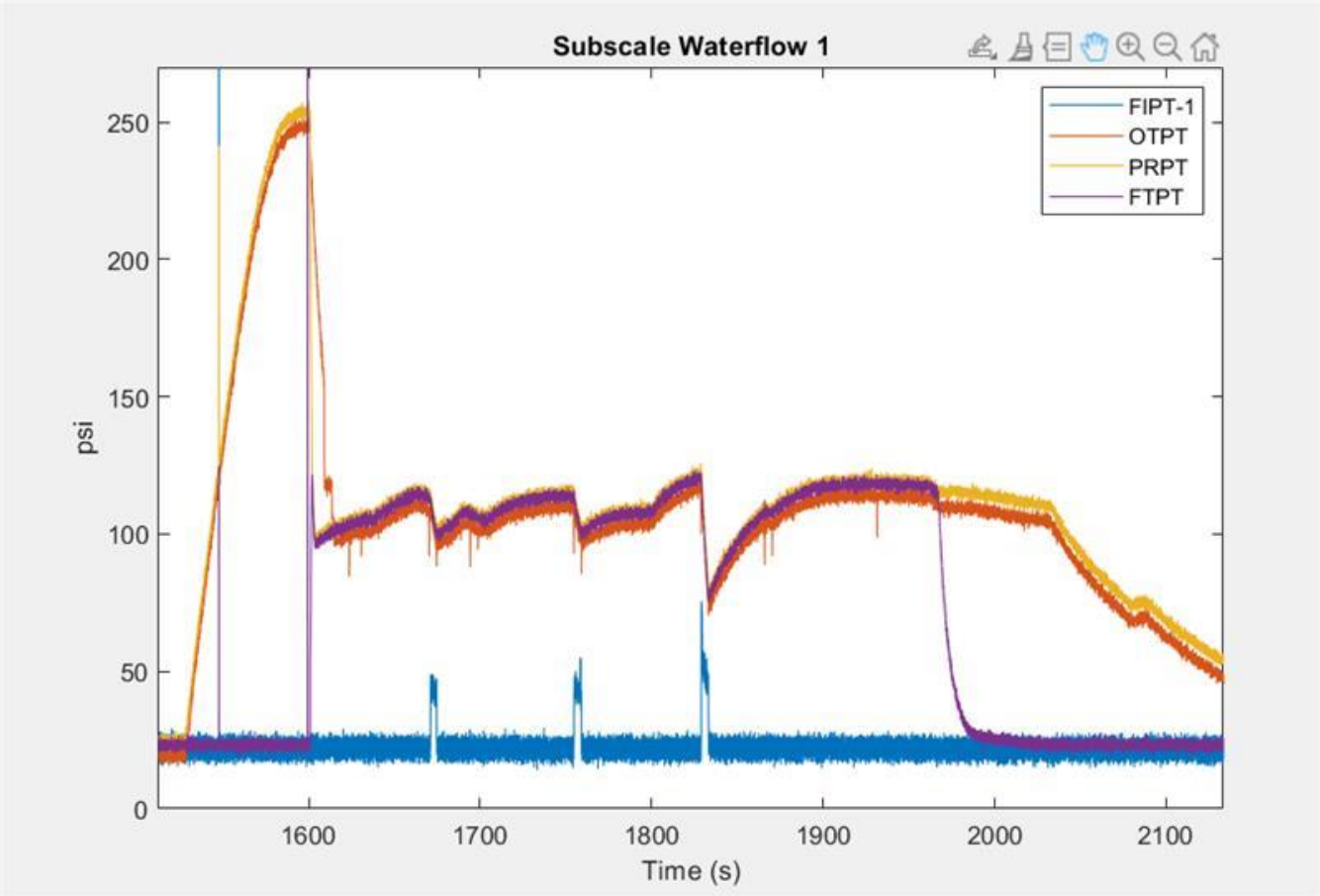
Test Site

- West most test cell with metal structure
- LFS is secured to the metal structure with ratchet straps shown in red
  - K-Bottles secured to LFS Fluids Box
  - Pressurant Fill Line Runs along metal structure and hose is secured with hose clamps shown in green
- FFS and the Vertical Stand is secured to the metal structure with ratchet straps

Data Acquisition

Low Pressure Water Flow

- Tank-Injector dP
- Injector Pressures
- Valve Timing



Data Acquisition

Target Mass Flows and Injector Pressure

- Pressure Drop
- Mass Flow
- Injector Pressure

Engine Parameters				
Chamber Pressure	18	Bar		
Ox Flow Rate	0.955	kg/s		
Fuel Flow Rate	0.53	kg/s		
Ox Mass	10.505	kg		
Fuel Mass	5.83	kg		
Total Propellant Mass	16.335	kg		
OX Injector Pressure	21.24	Bar	308.060712	psi
Fuel Injector Pressure	25.2	Bar	365.49576	psi
OX Tank to Engine P Drop	0.7	Bar		
Fuel Tank to Engine P Drop	1.14	Bar		
P Drop FoS	1.2			
OX Feed Pressure	22.08	Bar	320.243904	psi
Fuel Feed Pressure	26.568	Bar	385.3369584	psi
Engine Mass	3.5	kg		

Data Acquisition

COPV Remaining Pressure

- **After 11 Second Flow**
  - 4500 PSI Initial ⟶2700 PSI Final
  - 2000 PSI Initial⟶520 PSI Final

Initial and Final Moles/Pressure in COPV for Water Flow

Variable	Value	Unit	Value2	Unit2
Initial Pressure	**4500**	**PSI**	306.2068376	atm
Compressibility Factor (Z)	1.15		4500 PSI: Z = 1.15	2000 PSI: Z = 1.03
COPV + Upstr PRISO Volum	6.841848109	L		
Initial Moles	74.50006226	mol		
Fuel Pressure	385	PSI	26.19769611	atm
Fuel Volume	8.232006085	L		
Fuel Moles	8.819316857	mol		
Fuel Moles (Hermsen)	10.66050378	mol		
LOX Pressure	320	PSI	21.77470845	atm
LOX Volume	11.67366087	L		
LOX Moles	10.39502612	mol		
LOX Moles (Hermsen)	12.24876035	mol		
Final Moles	**55.28571928**	**mol**		
Final Pressure	**2903.828758**	**PSI**	197.5938269	atm
Final Moles (Hermsen)	**51.59079813**	**mol**		
Final Pressure (Hermsen)	**2709.75661**	**PSI**	184.3880005	atm

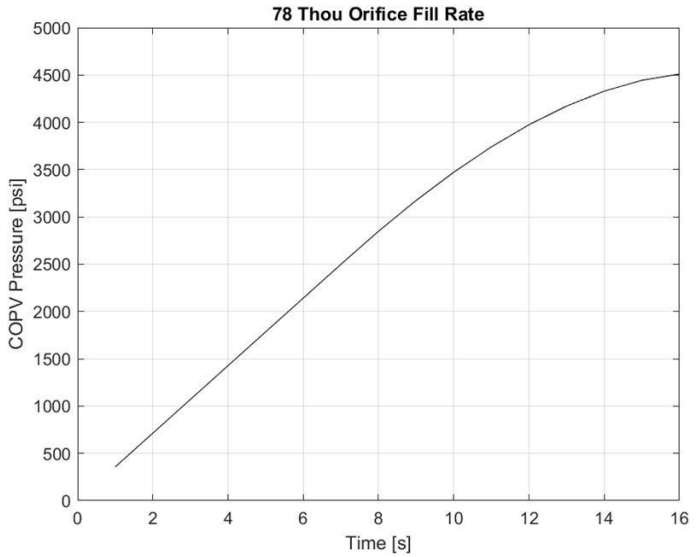
Initial and Final Moles/Pressure in COPV for Water Flow

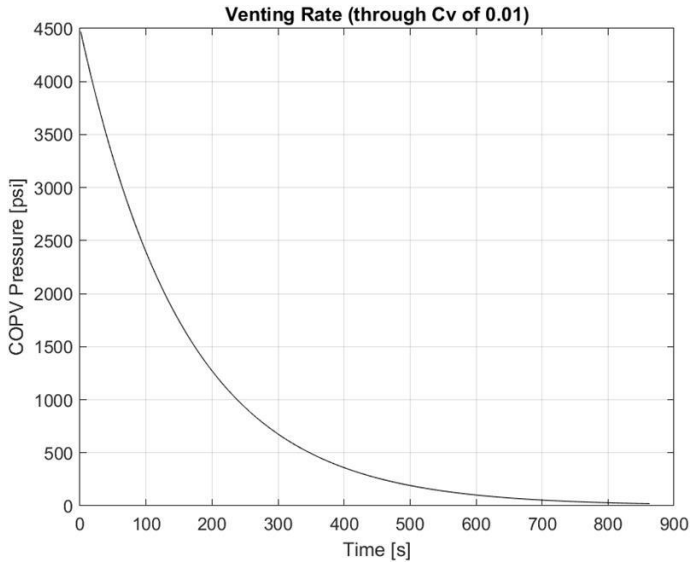
Variable	Value	Unit	Value2	Unit2
Initial Pressure	**2000**	**PSI**	136.0919278	atm
Compressibility Factor (Z)	1.03		4500 PSI: Z = 1.15	2000 PSI: Z = 1.03
COPV + Upstr PRISO Volum	6.841848109	L		
Initial Moles	36.96874718	mol		
Fuel Pressure	385	PSI	26.19769611	atm
Fuel Volume	8.232006085	L		
Fuel Moles	8.819316857	mol		
Fuel Moles (Hermsen)	12.74896969	mol		
LOX Pressure	320	PSI	21.77470845	atm
LOX Volume	11.67366087	L		
LOX Moles	10.39502612	mol		
LOX Moles (Hermsen)	14.2415876	mol		
Final Moles	**17.75440421**	**mol**		
Final Pressure	**932.5328529**	**PSI**	63.45509686	atm
Final Moles (Hermsen)	**9.978189888**	**mol**		
Final Pressure (Hermsen)	**524.0947414**	**PSI**	35.66253186	atm

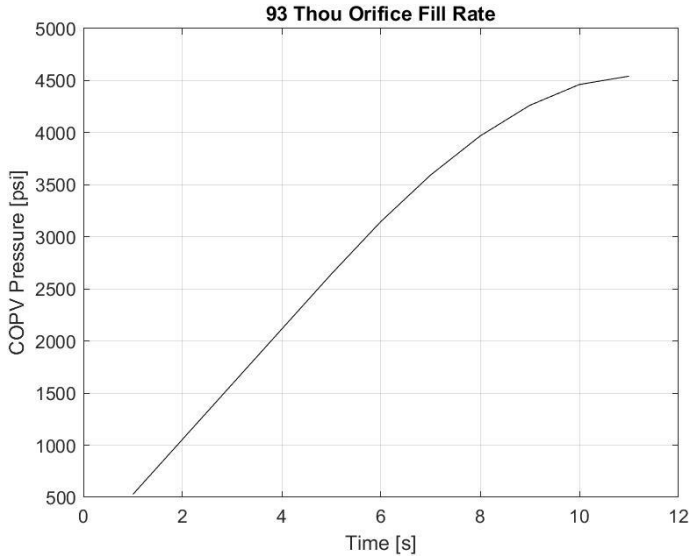
Data Acquisition

Filling and Venting

- **Filling Rate**
  - 78 Thou – 16 seconds
  - 93 Thou – 11 seconds
- **Venting Rate**
  - 850 seconds
  - ~14 minutes







Test Objectives

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  - Run Ground Electronics and MCFS, Find Leaks, Set Regulators
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- Long Water Flows: 2000 PSI, 11 Second Flows
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- COPV Fill Test: 4500 PSI
  - High Pressure Leak Test, Fill and Vent Times, Orifice Sizing, Hysteresis
- Full Water Flows: 4500 PSI and 11 Second Flows
  - Reconfirm Prior Results, Remaining COPV Volume, Purge

System Checks

Test Parameters: 1000 PSI, GN2, Horizontal Configuration

Objectives

- Verify ability to acquire data and control system accurately using our custom-made Master Computer Flight Software (MCFS) along with our ground electronics systems including the Data Acquisition Device (DAQ) and Engine Controller (EC).
- Ensure FFS and LFS hold low pressure. Fix leaks so that FFS has a leak rate no more than 3 PSI/min when it is isolated from LFS. FFS should be tested for leaks with PRISO both closed and opened.
- Regulators should be set to expected operating pressures within their acceptable ranges.

Procedure Outline

1. Set Up
    1. MCFS and Ground Electronics
    2. FFS and LFS
2. Click Checks
3. Horizontal Leak Check
    1. Pressurize, Check Reg Pressure, Depressurize, Adjust Regs, Repeat

Regulator	Acceptable Pressure Range
PNREG	60-90 PSI
MVREG	450-600 PSI
FSREG	Dependent on FREG
FREG	385 PSI (±10 PSI)
OSREG	Dependent on OREG
OREG	320 PSI (±10 PSI)

Short Water Flows

Test Parameters: 2000 PSI, GN2 and Water, Vertical Configuration

Objectives

- Determine pressure drop from tank PTs to injector PTs so that FSREG and OSREG can be set to obtain flight like pressures in both the LOX injector (308 PSI) and fuel injector (365 PSI).
- Quantify the delay between fuel and LOX entering the injector and adjust the fire auto-sequence so that both propellants enter the injector at the same time.

Procedure Outline

1. Set Up
    1. MCFS and Ground Electronics
    2. FFS and LFS
4. Click Checks
5. Go Vertical
6. Fill Tanks
7. Water Flow
    1. Flow for 3 sec 3 times, Purge, Refill, Repeat 3 more times
        1. Record the pintle to see delay between fuel and LOX
8. Go Horizontal
    1. Adjust Regs and Valve Timing
9. Repeat Procs with adjustments (likely on another day)

Long Water Flows

Test Parameters: 2000 PSI, GN2 and Water, Vertical Configuration

Objectives

- Reconfirm test results from short water flows including injector pressures and valve timing.
- Obtain flight like mass flow through the injector, 0.53 kg/s for fuel and 0.955 kg/s for LOX.
- Find the closing pressure of FMV.
- Verify filling methods into the fuel and LOX tanks to get accurate volumes of water in each tank using the LFS fuel fill system.

Procedure Outline

1. Set Up
    1. MCFS and Ground Electronics
    2. FFS and LFS
2. Click Checks
3. Go Vertical
4. Fill Tanks
5. Water Flow
    1. 11 seconds through FMV and OMV
        1. Record video of pintle, valve timing, and injector pressures
2. 11 seconds through FMV
    1. Measure mass flow
    2. Find closing pressure of FMV
3. 11 seconds through OMV
    1. Measure mass flow
6. Reset, Refill, Run each flow 2 times

COPV Fill Test

Test Parameters: 4500 PSI, GN2, Horizontal Configuration

Objectives

- Confirm the COPV and IT1 can hold 4500 PSI of GN2.
- Measure the fill time with various sized orifices (GPRORF) on LFS, options include a 78 and a 93 thou orifice.
- Measure the temperature change during and after fill to calculate the change in pressure as a result of temperature rise (as opposed to leaking).
- Measure the effects of hysteresis on the flight regulators by comparing their changes in outlet pressures as a result of an increasing or decreasing inlet pressure.
- Find the time to vent COPV from 4500 PSI to 0 PSI through PRVNT.

Procedure Outline

1. Set Up
    1. MCFS and Ground Electronics
    2. FFS and LFS
2. Click Checks (COPVTC and GTC)
3. Leak Check at Low-Pressure (1000 PSI)
    1. Depressurize
4. COPV Fill
    1. Fill 4500 PSI with LFS
    2. Hold Pressure for 5 minutes
    3. Vent with PRVNT to 4000 PSI
    4. Refill COPV to 4500 PSI
    5. Hold for 1 minute
    6. Vent to ambient, wait 3 minutes
    7. Repeat 1-6 of COPV Fill
    8. Switch Orifice and Repeat

Full Water Flows

Test Parameters: 4500 PSI, GN2 and Water, Vertical Configuration

Objectives

- Reconfirm test results from short and long water flows including mass flows, injector pressures, and valve timing.
- Find the remaining pressure in the COPV, starting with 4500 PSI, after a complete 11 second flow and 3 seconds of fuel purge. Compare the remaining pressure in the COPV when there is no top off from LFS after opening PRISO and when there is a top off filling back to 4500 PSI.
- Find the fuel purging rate, the rate that GN2 escapes through the fuel annulus from a known pressure in the COPV to the minimum closing pressure of FMV.

Procedure Outline

1. Set Up
    1. MCFS and Ground Electronics
    2. FFS and LFS
2. Click Checks
3. Go Vertical
4. Fill Tanks
5. COPV Fill
    1. Hold 4500 PSI for 1 min to quantify leak rate
6. Water Flow
    1. 11 second flow, 3 second fuel purge, run 3-5 times
        1. At least 1 measuring mass flow
        2. At least 2 recording pintle
    2. 11 second flow, purge till FMV closes, run 3 times
        1. Record pintle
7. Reset
    1. Vent COPV to 1000 PSI or less, Vent Tanks to ambient
    2. Refill
        1. Adjust Fill Volume if 11 seconds was not met
    3. Repeat Water Flow

Risk Avoidance

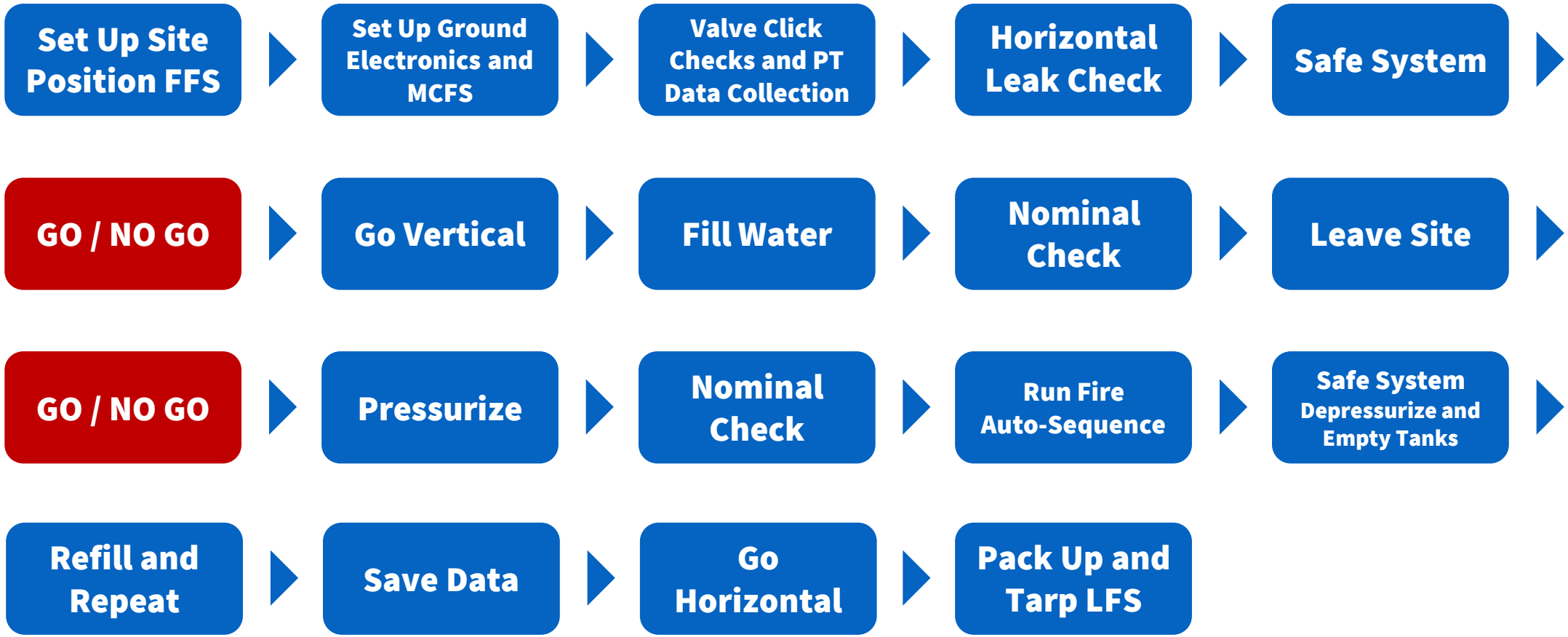
- PPE
  - Eye Protection
  - Ear Protection
  - Hardhats
- Safety Checks Prior to working with high pressure
  - Click Checks
  - Man Safe Leak Checks at 1000 PSI
- Remotely Controlled System while under high pressure
  - Operated from a safe distance
  - Live camera streaming of test site
  - Approaching system only when upstream of GPRFILL has pressure to open/close K-Bottle

Test Procedures

Personnel

- **Lead** (Ethan): Follows procedures and makes final decisions. Directs personnel and sends commands to MCFS Operator.
- **Critical Test Personnel** (Ethan, Hudson, Gabe, Simon): Set up test and inspect system to ensure test readiness.
- **MCFS Operator** (Gabe): Sets up and controls MCFS.
- **Scribes** (Simon & Gabe): Writes down every issue, solution, delay, and change to procedure. They also note important values from our data, time stamps for major events, and any other notable occurrences. There are two designated note takers, one down range and one in MC taking note of MCFS (The MCFS Operator may act as MC Scribe).
- **Go Vertical Crew:** Minimum of 6 required to go vertical.
- **K-Bottle Opener / Closer** (Ethan): Opens and closes specific K-Bottles when directed by procedures and given the go-ahead by both the Lead and MCFS Operator.
- **Water Fillers:** Minimum of 2 required. Fill tubs of water when preparing to water flow. Fill LFS Fuel Tank.

General Water Flow Test Procedure



Test Procedures

Overview – More Detail In TRR Document

1. **Set Up Site**
    1. Move FFS into place
    2. Set Up MC
2. **Set Up MCFS and Ground Electronics**
    1. Plug in every component to designated port
3. **Click Checks**
    1. Electronics, LFS, and FFS Integration
    2. Confirm every component and auto-sequence works
4. **Horizontal Leak Check**
    1. Test Personnel Only, PPE
    2. Raise pressure gradually to 1000 PSI and Find Leaks
    3. Actuate valves, run fire and abort sequences, safe system

Test Procedures

Continued

1. Go Vertical
    1. Lifting the Vertical Stand into place and securing it
2. Fill Tanks
    1. Use LFS Fuel Fill to Fill FFS Fuel and LOX Tanks
3. Water Flow
    1. Set LFS Pressures, Confirm GPRFILL Works, Clear Test Site
    2. Nominal Check: Correct Valve States and PTs and TCs Reading
        1. All valves closed except for OVNT. Ensure PRISO is closed.
    3. Pressurize COPV to 4500 PSI
    4. Open PRISO, Pressurize Tanks
    5. Fire Sequence - opens SVOMV and SVFMV, then closes them
    6. Abort Sequence - closes SVPRISO, closes GPRFILL, opens GPRVNT, opens PRVNT, opens FVNT, closes SVOMV, and closes SVFMV.
    7. Refill and Flow Again

COPV Fill Test Procedures

1. Set up live camera feed of FFS and LFS. Confirm visibility in MC.
2. Everyone except for the K-Bottle Opener/Closer Leaves the Test Site. They should have a walkie and all PPE, including over ears.
3. Confirm that everyone is wearing ear and eye protection, including those in MC.
4. Confirm PRISO is closed.
5. Set Up LFS
    1. Confirm GPNREG is backed out
    2. Open pneumatics K-Bottle
    3. Set GPNREG to 80 PSI
    4. Open and Close GPRFILL it to confirm it actuates.
    5. Confirm GPRFILL is closed.
    6. Confirm GPRREG is backed out
    7. Open pressurant K-Bottle
    8. Set GPRREG to 4500 PSI
    9. K-Bottle Opener/Closer goes to MC, Confirm the test site is empty of people
6. Nominal Check
    1. Confirm Correct Valve States for FFS
        1. All valves closed except for OVNT. Ensure PRISO is closed.
    2. Confirm PTs and TCs read ambient
        1. Ensure COPVTC and GTC are working
7. Pressurize COPV to 4500 PSI
    1. Open Plot of PRPT, COPVTC, and GTC
    2. Create MCFS Marker
    3. Open GPRFILL
    4. Wait until COPV is Filled to 4500 PSI
    5. Close GPRFILL
    6. Create MCFS Marker
8. Hold Pressure for 5 minutes
    1. Calculate leak rate for each minute
    2. Take Picture of All PT Readings
    3. Analyze Plots of PRPT, COPVTC, and GTC
9. Vent with PRVNT to 4000 PSI
10. Refill COPV to 4500 PSI
11. Hold for 1 minute
12. Vent to ambient, wait 1 minute, observe COPVTC
13. Repeat COPV Fill once with current orifice
14. Switch Orifice and Repeat COPV Fill

Contingency Planning

- Pressure Leak
  - System will depressurize automatically, and eventually become safe to approach. We will then redo the horizontal leak check and tighten each fitting to marked torque stripes.
- Pneumatics Loss
  - If pneumatic valves can no longer be actuated while OVNT is closed, the LOX tank can be vented manually by cracking a fitting. Everything else can be vented remotely beforehand.
- MCFS Power Loss
  - The system will remain in the same state, and we can reconnect without altering the state of the system.

Contingency Planning

- EC Power Loss
  - The system will immediately go to its default, unpowered state. This will open OVNT, venting the LOX tank, and FVNT, venting the fuel tank. We will then attempt to reconnect to the system, which will briefly power all valves, but we will do this remotely. If we are not able to reconnect to the system, we will be left with a trapped volume of gas in the COPV.
- DAQ Power Loss
  - Operators will safe the system using safing procedures and we will attempt to reconnect the DAQ.
- Flipped Logic
  - The valve will be noted and everyone will be informed, and if the valve is in the auto sequence, we will halt the test, safe the system, and fix the logic.

Contingency Planning

- Vertical Stand Falling
  - Stand will be secured to a rigid structure, and all personnel near the structure will wear hard hats. While the vehicle is pressurized, all personnel should be behind the concrete wall with ear protection, and if they must go to the vehicle at low pressure, should wear ear and eye protection along with a hard hat.
- PRVNT Failure
  - If the rest of the system has power and PRVNT fails, pressure can be vented through GPRVNT.
- OVNT Failure
  - If OVNT cannot be actuated, we will safe the rest of the system remotely and crack a fitting at man safe pressure.
- FVNT Failure
  - If FVNT is unable to actuate, we will vent out FMV to ~100 PSI, then go crack a fitting to vent the rest.

Appendix

Components

Regulators

- Dome Loaded Pressure Regulator
  - FREG – Fuel Regulator
  - OREG – Oxygen Regulator
- Spring Loaded Pressure Regulator
  - GPNREG
  - GPRREG
  - GFREG
  - FSREG – Fuel Set Regulator
  - OSREG
  - MVREG
  - PNREG
- Filter
  - GPRFILT
  - GPNFILT

Components

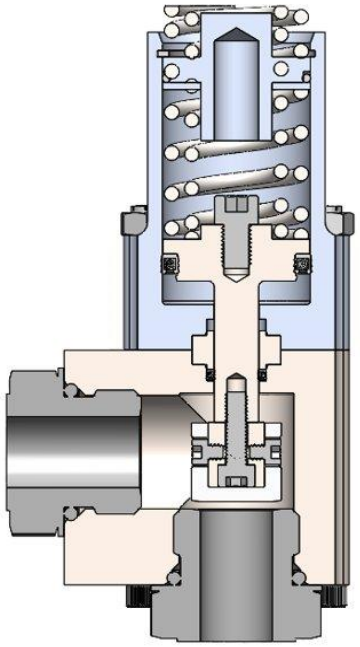
Valves

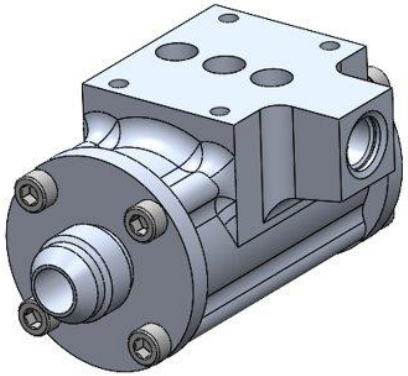
- Relief Valves
  - GPNRV
  - GPRRV–1
  - GPRRV–2
  - GFRV
  - PRRV
  - FRV
  - ORV
- Check Valves
  - OCK

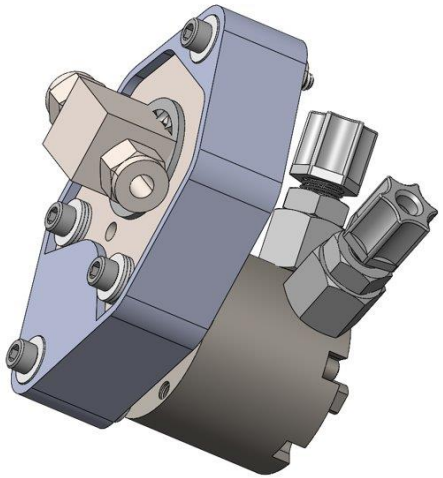
Components

Pneumatic Valves

- Main Valves - In-house built Main valves
  - OMV
  - FMV
- Pneumatically actuated ball valves
  - PRISO
  - OVNT
  - GOVNT







Components

Solenoid Valves

- 2 Way valves
  - PRVNT (normally closed)
  - FVNT (normally open)
  - GPRVNT (normally closed)
- 3/2 way solenoid valves
  - SVOMV (3/2 solenoid valve)
  - SVFMV (3/2 solenoid valve)
  - G-PNS-2(3/2 solenoid valve)
- 5/2 way solenoid valves
  - SVPRISO (5/2 solenoid valve)