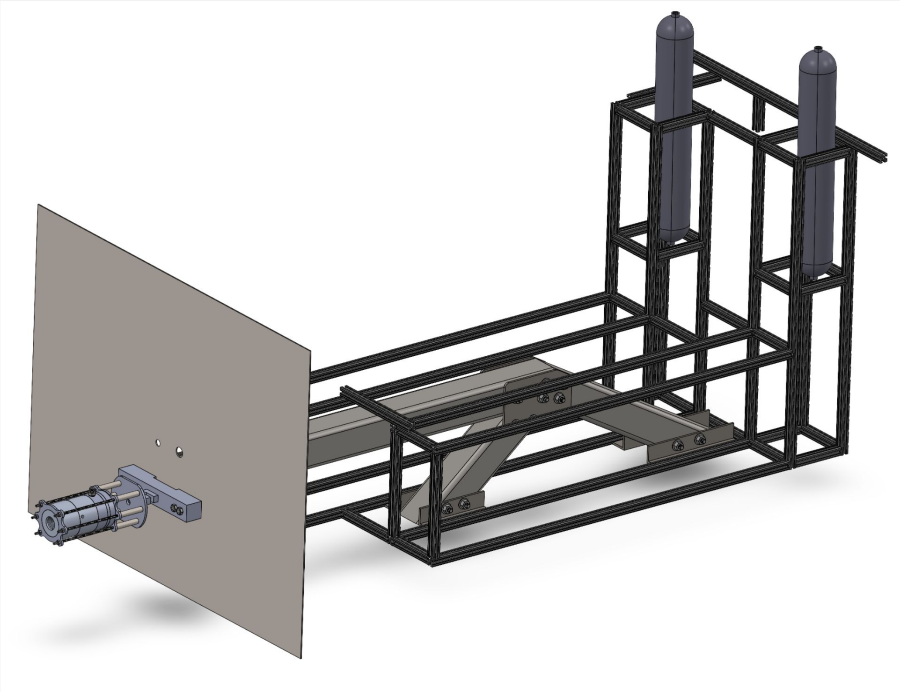
Torito Liquid Propulsion Test Readiness Review

Cesar Briones, Ethan Zylman, Hari Patel, Samuel Johnson, Alston Wang, Matthew West

July 11, 2026

Agenda

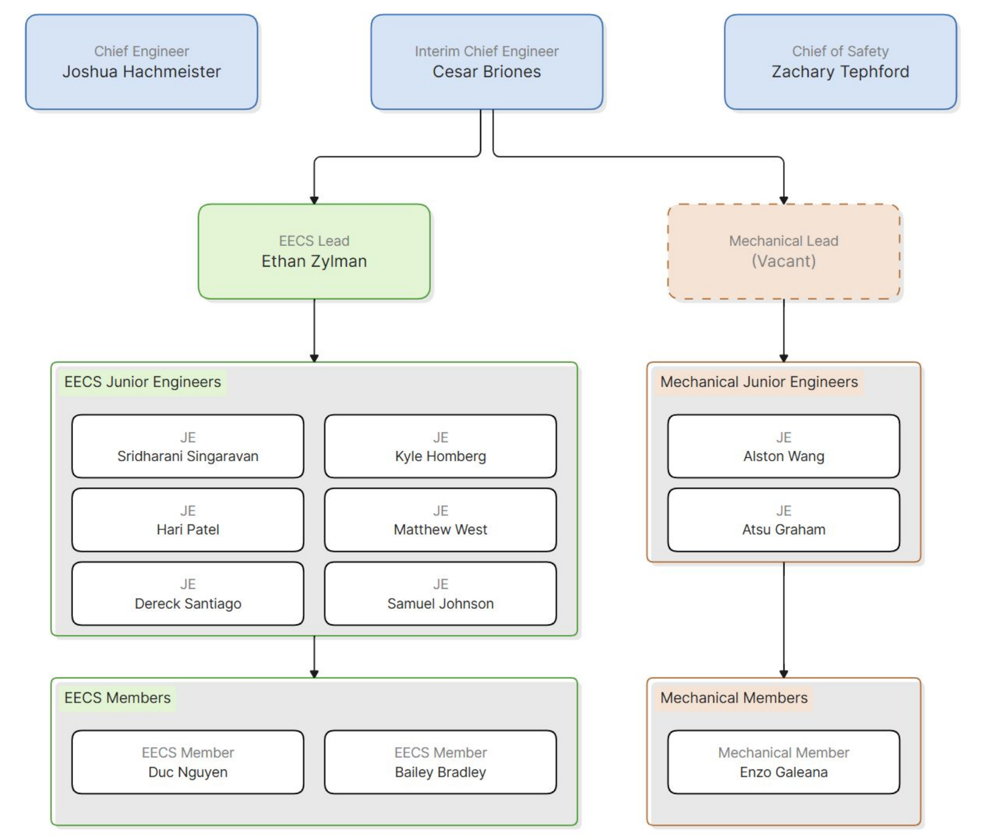
1. Introduction
2. Expected Engine Performance
3. Feed System
4. Test Stand
5. Electrical Control System
6. Timeline
7. Water Flow Tests
8. Cold Flow Tests
9. Safety
10. Logistics



Introduction - Purpose and Scope

- Showcase readiness of full system for a static fire test
- Detail important design criterias
- Present results from tests
- Obtain feedback and warnings of critical design decisions

Introduction - Structure



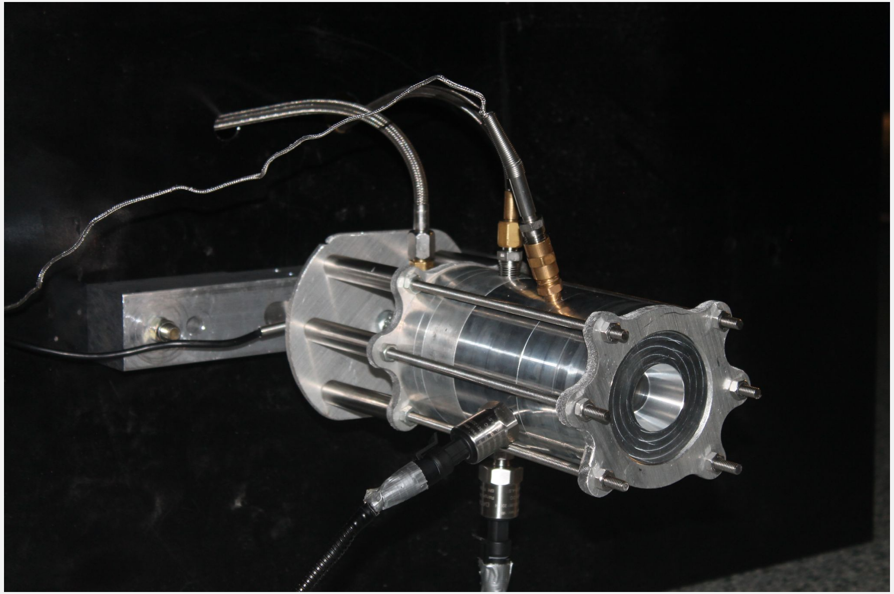
Introduction - Test Objectives

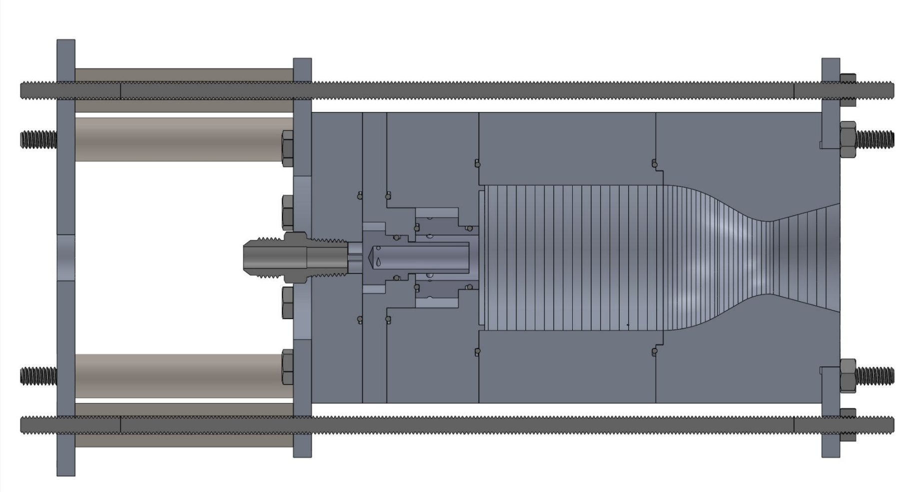
- A minimum of 150 lbf of thrust
- Validate design and predict thrust and mass flow rate with an uncertainty of 10%
- Stable burn over 3 seconds

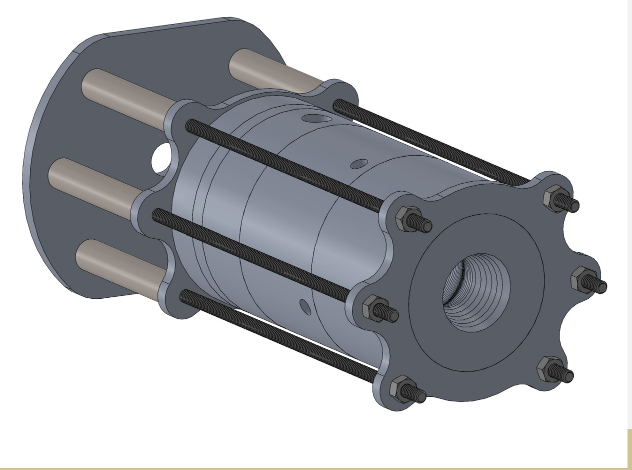
Questions?

Engine

Engine - Quick look







Engine - General Characteristics

Variable characteristics

OF Ratio: [1.5 - 5]

Thrust: [333 - 685] lbf

Pc: [235 - 465] psi

Mass Flow rate: [0.53 - 1.06]

Cd_Ox: [0.165 - 0.7]

deltaP%_OX: [68% - 38%]

deltaP%_Fuel: [58.4% - 17.7%]

Fixed characteristics

Throat r: 1 in

Chamber r: 2 in

Ae/At: 2.25

Material: Aluminum

Cd_fuel: 0.76

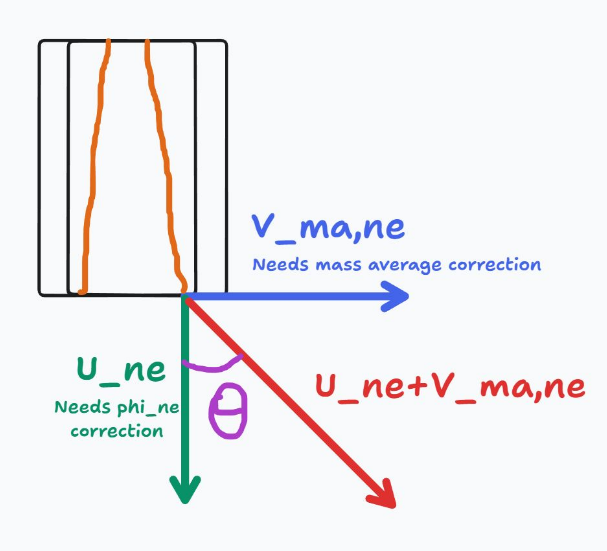
Burn time: 3 seconds

Engine - Margins of uncertainty

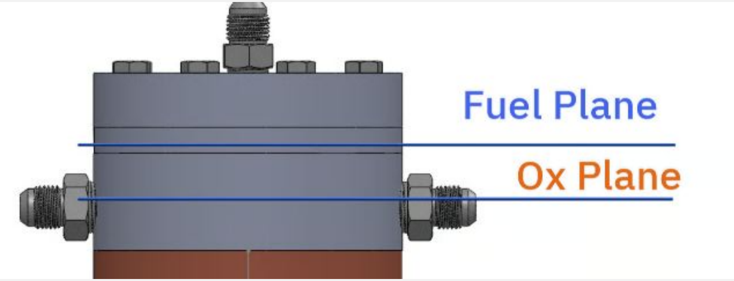
- Pressure and discharge coefficient of N2O
  - Drive oxidizer mass flow rate

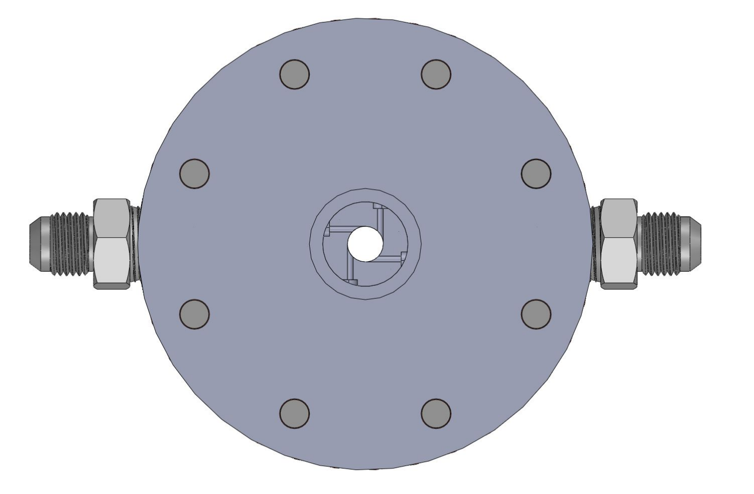
- Engine was designed to be robust
  - Very thick walls
  - High pressure drop% across injector
  - Underexpanded for lower and manageable thrust

Engine - Injector

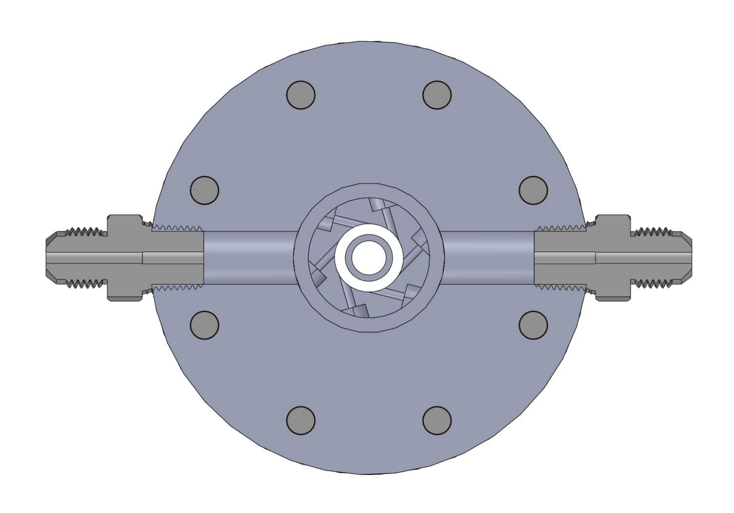


Engine - Injector Cont.2



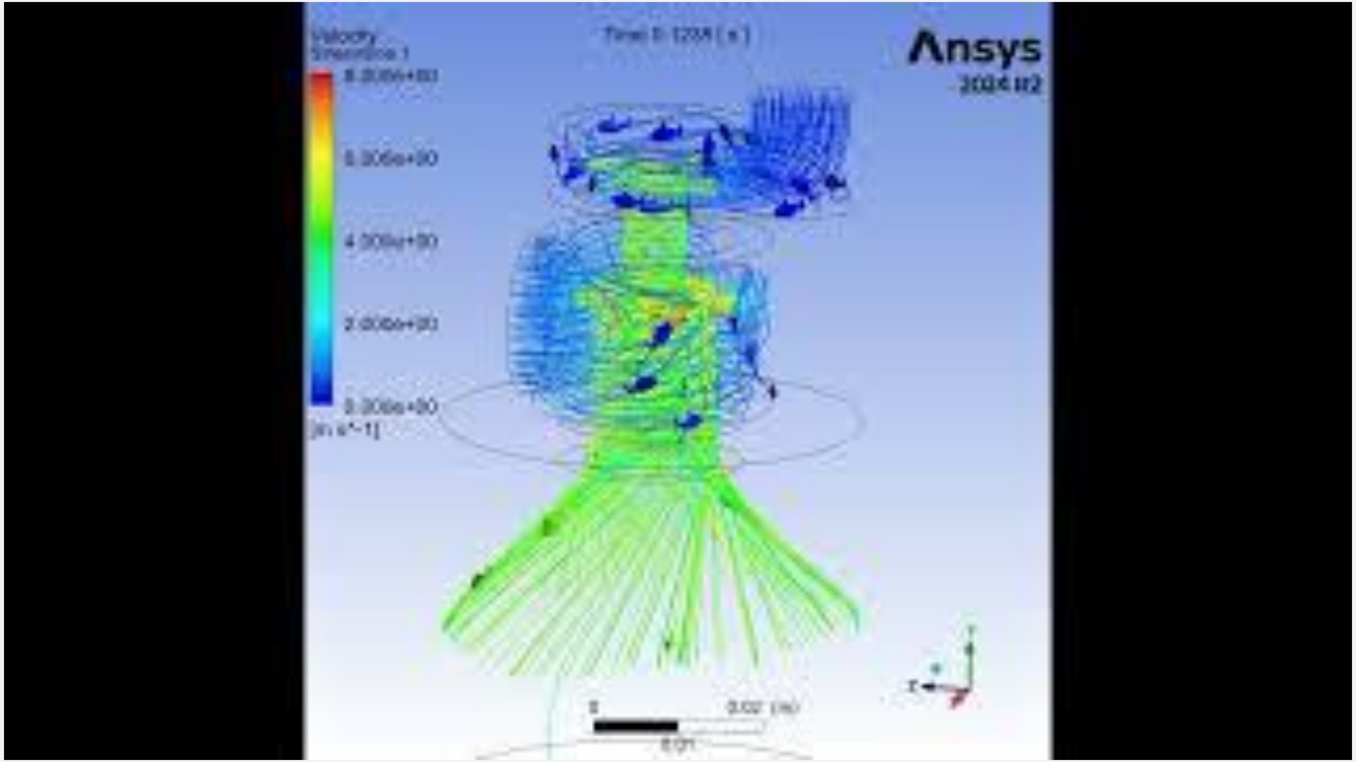


Fuel Plane

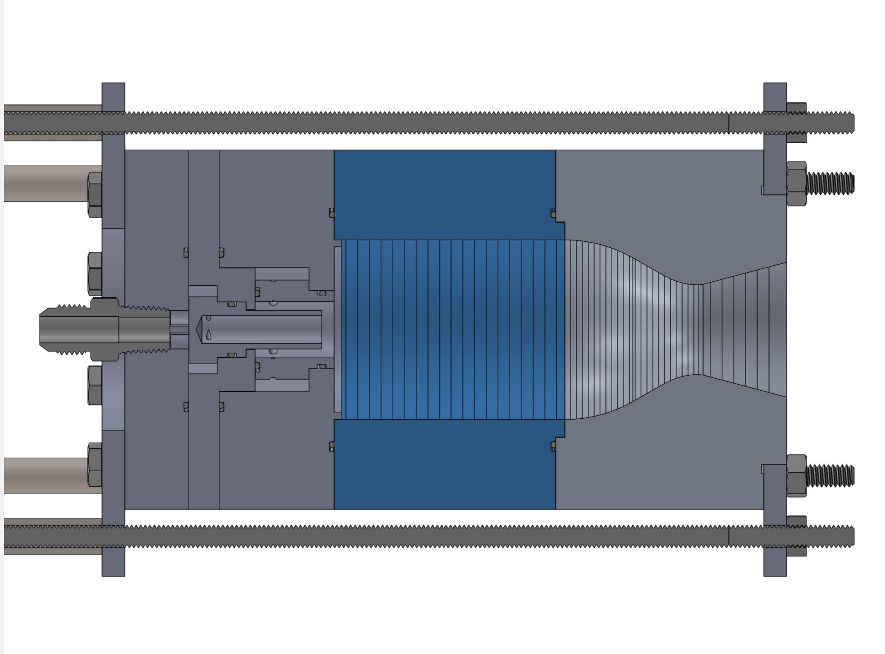


Oxidizer Plane

Engine - Injector Cont.3

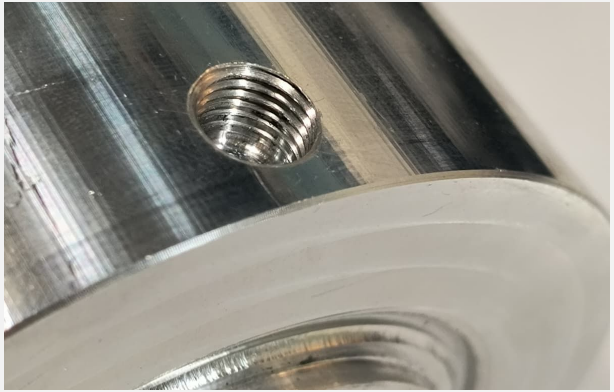


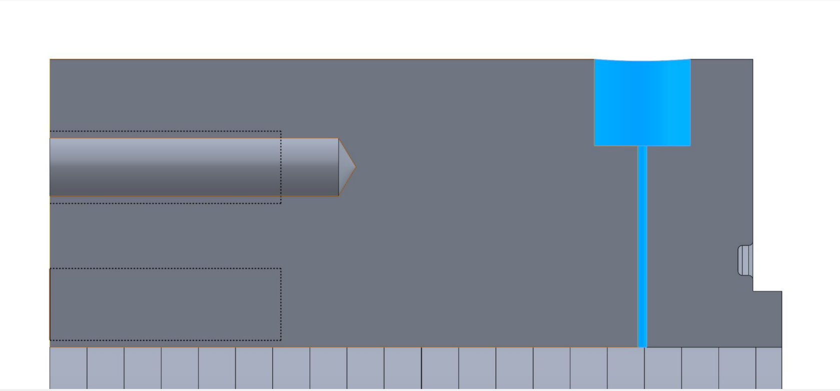
Engine - Chamber

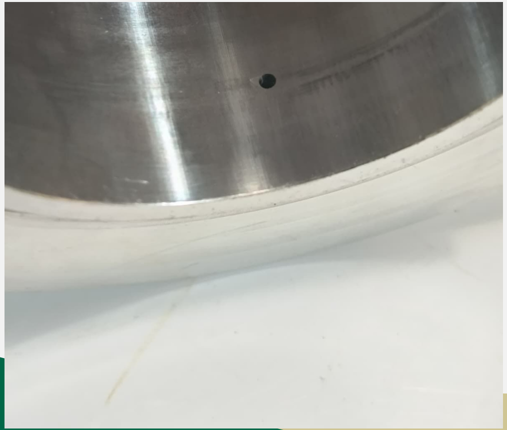


Engine - Chamber Cont.1

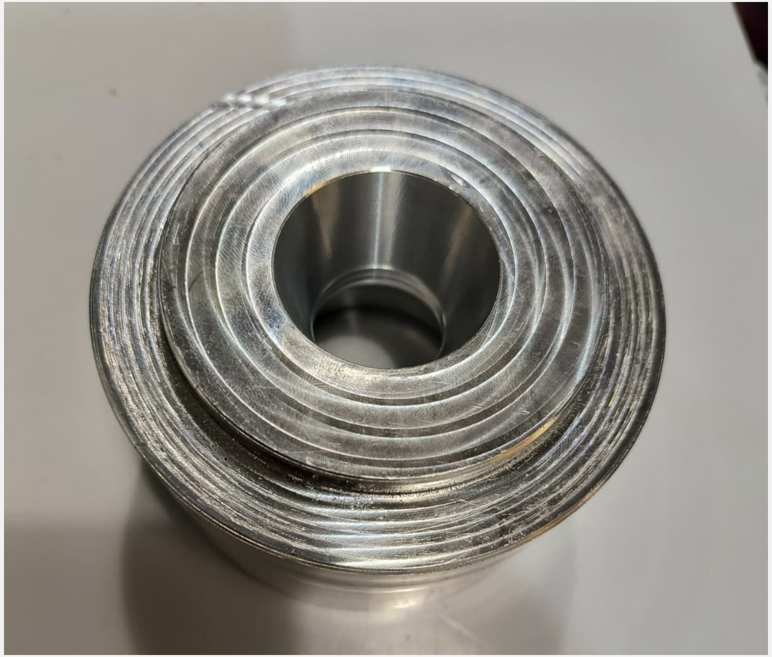
0.45 in depth for full engagement

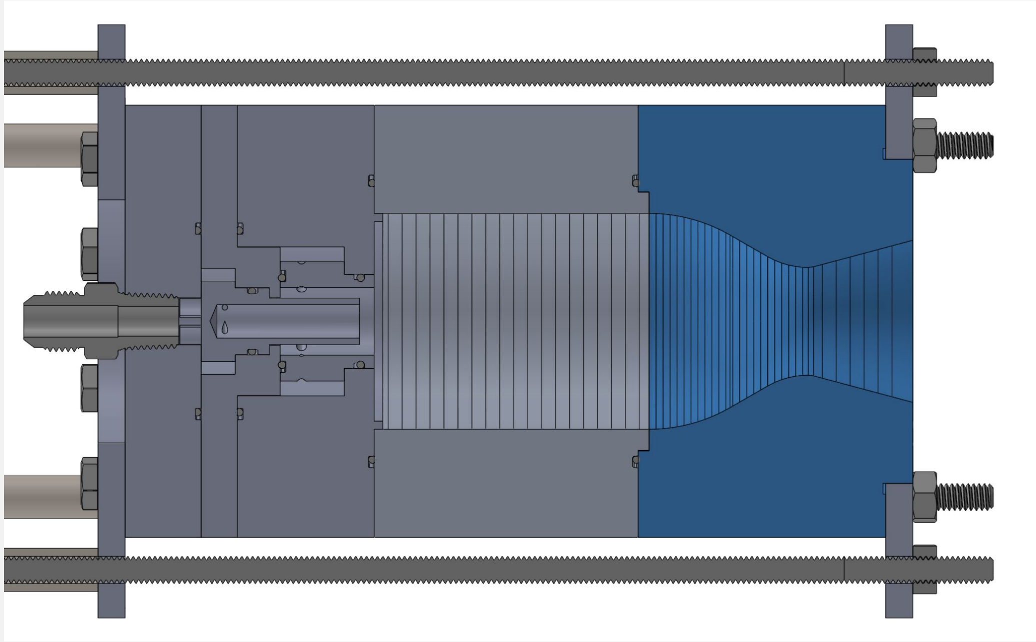






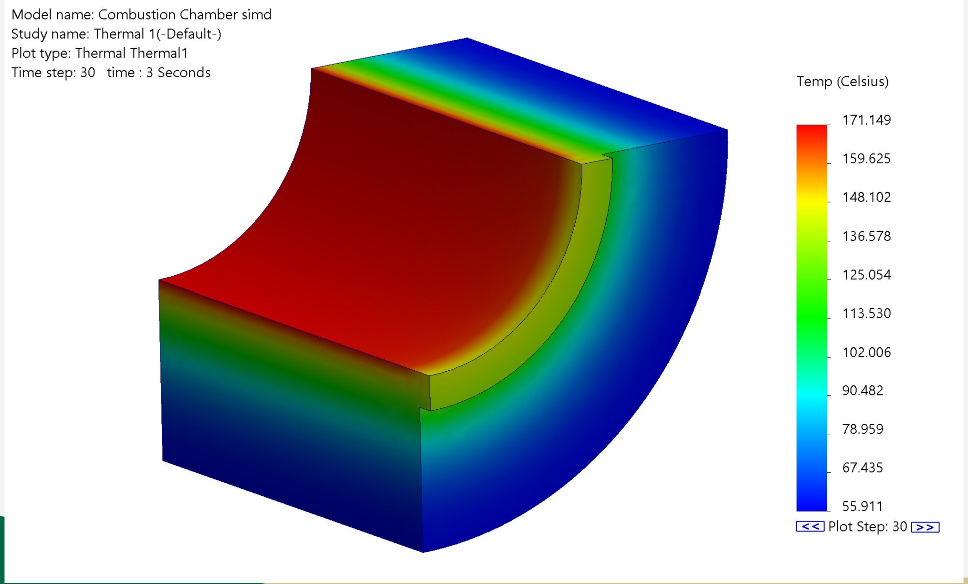
Engine - Nozzle

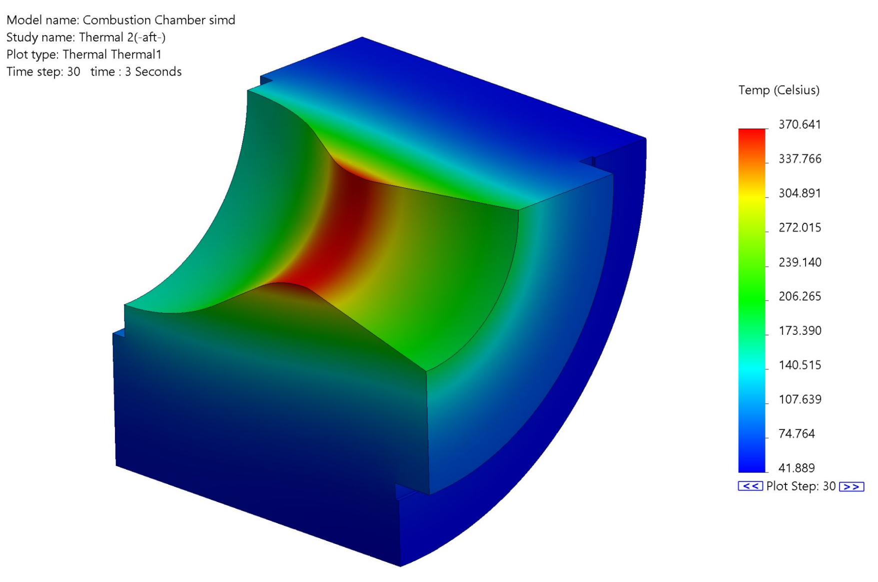




Engine - Thermal Analysis

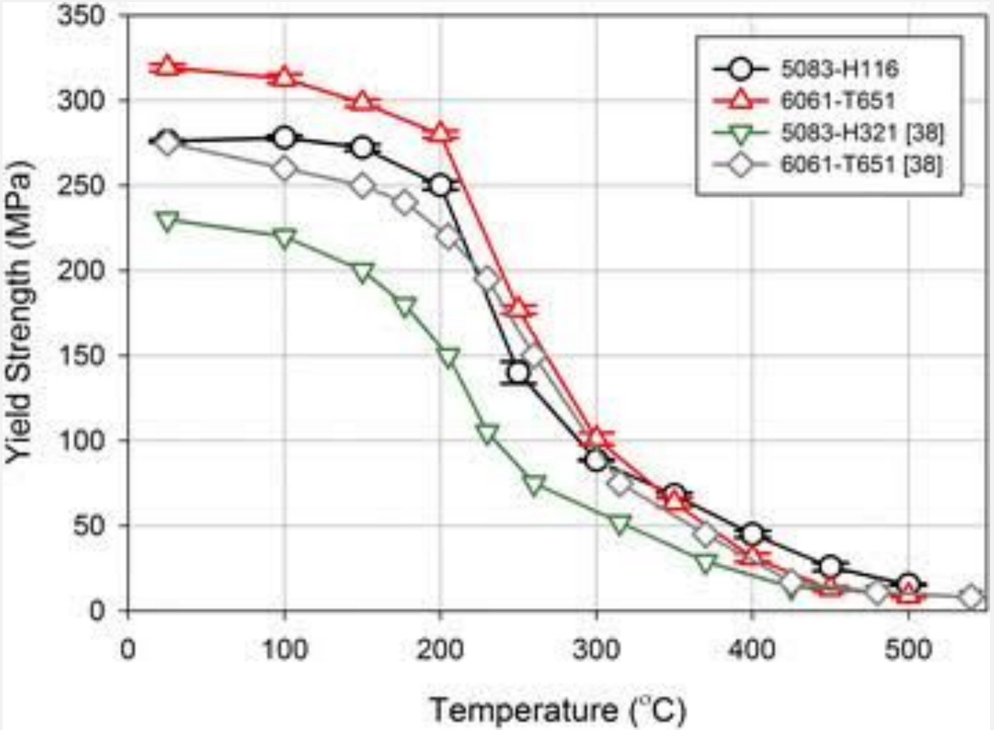
Gas temp: 3000K
Convection heat transfer coefficient: 700 to 2100 W/m^2K
Duration: 3 seconds



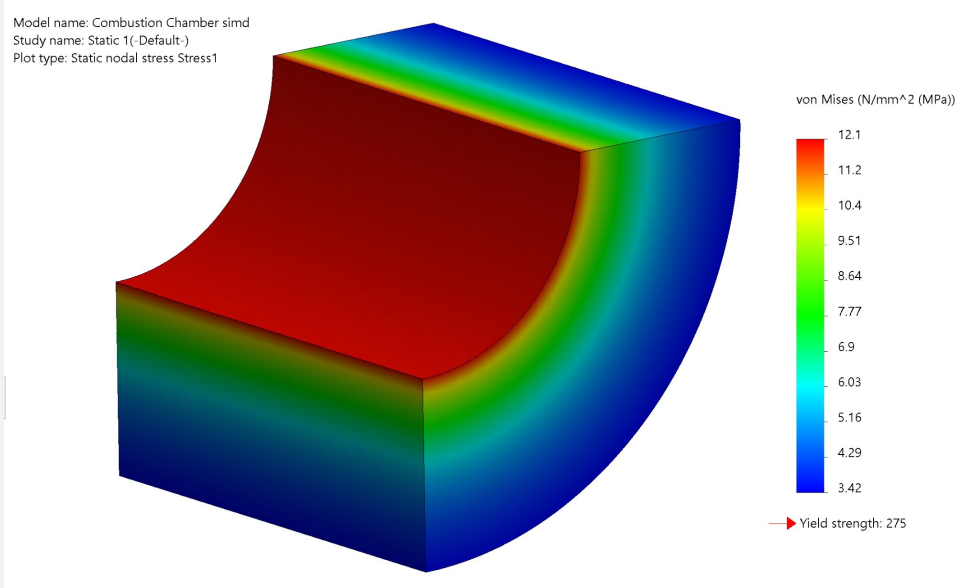


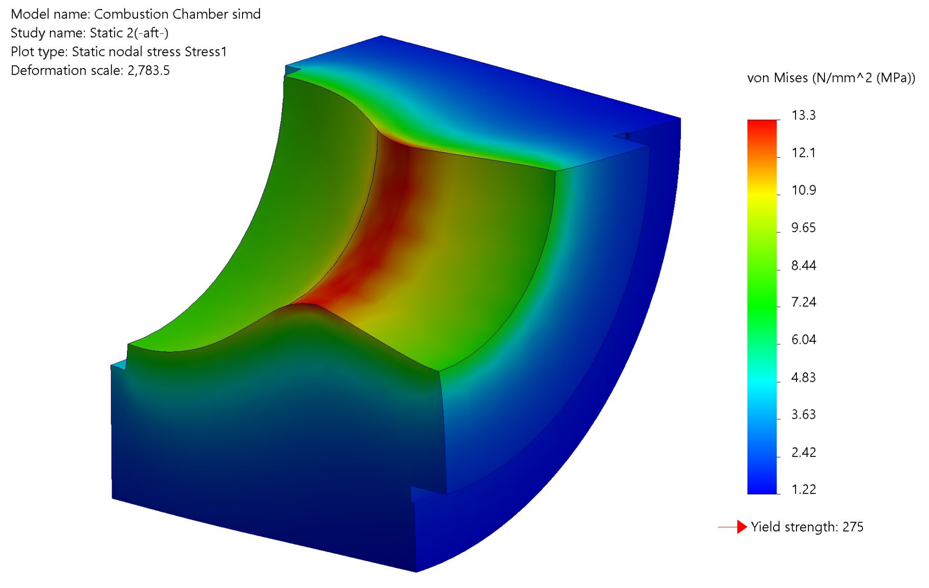
Engine - Structural Analysis

Material's yield stress decrease as temperature increases.



Engine - Structural Analysis



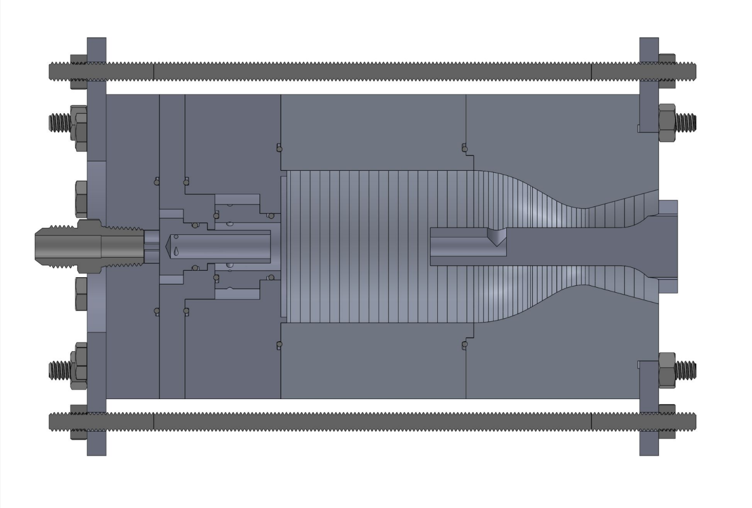


3.15 FOS at 370°C at 750 psi

Engine - Igniter

Engine - Igniter Holder

PLA 3D print that will hold the igniter in the center of the chamber.



Test - Igniter ignition

Delay of 2.7 seconds

Engine - Manufacturing

Thank you Riccardo!

Questions?

Feed System

Feed System

4 NC Solenoids

2 NC Pneumatic Valves

2 Spring Relief Valves (750 and 1500)

2 Check Valves

7 Ball Valves

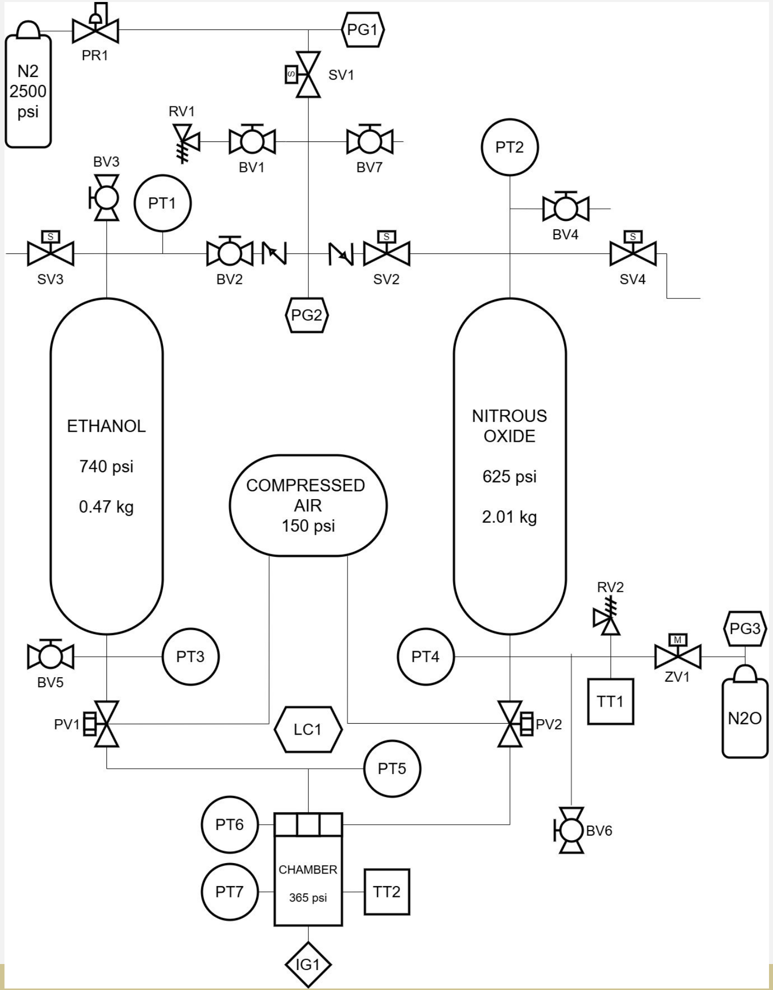
1 Servo Valve

7 Pressure Transducers

2 Thermocouples

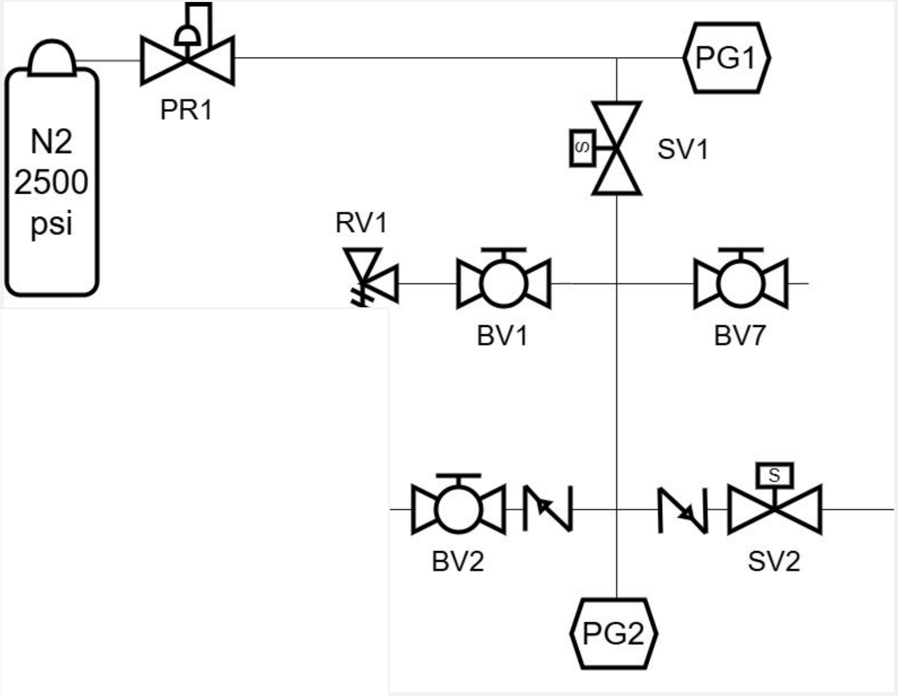
1 Load Cell

1 Igniter



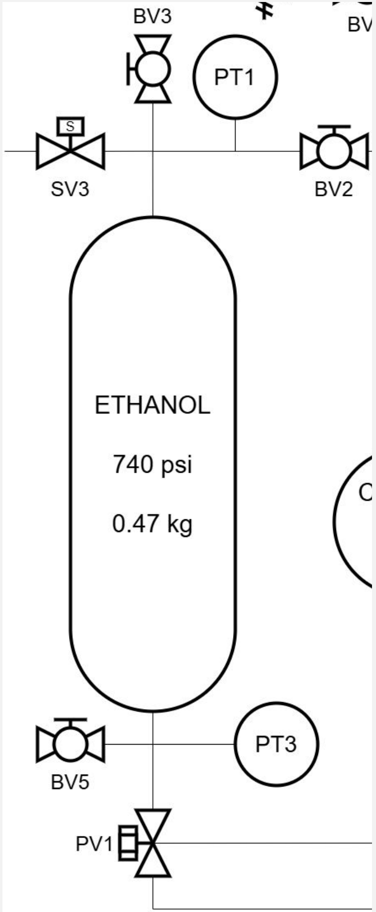
Feed System - Nitrogen

- Pressurize Fuel side
- SV1 Activates the system
- BV1 Blocks relief valve
- BV7 Allows air intake
- BV2 Blocks pressure fuel side
- SV3 Depressurizes the system
- BV3 Open during fuel filling
- SV2 Purge Oxidizer Side
- RV1 set at 750 psi



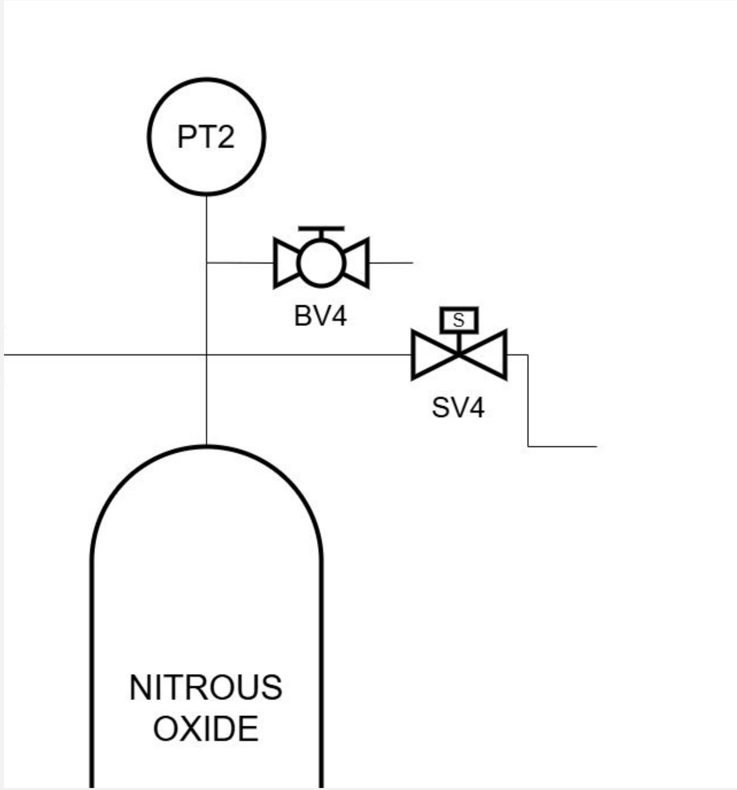
Feed System - Fuel Side

- BV5 open during filling
- PV1 is main run valve
- PT3 and PT1 for tank pressure
- PT5 for injector Pressure



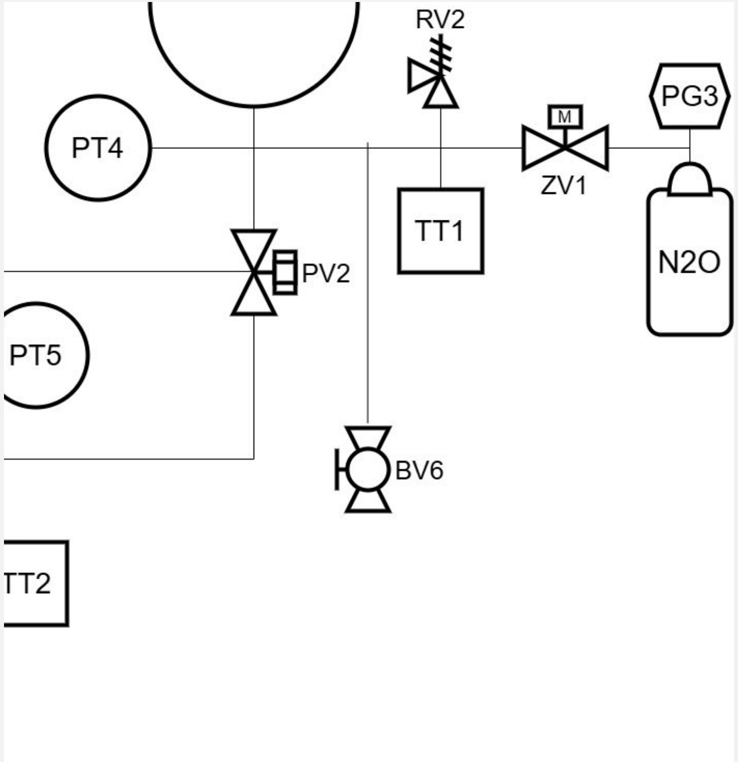
Feed System - Upper Oxidizer Side

- BV4 is passive optional vent
- SV4 bang bang pressure control
- PT2 tank pressure



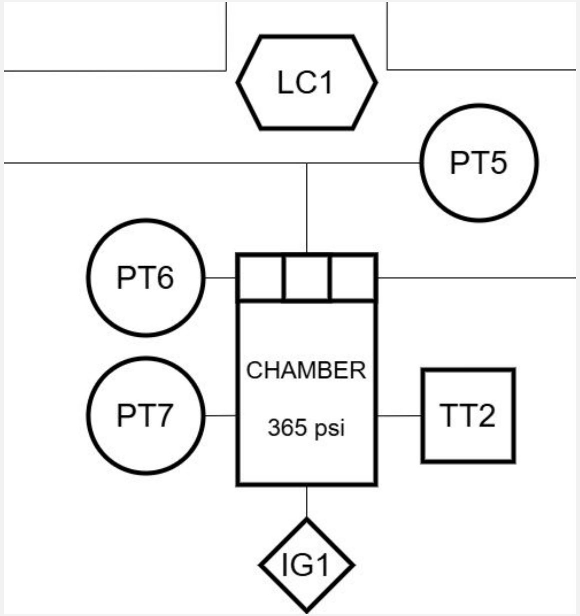
Feed System - Lower Oxidizer Side

- ZV1 Nitrous fill
- BV6 for water fill
- PT4 tank pressure
- PV2 is main run valve
- TT1 to measure N2O temp
- TT2 to measure chamber temp
- RV2 set to 1500 psi



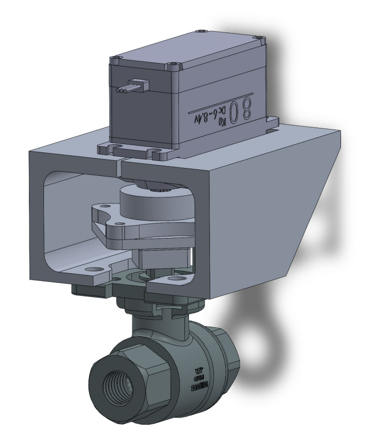
Feed System - Engine

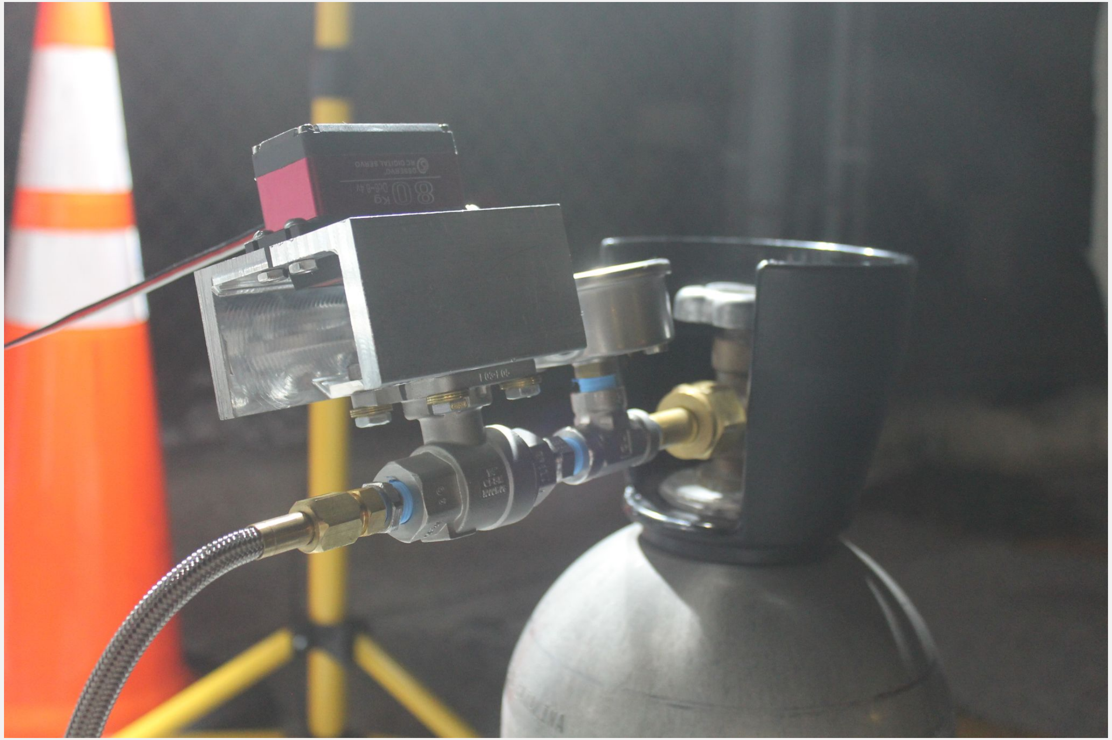
- PT5 for Injector Fuel
- PT6 for Injector Oxidizer
- PT7 for Chamber Pressure
- TT2 for Chamber Temperature
- LC1 Load Cell
- IG1 Igniter



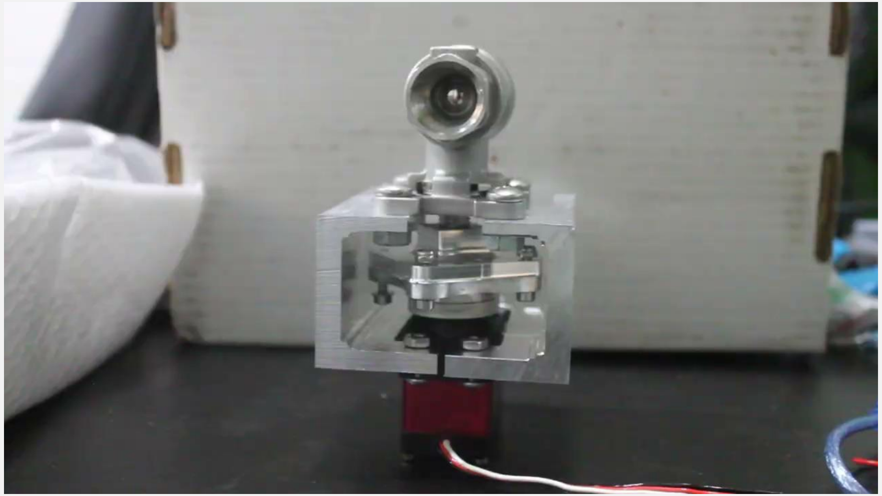
Feed System - Custom Servo Valve

An inexpensive solution to prevent vaporization during N2O filling



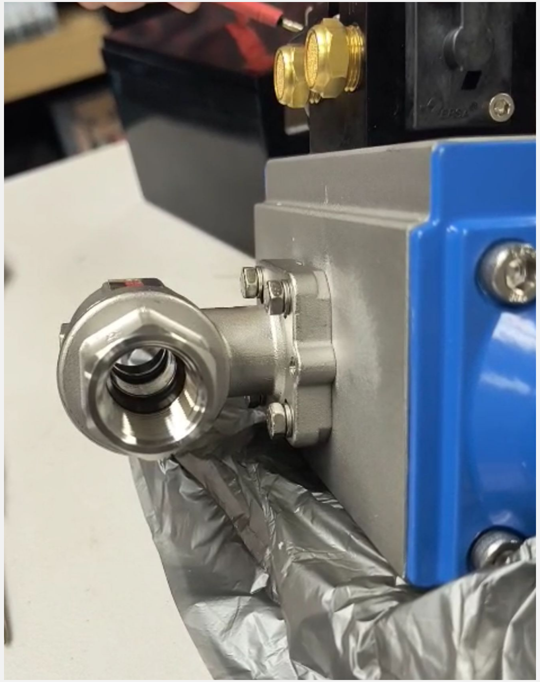


Feed System - Custom Servo Valve - Unit Test



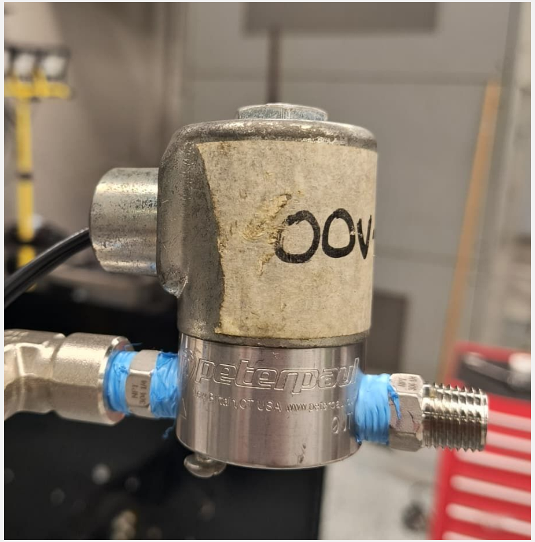
Feed System - Pneumatic Valves

- Fast actuation
- Ball valve (constant area)
- Requires low pressure air 150 psi



Feed System - Solenoid Vent Valves

- Fast actuation
- Normally Closed
- 5000 psi rated
- SV3 Cv = 0.02
- SV4 Cv = 1.4



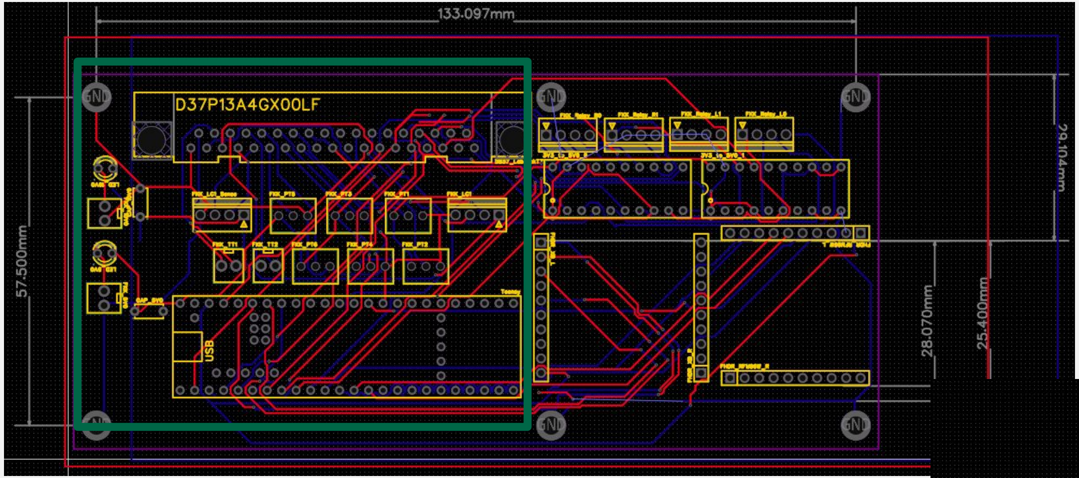
Eecs notes

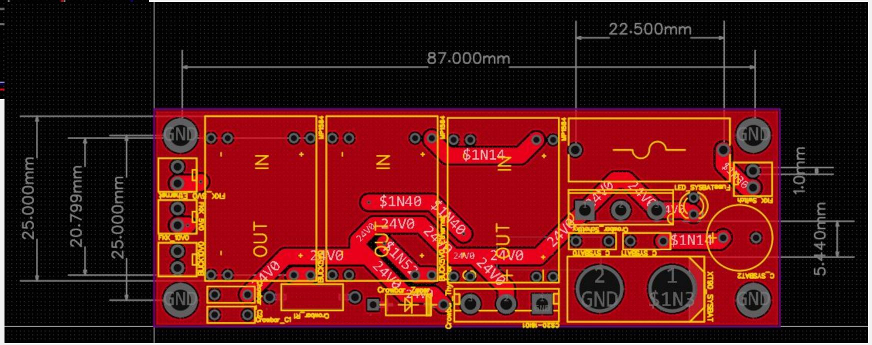
- Electrical System
  - Requirements, Success Criterias?
  - PCB
    - DAQ Box
    - Schematics
    - Wiring Diagrams
    - Physical
  - Components
    - PT, TT, LC, Valves, and Servo
- Software - Control System?
  - Requirements, Success Criterias?
  - Ground Station
    - Communication, Ethernet Switch, Fiber Optic Cable
    - GUI, Graphing, Valve Control, Sequence Manager
    - Bang Bang Algo
  - Teensy
  - LabJack/daq

Questions?

Data Acquisition

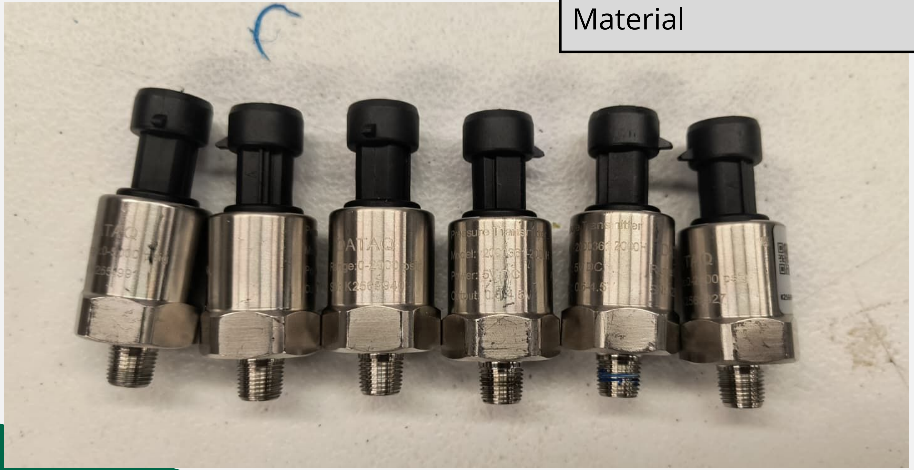
Data Acquisition - PCB





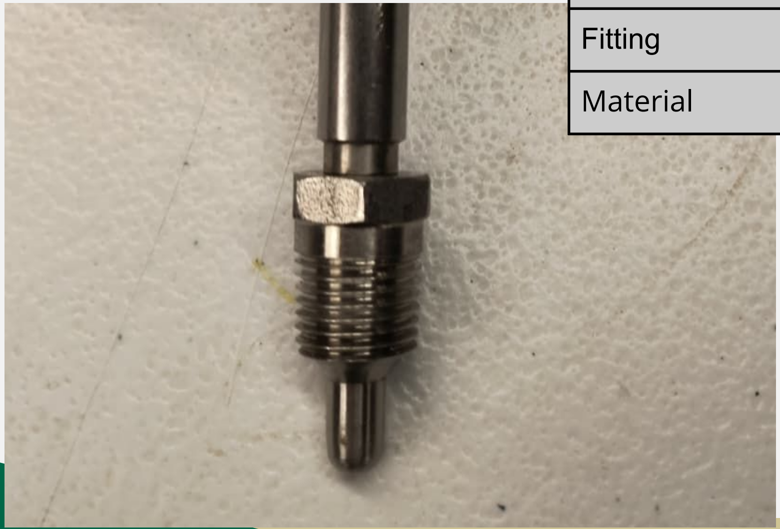
Data Acquisition - Pressure Transducers

Specification	Value
Pressure Range	0-2000 psig
Voltage Range	0.5-4.5V
Accuracy	±0.5% Full Scale
Fitting	1/8 NPT
Material	316 Stainless Steel



Data Acquisition- Thermocouples

Specification	Value
Type	T, Single Element
Pressure Rating	2500 psi
Temperature Range	0-370 C
Fitting	1/4 NPT
Material	316 Stainless Steel



Data Acquisition- Thermocouples - Unit Test

Verified accuracy of thermocouples in warm water.

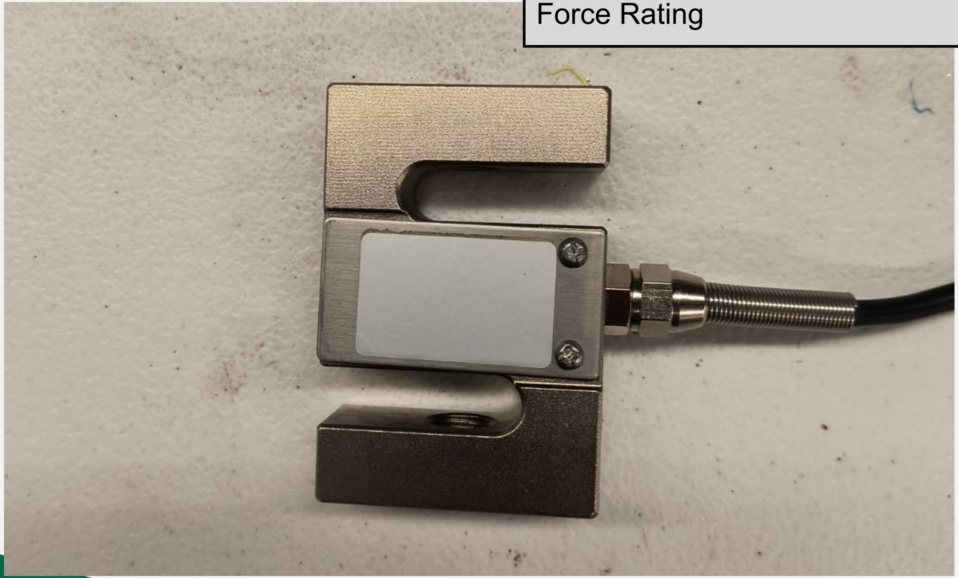
Thermocouple Accuracies

The accuracy of a thermocouple depends on many factors including but not limited to electrical interference and the purity of the metals used.

Temperature	B Type	E Type	J type	K Type	N Type	R Type	S Type	T Type
-200^{0}C	-	-	-	3	3	-	-	3
-100^{0}C	-	-	-	2.5	2.5	-	-	1.5
0^{0}C	-	1.7	1.5	1.5	1.5	1	1	0.5
200^{0}C	-	1.7	1.5	1.5	1.5	1	1	0.8
400^{0}C	-	2	1.6	1.6	1.6	1	1	-
600^{0}C	1.5	3	2.4	2.4	2.4	1	1	-
800^{0}C	2	4	-	3.2	3.2	1	1	-
1000^{0}C	2.5	-	-	4	4	1	1	-
1200^{0}C	3	-	-	9	9	1.3	1.3	-
1400^{0}C	3.5	-	-	-	-	1.9	1.9	-
1600^{0}C	4	-	-	-	-	2.5	2.5	-

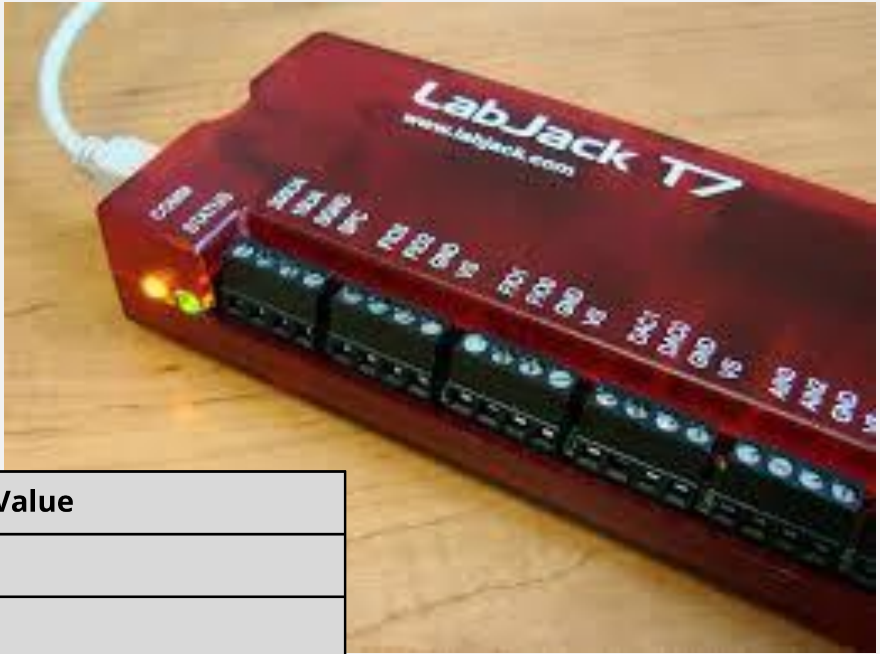
Data Acquisition - Load Cell

Specification	Value
Type	S, 4-Lead
Force Rating	300 kgf



Data Acquisition - LabJack T7

- Collects data from pressure transducers, thermocouples, and load cell.
- Scan Rate: 64 Hz



Specification	Value
Analog Inputs	14
Analog Resolution	16-bit
Max Stream Rate	100 kSamples/s Aggregate

Questions?

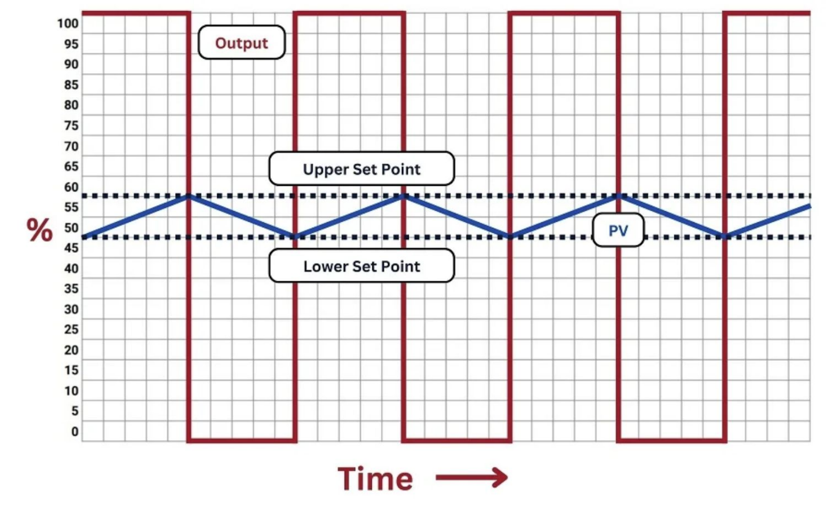
Control System

Control System - Ground Station App

Control System - Graph Display

Control Systems - Bang Bang Algorithm

- When ON, system regulates N_2O run tank pressure using PT2 data and SV4 to vent.
- When pressure rises above the upper limit, the valve opens.
- When pressure falls below the lower limit, the valve closes.
- Auto turns off when sequence is pressed, but waits until nominal pressure is reached.

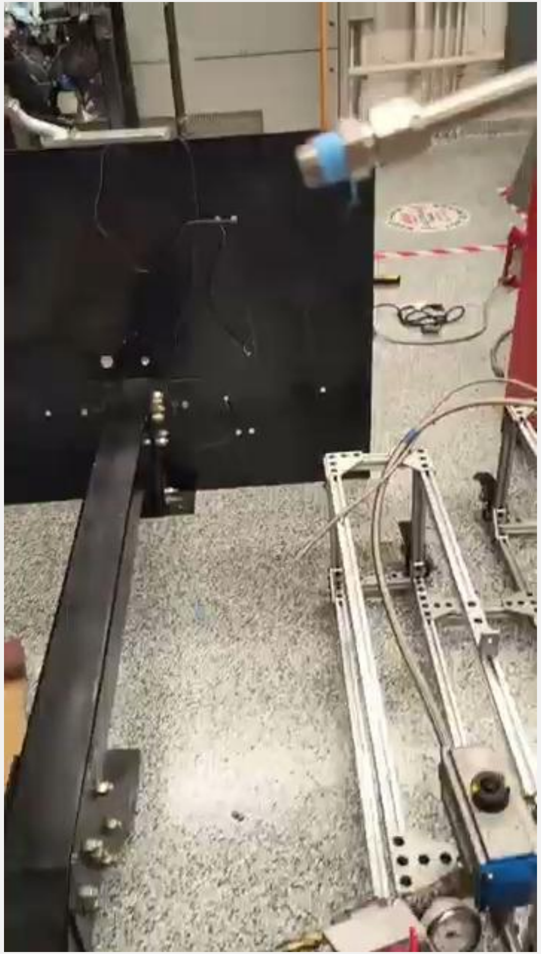


Test - NOS Active Vent

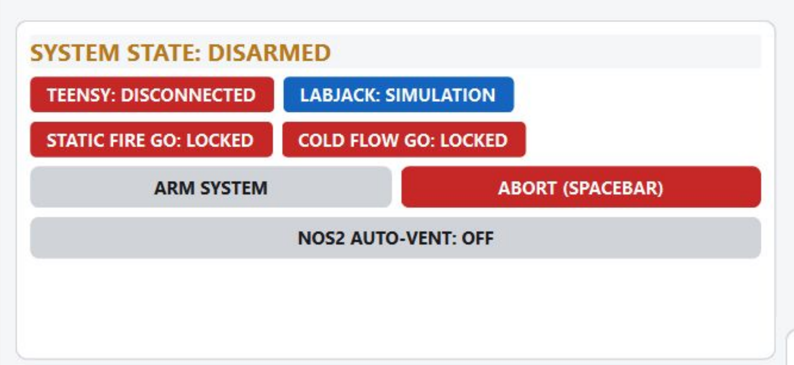
Inlet: 120 psi air inlet

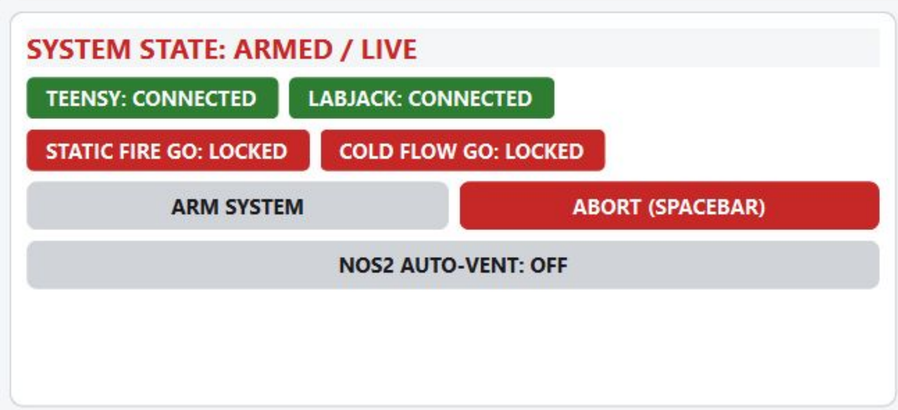
Target: 70 psi

Range: +-10 psi



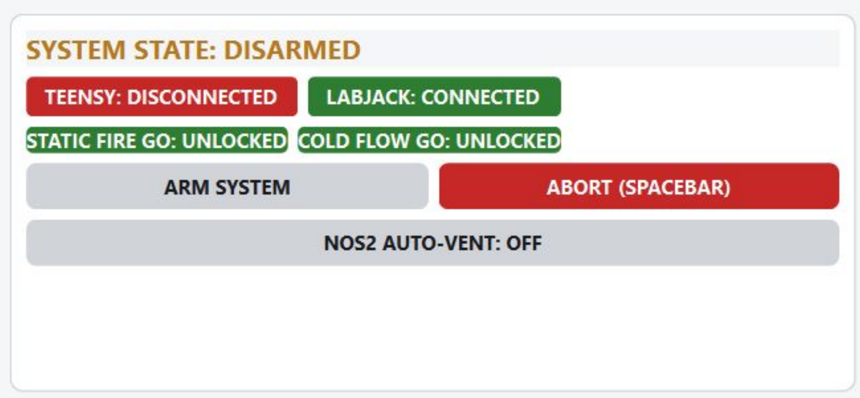
Control System - System Health/Status

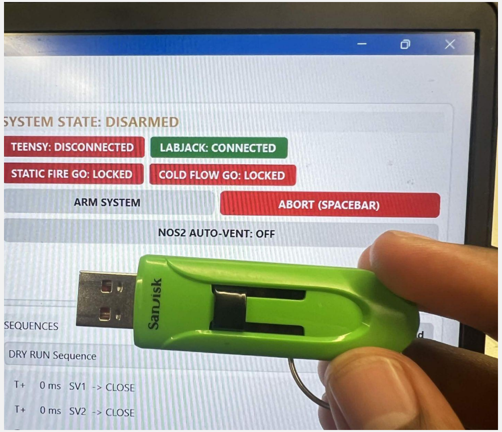




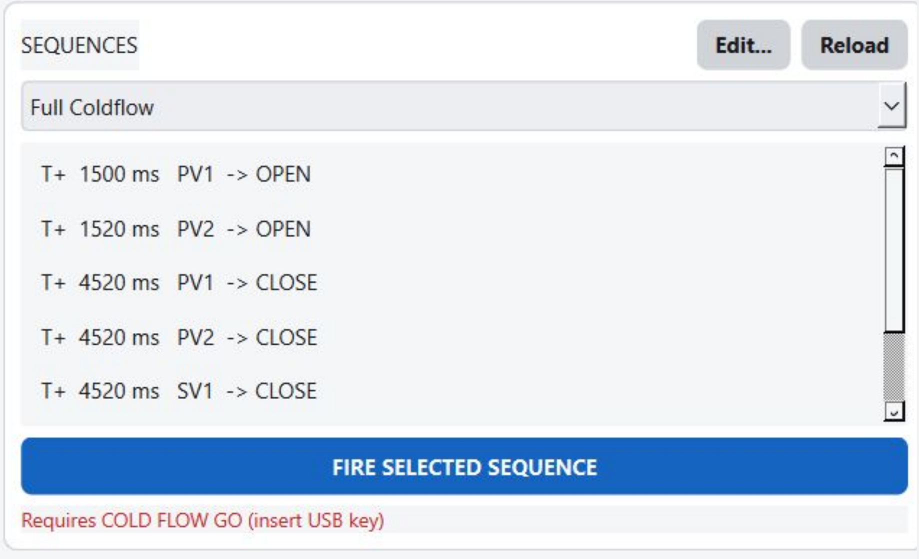
Control System - Software Interlock (Football)

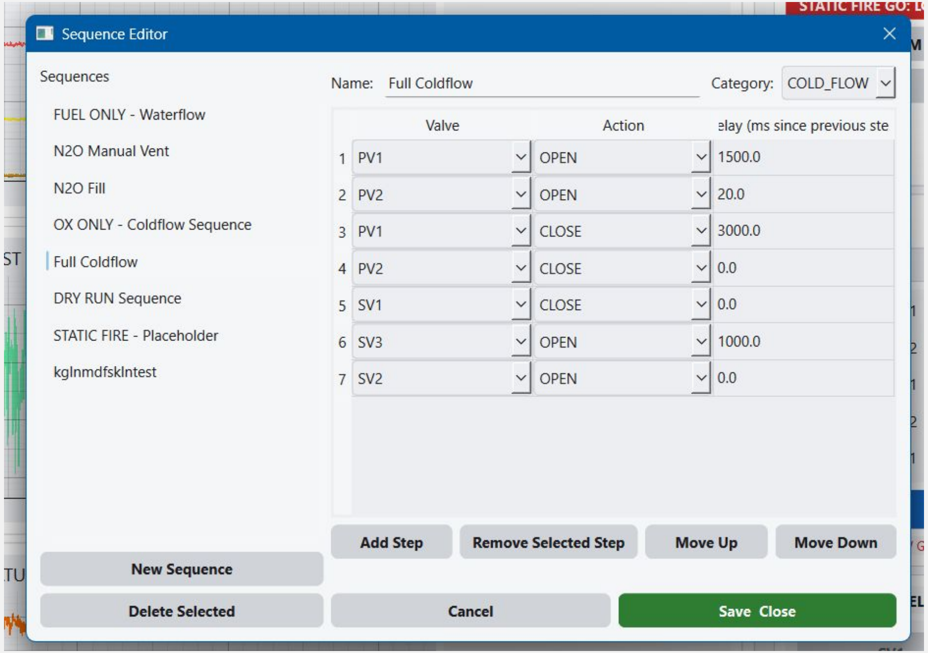
- Ground Station requires a physical key to be able to run Cold Flow Test and Static Fire Test



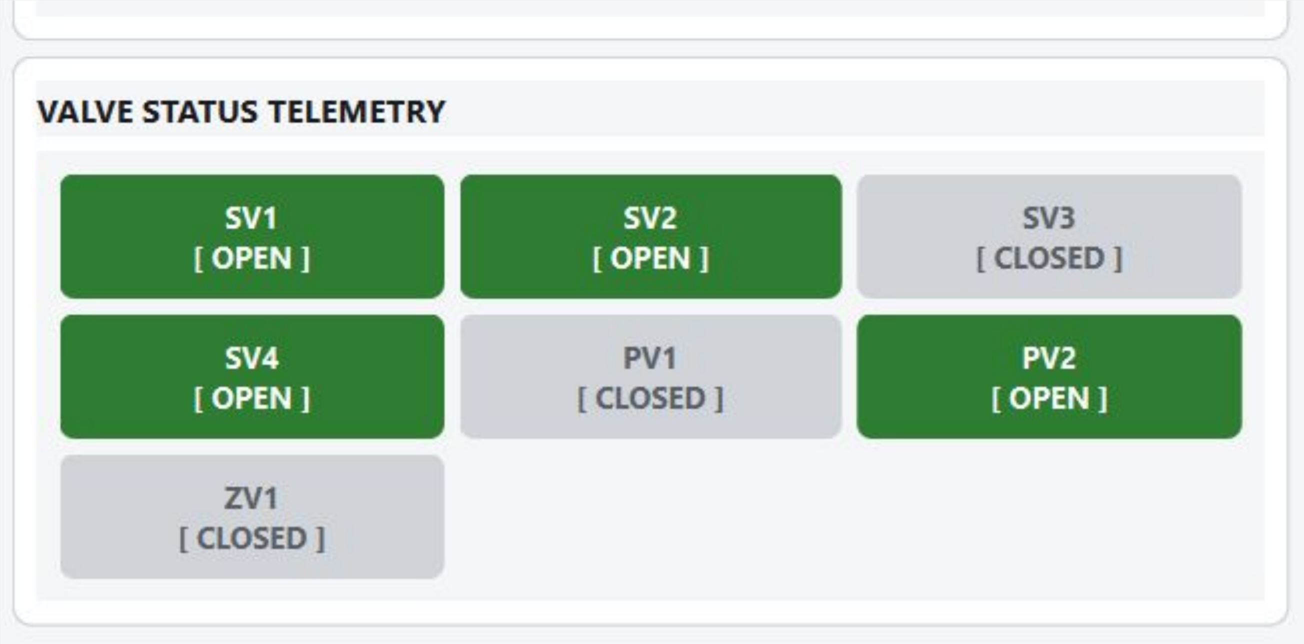


Control System - Sequence Manager



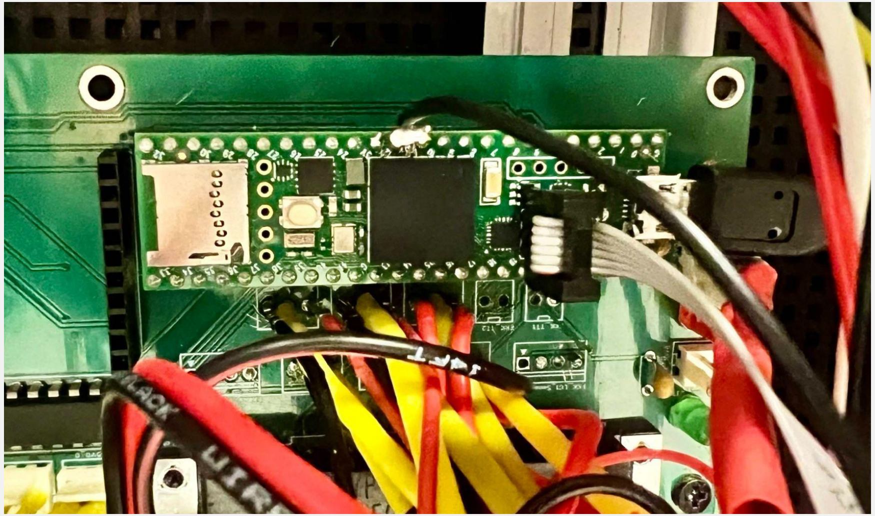


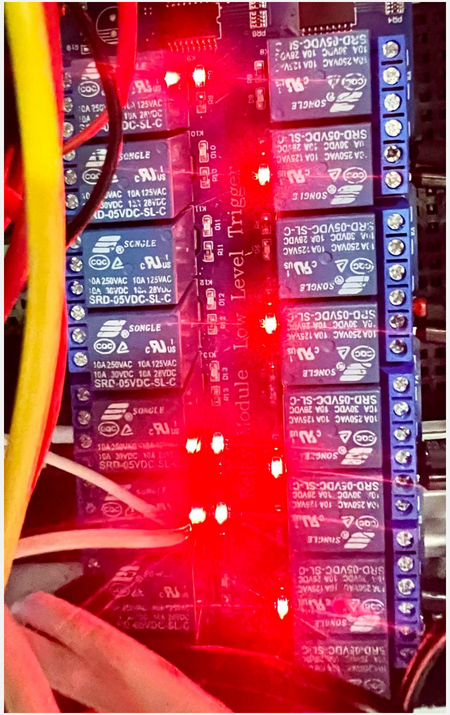
Control Systems - Valve Control



Control System - Teensy Controller

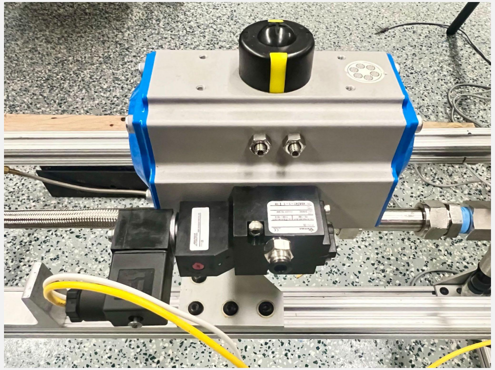
- Send signal to relay to actuate valves
- Sends PWM signal to actuate servo.





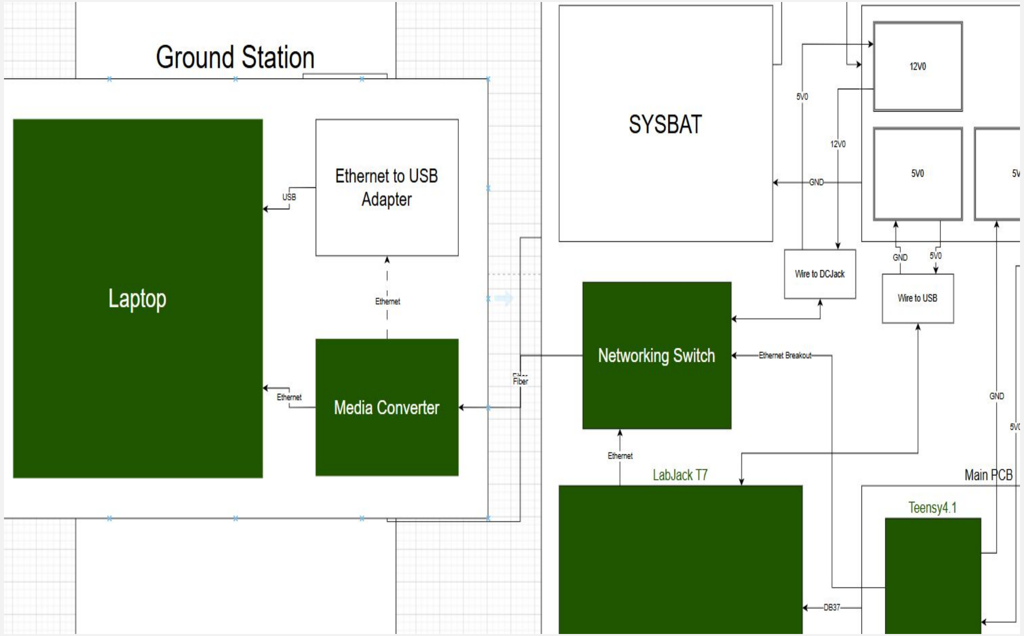
Electrical System - Valves

- Connected to relay and terminal blocks.



Control Systems - Fiber Optic/Ethernet

- Fiber link carries Ethernet between the ground station and switch.
- Provides the primary, low-latency path for LabJack data and Teensy commands.
- UDP communication and macros

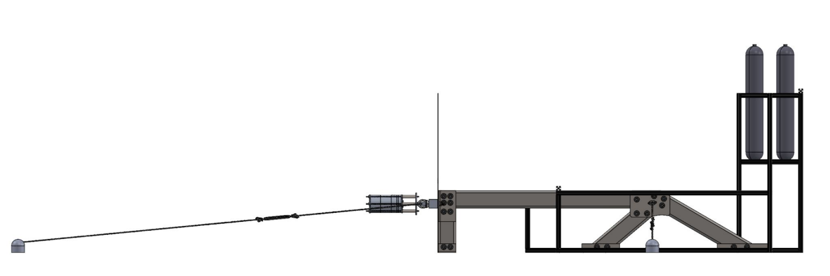


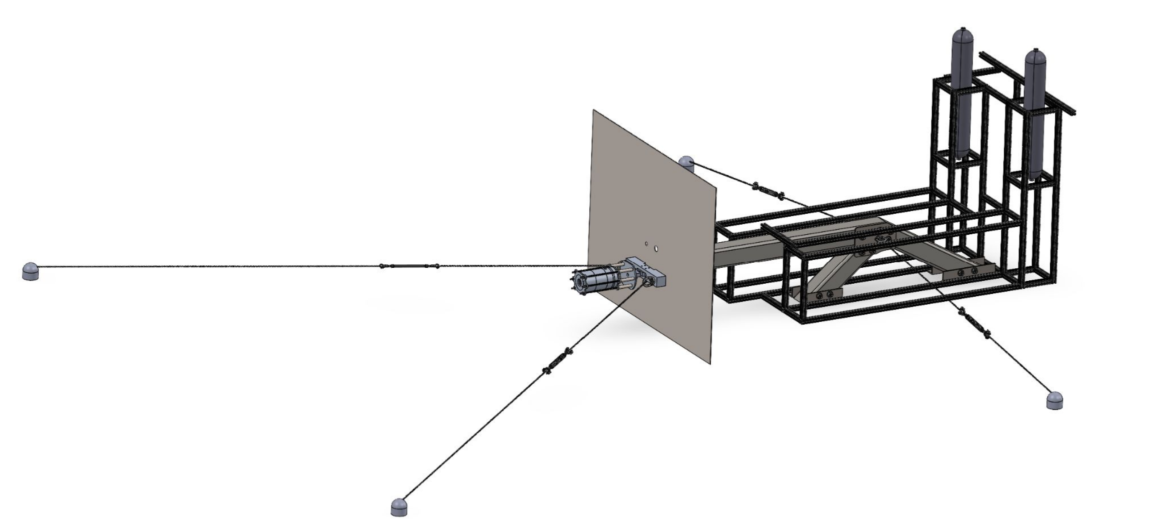
Questions?

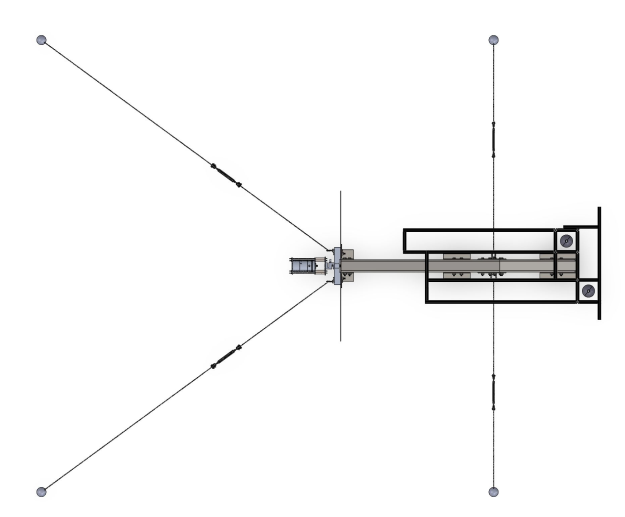
Test Stand

Test Stand - Tie Downs

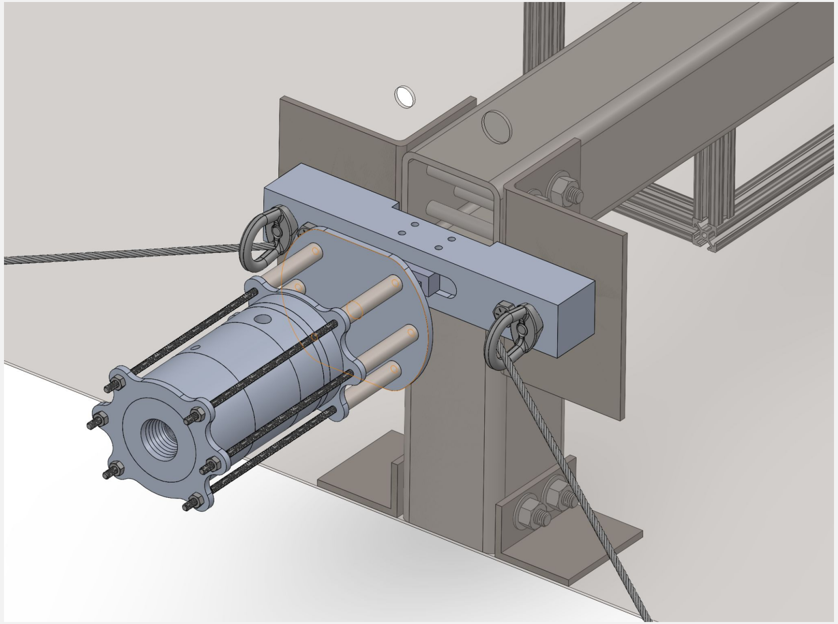
12 x 12 tie down square



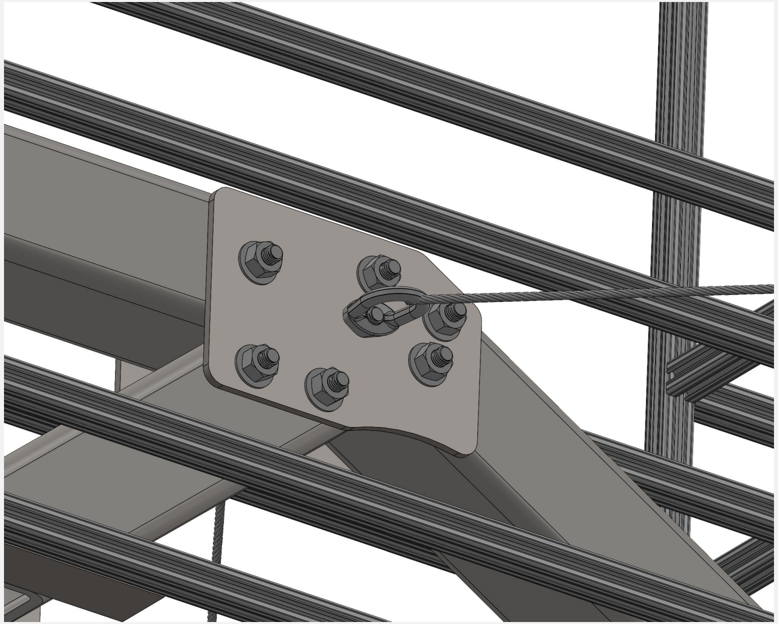




Test Stand - Mounting Locations



At engine



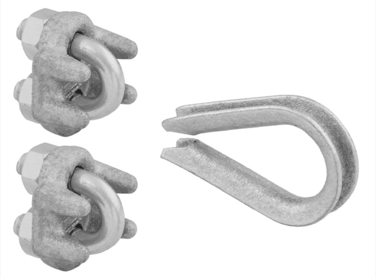
At rear
Gusset Plate

Test Stand - Mounting Hardware

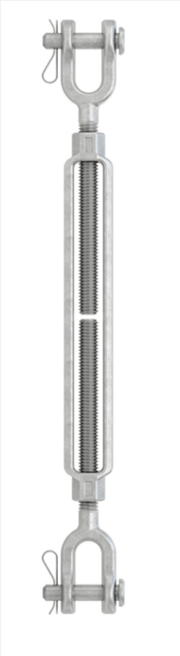
7/16 Steel
EyeNut
1700 lb

1/2 Steel
EyeNut
2225 lb

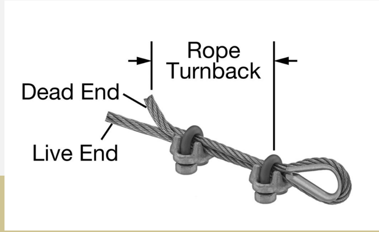
1/2 Steel
EyeNut
1200 lb



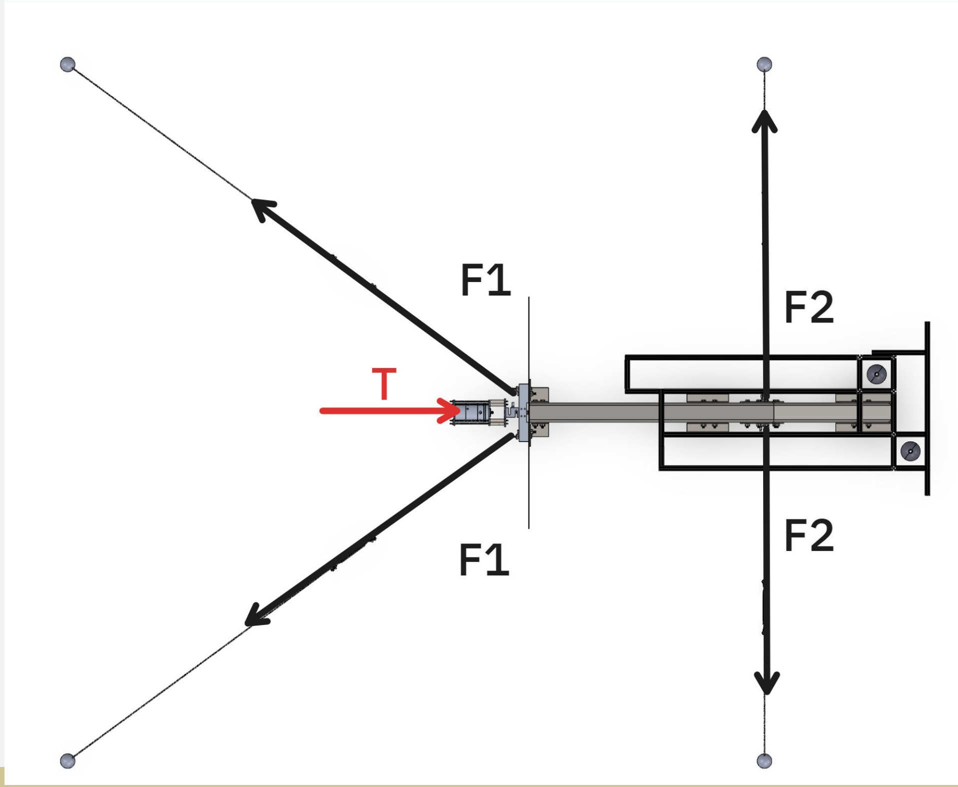
Clamp and
Thimble



Steel
Turnbuckle
1200 lb



Test Stand - Calculations



Test Stand - Calculations - F1

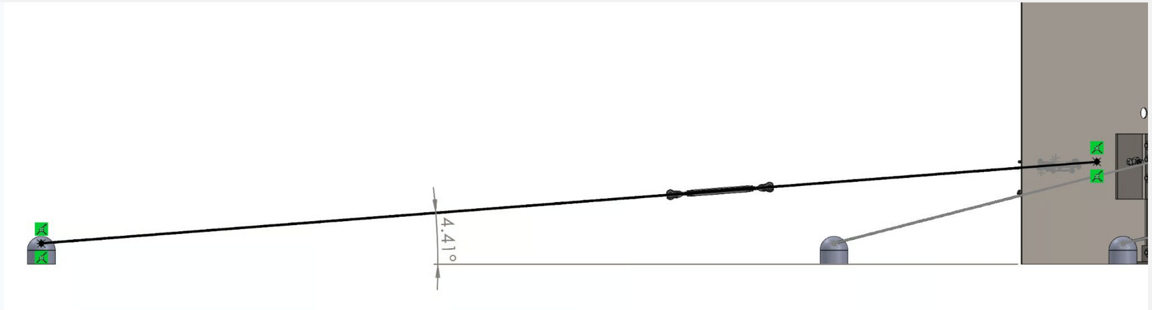
F_max = 685 lbf

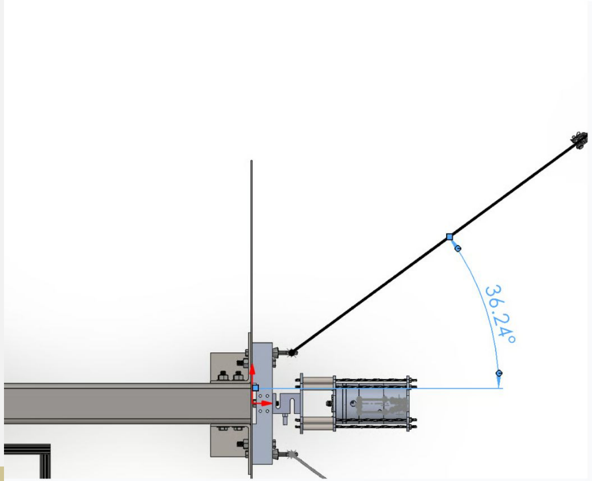
Alpha = 36.7 °

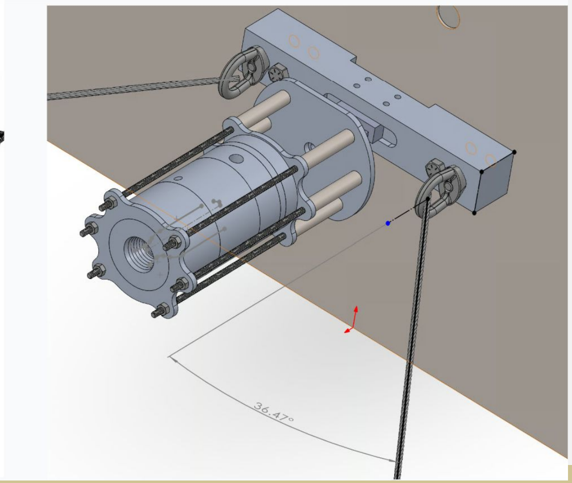
T = 425 lbf

Rated up to 1200 lbf

FOS = 2.81

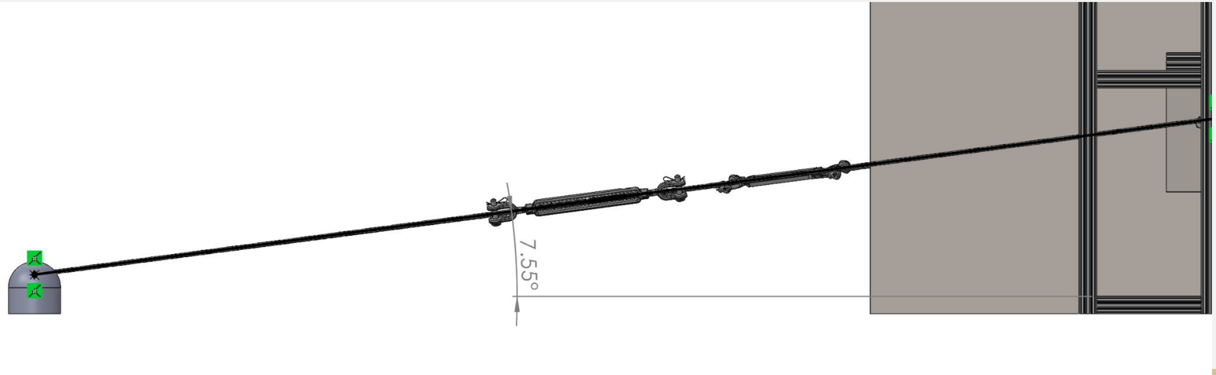




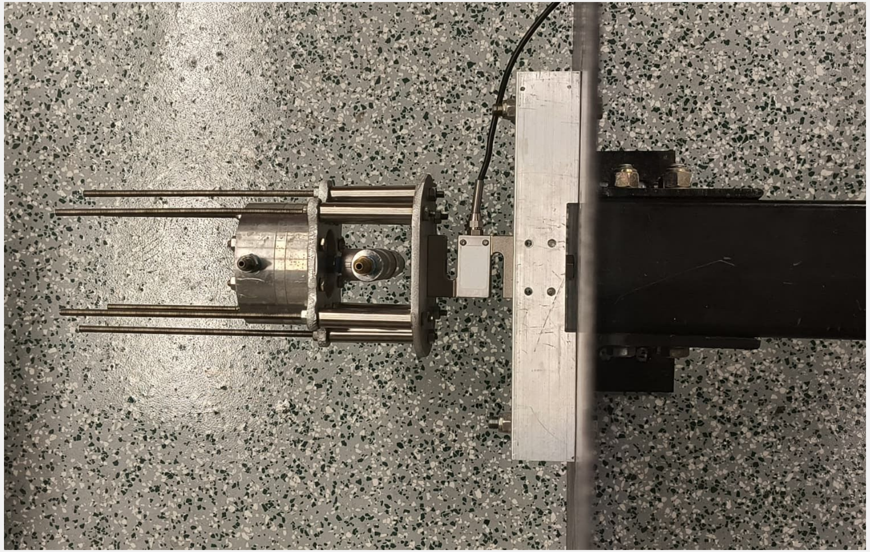


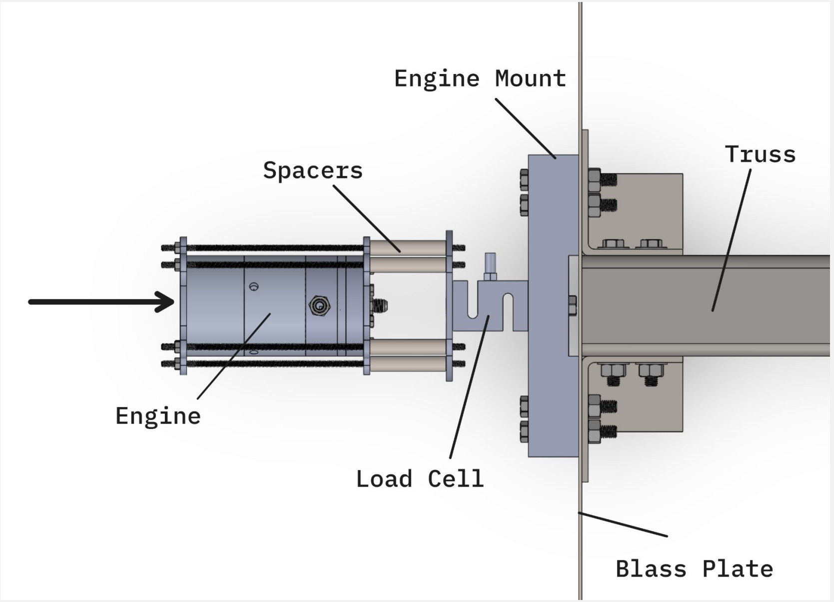
Test Stand - Calculations - F2

- Constrain Test Stand
- Slightly increase normal force



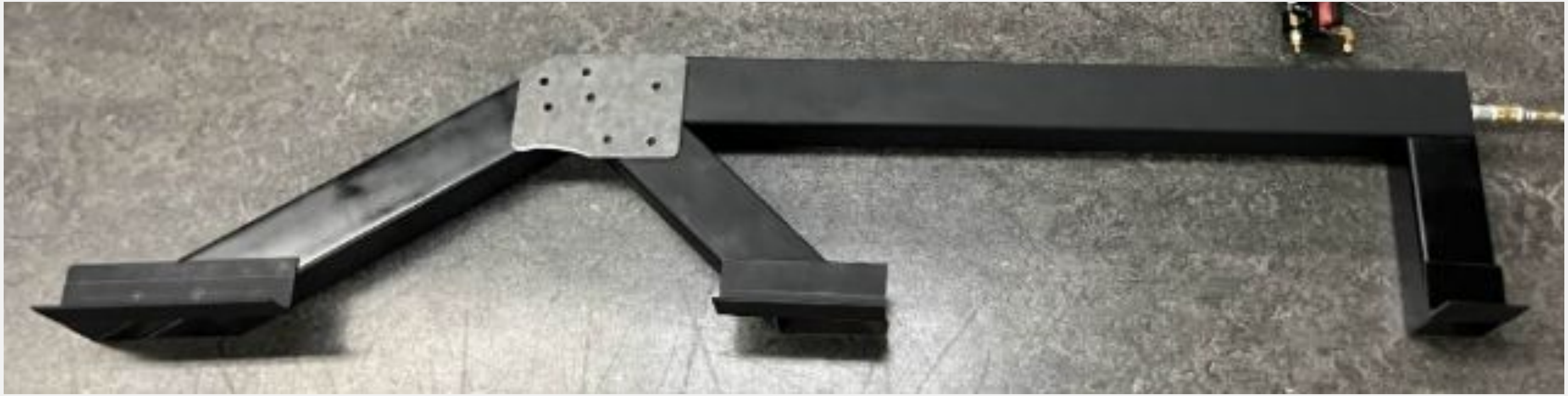
Test Stand - Engine Mounting





Test Stand - Legacy Design

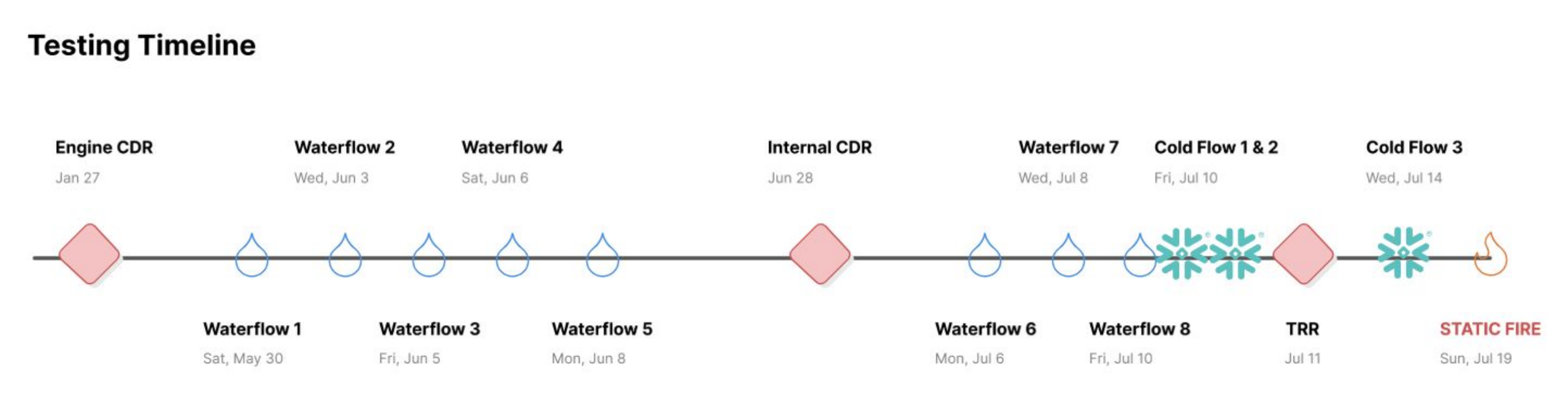
Designed and manufactured by Christopher Lemonds



Questions?

Integrated Systems Tests

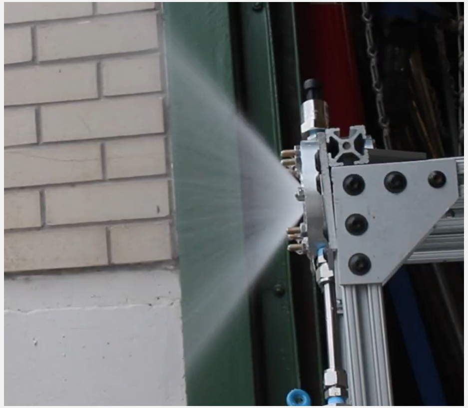
Timeline

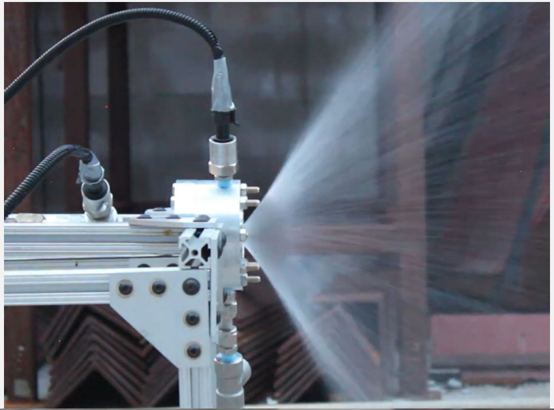

Testing Timeline
Engine CDR
Jan 27
Waterflow 2
Wed, Jun 3
Waterflow 4
Sat, Jun 6
Internal CDR
Jun 28
Waterflow 7
Wed, Jul 8
Cold Flow 1 & 2
Fri, Jul 10
Cold Flow 3
Wed, Jul 14
Waterflow 1
Sat, May 30
Waterflow 3
Fri, Jun 5
Waterflow 5
Mon, Jun 8
Waterflow 6
Mon, Jul 6
Waterflow 8
Fri, Jul 10
TRR
Jul 11
STATIC FIRE
Sun, Jul 19

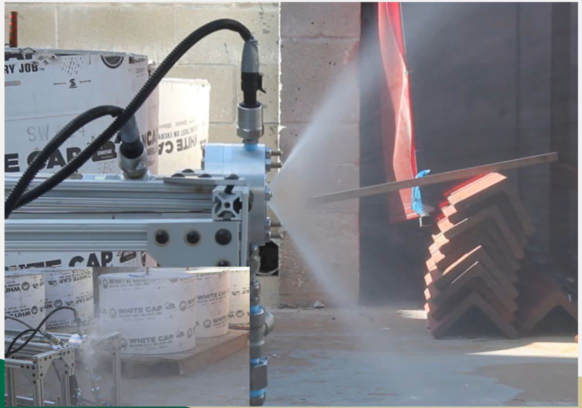
Questions?

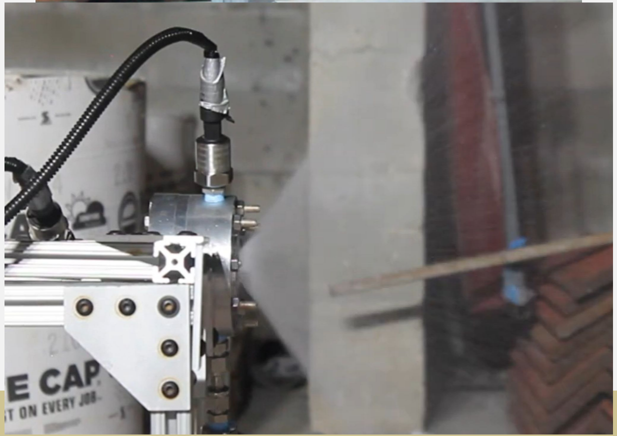
Water Flow Tests

Water Flow [1 - 4] - Early Steps





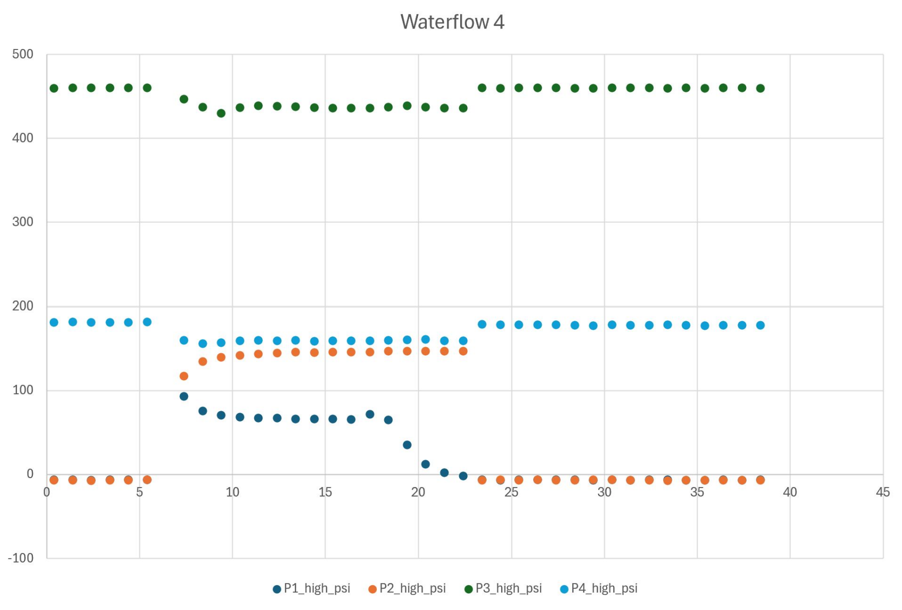




Water Flow [1 - 4] - Lessons Learned

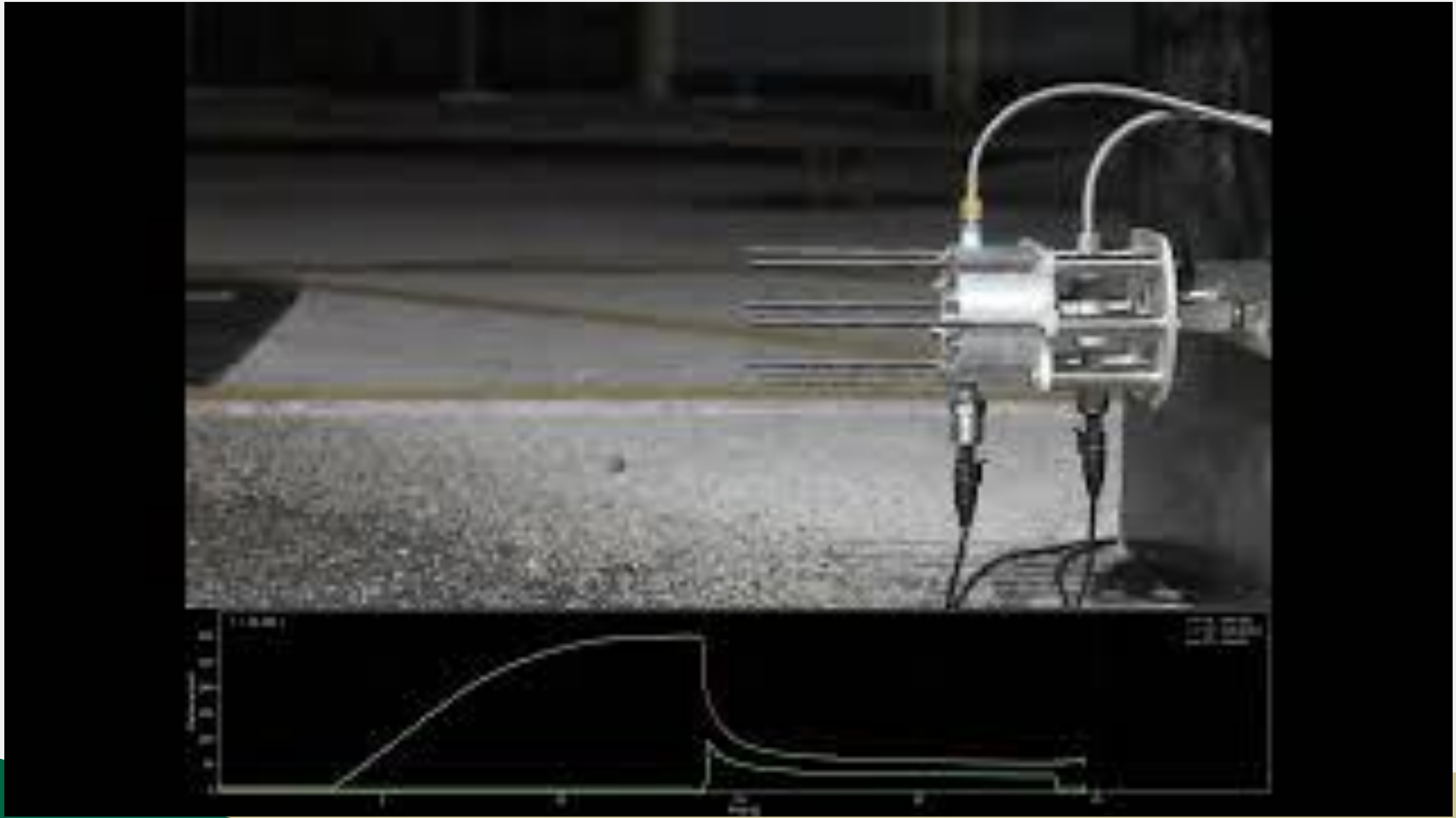
- Build momentum
- Proper Valve timing
- Independent sequencing
- Preliminary Cd calculation
- Testing DAQ

Water Flow 4 - First Successful Data

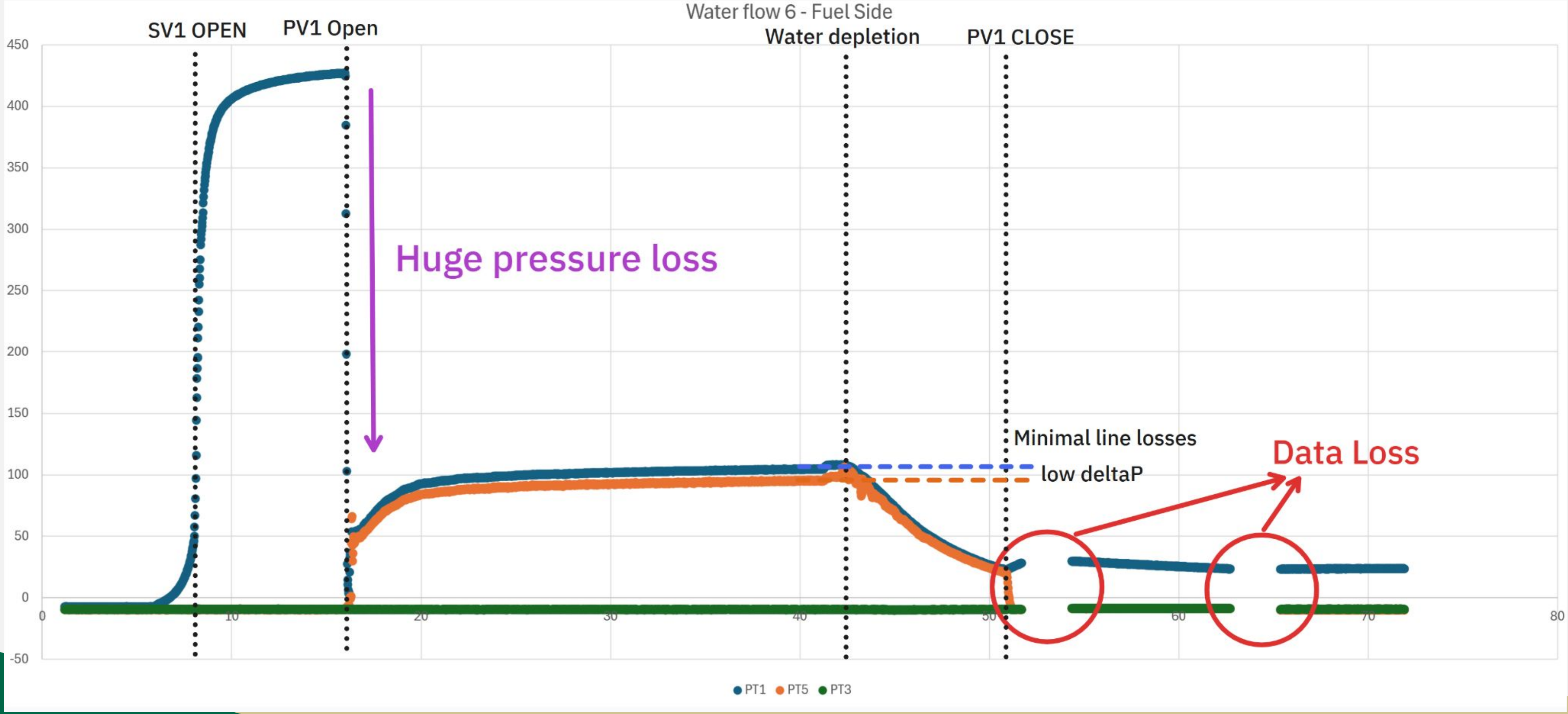


Water flow 5 - Kendall’s Injector

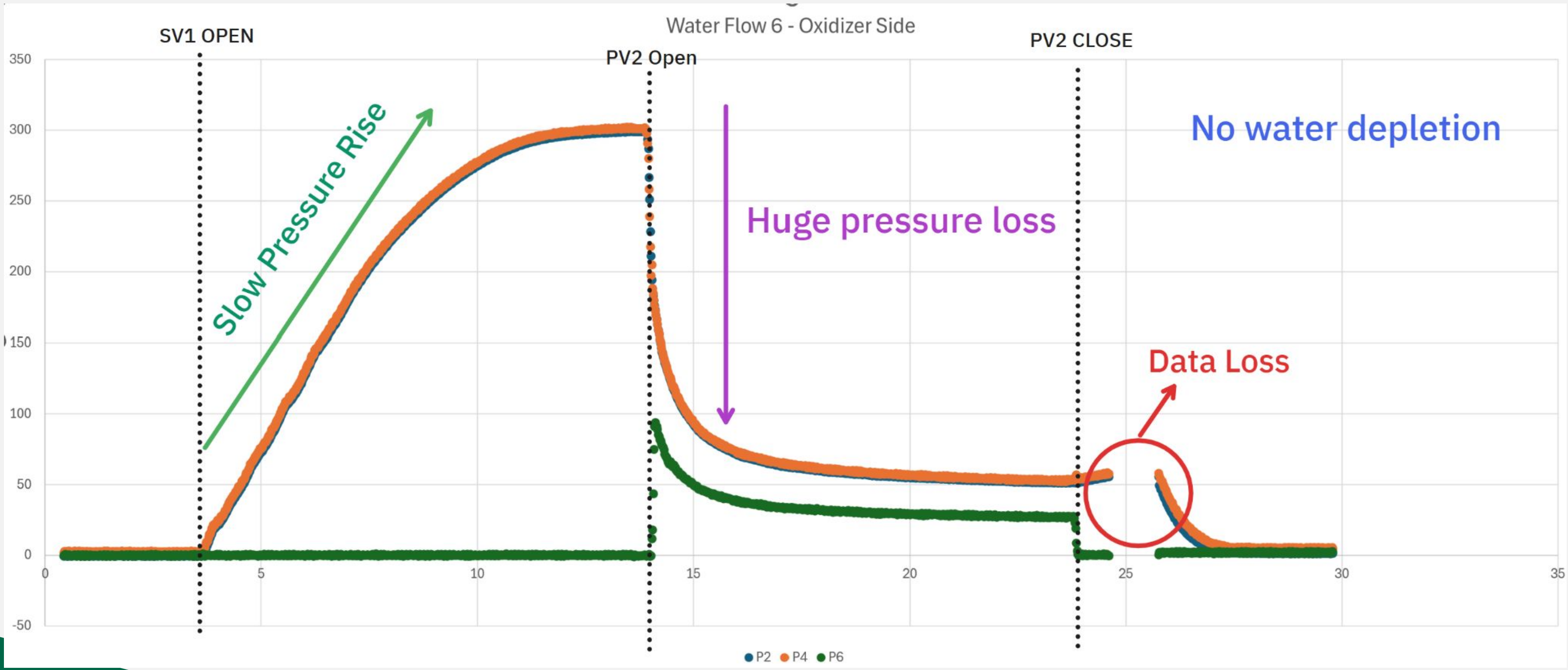
Water Flow 6 - Good data (?)



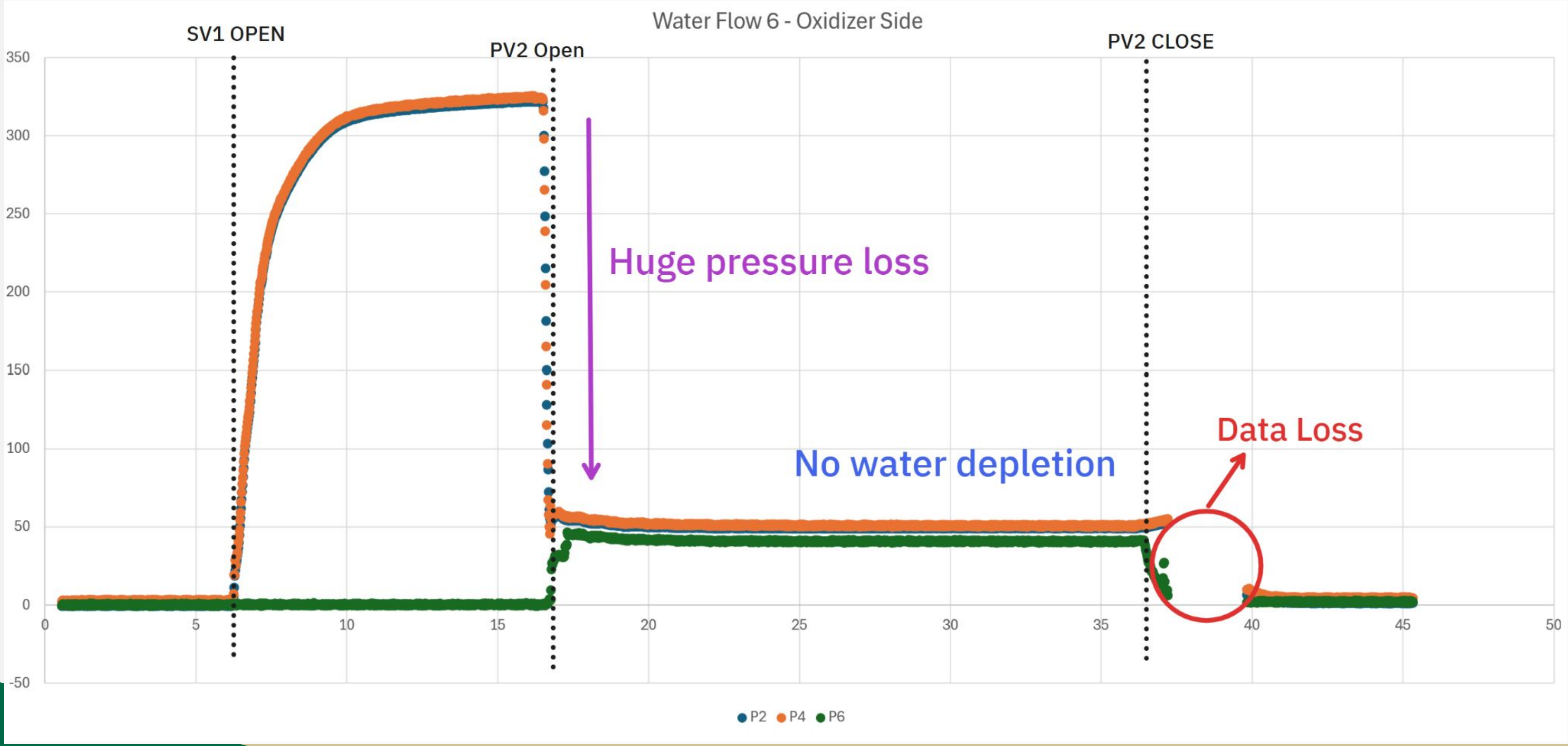
Water Flow 6 - Fuel Side Analysis



Water Flow 6 - Oxidizer Side 1 Analysis



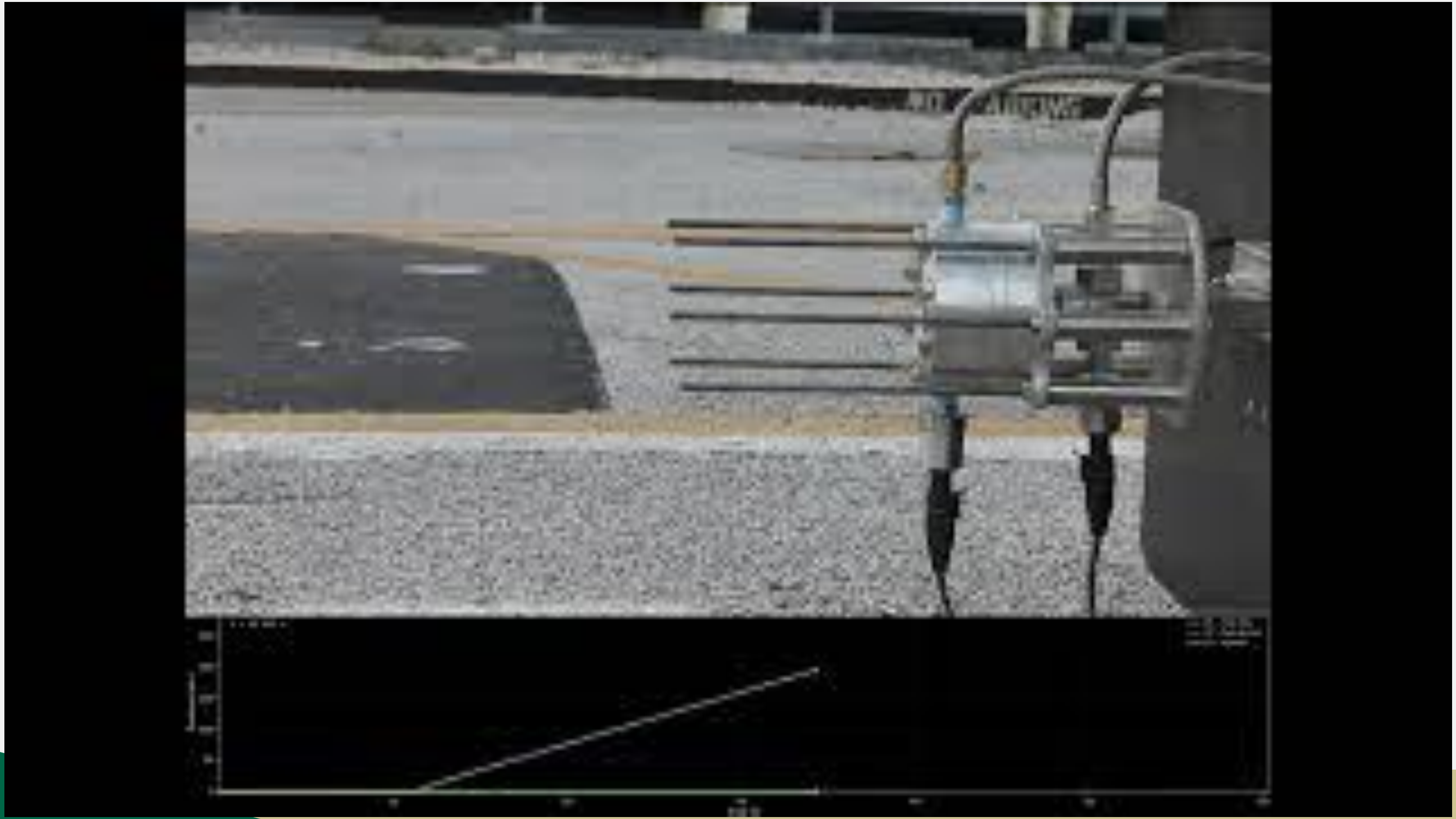
Water Flow 6 - Oxidizer Side 2 Analysis



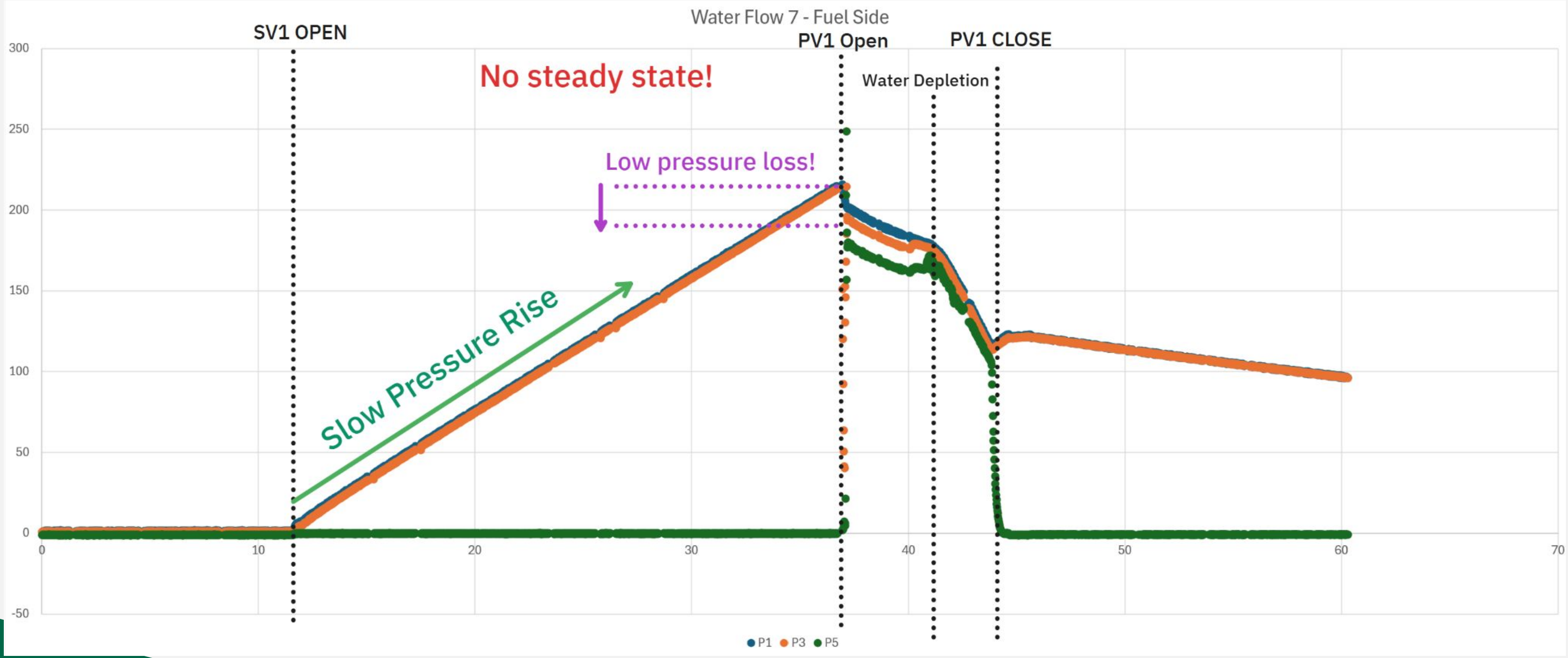
Water Flow 6 - Lessons Learned

Issue	Possible Cause	Possible Solution
Loss of data after closing a solenoid	Current spikes, Flyback	Diodes
Slow pressure rise	Low N2 mass flow rate, N2 tank not fully opened, too much restriction, running low on N2	Fully open N2 bottle, Refill bottle,
Huge pressure loss	Not enough N2 mass flow rate to sustain high pressures, too much restriction, 0% tank ullage	Increase tank ullage to 80%, Fully open N2 bottle, Refill bottle,
No water depletion	Not enough time given in sequence	Close main valve after confirming depletion

Water Flow 7 - Almost there!



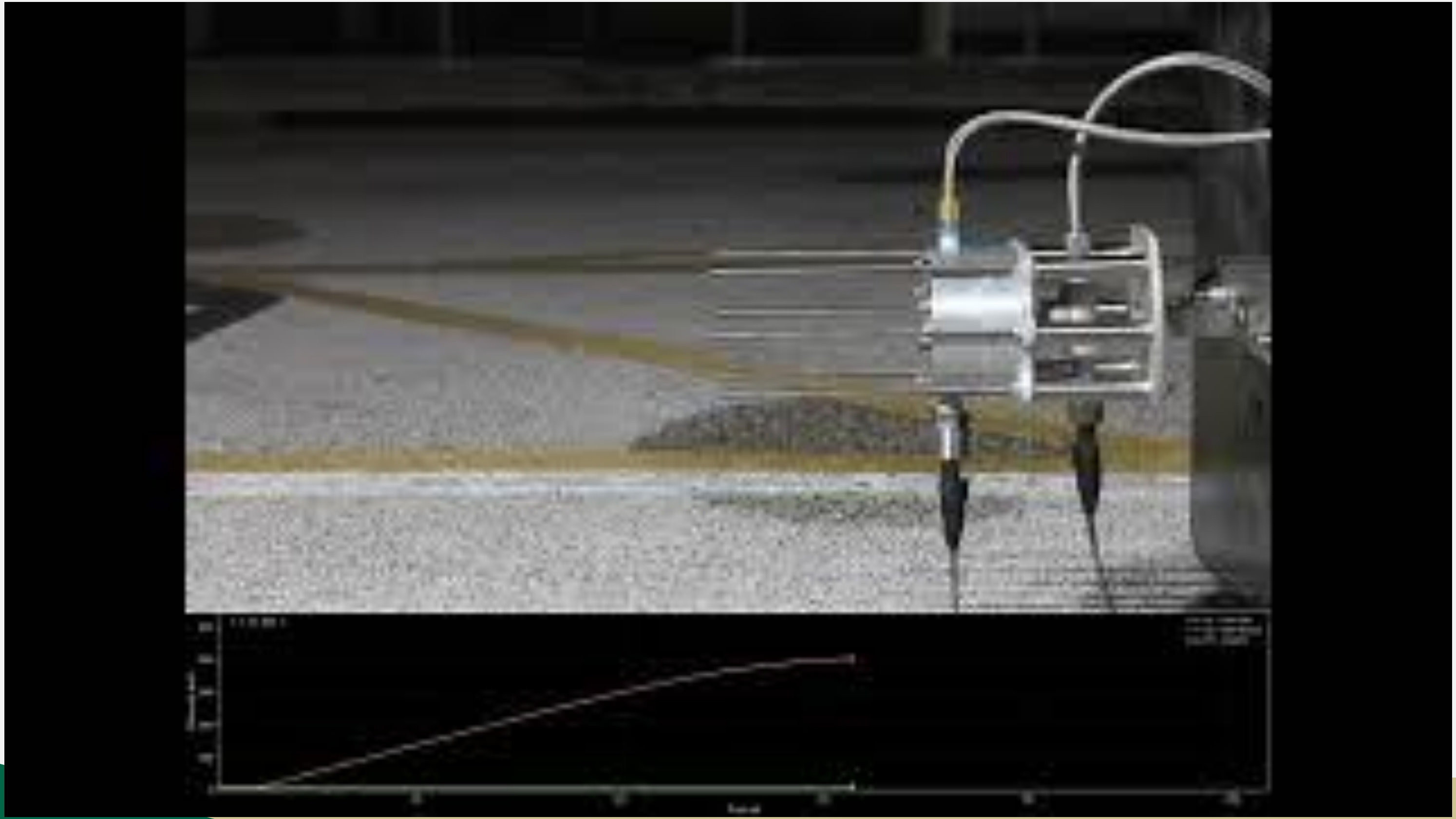
Water Flow 7 - Fuel Side Analysis



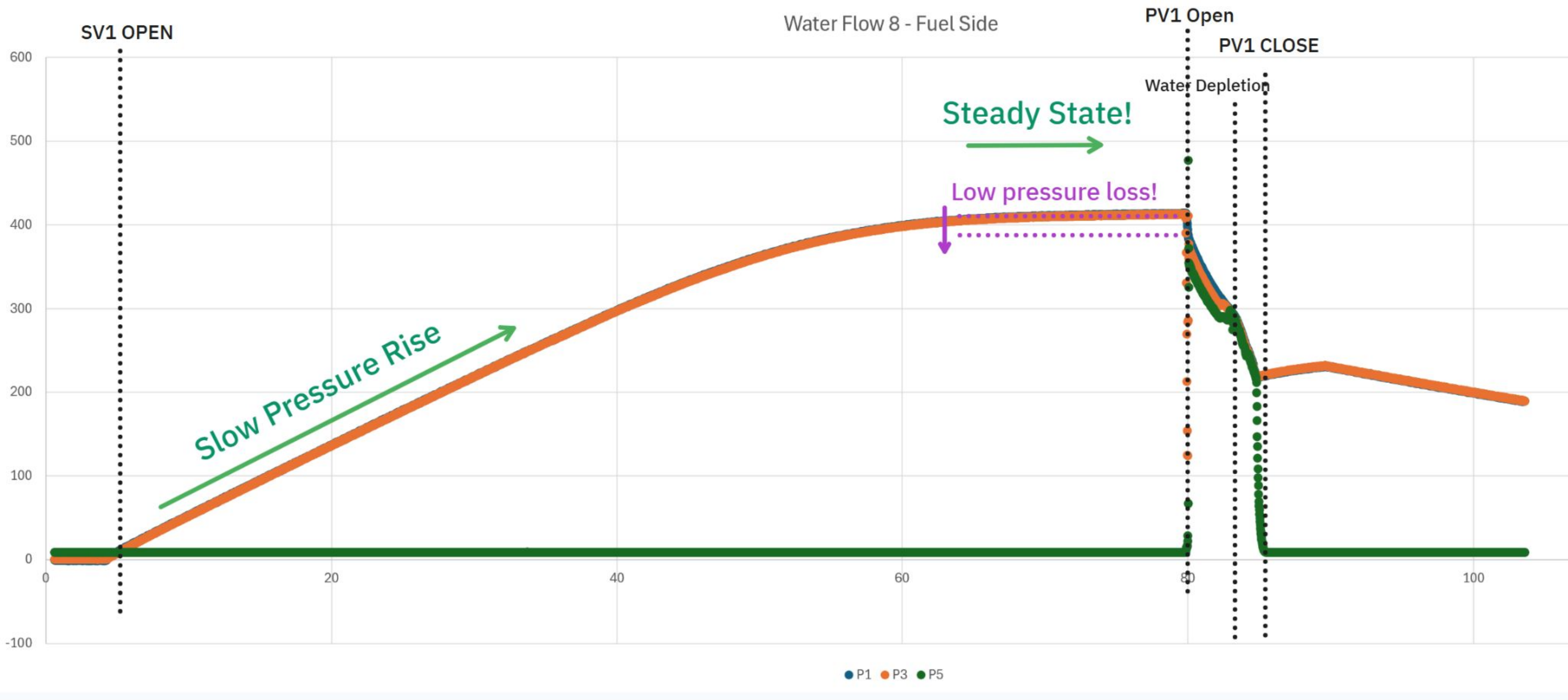
Water Flow 7 - Lessons Learned

Issue	Possible Cause	Possible Solution
Slow pressure rise	Low N2 mass flow rate, N2 tank not fully opened, too much restriction, running low on N2	Fully open N2 bottle, Refill bottle, wait until steady
Did not reach target pressure	Time for N2 filling was not enough, running low on N2	Greatly increase time for steady state N2, Refill bottle, manual confirmation
No data on oxidizer side	Loose cable	Verify data connectivity, confirm data before leaving test location

Water Flow 8 - Success



Water Flow 8 - Fuel Side



Water Flow 8 - Lessons Learned

Issue	Possible Cause	Possible Solution
Slow pressure rise	Low N2 mass flow rate, N2 tank not fully opened, too much restriction, running low on N2	Wait until steady state

Water Flow - Fuel Cd

```
Collected mass:        3.8000 kg
Collection time:       26.0000 s
Mass flow rate:        0.146154 kg/s
Hole radius:           0.6500 mm
Number of holes:       4
Total area:            5.309292e-06 m^2
Density:               998.00 kg/m^3
Pressure drop:         7.0300 bar
--------------------------------
Discharge coeff Cd:    0.7349
```

Waterflow 6
Cd: 0.735

```
Collected mass:        0.7500 kg
Collection time:       3.9000 s
Mass flow rate:        0.192308 kg/s
Hole radius:           0.6500 mm
Number of holes:       4
Total area:            5.309292e-06 m^2
Density:               998.00 kg/m^3
Pressure drop:         11.5100 bar
--------------------------------
Discharge coeff Cd:    0.7557
```

Waterflow 7
Cd: 0.756

```
Collected mass:        0.7500 kg
Collection time:       2.8000 s
Mass flow rate:        0.267857 kg/s
Hole radius:           0.6500 mm
Number of holes:       4
Total area:            5.309292e-06 m^2
Density:               998.00 kg/m^3
Pressure drop:         22.0600 bar
--------------------------------
Discharge coeff Cd:    0.7603
```

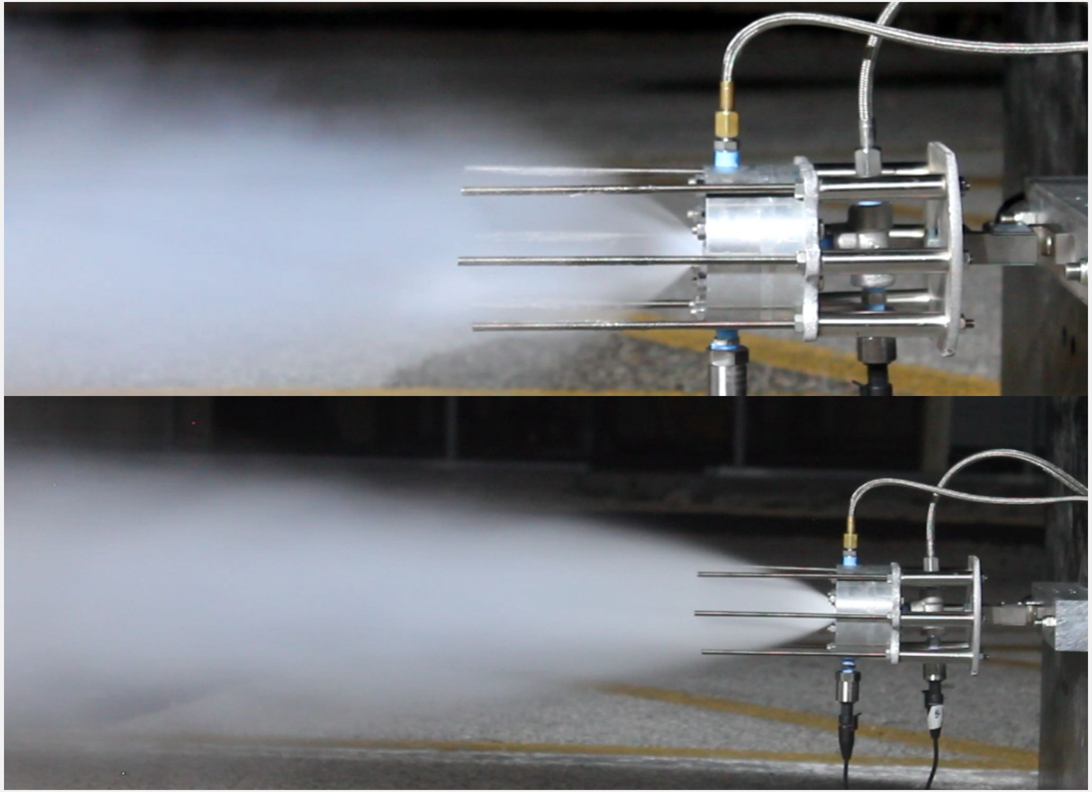
Waterflow 8
Cd: 0.76

Chosen Fuel Cd: 0.76

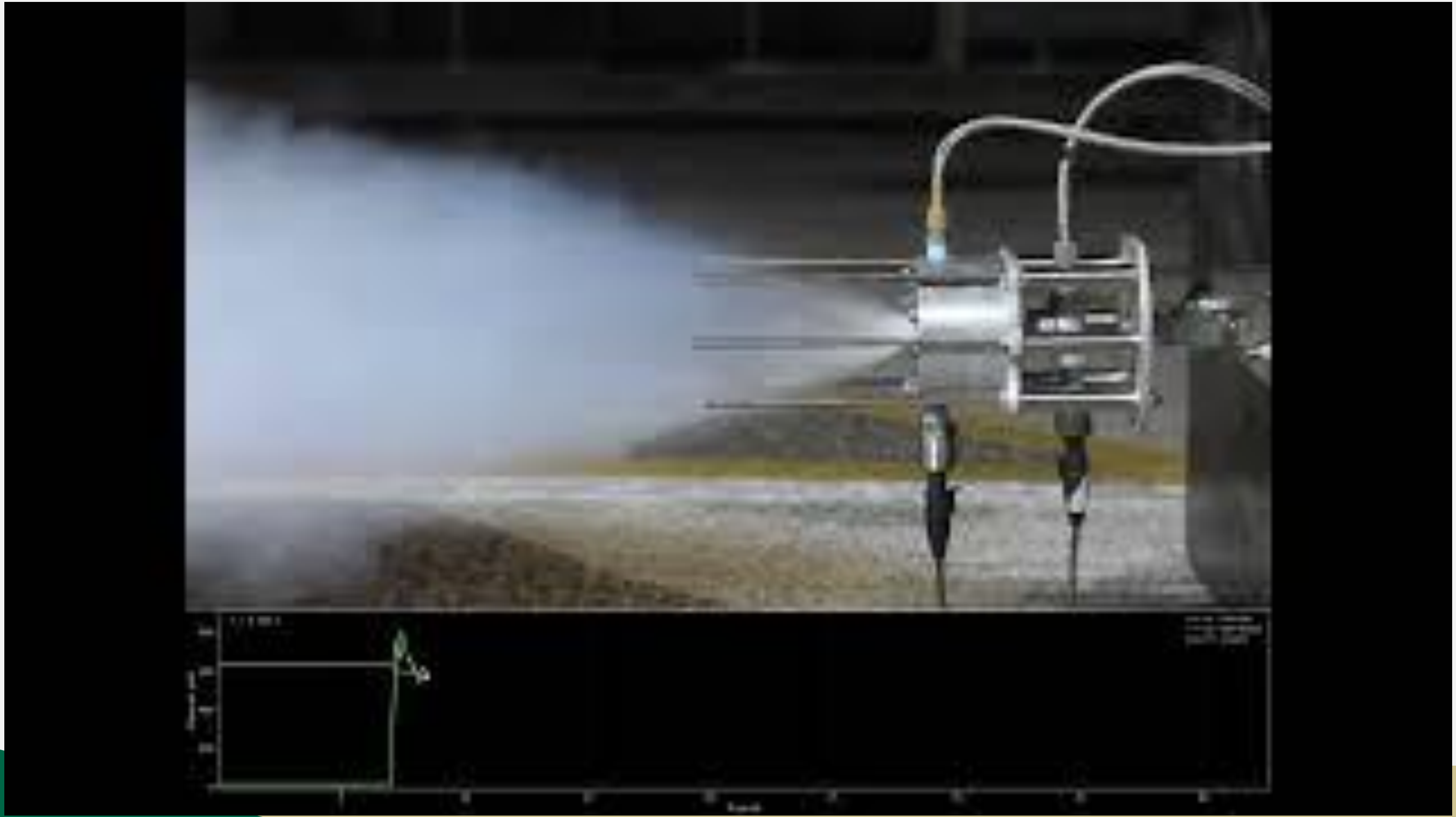
Questions?

Cold Flow Tests

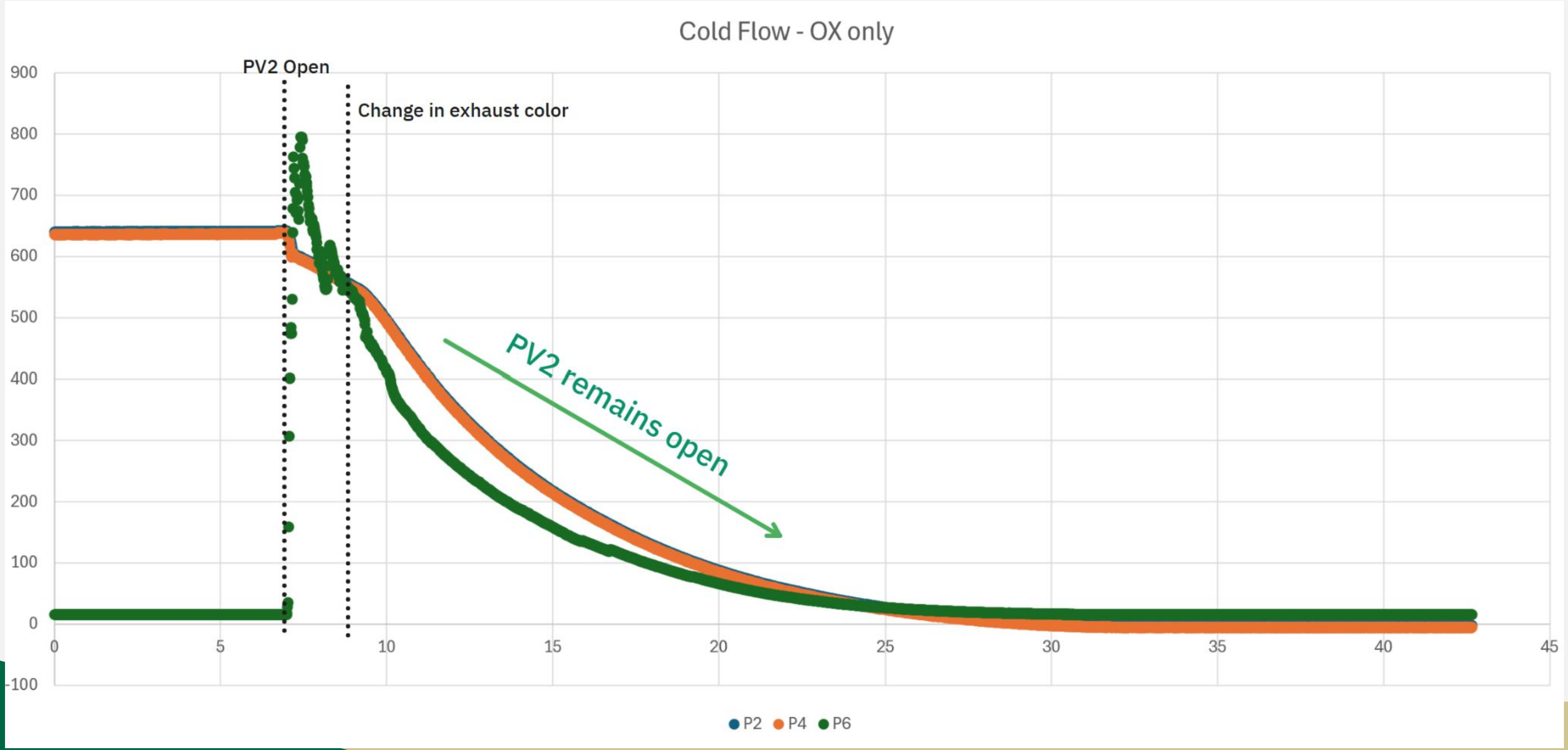
Cold Flow - Quick look



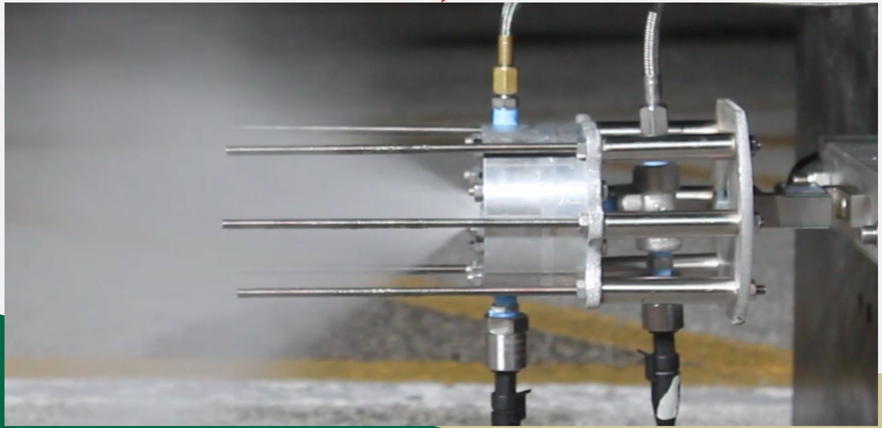
Cold Flow 1 - First Coldflow!

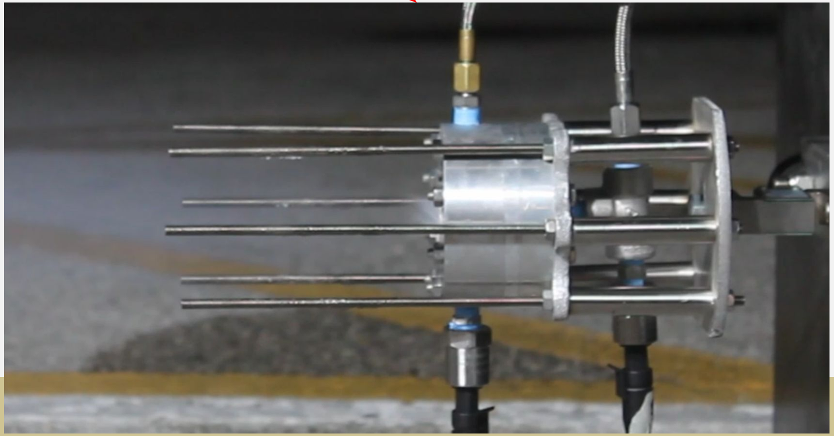


Cold Flow 1 - Data Analysis

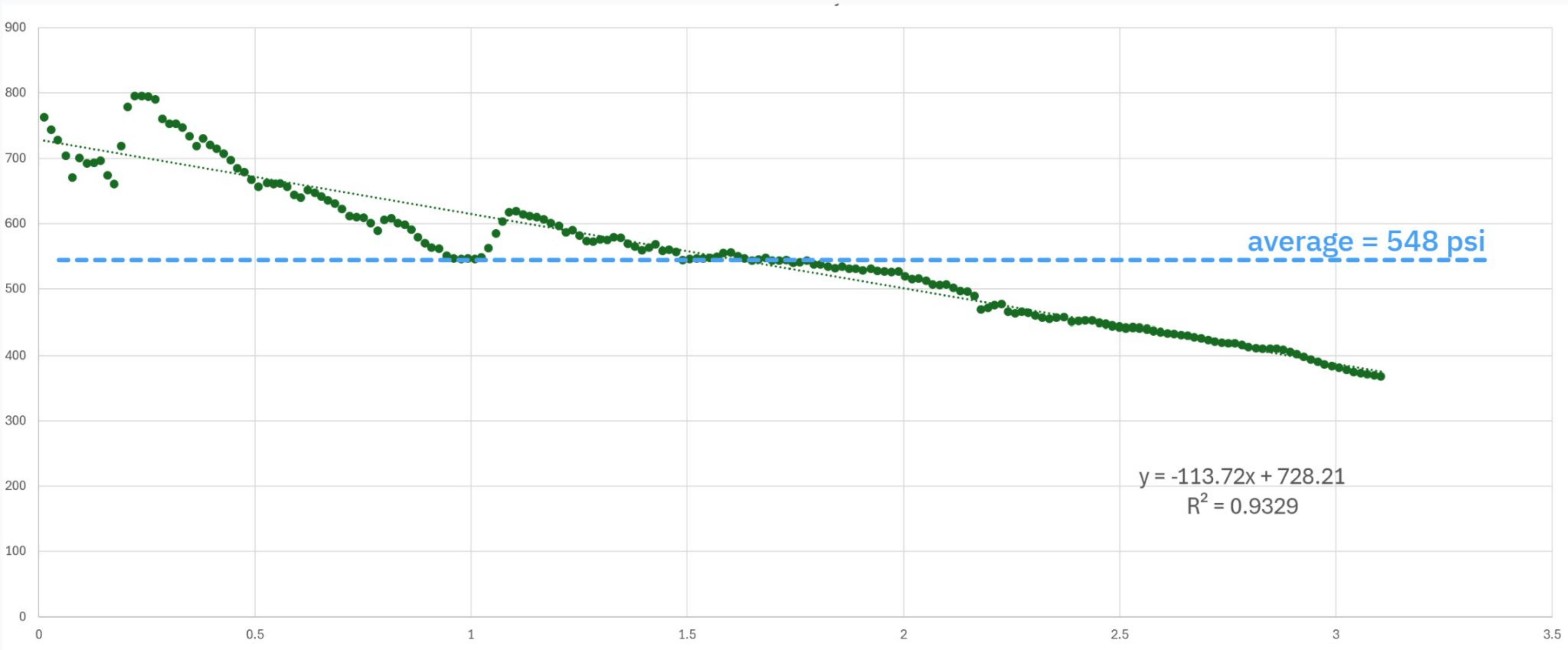


Cold Flow 1 - Cd





Cold Flow 1 - Data cropping



Cold Flow 1 - Oxidizer Cd

Used N2O: 0.82 kg

@ 800 psi, liquid 761 kg/m3, vapor 175 kg/m3

Approx liquid: 0.66 kg

DeltaT: 2.2s

DeltaP: 548 psi

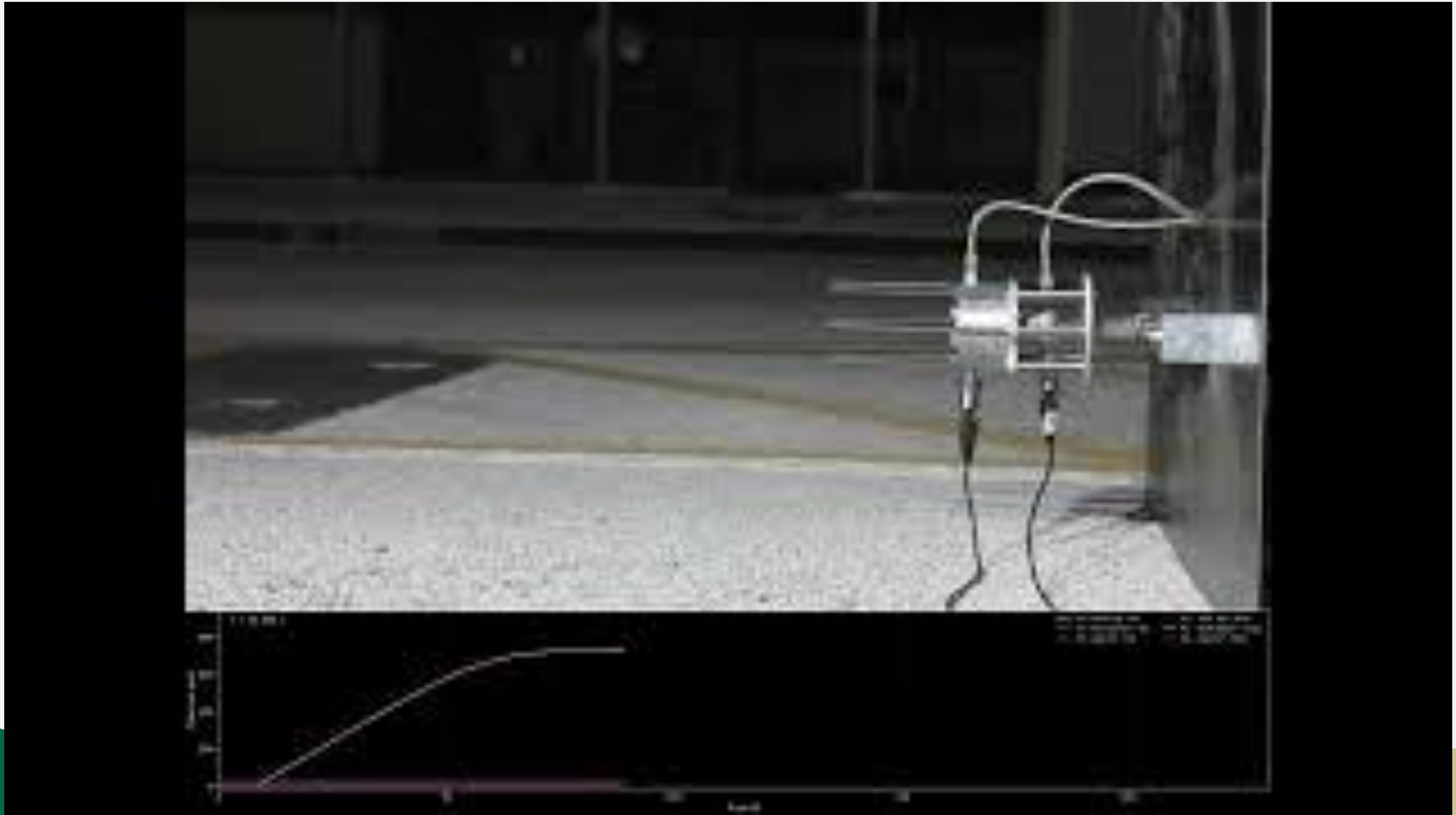
Cold Flow 1 - Oxidizer Cd

```
Collected mass:        0.6600 kg
Collection time:       2.2000 s
Mass flow rate:        0.300000 kg/s
Hole radius:           1.1300 mm
Number of holes:       6
Total area:            2.406900e-05 m^2
Density:               761.00 kg/m^3
Pressure drop:         37.5000 bar
--------------------------------
Discharge coeff Cd:    0.1650
```

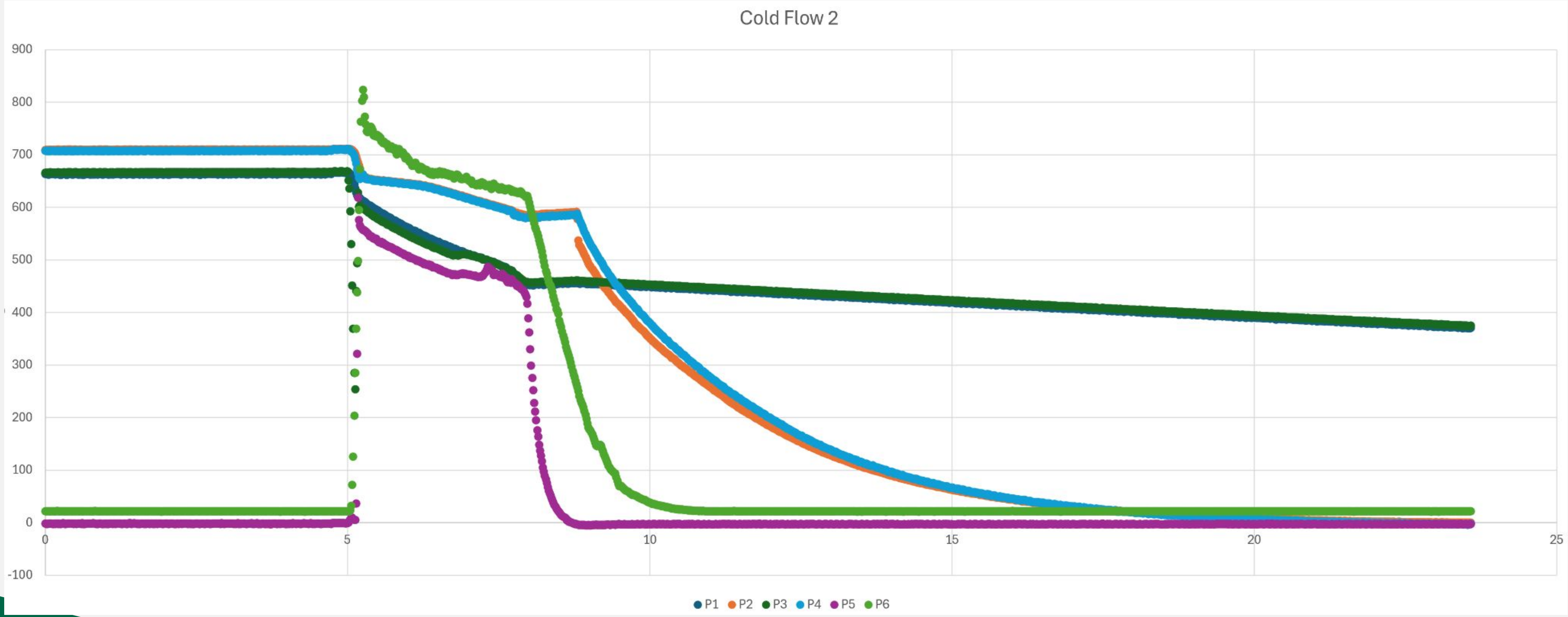
Cold Flow 1 - Lessons Learned

Issue	**Possible Cause**	**Possible Solution**
Critically low Cd	Vaporization before the injector	Chill N2O bottle before use
Thermocouple not working	Poor cable management	Cable clips

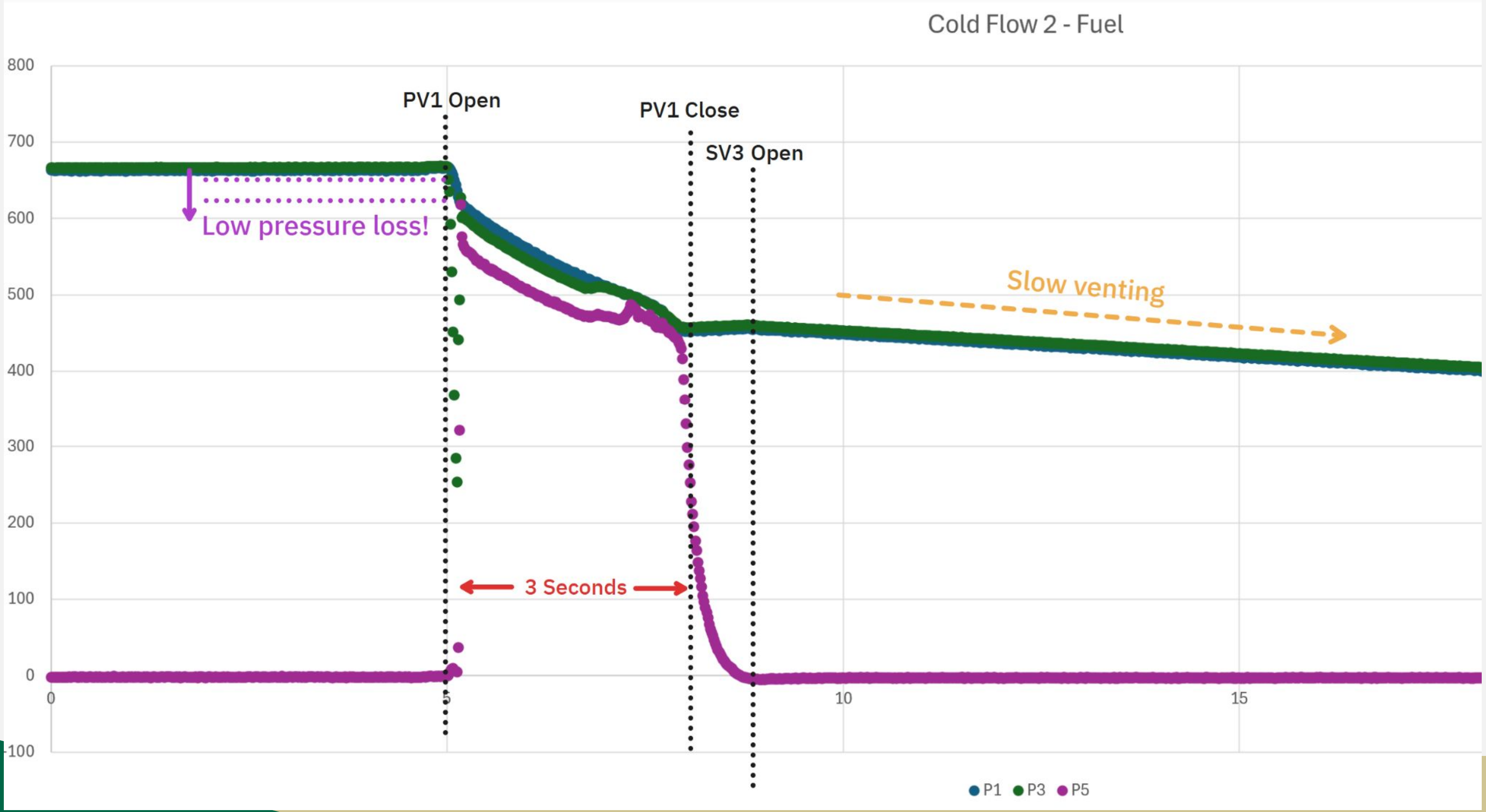
Cold Flow 2 - Fuel and Ox combined



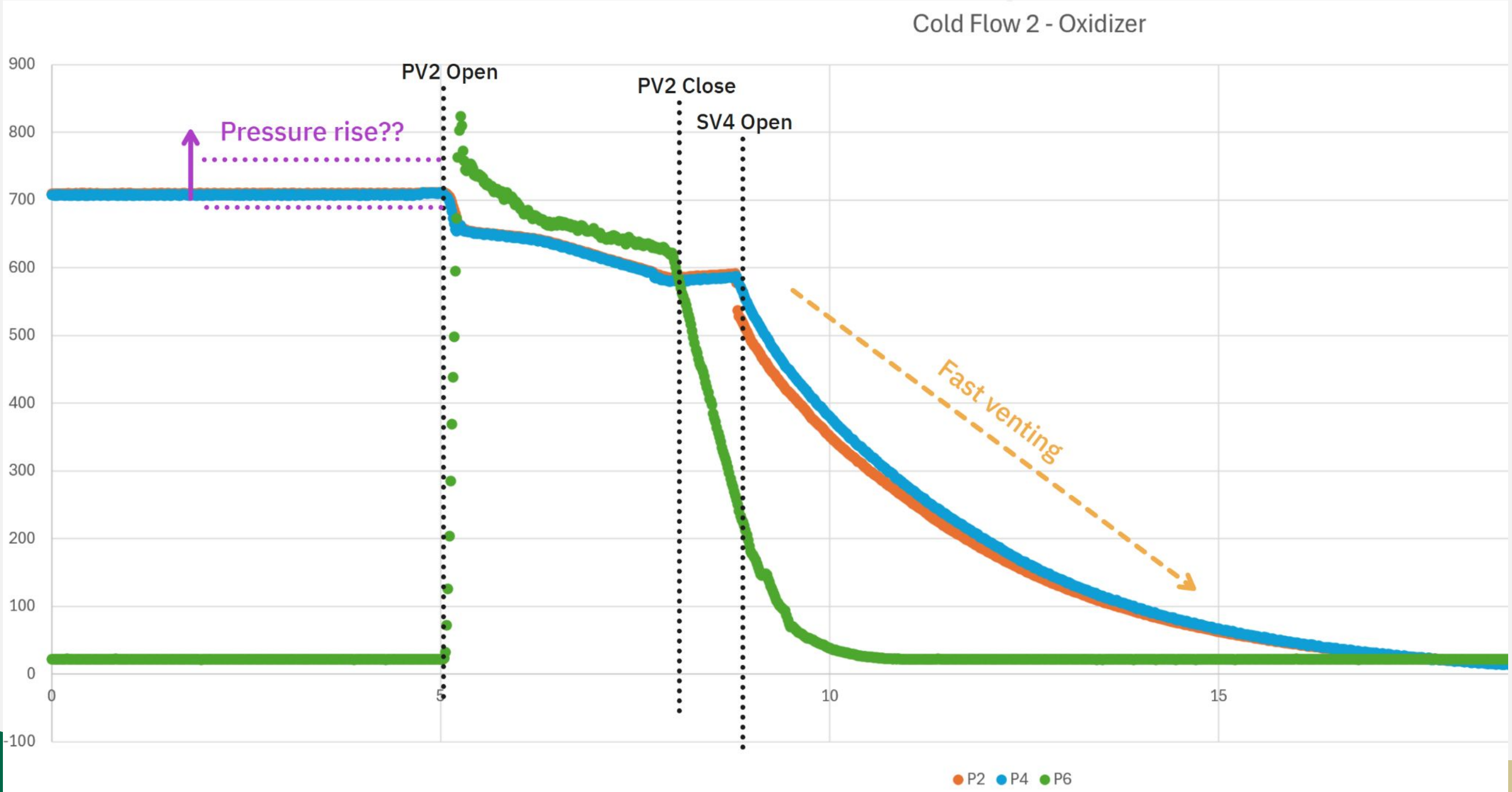
Cold Flow 2 - Data Analysis



Cold Flow 2 - Data Analysis Fuel



Cold Flow 2 - Data Analysis Oxidizer



Cold Flow 2 - What if it fired?

$$f(P_c) = \dot{m}_{total,inj} - \dot{m}_{nozzle} = 0$$

Injector

$$\dot{m}_{total,inj} = \dot{m}_{ox} + \dot{m}_{fuel}$$

$$\dot{m}_{ox} = C_{d,ox} \cdot A_{ox} \cdot \sqrt{2 \cdot \rho_{ox} \cdot (P_{inlet,ox} - P_c)}$$

$$\dot{m}_{fuel} = C_{d,fuel} \cdot A_{fuel} \cdot \sqrt{2 \cdot \rho_{fuel} \cdot (P_{inlet,fuel} - P_c)}$$

Nozzle

$$\dot{m}_{nozzle} = \frac{P_c \cdot A_t}{C^*}$$

$$C^* = \frac{\sqrt{R \cdot T_c}}{\Gamma}$$

Cold Flow 2 - What if it fired?

P_ox: 750 psi

P_fuel: 565 psi

Cd_oxidizer: 0.165

Cd_fuel: 0.76

```
             ROCKET SYSTEM CONVERGENCE RESULTS
==================================================
Calculated C* (C-star):       1534.22 m/s
Balanced Chamber Pressure:    237.50 psi
Nozzle Expansion Ratio:       2.25
Nozzle Exit Pressure:         134.04 psi
--------------------------------------------------
Total Mass Flow Rate:         0.5408 kg/s
 -> Oxidizer Flow Rate:       0.3190 kg/s
 -> Fuel Flow Rate:           0.2218 kg/s
Resulting O/F Ratio:          1.44
--------------------------------------------------
 -> Oxidizer P drop:         512.50 psi (68.3%)
 -> Fuel P drop:             327.50 psi (58.0%)
--------------------------------------------------
EXPECTED THRUST (Ideal):      1500.2 N (337.3 lbf)
==================================================
```

Cold Flow 2 - Lessons Learned

Issue	Possible Cause	Possible Solution
Critically low Cd	Vaporization before the injector	Chill N2O bottle before use
Piping support moved	Thrust on vent valve, piping support on wheels	Vent with PV2 and SV4 at the same time.

Cold Flow 3 - Next Steps

- Team will chill N_2O in an ice bath, targeting a temperature of 0°C
- Oxidizer line will be tested to obtain C_d
- Low temperature should prevent vaporization before the injector

Questions?

SOP's

Pipe Fitting Cleaning

Item	Quantity x Size
Liquinox	1 x Quart
Deionized Water	20 Gallons
Air Compressor	1x
Lint Free Paper Towel	1 Roll
Corrosion Inhibitor Bags	50x
Ultrasonic Cleaner	1x
Air Compressor Hose and Fittings	1x
PPE	2x

Pipe Fitting Cleaning Cont.

	Preparation
1	Mix Liquinox solution beforehand with manufacturer recommendations at 1%. So around 2.5 tbsp per gallon.
2	Rinse the bath with DI water to remove possible debris.
3	Inspect parts to make sure larger debris like Teflon residue is removed.
	Cleaning Procedure
1	Place all items into the basket.
2	**(Steel)** Heat up to 80 degrees Celsius and start the timer to clean for 30 minutes. **(Brass)** 50 degrees Celsius for 20 minutes.
3	Afterwards turn the cleaner off and take the entire basket and dump it into a bath of just DI water.
4	Agitate the water by moving the basket around.
5	Lay out each piece onto lint free towels.
6	Use an air compressor to blast residue and water off.
7	Both parties inspect each part so there's no leftover residue of detergent, water, or oxidized metal.
8	Items are then placed into VCI bags for storage.
9	The bag is then tagged and then documented within excel.
10	Bags are then placed into a sealed plastic container for storage.
11	The cleaner is set to rest for 20-30 minutes before the next batch. While it is cooling the old solution is drained and then the bath is rinsed with DI water.

Water Flow

Water Flow Procedure

Pre-Fill Check
Ensure all manual ball valves are closed via handle being perpendicular to the flow.
Ensure Pressure Regulators are closed.
Attach air compressor tubes to PV1 and PV2
Turn on the Air Compressor. Let it run until it shuts itself off.
Ground Station turns on the system and ensures full control of all electronically actuated equipment (Solenoids and Servos). Turn on each individual solenoid and servo and turn them off.

Water Flow Cont. Fuel Side

Fill
Connect fill tube to BV5
Open BV3
Open BV2
Place a bucket of Deionized Water on a ladder and use siphoning to fill the fuel tank.
Close BV3 once the tank is filled with 1.7 Pounds of DI Water.
Close BV5
Disconnect the tube.

Pressurizing Fuel Side
Slowly open PR1 to allow 300-400 psi of Nitrogen through.
Do one last check to make sure all manual valves are closed
Open BV1
Test Stand Personnel are ordered to move away from the test stand.
Chief Engineer gives go for ALL CLEAR
Open SV1
Let system sit for a minute to read DATA for leaks and to make sure Run Tank is filled with Nitrogen (When Pressure Stops Climbing)
(If there are leaks close SV1. Open SV2 to vent out pressure. Personnel return to tighten connections.)
Ground Station gives the clear for testing to go ahead
The Chief Engineer assumes full control of the system.

Water Flow Cont. Fuel Side

Test
Open PV1
After All fluids have been dispelled through the injector
Close SV1
Close PV1
Open SV3 to vent out any remaining pressure left in the system
Close SV3 once pressure readings drop to Zero
Personnel are allowed near the test stand.

ENSURE EVERYTHING IS CLOSED BEFORE PROCEEDING TO THE NEXT TEST

Water Flow Cont. Oxidizer Side

Fill
Connect fill tube to ZV1
Open BV3
Open ZV1
Place a bucket of Deionized Water on a ladder and use siphoning to fill the fuel tank.
Close ZV1 once the tank is filled with 1.7 Pounds of DI Water
Close BV3
Disconnect the fill tube.

Pressurizing
Slowly Open PR1 to allow 250-300 psi of Nitrogen through
Do one last check to make sure all manual valves are closed.
Test Stand personnel are ordered away from the test stand.
Chief Engineer gives go for “ALL CLEAR”
Open SV1
Let system sit for a minute to read DATA for leaks and to make sure Run Tank is filled with nitrogen (When Pressure Stops Climbing)
(If there are leaks close SV1. Open SV5 to vent out pressure. Personnel return to tighten connections.)
Ground Station gives the clear for testing to go ahead
Chief Engineer assumes full control of the system

Water Flow Cont. Oxidizer Side

Test
Open PV2
After All fluids have been dispelled through the injector
Close SV1
Close PV2
Open SV4 to vent out any remaining pressure
Once pressure returns to Zero
Close SV4

Cold Flow

Cold Flow Procedure

Pre-Fill Check
Ensure all manual ball valves are closed via handle being perpendicular to the flow.
Ensure Pressure Regulators are closed.
Attach air compressor tubes to PV1 and PV2
Turn on the Air Compressor. Let it run until it shuts itself off.
Ground Station turns on the system and ensures full control of all electronically actuated equipment (Solenoids and Servos). Turn on each individual solenoid and servo and turn them off.

Cold Flow Cont. Fuel

Fill
Connect fill tube to BV5
Open BV3
Open BV2
Place a bucket of Deionized Water on a ladder and use siphoning to fill the fuel tank.
Close BV3 once the tank is filled with 1.7 Pounds of DI Water.
Close BV5
Disconnect the tube.

Pressurizing Fuel Side
Slowly open PR1 to allow 300-400 psi of Nitrogen through.
Do one last check to make sure all manual valves are closed
Open BV1
Test Stand Personnel are ordered to move away from the test stand.
Chief Engineer gives go for ALL CLEAR
Open SV1
Let system sit for a minute to read DATA for leaks and to make sure Run Tank is filled with Nitrogen (When Pressure Stops Climbing)
(If there are leaks close SV1. Open SV2 to vent out pressure. Personnel return to tighten connections.)
Ground Station gives the clear for testing to go ahead
The Chief Engineer assumes full control of the system.

Cold Flow Cont. Fuel

Test
Open PV1
After All fluids have been dispelled through the injector
Close SV1
Close PV1
Open SV3 to vent out any remaining pressure left in the system
Close SV3 once pressure readings drop to Zero
Personnel are allowed near the test stand.

ENSURE EVERYTHING IS CLOSED BEFORE PROCEEDING TO THE NEXT TEST

Cold Flow Cont. Oxidizer

Oxidizer Side Test

Fill/Pressurizing
Connect NOS Tank to PG3
Have Test Stand Personnel Step Back from the Test Stand.
Open ZV1
Allow NOS to fill the Run Tank with 3.2 kg
Close ZV1
Allow NOS to stabilize
Activate Bang-Bang

Test
Open PV2
Close PV2 when no Fluid Exits out of the Injector
Open SV4 to Vent out any remaining Pressure.

Questions?

Safety

Safety - Summary

Risk Analysis		Severity				
		Negligible (A)	Minor (B)	Moderate (C)	Major (D)	Catastrophic (E)
Probability	Improbable (1)	A1	B1	C1	D1	E1
	Remote (2)	A2	B2	C2	D2	E2
	Occasional (3)	A3	B3	C3	D3	E3
	Likely (4)	A4	B4	C4	D4	E4
	Frequent (5)	A5	B5	C5	D5	E5

Safety - Personnel

ID	Failure Mode	Failure Effects	Causes	Risk Class (Initial)	Mitigation	Verification	Risk Class (Final)
PH.1	**In-house Manufactured Components -** Parts have sharp edges unless post-processed	Personnel gets skin lacerations	Metal is not fully smoothed out after machining, leaving sharp edges	C3	All manufactured parts will be chamfered. All personnel will wear proper PPE	Chiefs will inspect parts for chamfering, and only allow personnel with PPE in the testing area	A1
PH.2	**Fasteners and Holders -** Heavy, difficult to move and maneuver components	Blunt Force Trauma	Improperly supported & secured components during transport and set-up	B3	PPE such as safety glasses, hard hats, steel toes, etc	Chiefs will supervisor personnel and provide PPE within the testing area	A3
PH.3	**Miscommunication - Incorrect or delayed sequence being executed**	Increase hazards covered by EAP and slow emergency response	Personnel being unfamiliar with testing procedures and chain-of-command	C4	Standardize communication during test prep and operation	Chiefs explain the chain-of-command, testing sequence, and radio protocols before testing	B2

Safety - Injector

ID	Failure Mode	Failure Effects	Causes	Risk Class (Initial)	Mitigation	Verification	Risk Class (Final)
IN.1	**Erosion** - Injector experiences damage during firing sequence	Permanent changes in the geometry of the injector	High localized heat and extreme thermal exposure	B5	Restrict the test to a short burn duration	Only load and provide enough fuel for 3 seconds of burn time	A4
IN.2	**Incorrect Mixing Ratio -** Imbalances or blockages in fluid delivery paths	Incomplete combustion, soot deposition, or oxygen-rich combustion erosion	Orifice clogging, valve timing error, or cavitation	B4	Calibrate inlet pressures accurately for both feed lines before static fire operations	Validate and verify performance data during preliminary cold flow and water flow tests	B2
IN.3	**Unstable Mixing -** Non-homogenous mixing profile within the chamber	Holes closer to the main feed hose will sustain higher individual mass flow rates than outer orifices	Single inlet utilization while the second entry point is strictly isolated for data acquisition	B4	No mitigation will be implemented unless significant effects are observed during water and cold flow tests	Visual and sensory observation during live water and cold flow testing runs	B4
IN.4	**Engine Hard Start - Propellant Accumulation Prior to Ignition (Hard Start) / Deflagration-to-Detonation Transition (DDT)**	A violent overpressure detonation event, typical leading to complete structural loss of the engine, instrumentation destruction, and fluid line ruptures	A localized timing delay in the injection of propellants into the chamber relative to the initiation of the igniter spark	E3	Set the ignition sequence to always end with the ingiter firing at least 3 seconds before propellant begins mixing in the chamber	Strict continuous observation during testing along with data analysis	E1

Safety - Chamber

ID	Failure Mode	Failure Effects	Causes	Risk Class (Initial)	Mitigation	Verification	Risk Class (Final)
CH.1	**Erosion - Severe internal erosion of the chamber wall**	Progressive decrease in the internal wall diameter of the chamber, causing a severe mismatch with the nozzle inlet geometry	High heat flux and localized extreme temperature concentrations during combustion	B5	Restrict the active engine test to a short-duration burn profile	Only provide enough fuel for 3 seconds of burn time	A4
CH.2	**Overpressurization** - Greater pressure than thresholds of the chamber	Structural chamber failure if internal pressures spike above the material's yield strength limits	Poor discharging coefficient (Cd) planning or off-nominal high-pressure inlets	E2	Take direct regulatory control of all high-pressure gas and fluid inlets	Validate and verify all pressure inlet thresholds with preliminary water flow and cold flow testing	E1
CH.3	**Pressure Leaks - Pressure leaks developing directly through the instrumentation data ports**	Structural ejection/removal of transducers, secondary hot gas leaks, and possible unwanted thrust vectoring anomalies	Poor port sealing or thread engagement failure under high thermal loads	D3	Calculate expected force on the individual data ports given the maximum chamber pressure	Validate sealing and joint integrity structurally through a hydrostatic proof test prior to firing	C1

Safety - Nozzle

ID	Failure Mode	Failure Effects	Causes	Risk Class (Initial)	Mitigation	Verification	Risk Class (Final)
NO.1	**Erosion - Nozzle geometry damage during firing sequence**	Progressive decrease in the structural throat diameter of the nozzle, resulting in a decrease in overall engine performance	Extreme localized heat flux and exposure to peak combustion temperatures	B5	Restrict the active engine test to a short-duration burn profile	Only provide enough fuel for 3 seconds of burn time	A4
NO.2	**Nozzle Blowout -** Nozzle is structurally blown out of the engine assembly	Complete dynamic failure and catastrophic decompression; nozzle components become structural projectiles	Structural failure of the threaded rods or the capture plate to contain forces fixing the nozzle to the chamber body	E2	Complete hand calculations to isolate the exact forces acting on the nozzle in the axial direction	Validate structural and material margins via FEA	E1
NO.3	**Perimeter Exhaust Leakage** - Hot exhaust gas leakage developing directly from the side interfaces of the nozzle body	Degradation of overall propulsion performance, localized thermal damage to adjacent hardware, and a potential complete nozzle blowout	Mechanical seal failure, O-ring degradation, or thermal expansion mismatch at the nozzle-to-chamber joint	D3	Integrate high-temperature static seals and establish precision torque specs for the clamping plates	Confirm joint integrity through standard pressure checks and a hydrostatic leak inspection prior to hot fire	C1

Safety - Feed System

ID	Failure Mode	Failure Effects	Causes	Risk Class (Initial)	Mitigation	Verification	Risk Class (Final)
FD.1	**Overpressurization - Greater pressure than thresholds of the N2O side of the system**	Internal pressures exceed component operating limits, leading to potential structural failure or line rupture	Failure of both active and passive venting mechanisms	E1	Integrate dedicated mechanical relief valves into the fluid line architecture	Confirm physical relief valve locations match schematic designs and verify proper pressure setpoints prior to operations	C1
FD.2	**Overpressurization - Greater pressure than thresholds of the fuel (ethanol) side of the system**	Fluid pressures exceed part operating limits, risking line failure or fitting blowout	Malfunction or failure of the active venting system	E1	Install inline mechanical relief valves on the fuel delivery circuit	Verify proper relief valve placement, installation integrity, and crack-pressure configurations	C1
FD.3	**Low Actuation Pressure on Pneumatic Valve - Insufficient pilot pressure supplied to the air pneumatic control valve**	Complete failure to actuate or fully open the main pneumatic propellant valves	The portable actuation nitrogen tank was either not filled initially or has low residual pressure from a previous test run	B2	Re-fill and top off the portable pneumatic supply tank prior to the test sequence	Utilize a formalized pre-fire checklist step to read and log the pilot regulator pressure	B1
FD.4	**N20 Check Valve Failure - Structural or sealing failure of the main nitrous oxide check valve**	High-pressure N2O leaks past the seat and back-propagates into the fuel side, creating a severe hypergolic/combustion risk in the plumbing lines	Mechanical seat degradation, particulate contamination, or valve component fatigue	D2	Implement component-level pressure testing of all check valves before integration	Monitor and evaluate real-time pressure telemetry data upstream and downstream of the check valve interface	D1

Safety - Feed System (Cont.)

FD.5	**Incorrect Regulator Settings -** Incorrect pressure regulator configuration or setpoint drift	Over-pressurization or under-pressurization of the feed system, leading to off-nominal propellant mass flow rates and combustion instability	Operator setup error during manual adjustments or internal regulator mechanical drift	C2	Explicitly define and document the target regulator setpoints within the test plan	Integrate a mandatory checklist sign-off to visually confirm and lock regulator gauges before loading propellants	C1
FD.6	**Fitting Connection Leakage -** Fluid leakage developing directly across mechanical fitting connections or joints	Hazardous external propellant release, localized fire risk, and an unmitigated loss of master system pressure	Improper assembly, damaged seals, or over-torqued/under-torqued fittings	D2	Conduct a leak check on all fluid connections using a pressurized inert gas prior to introducing live propellants	Confirm a zero-pressure-drop status across the system during a designated pressure-hold inspection period	C1
FD.7	**Incorrect Ball Valve Setting - Incorrect manual or remote alignment setting of critical ball valves**	Inability to pressurize the run tanks or accidental external spillage of propellants during loading	Human error or miscommunication during setup operations	D2	Require checklist verification to ensure proper valve positioning prior to system lockup	Implement a dual-operator verification protocol where two personnel independently verify and check off the valve positions	C1
FD.8	**Igniter Failure to Actuate - Total failure of the ignition system to initiate a spark**	Unignited propellants accumulate rapidly in the combustion chamber cavity, risking a catastrophic engine hard start if late ignition occurs	Loose electrical terminations or poor e-match installation	E3	Utilize dual-redundant e-matches and verify connections before securing the pad	Continuous remote continuity logging monitored by the EECS console prior to authorizing the countdown sequence	E1

Safety - Test Stand

ID	Failure Mode	Failure Effects	Causes	Risk Class (Initial)	Mitigation	Verification	Risk Class (Final)
TS.1	**Test Stand Movement -** Test stand shifts, slides, or moves out of alignment during live operations	Structural configuration becomes fully dynamic, introducing extreme physical hazards and degrading/corrupting thrust data gathering	Poor anchoring, inadequate ground fixing, or insufficient structural ballast	E2	Conduct analytical hand calculations to model the mechanical constraint requirements	Validate structural integration parameters with the designated off-site testing facility constraints	E1
TS.2	**Load Cell Deflection -** Structural bending or off-axis deflection of the load cell assembly	Unwanted thrust vectoring, physical failure/yielding of the load cell, or an uncontrolled dynamic structural failure during a firing run	Static/dynamic engine weight loading combined with a lack of localized deflection or structural alignment calculations	E1	Conduct FEA on the load cell interface	Review, verify, and sign off on the finalized structural FEA deflection results	C1
TS.3	**Fastener Security -** Structural bolts and hardware coming loose over the course of operation	Test stand fasteners backing out completely, leading to an unsafe degradation of structural joint integrity across critical test stand segments	Intense vibrations generated during firing sequence coupled with missing locknuts or improper application of Loctite	E2	Perform visual inspections of all structural joints and implement strict torque specifications across all hardware assemblies	Mandate a pre-test torque specification checklist to double-verify every critical joint prior to tank pressurization	E1
TS.4	**Cable Tie-Downs Snap -** Snapping or structural yielding of the tie-down cable assemblies	High-velocity upward movement or clean dislocation of the main blast plate during static fire operations	Inaccurate calculation models or mechanical tension specifications	E3	Conduct visual inspections paired with verified structural hardware specifications	Finalize calculations and run a complete assembly review.	E1

Safety - Chemicals

ID	Failure Mode	Failure Effects	Causes	Risk Class (Initial)	Mitigation	Verification	Risk Class (Final)
CE.1	**Fire** - Ethanol fuel catches on fire	Fire completely engulfs the test stand assembly or poses an immediate life-safety hazard to personnel	An electrical arc or spark path lights the volatile fuel vapor on fire	E2	Verify all electrical circuits, terminations, and instrumentation lines are insulated.	Conduct a thorough safety review and pre-fire check by designated personnel.	E1
CE.2	**N2O Decomposition -** N2O rapidly and catastrophically decomposes	N2O within the supply cylinder or active feed system undergoes a rapid phase change and decomposes fast enough to cause an explosive overpressure event.	Exposure to abnormally high ambient or structural temperatures.	E3	Ensure the live N2O canister is continuously kept in a shaded area or submersed in an ice bath.	Perform a strict review and visual inspection by designated personnel prior to system lockup.	E1

Emergency Action Plans

An **Emergency Action Plan (EAP)** is a written document that outlines how to respond to emergencies to prevent injury and property damage. The following is a list of potential emergencies that will require an EAP. All testing personnel are required to read each EAP and verify that they understand the dangers outlined and their respective responsibilities during an emergency event.

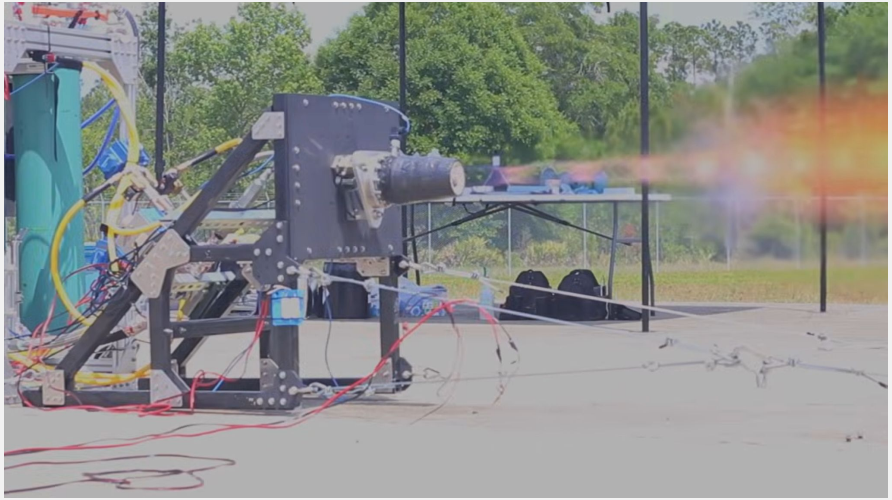
Scope of Emergency Action Plans:

- IN.4 - Engine Hard Start
- CH.2 - Chamber Overpressurization
- NO.2 - Nozzle Blowout
- FD.8 - Igniter Actuation Failure
- TS.1 - Test Stand Structural Movement
- TS.3 - Fastener Failure
- TS.4 - Cable Tie-Downs Snap
- CE.1 - Ethanol Fire
- CE.2 - N2O Decomposition

Questions?

Logistics

Logistics - Test Location



ERPL - Triton Engine Testing

Logistics - Insurance

- Shared Insurance with KXR.
- Renewable deal for whole year access
- Waiting for Cecil confirmation to sign

Thank you!
Questions?