Base 11 Space Challenge

Preliminary Static Test Fire Approval

October 2019

Society of Aeronautics and Rocketry

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PURPOSE & GOALS

Similar to the spirit of USF, the Society of Aeronautics and Rocketry plans to break the boundaries of what was deemed impossible for decades. We want to be the first amateur team to successfully launch a liquid-propelled rocket into space! The first step is to develop the infrastructure necessary for the longevity of this project which includes the mobile testing trailer we are calling Rocketman Rick's test stand (named after our mentor).

This testing trailer once built can be made available for any team to use and can be tested in virtually any location allowing for rapid development and prototyping of rocket engines. This trailer will also be modular, so we can easily make improvements, swap out components, and even test experimental components on it (like our own flight tanks).

This testing trailer is the pivoting point for this competition for us as it marks the first liquid engine to be developed at the university.

TEST STAND OVERVIEW

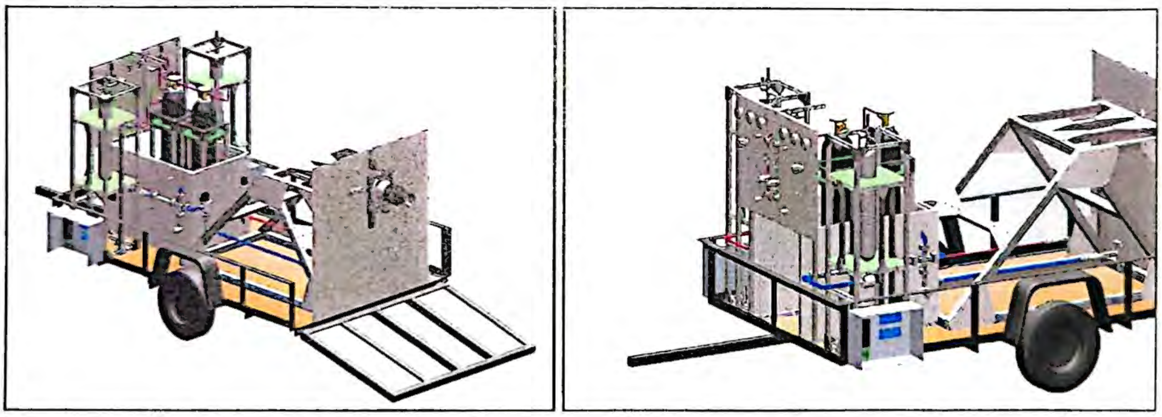


Figure 1: Isometric views of the test stand trailer, equipped with all required components.

- The SOAR Liquid Engine Test Stand will have the full capability to safely test and analyze the performance of the SOAR sub scale liquid engine.
- The SOAR Liquid Engine Test Stand will be trailer mounted and have the capability of being transported to various testing locations.
- The SOAR Liquid Engine Test Stand will be built to allow for easy adaptation for future full scale testing.
- The SOAR Liquid Engine Test Stand will have the full capability to withstand 1000 lbf thrust
- The SOAR Liquid Engine Test Stand will have the full capability to safely support testing of liquid propellants.
- The SOAR Liquid Engine Test Stand will have the full capability to safely record system performance data for design analysis.

Table 1: Motor Datasheet. A consolidated table containing important Info on propulsion characteristics.

Name	Jimbo 1
Motor Type	Liquid Bi-propellant
Diameter	203.2 mm (8 inches)
Total Engine Length	279.4mm (11 inches)
Dry Mass	4.5 kg (10 lbs)
Targeted Mass Flow	1.833 kg/s (4.04 lbs)
O/F Ratio (By Mass)	7:1
Maximum Thrust	3781 N (850 lbf)
Estimated Specific Impulse	214 sec
Burn Time	2 sec
Total Impulse	7562 N-s (1700 lb-s)

The control room/area will be a pre designated area on test day located approximately 300-350ft from the test stand structures. The area will be in the center of the street leading to the cup-de-sac. Since all test will occur outdoors and away from SOAR workspaces and warehouses the control area must be simple and easily moved to the testing location. The control area will be made up of an expandable tent, a table, 3 chairs, and a laptop and monitor. This simple setup has matched that of the setup used for all system test that have been conducted thus far. The control room will receive power from a power supply located within a members truck. This power source will provide power to the laptop & monitor. There will be three primary individuals located inside the control area they are the CSO, CCO, and the CRO who will be the essential personnel on test day. Approximately 50-100ft behind the control area (400-450ft) will be the viewing area which is where all non-essential testing personnel will view the test.

POTENTIAL TESTING LOCATION

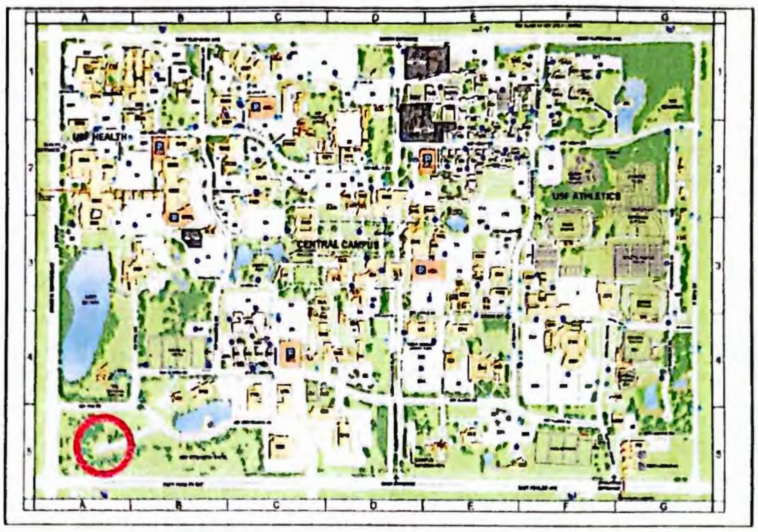


Figure 2: The testing site, located on campus. The topmost image being the entire campus, and the bottom is zoomed into the cul-de-sac on USF Rocky Road.

To determine the radius for a safe distance for this hot fire we followed the guidelines given by the Department of Defense manual: 6055.09-M Volume 3. This manual describes General Quantity-Distance Criteria for Accidental Detonations. In conjunction with the DoD manual the FAA guide no: 437.53-1 was used. The FAA guide was created to help determine safety distances for rockets lunches, and therefore by extension, engine testing.

For our hot fire we plan to burn 9 lbs (4.08kg) of liquid kerosene and liquid nitrous oxide. Since the DoD guideline is made specifically for TNT a conversion is needed to equate pounds of our liquid propellants to pounds of TNT.

Thankfully, there is a conversion made readily available in Table E-2 in Appendix E of 14 CFR part 420 (part of a series of tables for explosive site plans). This table is pictured below:

Energetic liquids	TNT Equivalence	TNT Equivalence
	Static Test Stands	Launch Pads
LO^2/LH^2	See Note 3	See Note 3
LO^2/LH^2 + LO^2/RP-1	Sum of (see Note 3 for LO^2/LH^2) + (10% for LO^2/RP1)	Sum of (see Note 3 for LO^2/LH^2) + (20% for LO^2/RP1)
LO^2/RP-1	10%	20% up to 500,000 lbs Plus 10% over 500,000 lbs
IRFNA/UDMH	10%	10%
N^{2}O^4/UDMH + N^{2}H^4	5%	10%

[1] A launch site operator must use the percentage factors of table E-5 to determine TNT equivalencies of incompatible energetic liquids that are within an intraline distance of each other.

[2] A launch site operator may substitute the following energetic liquids to determine TNT equivalency under this table as follows:

Alcohols or other hydrocarbon, for RP-1

H^{2}O^2 for LO^2 (only when H^{2}O^2 is in combination with RP-1 or equivalent hydrocarbon fuel)

MMH for N^{2}H^4, UDMH, or combinations of the two.

[3] TNT equivalency for LO^2/LH^2 is the larger of:

(a) TNT equivalency of 6*W [illegible], where W is the weight of LO^2/LH^2 in lbs; or

(b) 14 percent of the LO^2/LH^2 weight.

Figure 3: The TNT equivalence for liquid propellants as stated by the DoD

Using the most conservative value, the TNT equivalence is determined to be 20% of the weight of the propellants. This was determined to be an acceptable value since LOX/RP-1 is a more energetic mixture than 1-K/N2O. With that , our 9lbs of propellants is equivalent to 1.8lbs of TNT (~2lbs).

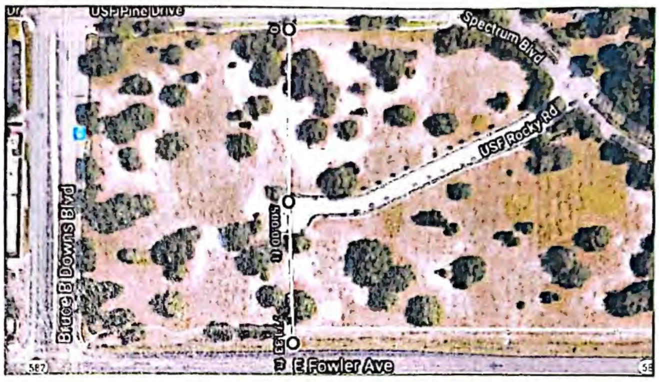
Referencing the DoD guideline a table listed below gives the minimum distance from the point of explosion to the point at which the density of hazardous fragments (those having an impact energy of 58 ft-lb (79 joules) or greater) has decreased to less than 1 hazardous fragment per 600 ft2 (55.7 m2):

Table 2: DoD guideline reference of the minimum safety distance.

Table V3.E3.T2. HD 1.1 HFD[a, b]

NEWQD	Open[c, d]	Structure[e, f]
(lbs)	(ft)	(ft)
[kg]	*[m]*	*[m]*
≤ 0.5	236	200
≤ 0.23	*71.9*	*61.0*
0.7	263	200
0.3	*80.2*	*61.0*
1	291	200
0.45	*88.8*	*61.0*
2	346	200
0.91	*105.5*	*61.0*

Taking the most conservative value the minimum distance to be safe from shrapnel is 346 for 2 lbs of TNT in the open.



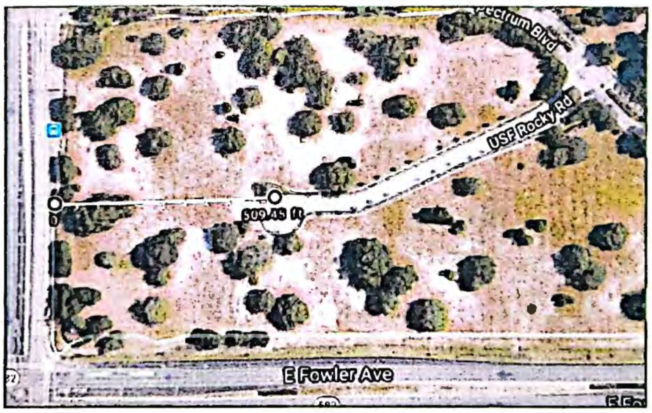


Figure 4: The distances from the testing site to the nearest local roads.

Based on google maps distance tool there is a clear and safe radius around the test site for all areas to be safe from shrapnel.

To be extra cautious USF roads around the test site will be shut off from public access and a visible border will be placed around the area. Procedural steps included ensure that a warning sounds will be made before firing. Fire department has agreed to provide stand-by support during testing pending approval from competition judges for go-decision.

Figure 5: A Google Maps Street View of the testing site on USF Rocky Road

Plumbing and Instrumentation

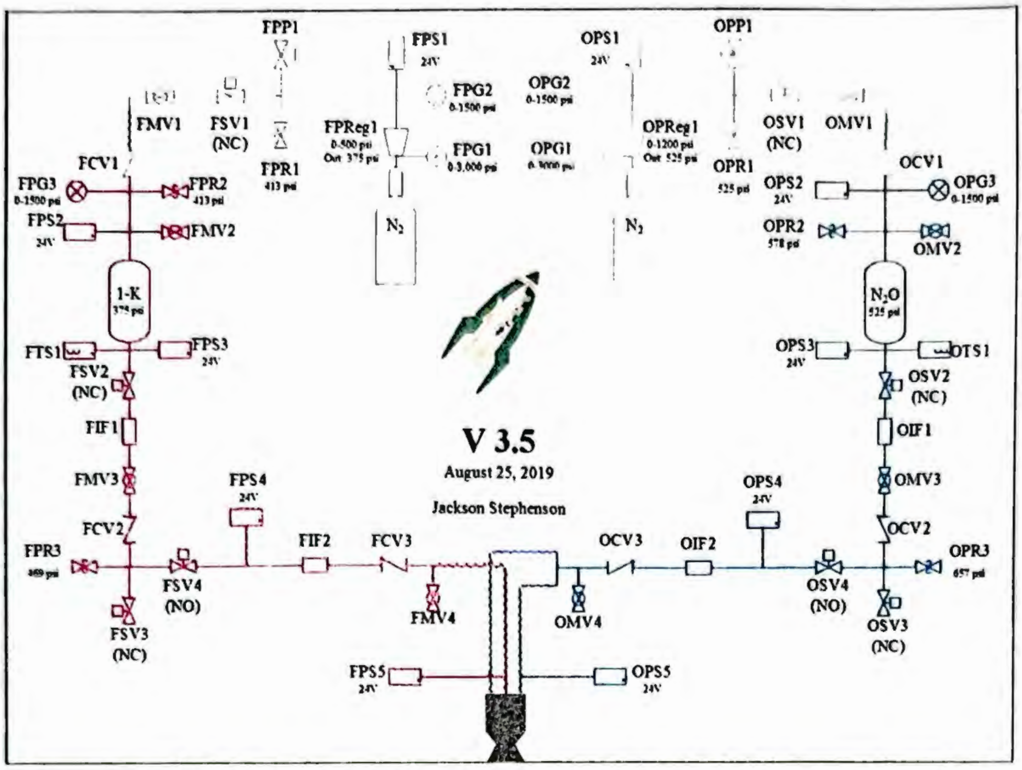


Figure 6: A condensed version of V3.5 of SOAR's Plumbing and Instrumentation Diagram (P&ID)

Overview

The current Plumbing and Instrumentation Diagram is displayed above in Figure []. The fuel and oxidizer plumbing components, valves and tanks have *National Pipe Taper Fuel (NPTF)* connections. *304 Stainless Steel* tubing will be used to connect all components and valves in a manner that reduces pressure losses as much as possible. Compression fitting adapters will allow connection of NPTF valves and SS tubing. The diameter of the SS tubing is dependent on the mass flow rate, density and desired velocity of each propellant, and these values are tabled below in Table 2.

Table 3: Characteristics of the plumbing and instrumentation system.

Propellant/System Characteristic	Value
O:F Ratio	7
Oxidizer Mass Flow Rate	1.604 kg/s (3.536 lb/s)
Oxidizer Density	1051.4 kg/m^3 (65.637 lb/ft^3)
Fuel Mass Flow Rate	0.229 kg/s (0.505 lb/s)
Fuel Density	820 kg/m^3 (51.191 lb/ft^3)
Fuel Tubing Diameter	6.223 mm (0.245 inches)
Fuel Velocity	9.182 m/s (30.125 fps)
Oxidizer Tubing Diameter	12.954 mm (0.51 inches)
Oxidizer Velocity	11.576 m/s (37.979 fps)
Oxidizer Temperature	233.15 K (-40 F)

Nitrous Oxide (N2O) was selected as the oxidizer for the first static engine test campaign. Though not as efficient of an oxidizer as Liquid Oxygen (LOX), N2O can be sub-cooled to reach densities similar to LOX without the extremes of cryogenic temperatures. There were months of research into understanding nitrous oxide and its properties, and it seemed most appropriate to use it for the first round of propulsion tests. Furthermore, the N2O used for this static fire will be subcooled to 233.15 Kelvin (-40 degrees Fahrenheit). This temperature falls within range for valves and other plumbing components from multiple standard wholesalers like McMaster-Carr and Grainger Supply. This temperature also provides a density slightly more than liquid water, with a specific gravity of 1.05. N2O exists as a liquid under atmospheric pressure in a narrow temperature range of 182 to 184 Kelvin, but provides sufficient vapour pressure when contained in warmer temperatures and thus can be used to pressurize itself.

The fuel was selected to be kerosene, however RP-1 is unavailable at the moment of this document's submission. 1-K kerosene is the primary alternative to be used for this upcoming testing campaign until RP-1 or a more suitable fuel is acquired. 1-K kerosene is stable and requires only a pressure of 0.7 kPa (0.1 psi) to remain a liquid, and is readily available through many retailers and wholesalers. However, the only downside to using kerosene is that the optimum O/F ratio is high at 7:1 but is negligible and appropriate for testing purposes.

With reference to the feed pressures of the fuel line (224 psi) and the oxidiser line (300 psi), which is explained in more detail in the below section, the tank pressures were calculated using the formula for the pressure difference between the tank and injector as:

$$\Delta p = \left(\frac{1.296E12}{998\,(\sum C_v . A)} + \frac{\sum k}{2} + f\frac{L}{2d} \right) \rho V^3$$

where,

Cv = coefficient of flow for the valves

k = K-factor of the pipe fittings (ref. Engineers Data Book, Author J. Smith, pg. 143)

f = Darcy-Weisbach friction factor

L = length of the pipe

This gave the tank pressure values at 2,585.5 kPa (375 psi) and 3,619.75 kPa (525 psi) respectively.The pressure relief valve on each tank was set to comply with 3.6.5 in the Base 11 Safety Guidelines: "All pressure vessels must have a relief valve, selected and set to ensure the pressure does not exceed 110% of the maximum expected operating pressure of the system, or does not exceed a value that would cause general yielding of the pressure vessel or system."

The secondary pressure relief valve, FPR3 and OPR3, located downstream from the tank are set to comply with 7.2.4: "Perform leak and relief pressure tests. A relief valve is a safety device that should be set to relieve at 125% of the MEOP. This device should be tested to verify the relief pressure. Perform this test off the rocket using a regulator and pressure gauge." The chart below shows the estimated pressure drops throughout the plumbing system from the tank outlet to the injector manifold in Figure 7:

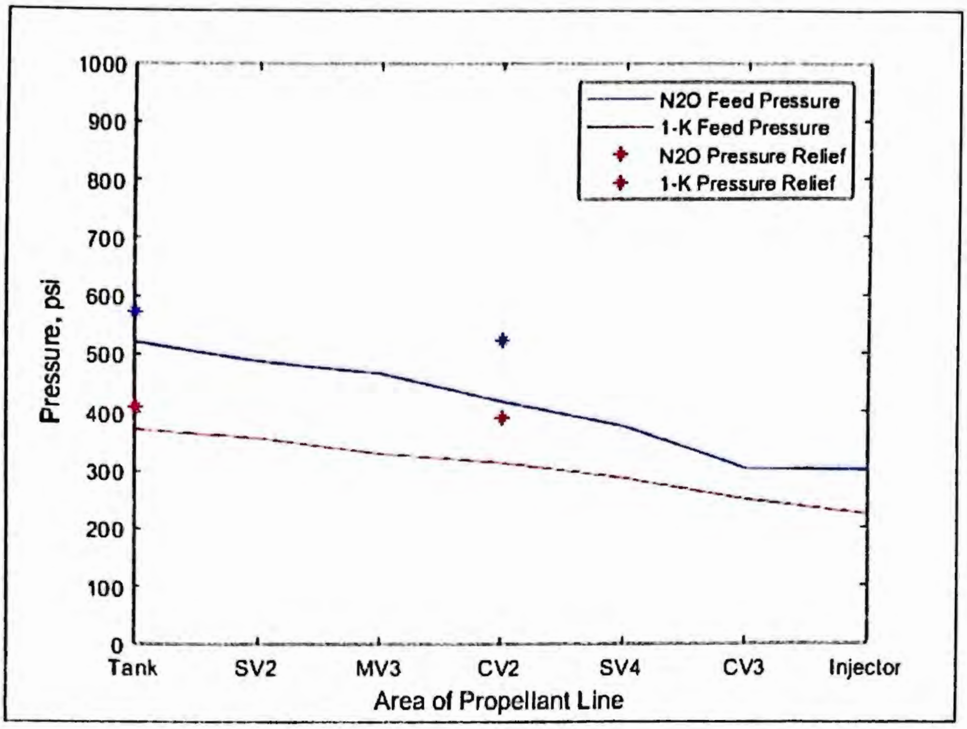


Figure 7: EThe chart above depicts the estimated pressure drops through each valve and component in the plumbing system for both fuel and oxidizer, along with the pressure relief settings.

PRESSURE RELIEF VALVE SIZING

The primary area of concern for pressure relief is the ullage pressure in the propellant tanks, which induces the highest propellant pressures in the system. The pressure relief valves purchased for this role were Swagelok SS-4R3A5. These valves have an attractive pressure rating of 6000 psig. This creates a minimal system safety factor of 2.73 with the nitrogen tank and an operational safety factor of 16 and 11.43 with the fuel and oxidizer respectively. These valves also have spring kit options should our team decide to work with higher and lower pressures for future tests. For the tanks, the relief valve setting is 10% over the set Operating Pressure, and these valve settings will be verified through testing. To understand the depressurization flow of a system failure, let us look at the conditions and and find the limits of the valve;

$$A = \frac{V\sqrt{M*T*Z}}{6.32*C*P_1*K_b*K_c*K}$$

Where *A* is the orifice area of the valve, *V* is the relieving capacity or discharge rate, *M* is the molecular weight of the pressurant gas, *T* is the pressurant temperature, *Z* is the compressibility factor, *C* is the pressurant gas constant, P_1 is the operating pressure of the tank, K_b is the back pressure factor for the pressurant gas, K_c is the rupture disc combination factor (equates to 1 if rupture disc is obsolete), and *K* is the discharge coefficient. Finding the discharge rate, or maximum flow, will reveal the depressurization time of the tank ullage should it reach the relief setting.

Table 4: Pressure Relief Valve characteristics for the oxidizer propellant tank

Oxidizer Relief Valve Parameters	**Units (English,SI)**
A, Orifice Area	0.0154 in^2, 10.179 mm^2
M, Molecular Weight	28.01
T, Pressurant Temperature	535 R , 298 K
Z, Compressibility Factor	1
C, Pressurant Gas Constant	365
P_1, Operating Pressure	(575 psia*1.03), 592.5 psia, 4083 kPa
K_b, Back Pressure Factor	1 (Minimal orifice area)
K_c, Rupture Disc Combination Factor	1
K, Discharge Coefficient (Estimate)	0.33

$$V = \frac{A*6.32*C*K_b*K_c*K}{\sqrt{M*T*Z}} = \frac{0.0154in^2*6.32*356*592.5psia*1*1*0.33}{\sqrt{28.01*535R*1}} = 55.34\ scfm$$

At this rate, if the entire nitrogen tank were to depressurize into the oxidizer tank, it would take roughly 2 minutes to empty through this safety relief valve. This is a low rate of depressurization, but the pressurant solenoid valve from McMaster-Carr (1190N240) outputs a lower volume of gas than the relief valve can. This eliminates any pressure buildup in the ullage. The flow rate was selected off the condition that the upstream pressure was greater than twice the downstream pressure ($P_1 > 2P_2$);

$$FSV1, OSV1\ scfm = \frac{C_v*816*P_N}{60*\sqrt{SG*T}}$$

Where C_v is the flow coefficient of the pressurant solenoid valve, P_N is the pressure of the nitrogen tank in psia, *SG* is the specific gravity of Nitrogen, T is the temperature of the Nitrogen in Rankine and the 60 is the unit adjustment from cubic feet per hour to cubic feet per minute.

$$\frac{0.01*816*2200psia}{60*\sqrt{0.9723*535R}} = 13.12\ scfm$$

The pressurant solenoid valve from McMaster-Carr was selected because of its pressure rating of 5000 psig, and the low flow coefficient of 0.01. Quick pressurization was not a necessity or concern for our testing purposes and all pressurant gas must pass through this solenoid valve.

Table 5: Pressure Relief Valve characteristics for the fuel tank

Fuel Relief Valve Parameters	Units (English,SI)
A, Orifice Area	0.0154 in^2, 10.179 mm^2
M, Molecular Weight	28.01
T, Pressurant Temperature	75 F, 298 K
Z, Compressibility Factor	1
C, Pressurant Gas Constant	365
P_1, Operating Pressure	(325 psia*1.03), 334.75 psia, 2308 kPa
K_b, Back Pressure Factor	1
K_c, Rupture Disc Combination Factor	1
K, Discharge Coefficient (Estimate)	0.33

$$V = \frac{A*6.32*C*K_b*K_c*K}{\sqrt{M*T*Z}} = \frac{0.0154in^2*6.32*356*334.75psia*1*1*0.33}{\sqrt{28.01*535R*1}} = 31.27\ scfm$$

Pressurant Flow

The Pressurant Flow Stage is responsible for transferring the inert pressurant gas to the propellant tanks. The pressurant gas of choice for both fuel and oxidizer is Nitrogen, due to its availability and performance as a pressurant in other systems. In the event that SV1 fails and cannot open, there are two options to depressurize the line: PR1 and PP1. **PR1** is a Swagelok SS-4R3A5-MO set to relieve pressures at 413 and 578 psi for fuel and oxidizer resepctively. **PP1** is designed to manually expel pressure from the line for disassembly during post-test and post-fire procedures. Due to the operating pressures, the available pressure regulators were panel-mount instead of a more common tank-mount regulator. Although each pressure regulator has different pressure ranges and are panel-mount, both share the same number of gauge ports: two for both inlet and outlet. These gauge ports will be used to attach **PG1** and **PG2** for visual verification of pressure within the system. **PS1** is a pressure sensor used to confirm and verify the reading on PG2, and is used for data acquisition. The first solenoid valve, **SV1**, is used to remotely pressurize the propellants downstream from the pressurant tanks.

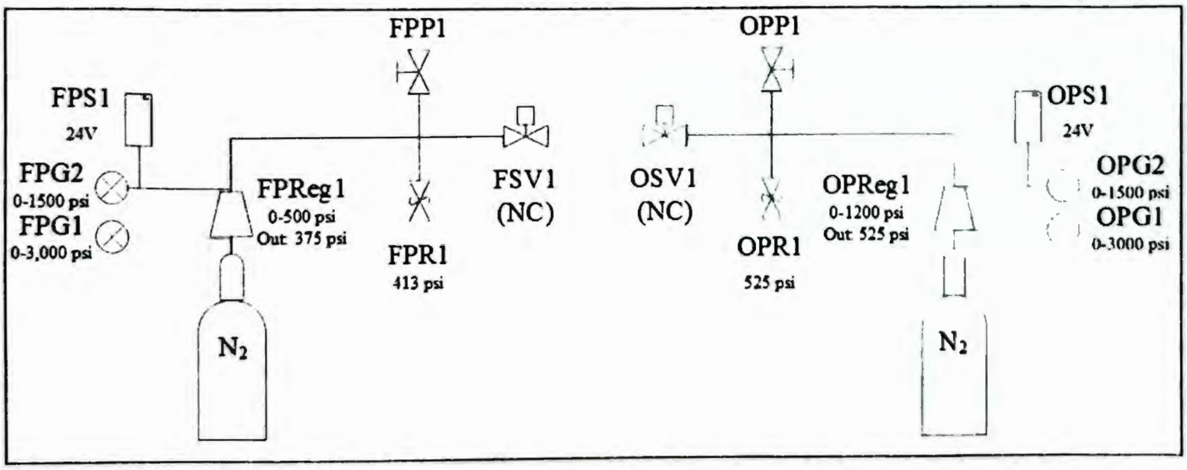


*Figure 8: The Pressurant Flow Stage, showing parts and components for the **Fuel** and **Oxidizer** sides.*

TANK PRESSURIZATION

The Tank Pressurization Stage is responsible for receiving pressurant from the Pressurant Flow stage and utilize this pressurant to ready the propellants for a specific flow rate. This stage starts where pressurant is received from the tanks via SV1 and ends where propellants exits the tanks through SV2. The first manual valve in the system, **MV1**, after SV1 serves as a manual safety check to ensure that no pressurant enters the tanks in the event that SV1 fails. The first check valve, **CV1**, eliminates back-pressure flow from the tank ullage upstream towards the Pressurant Flow Stage. Steel-braided hoses are used to make the connection between MV1 and CV1 easier during setup and breakdown. The stem atop of the propellant tank utilizes a variety of instruments and valves for several reasons. The third pressure gauge, **PG3**, is used to read the tank ullage pressure. The second pressure sensor, **PS2**, is used to verify and confirm the readings from PG3 and to collect data for any pressure differences that might occur from PS1 in the Pressurant Flow stage. The second pressure relief valve, **PR2**, is to protect the propellant tank from overpressurization and are set to relieve pressure at 1.1 times the MEOP. The pressure relief setting for fuel and oxidizer, at 413 psi and 578 psi respectively, are the highest pressure relief points in the plumbing system. The second manual valve, **MV2**, is for loading propellants into the tank. At the bottom of each propellant tank are a temperature and pressure sensor, **TS1** and **PS3** respectively. TS1 and PS3 are for monitoring and recording pressures/temperatures of the propellants, and will provide insight between pressure differences between PS3 and PS2. The second solenoid valve, SV2, is responsible for fully obstructing propellant flow exiting the tanks for pressurization and to prevent premature flow, therefore SV2 is a normally closed valve.

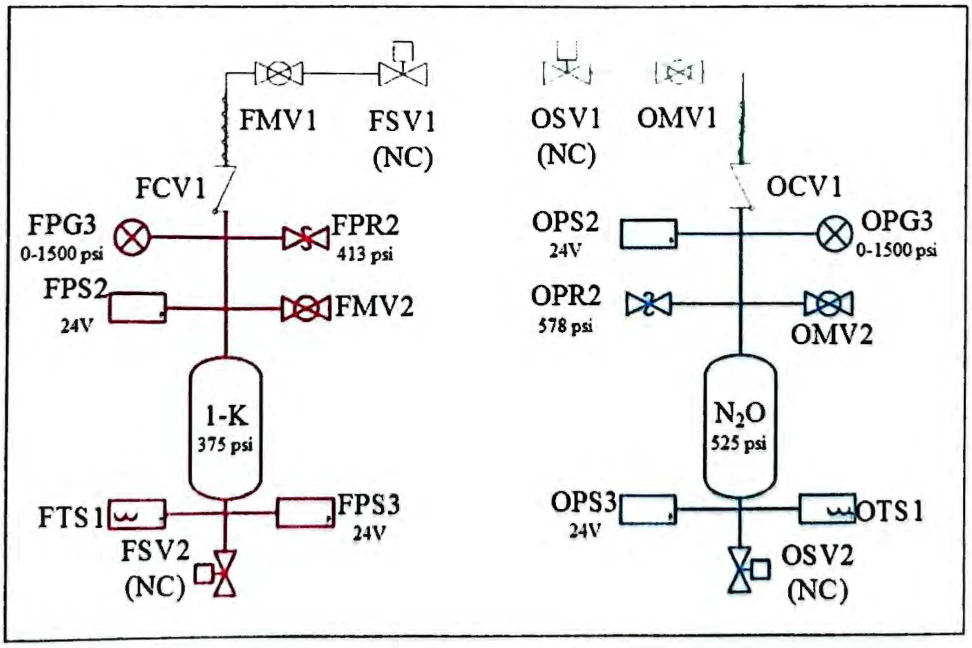


Figure 9: The Tank Pressurization Stage, including some parts and components from the Pressurant Flow Stage, for Fuel and Oxidizer.

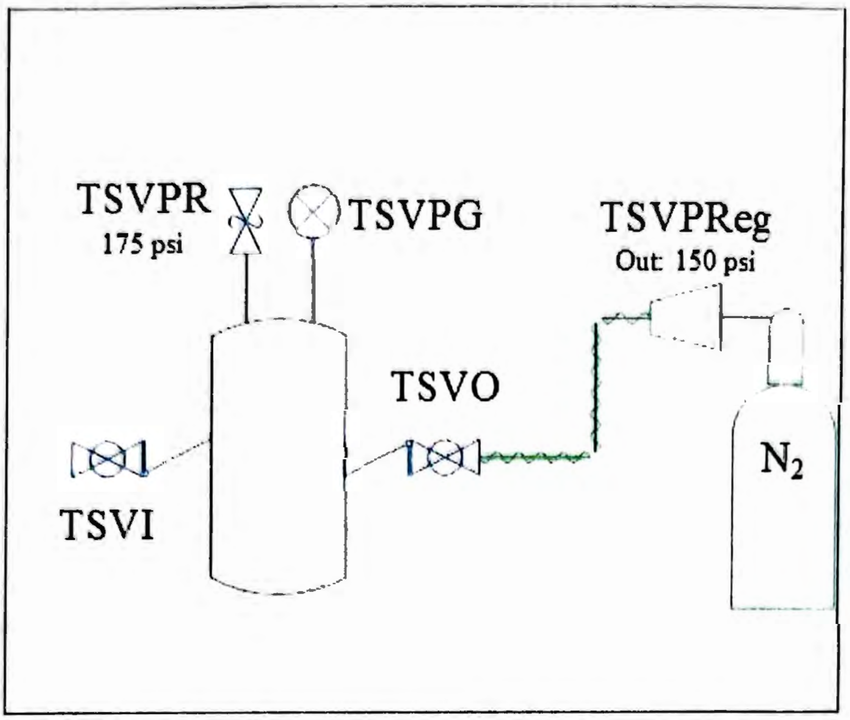


*Figure 10: The Oxidizer Loading System, composed of two main vessels: The **Loading Pressurant Vessel** (LPV) and the **Transport and Storage Vessel** (TSV). The TSV is a container/dewar that stores sub-cooled to be pressure-fed by the LPV into the oxidizer tank.*

PROPELLANT FLOW

The Propellant Flow Stage is responsible for initiating the delivery of propellants from the propellant tank to the engine. This stage starts with the propellant leaving the tanks through SV2 and ends through SV4. The second solenoid valve, **SV2**, is normally closed and sits below the propellant tank and is intended to stop and start propellant flow in accordance to test firing and testing procedures. The first inline filter, **IF1**, is responsible for filtering out any impurities in the propellant due to loading the propellant and general handling. The third manual valve, **MV3**, is a manual safety check in the event SV2 fails and allows propellant to flow prematurely. The second check valve, **CV2**, is an additional check valve downstream from the propellant tanks to prevent backflow during any flow anomalies. The third pressure relief valve, **PR3**, is intended to open and relieve fluid pressure at 1.25 times the expected tank operating pressures. In the event that SV4 and SV3 is closed, PR3 is adjacent to the trapped fluid and will expel propellants/pressurants if pressures increase in this region. The third solenoid valve, **SV3**, is a remote dump valve used in the event of a test abort, or to expel fluids in the event that SV4 fails. The fourth and final solenoid valve, **SV4**, is the last remote controlled valve in the system, and is normally open (NO). SV4 is normally open to reduce power consumption and complexity during the test fire. In the event of a propellant dump during the test fire, then SV3 and SV4 will switch polarity thus redirecting flow from the engine and into a dump container through SV3.

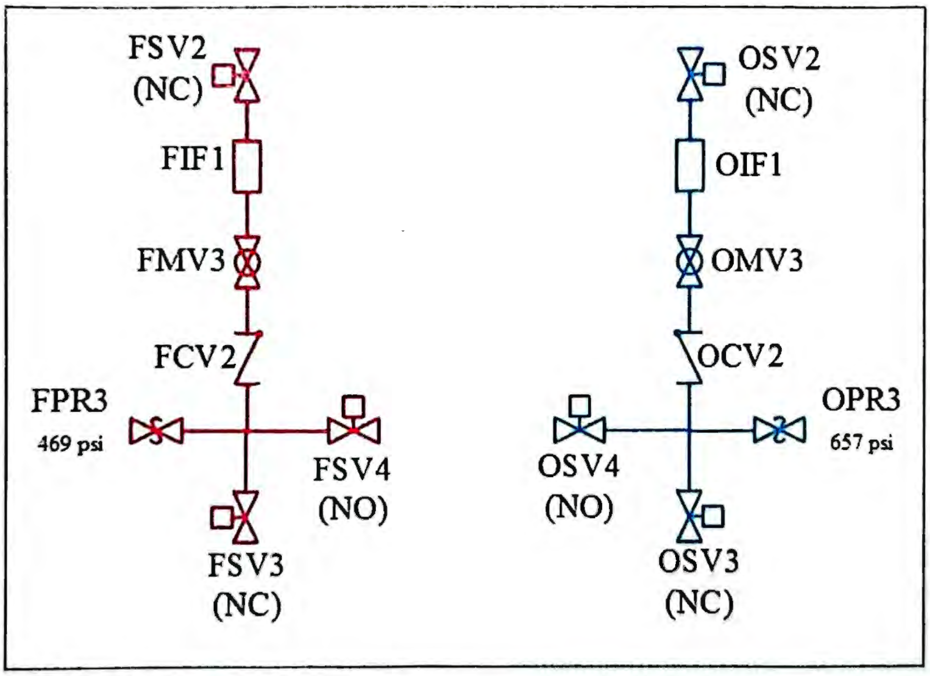


*Figure 11: The Propellant Flow stage, showing all parts and components for both **Fuel** and **Oxidizer**.*

INJECTION FLOW

The Injection Flow stage enters through Solenoid Valve 4 and exits through the propellant injector and into the combustion chamber of the nozzle. This stage utilizes steel-braided hoses for both fuel and oxidizer to make the connections easier during setup and breakdown. The two pressures in this stage, **PS4** and **PS5**, are purely for data acquisition purposes and are not intended to control performance or fluid flow. The second inline filter, **IF2**, acts as an additional filter to clean the propellant before injection. The third check valve, **CV3**, is the last check valve in the system. The manual valve, **MV4**, is used for post-testing and post-fire propellant dumping after the entire system has been deemed safe. CV3 is placed before MV4 and the hoses for the reason that the hoses for fuel and oxidizer are vertical when transferring propellant to the injector. MV4 is intended to collect any residual propellants and fluids remaining in the pipeline.

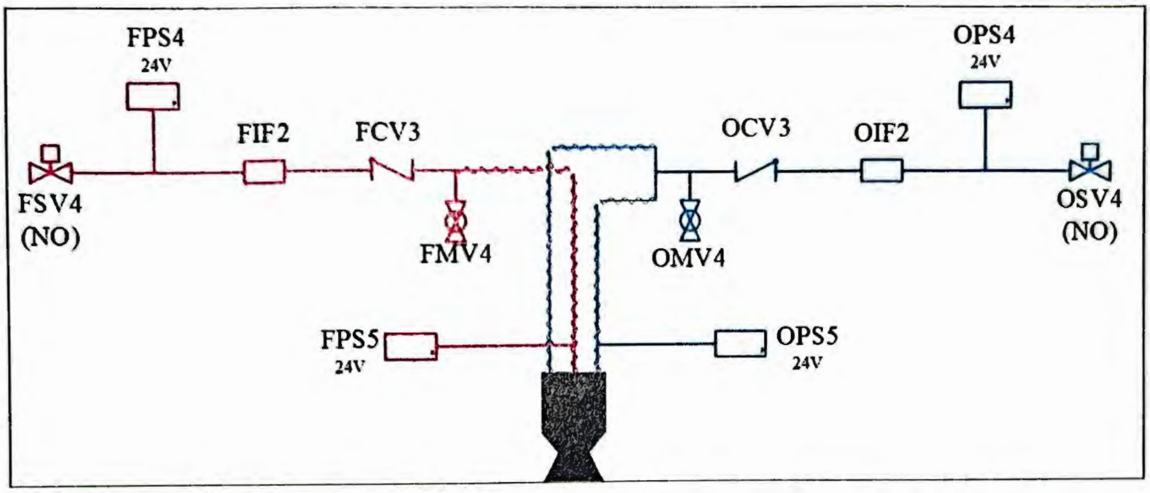


*Figure 12: The Injection Flow Stage, showing all parts and components for both **Fuel** and **Oxidizer**.*

COMPONENTS

The complete list of all the components used for the P&ID are summarized in the table below:

Table 6: Summary of P&ID parts.

P&ID part	Part Name	Manufacturer	Body Material	Seal Material	Max Pressure
FCV 1,2,3	7775K52	McMaster-Carr	Brass	Fluoroelastomer Rubber	1000 psi @ 70 F
FIF 1,2	9811K85	McMaster-Carr	316 Stainless Steel	NA	3000 psi
FMV 1,2,3,4	4112T22	McMaster-Carr	Brass	Fluoroelastomer Rubber	1000 psi @ 70 F
FPG 1	4003K81	McMaster-Carr	304 Stainless Steel	NA	0-6000 psi
FPG 2,3	4003K61	McMaster-Carr	304 Stainless Steel	NA	0-6000 psi
FPP 1	4800K62	McMaster-Carr	316 Stainless Steel	NA	6000 psi @ 100 F
FPR 1,2,3	SS-4R3A5-MO	Swagelok	316 Stainless Steel	Fluorocarbon FKM	6000 psi @ 100 F
FPReg 1	3811T11	McMaster-Carr	Brass	PTFE	3500 psi
FPS 1,2,3,4,5	SPT25-10-1000A	Automation Direct	304 Stainless Steel	NA	0-1000 psi
FSV 1,3	1190N240	McMaster-Carr	303 Stainless Steel	CTFE Plastic	5000 psi @ 150 F
FSV 2	SVH-121-24D	Omega	316 Stainless Steel	NA	3500 psi
FSV 4	SVH-121-24D-NO	Omega	316 Stainless Steel	NA	3500 psi
FT 1	TC-T-NPT-G-72	Omega	304 Stainless Steel	NA	
OCV 1	7775K52	McMaster-Carr	Brass	Fluoroelastomer Rubber	1000 psi @ 70 F
OCV 2,3	4620K83	McMaster-Carr	303 Stainless Steel	NA	5000 psi
OIF 1,2	9811K85	McMaster-Carr	316 Stainless Steel	NA	3000 psi
OMV 1,2,4	4112T22	McMaster-Carr	Brass	Fluoroelastomer	1000 psi @ 70 F

				Rubber	
OMV 3	47275K43	McMaster-Carr	316 Stainless Steel	PTFE Plastic	4500 psi @ 120 F
OPG 1	4003K81	McMaster-Carr	304 Stainless Steel	NA	0-6000 psi
OPG 2,3	4003K61	McMaster-Carr	304 Stainless Steel	NA	0-6000 psi
OPP 1	4800K62	McMaster-Carr	316 Stainless Steel	NA	6000 psi @ 100 F
OPR 1,2,3	SS-4R3A5-MO	Swagelok	316 Stainless Steel	Fluorocarbon FKM	6000 psi @ 100 F
OPReg 1	4428T24	McMaster-Carr	Nickel-Plated Aluminium	Polyimide	6000 psi
OPS 1,2,3,4,5	SPT25-10-1500A	Automation Direct	304 Stainless Steel	NA	0-1500 psi
OSV 1	1190N240	McMaster-Carr	303 Stainless Steel	CTFE Plastic	5000 psi
OSV 2,3	SVH-122-24D-OX	Omega	316 Stainless Steel	NA	3600 psi
OSV 4	SVH-122-24D-NO	Omega	316 Stainless Steel	NA	3600 psi
OT 1	TC-T-NPT-G-72	Omega	304 Stainless Steel	NA	NA

RISK MANAGEMENT

Measures have been prepared to reduce risk during testing. During testing, the tanks will be covered from each other using shields to reduce the chance of damage on the tanks and to make the tanks more stable. To protect the wooden planks from possible leaks, the wooden planks would be covered in sheet metal. Only the Chief Safety Officer (CSO), Control Room Operator (CRO), Range Safety Officer(RSO), Communications Chief (CC), Ranger Test Operator 1 (RTO 1), and Ranger Test Operator 2 (RTO 2) will be allowed in the control room during our Hot Fire test. All personnel that were not listed above will be relocated to a designated safe viewing area. The CC will be in charge of calling out Radio C.C.Cs(Communication Codes & Callouts) to provide quick communication with our CSO, RSO, CRO, and other personnel near the range to report damage, plumbing errors, and to clear the range. The safe viewing area will be located 100 feet behind from the Control Room to minimize interference and at a safe distance from the test site to avoid any risk on the viewers.

For leak contingencies, galvanized sheet metal will be laid in areas adjacent to propellant lines to prevent saturation of propellant into trailer boards and resist ignition sources. Additionally, sheet metal or ⅛" fiberglass will be placed on the tank structures to barricade and isolate the propellant tank and prevent any mixing due to leakage.

ENGINE

ABLATIVE TESTING

The nozzle will use ablative cooling to prevent a rapid unplanned disassembly. Ablative cooling was chosen for its simplicity and cost. Ablative cooling is the simplest way to cool a nozzle. There is only a single chamber wall that chars and ablates away during an engine fire. This has a couple major advantages over a regeneratively cooled nozzle. First is the cost to build a single nozzle. An ablative nozzle will cost in the area of $250 per nozzle where a regeneratively cooled nozzle could cost thousands of dollars to either machine or print. As this is SOAR's first liquid engine nozzle and is far smaller than the final design, going ablative is better than regenerative for a single fire nozzle. Second advantage of going ablative is the development cost. Development of ablative material cost in the area of $50. An alternative regeneratively cooled nozzle would cost far more, thousands of dollars to either machine or print each nozzle and then conduct hot fires.

The ablative nozzle will be built using silica fabric, carbon fiber, and aeropoxy. Silica fabric will be used as the ablative chamber wall. It offers good heat resistance while maintaining its strength. Carbon fiber will be used as an overwrap for the nozzle to maintain the strength of the nozzle walls, holding the pressure in the chamber and transferring the thrust into the structure. Aeropoxy will be used to glue all the layers together. Aeropoxy was decided on because it is inexpensive, a standard in SOAR's stock, and has shown to be better in subscale ablative tests compared to other epoxies that SOAR uses.

Nozzle construction will begin with placing plastic and porous film as a barrier between the mold and the nozzle. Aeropoxy will then be placed on top, followed by a layer of silica fabric. The silica fabric will then be saturated with aeropoxy. Layers of Silica fabric and aeropoxy will be layered for a total of 5 layers of aeropoxy. This will then be followed up with vacuum bagging the nozzle. After vacuum bagging, the nozzle flange will be fitted to the nozzle. Carbon fiber and aeropoxy will then be layered on top, for a total of 20 layers of carbon fiber. This will then be vacuum bagged. After curing, the vacuum bag will be removed from the nozzle. The nozzle will then be inspected for any cracks or obvious deformities.

Testing began with constructing two ablative samples using silica fabric and either aeropoxy or 30-minute epoxy. These samples were then placed under a normal torch, reaching around 3,000 degrees fahrenheit, for 15 seconds each. After the tests, the samples were visually compared. The sample using aeropoxy visually appeared to perform better than the 30-minute epoxy, generating less char. As aeropoxy performed better, it was chosen for use in the nozzle. Later, a second round of testing was done, constructing 6 different samples, varying the use of silica fabrics and graphite felt. This provided an opportunity to test manufacturing processes with the materials. Afterwards, it was decided to forego the graphite felt as it would be difficult to use in the manufacturing process. The burn time is also small enough that insulation provided by the graphite felt would not be required.

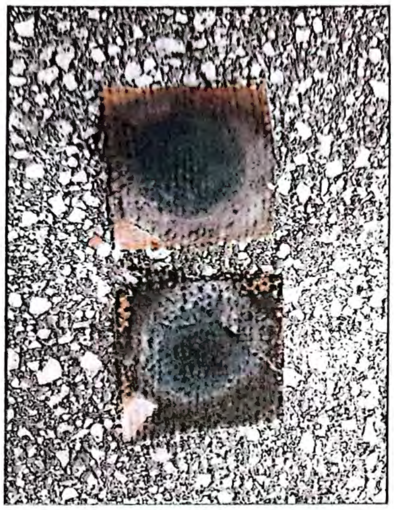


Figure 13: Example of a post burn sample. Both of the samples were single 3'x3' squares of silica fabric, with the top using Aeropoxy and the bottom using 30-minute. From visual observation alone, the Aeropoxy doesn't char as much as the 30-minute.

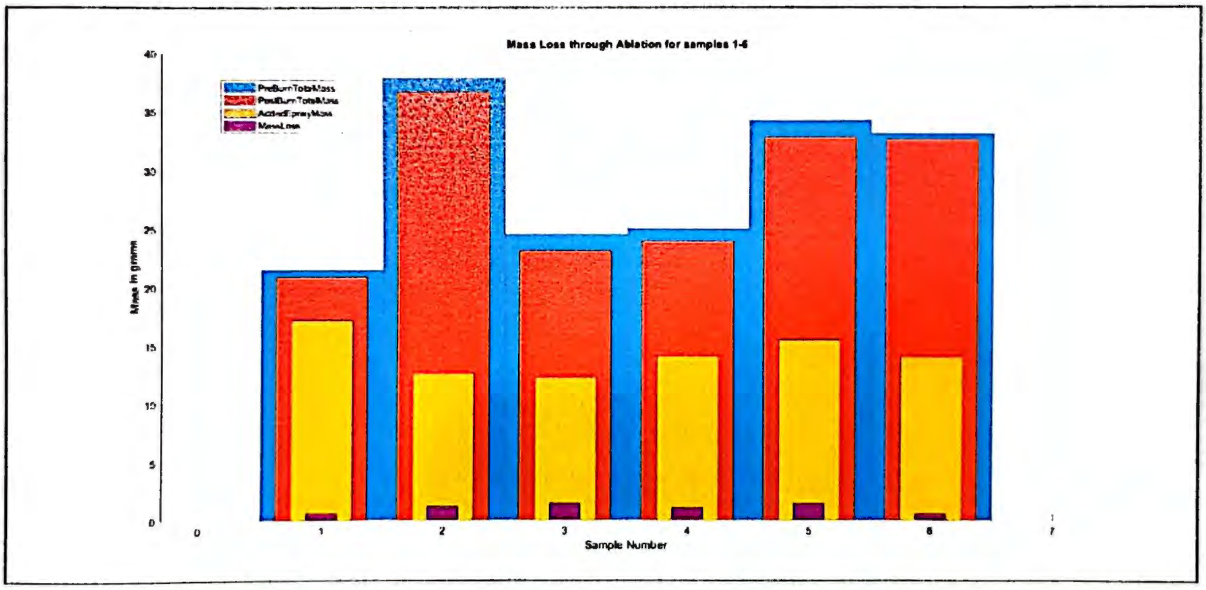


Figure 14: Bar Graph comparing the Mass loss of for the 6 silca/graphite felt samples during the second round of ablative testing. Sample 6 had the least amount of mass loss out of the tested sample, with .056g of mass lost through ablation. The Epoxy-to-Mass ratio of the epoxy vs. the total mass in sample 6 is 0.42

INJECTOR

The design of a liquid bi-propellant injector was one of the most taxing features of the project this far, and is the first of its kind for SOAR. It is named Jimbo I after one of our club mentors, Jim West.

The injector, pictured below in Figure [], is a three-piece injector made out of 6061-T6 Aluminum. Two of the pieces, Nozzle Flange and Injector Chamber are nickel-plated for corrosion and oxidation resistance. The Injector Chamber has two circular chambers, the center being for Kerosene and the outer for Nitrous Oxide. The Injector Ports is the piece that caps the Injector Chamber, and has a total of three inlets. Two of the inlets are for Nitrous Oxide since the O/F ratio is high at 7:1. The engine ablatives will be cast around a mold and set inside the sleeve of the Nozzle Flange. Carbon Fiber will then be set over the ablative material and the external skin of the sleeve to bond the two together.

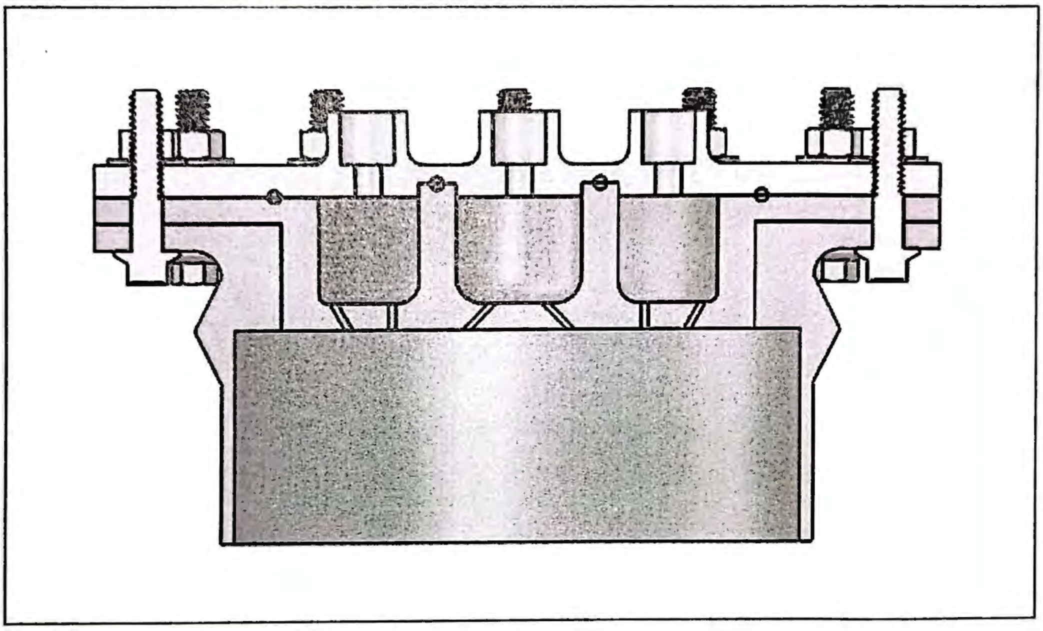


Figure 15: A cross-sectional view of Jimbo 1

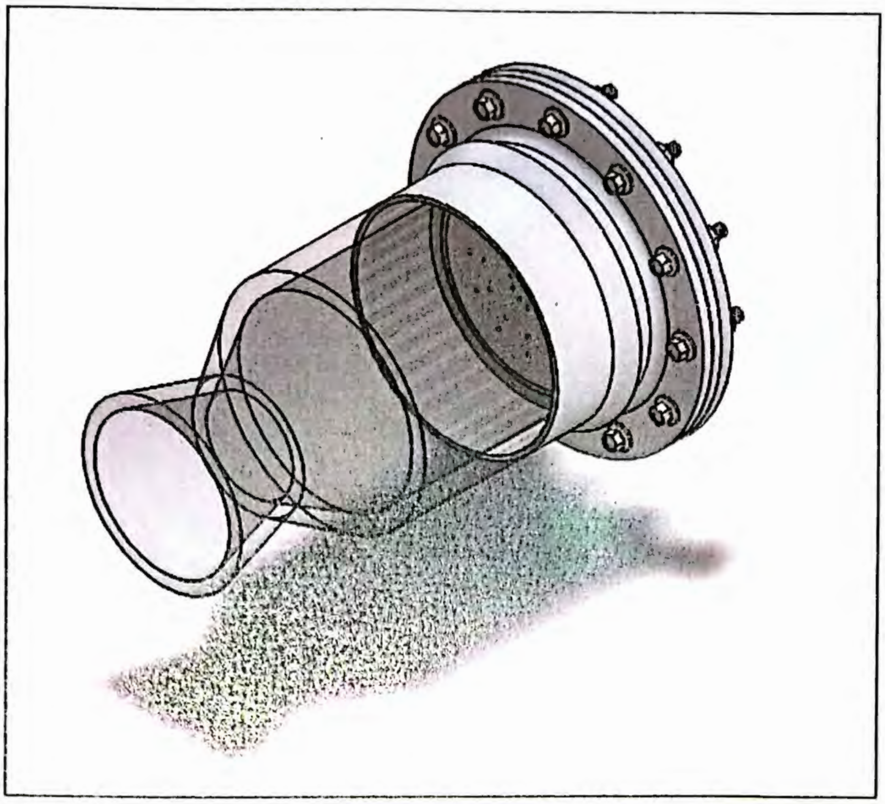


Figure 16: The Jimbo 1 injector, coupled with the transparent nozzle shape for scale.

The injector itself was designed around the key properties and characteristics of propellant flow. The characteristics are above in Table 2.

The engine characteristics itself have changed over the course of the project. For example, the first engine iteration was designed to have a chamber pressure of 3,447.379 kPa (500 psi). This was changed in early Spring of 2019 and thus reduced to 1,034.214 kPa (150 psi) due to several reasons. For one, a higher chamber pressure of 1,034.214 kPa would require higher operational pressures in the plumbing lines and tanks and create additional hazards to be considered and dealt with. Second, it was decided that a more conservative chamber pressure would be more suitable for a custom ablative nozzle. We found some reports of ablative nozzles to refer to for compositions, and many such nozzles used chamber pressures around 1,034.214 kPa.

The engine itself is optimized for sea-level performance, and was heavily inspired by the nozzle used by Purdue SEDS on their liquid engine launch vehicle, Boomie Zoomie. The combustion and fluid characteristics below were considered throughout the injector design phase:

Table 7: Chamber characteristics/properties.

Characteristic/Property	Value (SI Units)
Chamber Pressure	1,034.214 kPa
Exit Pressure	101.353 kPa
Chamber Temperature	3200 K
Chamber Enthalpy	1368.77 kJ/kg
Chamber Specific Heat Ratio	1.147

Table 8: Propellant characteristics/properties.

Fluid Property	Value (SI Units)
Oxidizer Viscosity	1.325e-4 Pa-s
Oxidizer Vapor Pressure	1,119 kPa
Oxidizer Volumetric Flow Rate	1.526e-3 m^3/s
Fuel Viscosity	1.64e-3 Pa-s
Fuel Vapor Pressure	0.7 kPa
Fuel Volumetric Flow Rate	2.793e-4 m^3/s

One of the most pressing design issues concerning the injector was orifice type, arrangement and size. In the end, an unlike-triplet impingement style was selected as the orifice type. Pintle type injectors were considered in the beginning, but were not investigated further due to machining constraints. Pintle injectors in general encourage high temperatures very close to orifices and their consequent machined surfaces because of the locality of mixing and combustion. Utilizing impinging streams of oxidizer and fuel will aid in atomization, particularly for nitrous oxide entering in at borderline vapor pressure.

Two parameters for determining the size of the orifices was based on certain pressure conditions: pressure drop and injected pressure. Injected pressure refers to the propellant's pressure after it has exited the orifice and is in the combustion chamber. It was imperative that both propellants remain under enough pressure after injection in order to impinge upon one another and atomize, and to hinder the chance of combustion instability. The injected fuel and oxidizer pressure are to be 30% higher than the chamber pressure. The unlike-triplet design on the injector face featured 12 total instances of impingement between the fuel and oxidizer. There are a total of 24 orifices for the oxidizer, each with a diameter of 2 mm. There are 12 orifices for the fuel, each with a diameter of 1.57 mm. The oxidizer features more orifices due to the high O/F ratio stated in Table 5. Calculating the nominal propellant velocity out of the orifices can be found by dividing the volumetric flow rate by the total orifice area for each propellant:

$$v = \frac{Q}{A}$$

$$v_{fuel} = \frac{0.000279}{(12 * 0.000001936)} = 12\ \frac{m}{s}$$

$$v_{oxidizer} = \frac{0,001526}{(24 * 0.000003142)} = 20.24\ \frac{m}{s}$$

To find a suitable feed pressure for both the fuel and oxidizer, the injected pressure, pressure drop and velocities have to be evaluated seemingly simultaneously to find a solution. Bernoulli's equation can be utilized in this scenario and was used to find the needed feed pressure leading into the injector from the plumbing. Writing Bernoulli's in terms of pressure satisfies the assumption of conservation of energy:

$$P_{feed} = P_{injected}$$

$$P_{feed} = (1.3 * P_c) + (\tfrac{1}{2} * \rho * v^2) + \Delta P$$

P_c is the chamber pressure, ρ is the density of the propellant, v is the propellant velocity and ΔP term correlates to the pressure drop across the injector elements. The ΔP is an expression found in Rocket Propulsion Elements (ref. 8-5, 9th ed.):

$$\Delta P = \frac{\rho}{2} * \left(\frac{V}{Cd}\right)^2$$

The term Cd refers to the discharge coefficient of the injector orifice, and has been estimated to be 0.65. This estimate is from Table 9-2 in Rocket Propulsion Elements (9th ed.), and corresponds to a "sharp-edged" orifice below 2.5 mm in diameter. Since both the fuel and oxidizer orifices are below 2.5 mm in diameter, and were machined to have sharp edges rather than rounded entrances then the estimate was selected at 0.65. Future cold flow tests will be conducted to verify this estimate, or discover a new one altogether. Combining the pressure drop term and all other values will yield the following equation:

$$P_{feed,\ oxidizer} = (1.3 * 1{,}034{,}214\ Pa) + (\tfrac{1}{2} * 1{,}051.4 \tfrac{kg}{m^3} * (20.24 \tfrac{m}{s})^2) + ((\frac{1.051.4 \frac{kg}{m^3}}{2}) * (\frac{20.24 \frac{m}{s}}{0.65})^2)$$

$$P_{feed,\ oxidizer} = 2{,}069.555\ kPa = 300.164\ psi$$

$$\Delta P_{oxidizer} = 509.721\ kPa = 73.929\ psi$$

$$P_{feed,fuel} = (1.3 * 1{,}034{,}214\ Pa) + (\tfrac{1}{2} * 820\tfrac{kg}{m^3} * (12\tfrac{m}{s})^2) + ((\frac{820\frac{kg}{m^3}}{2}) * (\frac{12\frac{m}{s}}{0.65})^2)$$

$$P_{feed,fuel} = 1{,}543.258\ kPa = 223.832\ psi$$

$$\Delta P_{fuel} = 139.739\ kPa = 20.267\ psi$$

These values are recorded in Table 6 below for reference.

Table 9: Unlike figures and equations, table captions go before the table.

Propellant Characteristic	Value (SI Units)
Oxidizer Pressure Drop	509.721 kPa
Oxidizer Feed Pressure	2,069.555 kPa
Fuel Pressure Drop	139.739 kPa
Fuel Feed Pressure	1,543.258 kPa

Another important design characteristic that can be calculated is the effect of impingement, and how the streams of propellant interact. To understand the resulting angle after impingement, conservation of momentum can be applied using geometry:

$$tan\beta = \frac{(\frac{1}{12}m_f * V_f * sin45) - (\frac{1}{24}m_o * V_o * sin30)}{(\frac{1}{24}m_o * V_o) + (\frac{1}{24}m_o * V_o * cos30) + (\frac{1}{12}m_f * V_f * cos45)}$$

$$\beta = tan^{-1}(\frac{0.161-0.676}{1.353+1.171+0.161}) = -10.85^o$$

The resultant angle of -10.85 degrees reflects a deflection angle Now to find the consequent velocities. Using the conservation of momentum in this case requires the assumption that no propellant mass is lost and all is transferred along a streamline. For this model, a 2D model was used to simulate ideal conditions. This equates to a minimum impingement velocity, and suggests that the real velocity will be higher and thus real pressure will be lower since the resulting stream will not contain the total mass flow rate from each of the twelve instances.

$$V_y = \frac{(\frac{1}{12}m_f * V_f * sin45) - (\frac{1}{24}m_o * V_o * sin30)}{-(\frac{(m_o+m_f)}{12}) * sin10.85} = \frac{0.161-0.676}{-0.0288}$$

$$V_y = 17.882\frac{m}{s}$$

$$V_x = \frac{(\frac{1}{12}m_f * V_f * cos45) + (\frac{1}{24}m_o * V_o * cos30) + (\frac{1}{24}m_o * V_o)}{(\frac{(m_o+m_f)}{12}) * cos10.85} = \frac{0.161+1.171+1.353}{0.15}$$

$$V_x = 17.9\frac{m}{s}$$

$$V_{total} = \sqrt{V_x^2 + V_y^2} = 25.3\frac{m}{s}$$

Knowing the resulting velocity after propellant impingement and assuming all mass is conserved within a streamline, the pressure after impingement can be checked. The states in question are before and after impingement, referred to below as injected and resultant respectively. The calculation below shows the resultant pressure for the oxidizer:

$$P_{injected} + \frac{1}{2} * \rho_{injected} * V_{injected}{}^2 = P_{resultant} + (\frac{1}{2} * \rho_{resultant} * V_{resultant}{}^2)$$

$$(1.3 * 1,034,214) + (\frac{1,051.4\frac{kg}{m^3}}{2} * (20.24\frac{m}{s})^2) = P_{resultant} + (\frac{1,051.4\frac{kg}{m^3}}{2} * (25.3\frac{m}{s})^2)$$

$$P_{resultant} = 1,223.339\ kPa = 177.43\ psi$$

INJECTOR TESTING

Rocket engine injectors are the epitome of Goldilocks. They require every hole to be machined to the tightest of tolerances. The slightest deviation from perfect, and the injector, along with the engine, will rapidly deviate from expectations. To prevent this, the injector will go through various cold flow tests to verify that it will meet performance requirements and that all seals perform nominally.

The first series of cold flows the injector went through were to determine if the injector could meet the pressure drop and mass flow rate design numbers. Water was pushed through the injector at lower pressures and collected in a bucket. The mass of water was measured and compared to the amount of water that was placed into the tanks. The oxidizer and fuel side were ran separately.

The second round of testing on the injector involved flowing water through both the oxidizer and fuel sides. This was to verify that the oxidizer and fuel elements were drilled at the correct angles for proper impingement. These tests were successful and proper impingement was achieved.

To guarantee a perfect seal between the oxidizer and fuel manifolds, SOAR is pursuing in-house manufacturing of custom o-rings. This will save on cost of purchasing o-rings commercially and will result in o-rings that fit the glands machined in the injector. These o-rings will be subjected to rigorous testing to verify that the seal between oxidizer and fuel manifolds does not leak. The o-rings will first be tested to verify that they will not leak. Then, once it is verified that they will not leak, the o-rings will be stress tested to determine their maximum fatigue limits.

Figure 17: Image of the water flow set up. The injector can be seen on the thicker truss. During the first round of testing, the injector is placed in the vertical position and placed on a bucket.

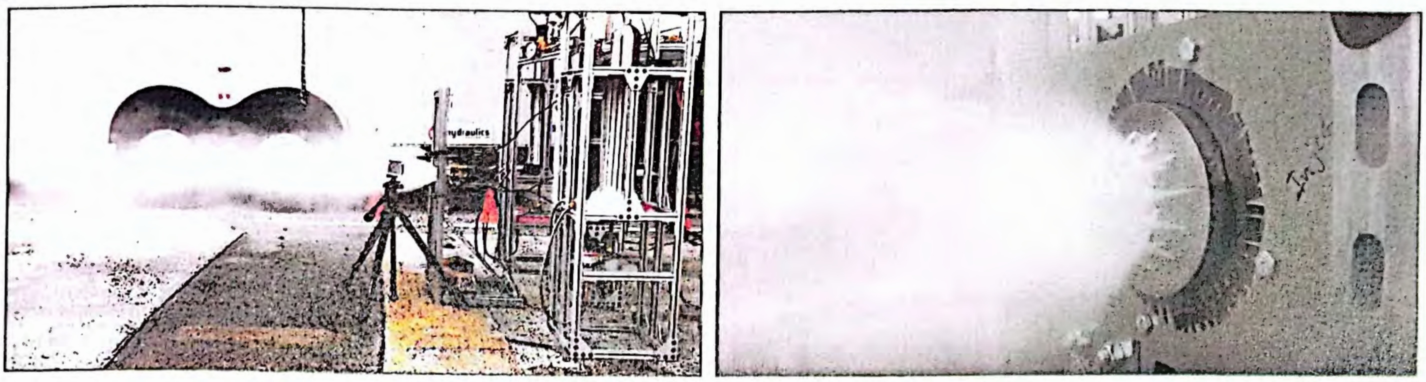


Figure 18: The image on the left is of the impingement test taken from outside of the testing area. The image on the right is from the GoPro placed next to the injector.

TEST STAND STRUCTURES

The trailer being used for the test stand is 5 feet by 8 feet, with a mesh floor and a lift gate. The trailer has a specified payload capacity of 1638 pounds. The tanks used for the fuel, oxidizer, and pressurants will be housed in structures made with aluminum T-Slot Framing. We chose this method for the ease of assembly, and for the stability the T-Slot Framing provides. The fuel and oxidizer tank holders are the same, an image is shown below on the left in Figure 19. Similarly, the pressurant tanks holders are the same and can be seen below on the right in Figure 19.

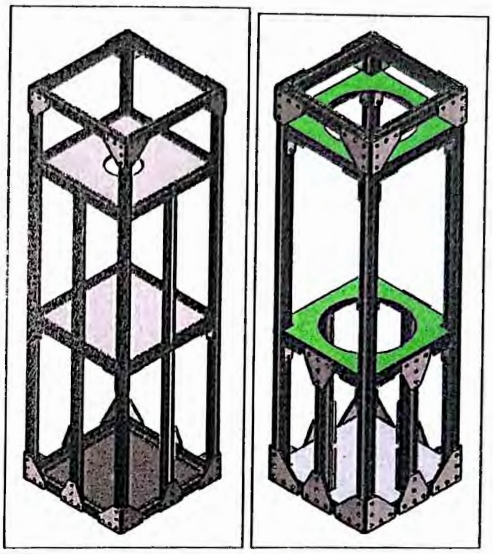


Figure 19: The tank holders; propellants on the right and pressurant on the left

The fuel and oxidizer tank structures will stand 48 inches in height and be 12 inches square on the top and bottom, and weight around 41.32 pounds. The pressurant tank structures will be 36 inches in height and be 8 inches square on the top and bottom and weight around 21.64 pounds.

Engine Truss - The engine truss was designed to withstand the total force of the subscale engine, and is made of galvanized steel. The length of the truss is 48.84 inches, the width is 37.25 inches, and the height is 28 inches. A blast plate is on the engine side of the truss, this is where the engine will be mounted for testing, the blast plate is a 54 inches on all sides. The overall weight of the truss will be 210 pounds. The truss is pictured below in Figures 20, 21 and 22.

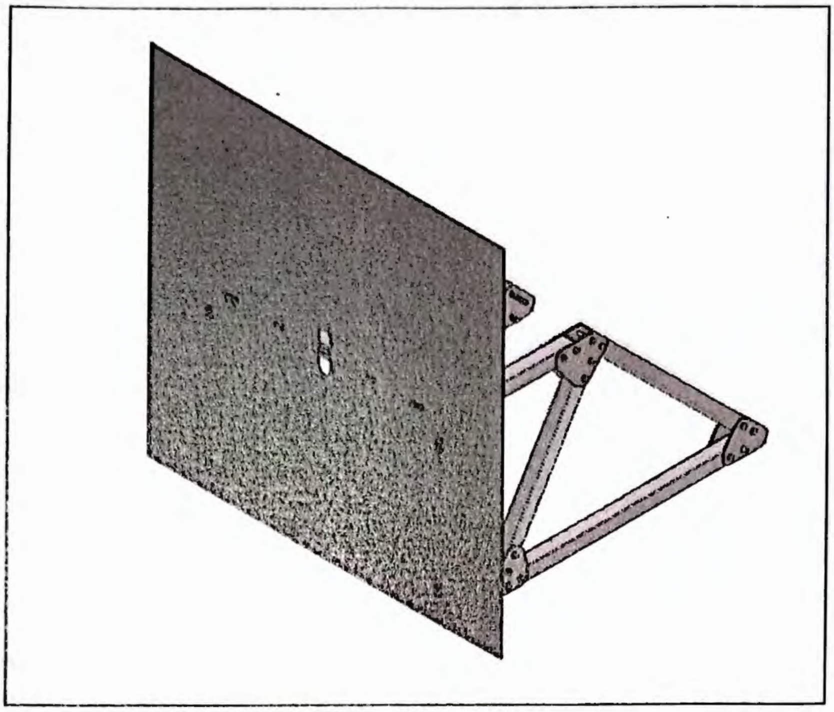


Figure 20: Isometric view of the engine truss

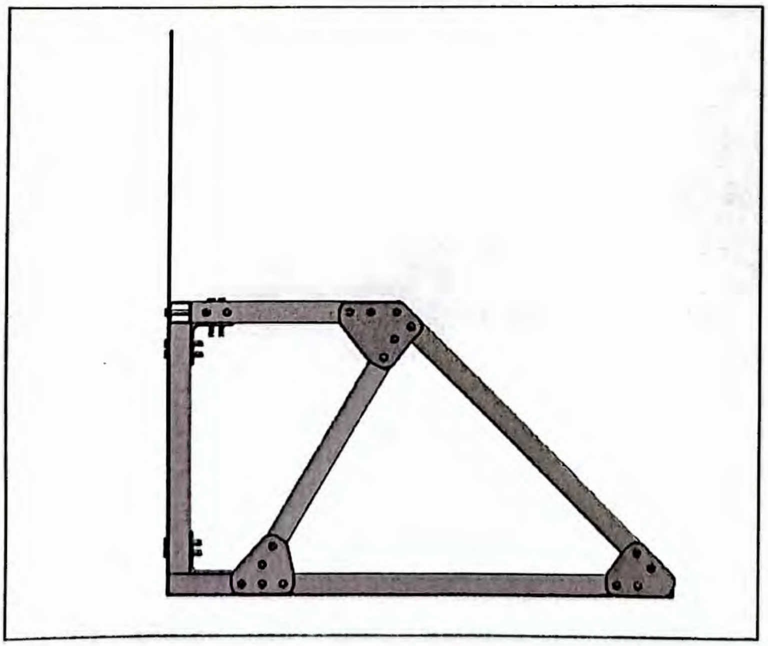


Figure 21: Side view of the engine truss

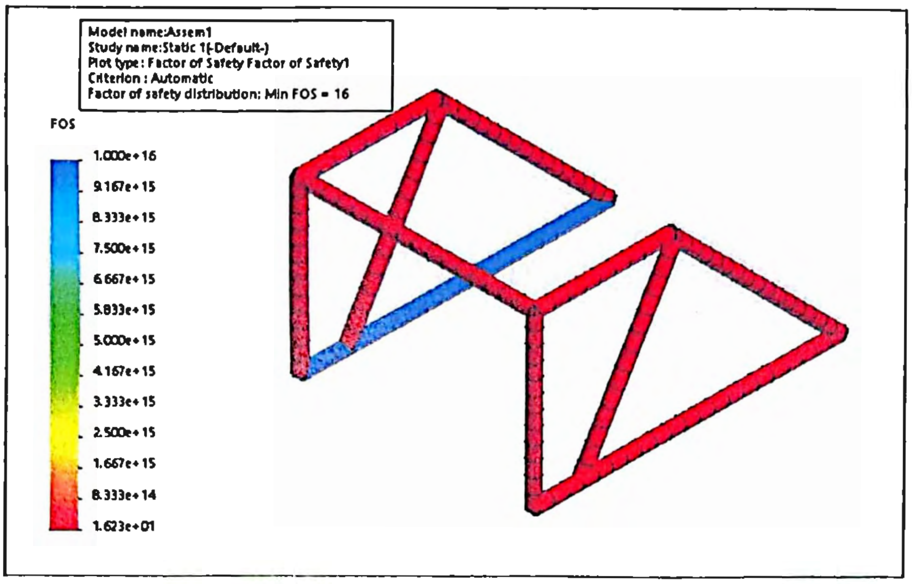


Figure 22: An isometric view of a SolidWorks Static simulation. Under the maximum thrust expected the truss is reading a factor of safety of 16

Test Stand Anchoring

The test stand will use a multitude of methods to anchor the trailer and prevent any possible movement. The first method towards anchoring will be to simply make use of a single jack placed at the neck of the trailer. This will balance the trailer and keep it horizontal. The second method of anchoring will be to place wheel chocks on either side of each wheel. This will remove most, if not all, possible rolling movement.

The third method of anchoring is a bit more unconventional. A pair of 35 lbs M1 Mantus anchors that can hold up to a 20,000 lb boat each will be dug into the dirt down range of the engine. Each anchor will be placed roughly at an angle of 45 degrees away from the engine. Ratchet straps will then be tightened down between the anchors and the truss structure. To span any extra distance between the stand and the anchors' locations, anchor chain will be used. Mantus anchors are known for their reliability and holding power in even the worst of anchoring conditions. While unconventional, this will guarantee that the test stand will not move.

Data Acquisition & Performance Monitoring

Data acquisition and performance monitoring is key to any successful test or experiment. The ability for SOAR to successfully and accurately capture performance metrics throughout the entirety of the system is crucial to our ability to progress and improve the design of all systems and subsystems.

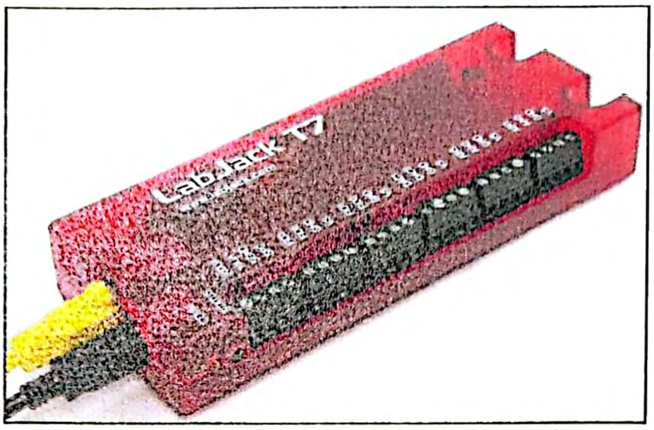


Figure 23: The T7 module developed by LabJack.

All data acquisition will be executed using a LabJack T7 High Performance Multifunction DAQ device which offers flexibility to the data acquisition process. This system offers a feasible alternative to the NI DAQ systems commonly used. Below is a list of key highlights and features of the T7.

<u>T7 Module:</u>

- 16-bit high-speed ADC
- Up to 100k samples/s
- 14 Analog inputs
- 23 Digital I/O
- Software packages for configuration, testing , & data logging
- compatibility with all major programming languages including LabVIEW

The T7 device will be paired with a LabJack MUX80 Expansion Board and two LabJack CB37 Terminal Boards. The MUX80 is an expansion board which will give the test stand DAQ system the capability to collect data from up to 80 analog inputs. For the current stage of the test stand only two of the possible four CB37 boards will be used, as there is no current plans to require data collection from 80 inputs.

The entire DAQ system will be housed inside of a set of large junction boxes that will be mounted directly to the trailer of the test stand as seen below. The junction boxes will be bolted and framed on the backside of the trailer frame away from the engine.

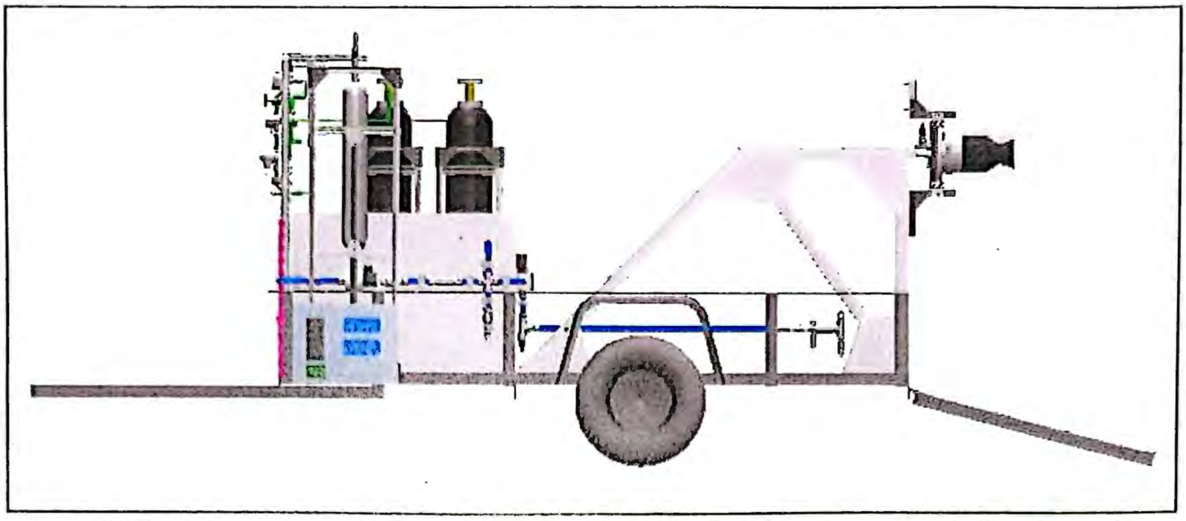


Figure 24: Side view of the test stand. The junction box is in the back left of the trailer, equipped with batteries, relay modules, T7 device(s) and LabJack CB37 expansion boards.

This centralized hub will serve to organize the influx of wiring that will be connected throughout the system. The DAQ system will be connected to a laptop via a series of 250 ft Ethernet cables. Ethernet cables are capable of carrying large amounts of data up to 100 meters without any reduction in speed or reliability. This will allow the system to send signals and receive data from a safe operating distance. The entirety of the DAQ system will be powered by a set of two 24 VDC car batteries. One for fuel side sensors and valves and another for oxidizer side sensors and valves.

The DAQ system explained above will be responsible for collecting data from a range of sensors and data collection devices. In total the system will be responsible for collecting data from 14 independent sensors. The layout of each sensor mentioned below can be seen in the detailed P&ID above.

Load Cells

Two load cells that will be used to record the axial thrust output of the engine via cantilever motion. The below load cell will be used in the 500kG configuration. The combination of these two load cells will provide accurate performance data as well as insight into the manufacturing precision of the custom nozzle.

Figure 25: Aerocon Systems 500 kg load cell

Table 9: The datasheet for the Aerocon load cell

Rated Load(kg)			500 kG and 1,000 kG		
Precision	C2	C3	Insulation Resistance(MΩ)	≥5000(100VDC)	
Comprehensive Error(%F.S)	0.03	0.02	Excitation Voltage (V)	9~12 (DC)	
Rated output(mv/v)	2 ± 0.01		Compensated temp.Range(°C)	-10~+40	
Non-linearity(%F.S)	0.03	0.017	Use Temp. Range(°C)	-35~+65	
Hysteresis(%F.S)	0.03	0.02	Temp.Effect on Zero(%F.S/10°C)	0.03	0.017
Repeatability(%F.S)	0.01		Temp.Effect on Span(%F.S/10°C)	0.02	0.014
Creep(%F.S/30min)	0.02		Safe Overload (%F.S)	120	
Zero Balance(%F.S)	± 2		Ultimate Overload(%F.S)	150	
Input Resistance(Ω)	405 ± 5		Defend Grade	IP65	
Output Resistance(Ω)	350 ± 5		Cable	φ3, 0.42m	

Pressure Sensors

The system will read live data from 10 pressure sensors located throughout the test stand plumbing. Each sensor will be positioned to collect live pressure readings at crucial stages, allowing the team to track the pressure differentiation throughout the system.

- FPS1 - Responsible for measuring and ensuring the fuel pressurant pressure is within operating ranges.
- FPS2 - Responsible for measuring the pressure of fuel pressurant as it enters the fuel tank.
- FPS3 - Responsible for measuring the fuel pressure leaving the fuel tank.
- FPS4 - Responsible for measuring a mid flow fuel pressure for use in pressure drop analysis
- FPS5 - Responsible for measuring fuel pressure directly prior to the injector.

- OPS1 - Responsible for measuring and ensuring the oxidizer pressurant pressure is within operating ranges.
- OPS2 - Responsible for measuring the pressure of pressurant as it enters the oxidizer tank.
- OPS3 - Responsible for measuring the oxidizer pressure leaving the oxidizer tank.
- OPS4 - Responsible for measuring a mid flow pressure for use in pressure drop analysis.
- OPS5 - Responsible for measuring oxidizer pressure directly prior to the injector.

Each pressure sensor mentioned above will be of the same type and have operational ratings from 0 to 1000 psig and will output a voltage between 0-10 VDC. The purpose of using the same sensor throughout the entirety of the system is to decrease the likelihood of errors due to calibration differences. With the same brand of sensor operating throughout the system we can increase our level of confidence that the data we receive from each sensor will be proportionate to those up or downstream.

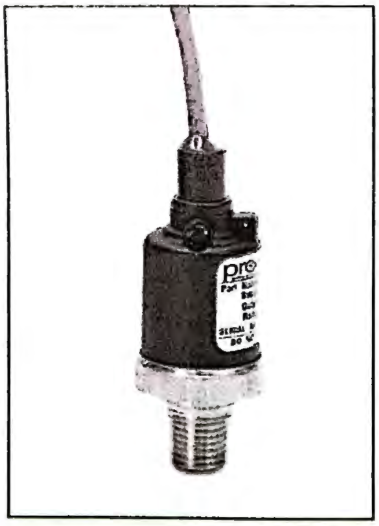


Figure 26: ProSense SPT25-10-1000A

Thermocouples

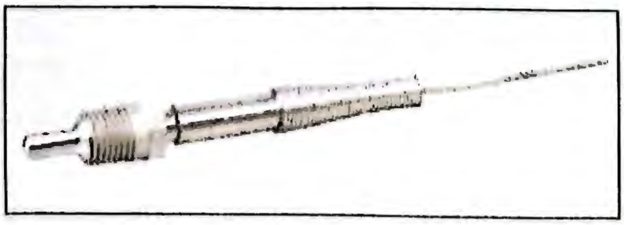


Figure 27: Omega TC-T-NPT-G-72

There will be 2 thermocouples located directly after both the fuel and oxidizer tanks. which will each serve to measure the fluid temperatures leaving both the fuel and oxidizer tanks. The below Omega thermocouple will be used on both sides of the system once again for data consistency purposes. This is a T type thermocouple with a max operating temperature of 650 degrees Celsius and can withstand pressures up to 2500 psi.

- FT1 - Temperature of the fluid leaving the fuel tank.
- OT1 - Temperature of the fluid leaving the oxidizer tank.

WIRING SCHEMATIC

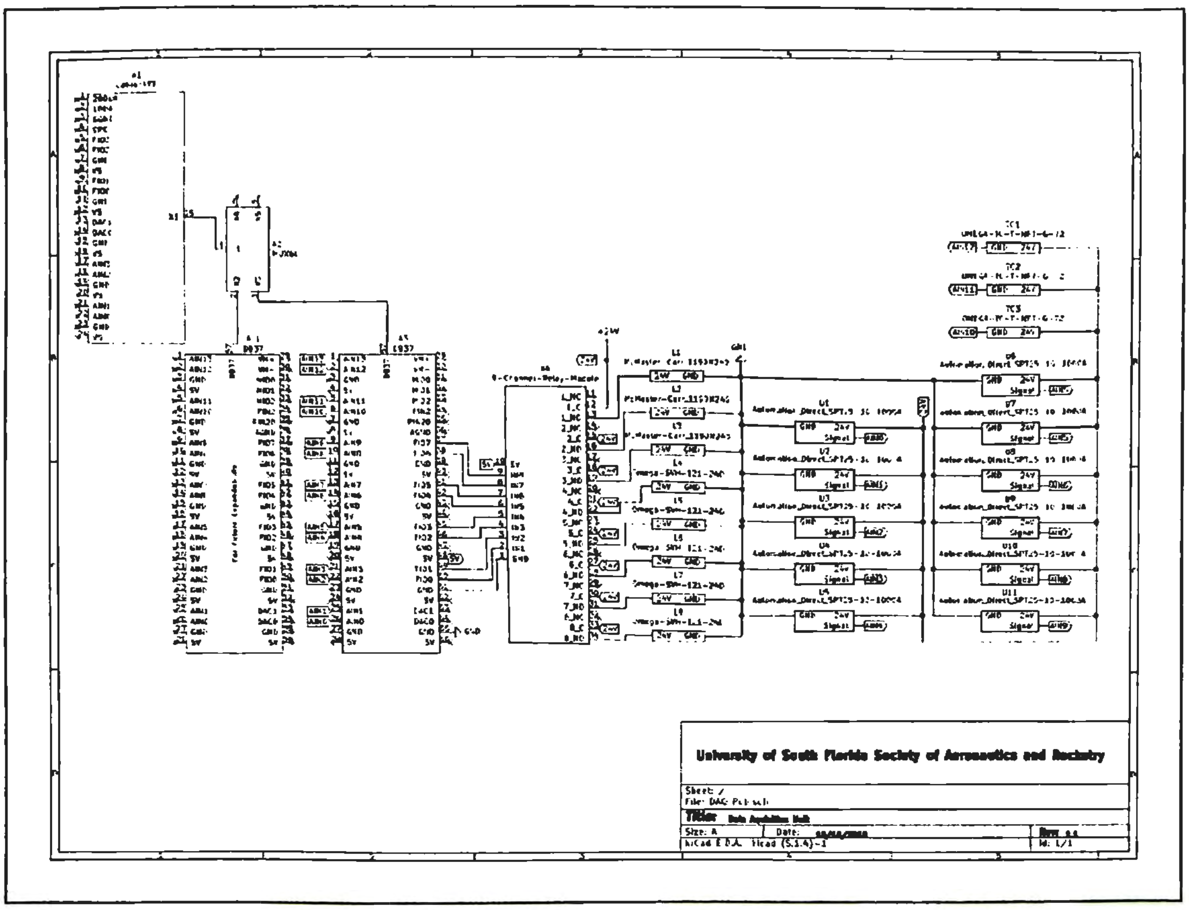


Figure 28: Above is the full electrical schematic for the test stand, complete with all controlled valves and sensors. Reflected on the schematic are 8 solenoid valves, 11 pressure sensors and 3 thermocouples.

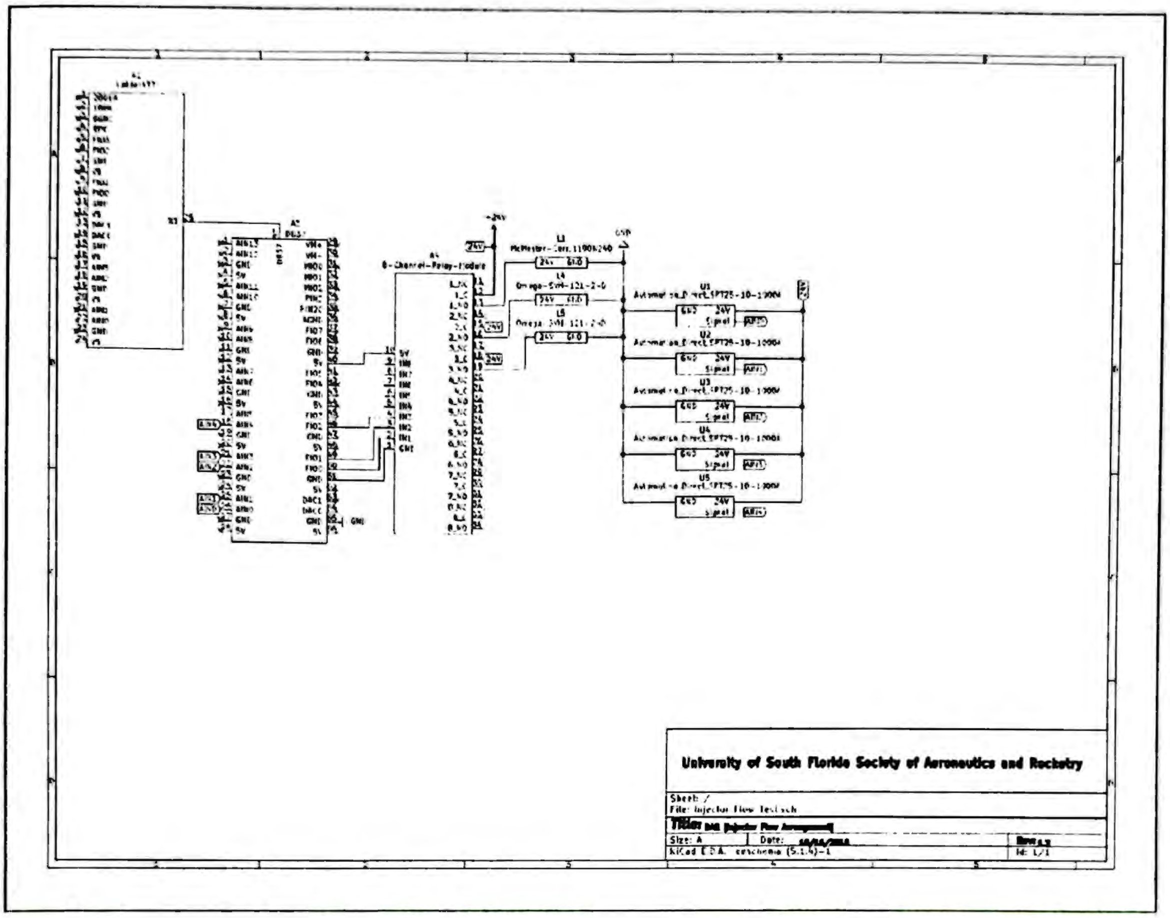


Figure 29: The wiring schematic used for the flow and impingement tests. This is a much simplified version compared to the full test stand schematic, but includes a total of 8 controls including solenoid valves and pressure sensors.

CONTROLS

Like data acquisition, all test stand controls with the exception of ignition will be operated via the LabJack T7. The T7 offers the ability to send signals to valves and receive data from sensors simultaneously, therefore allowing all system controls and test sequences to be operated through the T7. The T7 offers 23 Digital I/O, which will be sufficient for SOAR's test stand needs. This device will be connected to a remote laptop located with the test stand operations team via the same 250 ft Ethernet cable mentioned above. A custom GUI is in development using LabVIEW as the software interface. This GUI will allow all system controls to be operated remotely and precisely. This GUI will act as a dashboard and will display a controls configuration (solenoids) as well as live systems data collected from the sensors (pressure graphs, thrust gauge, temperature gauges, etc.).

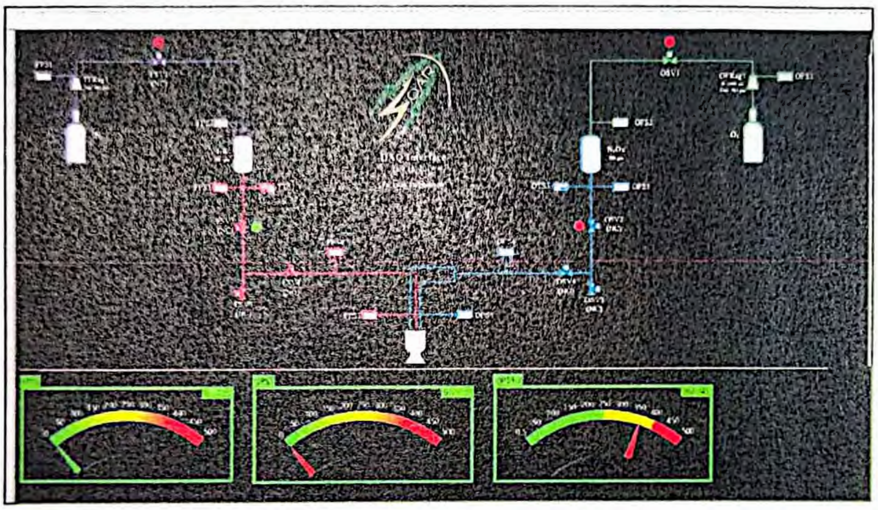


Figure 30: Early LabView sample GUI.

This GUI and controls interface will be responsible for controlling the 4 operational solenoids, and 4 emergency dump solenoids. Two solenoid valves will be actively controlled on both the fuel an oxidizer sides of the test stand.

Solenoid Valves

- FSV1(NC) - Responsible for initiating fuel tank pressurization.
- FSV2(NC) - Responsible for initiating fuel flow to the injector.
- FSV3(NC) - Emergency Dump
- FSV4(NO) - Responsible for preventing fuel flow to the injector upon emergency dump.
- OSV1(NC) - Responsible for initiating oxidizer tank pressurization.

- OSV2(NC) - Responsible for initiating oxidizer flow to the injector.
- OSV3(NC) - Emergency Dump
- OSV4(NO) - Responsible for preventing oxidizer flow to the injector upon emergency dump.

Fuel Side Solenoid Valves

FSV1 - McMaster-Carr High-Pressure Compact Solenoid On/Off Valve (NC)

FSV2 - Omega High Pressure Solenoid Valve

FSV3 - McMaster-Carr High-Pressure Compact Solenoid On/Off Valve (NC)

FSV4 - McMaster-Carr High-Pressure Compact Solenoid On/Off Valve (NO)

Oxidizer Side Solenoid Valves

OSV1 - McMaster-Carr High-Pressure Compact Solenoid On/Off Valve (NC)

OSV2 - Omega High Pressure Solenoid Valve (NC & Oxygen Clean)

OSV3 - Omega High Pressure Solenoid Valve (NC & Oxygen Clean)

OSV4 - Omega High Pressure Solenoid Valve (NO)

Omega High Pressure Solenoid Valve

The Omega High Pressure Solenoid Valve (PN: SVH-121-24D) is a 316 stainless steel, normally closed/normally open solenoid valve. This valve is rated for a maximum pressure of 3500 psig and requires a supply voltage of 24 VDC. The flow coefficient for this valve is 1.1 Cv

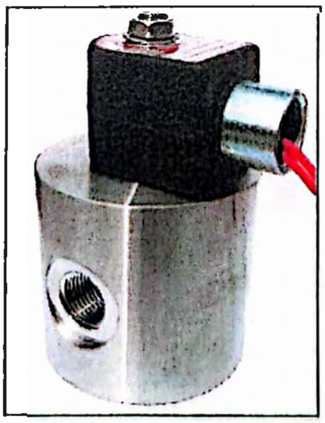


Figure 31: Omega SVH-121-24D

McMaster-Carr High-Pressure Compact Solenoid On/Off Valve

The McMaster-Carr High-Pressure Compact Solenoid On/Off Valve (PN: 119N240) is a 303 stainless steel, normally closed solenoid valve. This valve is rated to a maximum pressure of 3600 psig, and requires 24 VDC. The flow coefficient for this valve is 0.01 Cv.

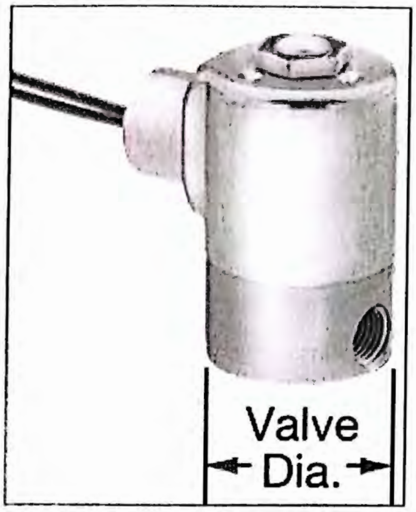


Figure 32: McMaster-Carr 119N240

Omega High Pressure Solenoid Valve Oxygen Clean

The Omega High Pressure Solenoid Valve (PN: SVH-121-24D-OX) is a 316 stainless steel, normally closed and oxygen clean solenoid valve. This valve is rated for a maximum pressure of 3500 psig and requires a supply voltage of 24 VDC. The flow coefficient for this valve is 4.5 Cv.

Figure 33: Omega SVH-121-24D

LabView Controls Logic

The test stand software and data team are currently developing logic to allow for the automation of the pressurization, flow, and abort sequences. This means that once developed, the sequential opening and closing of the solenoid valves to allow for automated pressurization and firing will be majorly autonomous. This process will consist of 5 control elements, 1 system lockout toggle switch (safety switch), 1 toggle switch for fuel tank pressurization, 1 toggle switch for oxidizer tank pressurization, 1 toggle for the propellant flow sequence, and 1 toggle switch for emergency shutdown (emergency dump). All 5 control elements mentioned above are being integrated into the LabView GUI discussed in the above sections.

Pressurization Process Automation

The goal for the pressurization process is to enable the entire pressurization sequence for both the fuel and oxidizer side of the test stand to be executed independently via a LabView control (toggle switch) . The logic sequence can be seen below.

Fuel Pressurization Logic

- System lockout is dis-engaged if not already dis-engaged
- FSV1 is opened on toggle
- Pressurization of fuel tank begins
- Once fuel tank reaches operating pressure the toggle is autonomously dis-engaged or closed.
- Fuel tank pressurization complete

Oxidizer Pressurization Logic

- System lockout is dis-engaged if not already dis-engaged
- OSV1 is opened on toggle
- Pressurization of oxidizer tank begins
- Once oxidizer tank reaches operating pressure the toggle is autonomously dis-engaged or closed.
- Oxidizer tank pressurization complete

Once both fuel and oxidizer pressurization are complete the system lockout/safety toggle switch is re-engaged to ensure no un planned propellant flow occurs.

Propellant Flow Process Automation

The goal for the propellant flow process is to enable the entire propellant flow sequence for both the fuel and oxidizer side of the test stand to be executed autonomously in unison via a single LabView control (toggle switch). The logic sequence can be seen below.

Propellant Flow Logic

- Toggle switch is toggled
- FSV1 and OSV1 are immediately opened (pressurization toggles are re-engaged)
- One second later OSV2 is opened
- 0.25 seconds after OSV2 is opened
- Propellant flows to injector

Abort Process Automation

The goal for the abort process is to enable the entire propellant flow sequence for both the fuel and oxidizer side of the test stand to be executed autonomously in unison via a single LabView control (toggle switch). The logic sequence can be seen below.

Abort Logic

- Toggle switch is toggled
- FSV4 is closed and FSV3 is opened, OSV4 is closed and OSV3 is opened
- Simultaneously FSV1 and OSV1 are closed
- Propellant begins to dump

IGNITION

The ignition control system (ICS) was built to operate both physically and electrically isolated from all other operational systems.

Ignition System Design and Simulation

In order to ensure the ignition system was designed and built in a safe and functional manner, the Ignition control system (ICS) design and simulation was performed using the LogixPro software on USF Citrix Receiver. A discussion and analysis of the simulation and design can be seen below.

INPUTS:

PS - Master Power Switch/Master Ignition Kill Switch (I:1/0)
ISS - Ignition Safety Switch (I:1/1)
IB - Ignition Button (Momentary button that must be depressed to send signal) (I:1/2)

OUTPUTS:

PL - Power Light, This signals that the system is on and receiving power. (I:2/0)
ISL - Ignition Safety Light, This signals that the system is SAFED. (I:2/1)

IRL - Ignition Ready Light, This signals that the safety switch (ISS) has been ARMED. (I:2/2)
IL - Ignition Light, This signals that the ignition signal is being sent from the ignition button (IB). (I:2/3)
I - Ignition, This represents the signal being sent to the ignitor from the ignition button (IB). (I:2/4)

The below figures represent the unpowered state of the ICS when all switches are not activated or in their normally open state, as seen in *figure 1*. In this state ICS has no power and therefore is not capable of any ignition events. **(**I:1/3 and I:1/4 are not used**)**

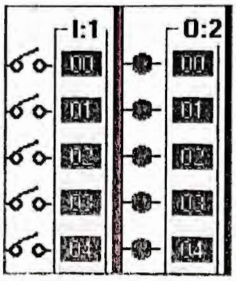


Figure 33: Control switches and output lights all open.

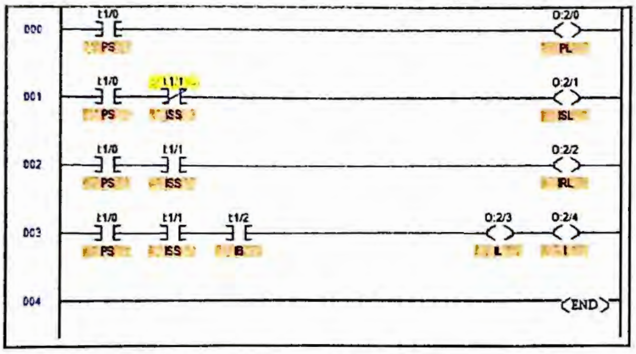


Figure 34: Ladder logic of ICS when unpowered.

The below figures represent the state of the ICS when the power switch (PS) has been activated and there is power in the system. All other switches (ISS and IB) are in their off or open state. This means that the ICS has power but is SAFEhenD from an ignition event.
(I:1/3 and I:1/4 are not used**)**

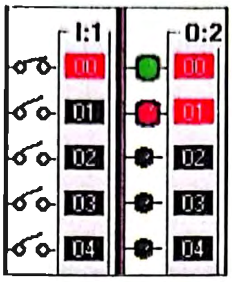


Fig 35: Control switches and output lights when PS is closed, PL is on meaning power has entered the system. ISS is open therefore ISL is on and IRL is off, and IB is open (IL and I are off).

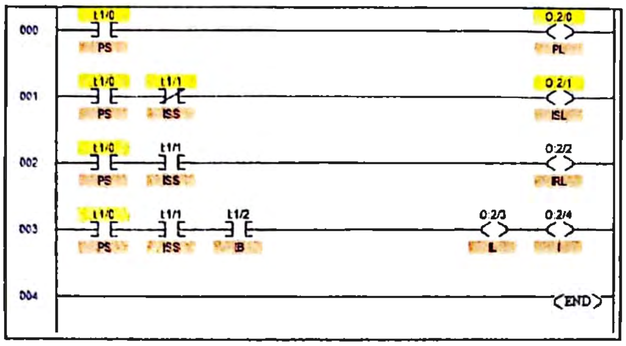


Figure 36: Ladder logic of ICS on power up.

The below figures represent the state of the ICS when the power switch (PS) has been activated and there is power in the system. The safety switch has also been activated and the system is now ARMED and ready for an ignition event. All other switches (IB) are in their off or open state. This stage in the procedure represents when the the ignition countdown has reached a point where ICS is to be ARMED and ready for the ignition signal to be sent.

(I:1/3 and I:1/4 are not used**)**

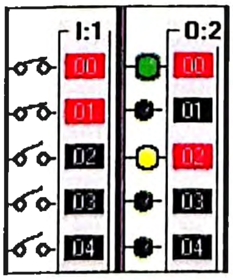


Figure 37: Control switches and output lights when PS is closed, PL is on meaning power has entered the system. ISS is closed therefore ISL is off and IRL is on. IB is open (IL and I are off).

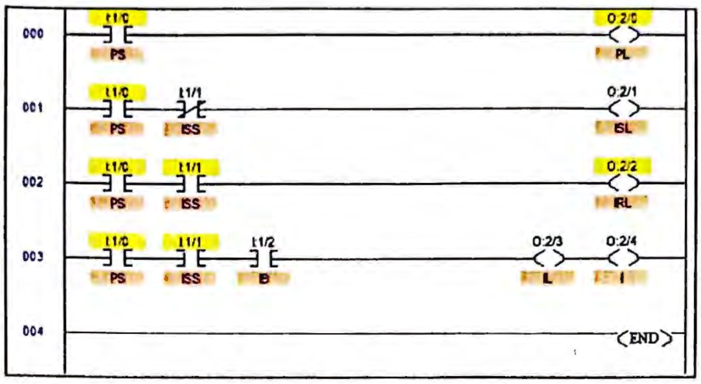


Figure 38: Ladder logic of ICS when powered and ARMED.

The below figures represent the state of the ICS when the power switch (PS) has been activated and there is power in the system. The safety switch has also been activated and the system is ARMED. The ignition button (IB) has been engaged and the ignition signal has been sent to the ignitor. The ICS has now completed the ignition procedure and the ignitor has been ignited.

(I:1/3 and I:1/4 are not used**)**

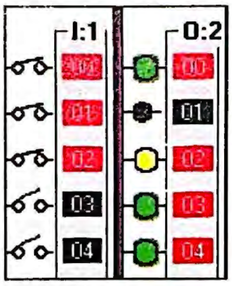


Figure 39: Control switches and output lights when PS is closed, PL is on meaning power has entered the system. ISS is closed therefore ISL is off and IRL is on and system is ARMED. IB is closed IL and I are on meaning ignition signal is being sent.

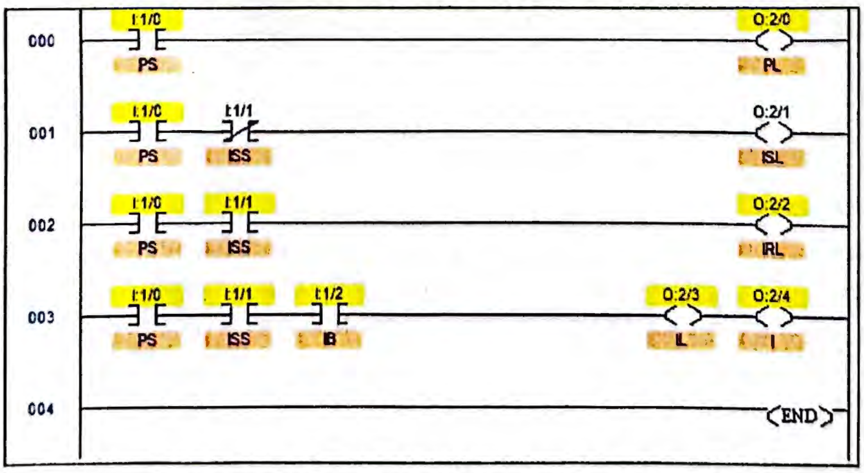


Figure 40: Ladder logic of ICS when ignition signal is sent.

Off Nominal sequencing safety check

In order to validate that the safety features of the ICS are functional all scenarios that don't follow the nominal ignition procedure can be seen below. The design of the system was to ensure that the procedures detailed above were the only was in which an ignition event could be triggered.

The below figures represent the state of the ICS when the power switch (PS) is not activated. If the power switch is off no other switches (ISS and IB) have the capability to trigger an ignition event. With no power the system will always remain in its SAFED configuration.
(I:1/3 and I:1/4 are not used**)**

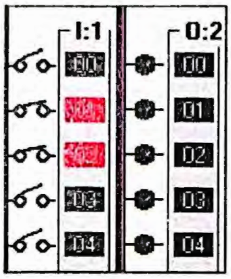


Figure 41: Control switches and output lights when PS is open. ISS and/or IB are activated.

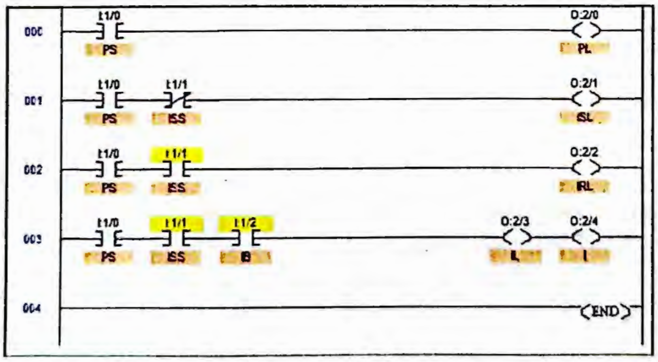


Figure 42: Ladder logic of ICS when powered off, safety off and ignition on.

The below figures represent the state of the ICS when the power switch (PS) is activated and the ignition button is also activated. The below figures show that no ignition event will occur without the safety switch being activated. In this state there is power but the system is SAFED because safety switch isn't activated.
(I:1/3 and I:1/4 are not used**)**

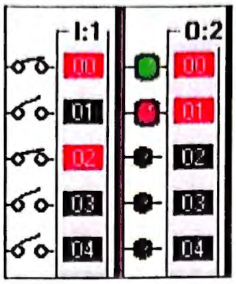


Figure 43: Control switches and output lights when PS is open. ISS and/or IB are activated.

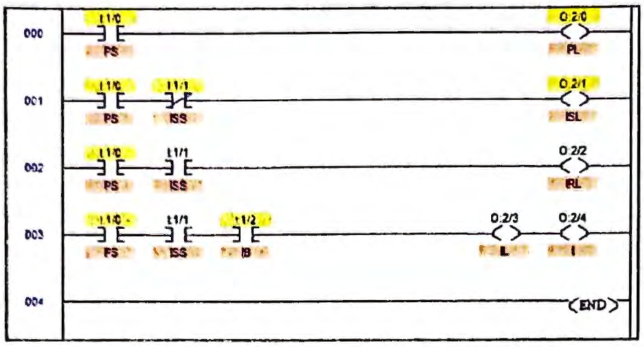


Figure 44: Ladder logic of ICS when powered off, safety off and ignition on.

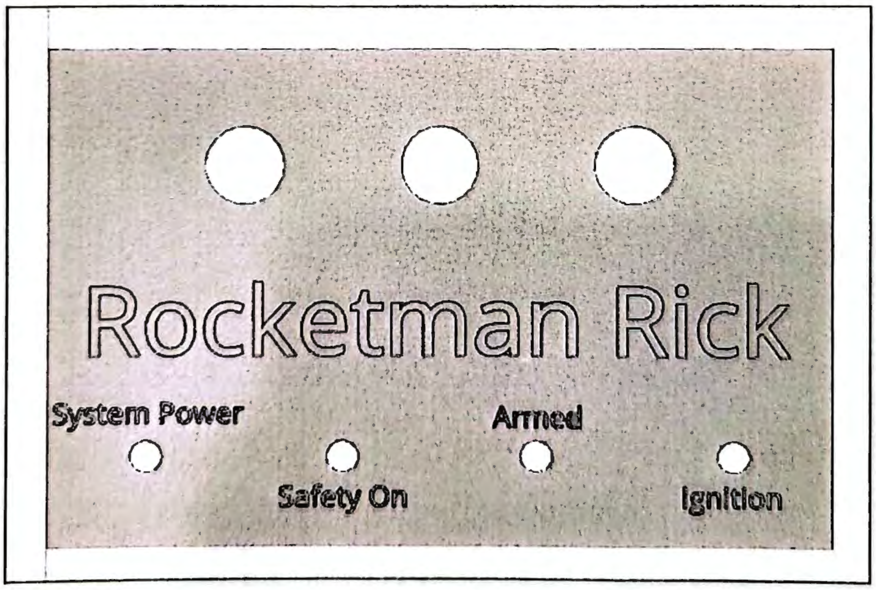


Figure 45 :Version 2 panel design

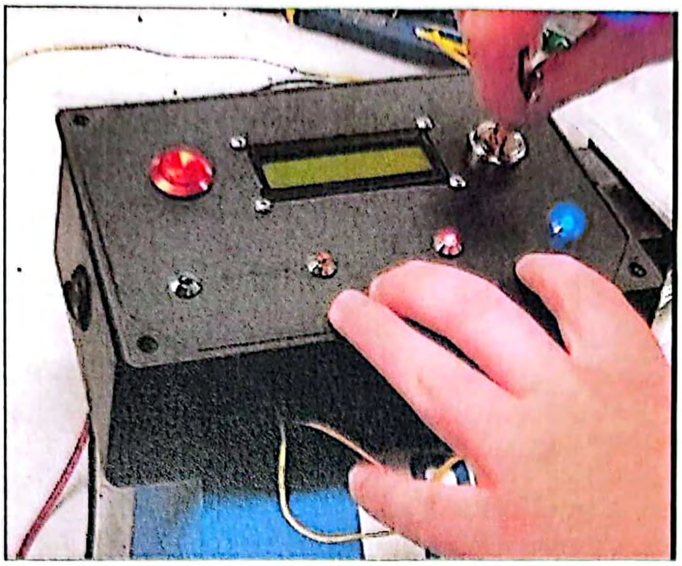


Figure 46: Version 1 of the SOAR ICS

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2. Kingery, C. N. and Bulmash, G., "Airblast Parameters from TNT Spherical Air Burst and Hemispherical Surface Burst," ARBRL-TR-02555, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, 1984.

3. Smith, Jay. *Engineers Practical Databook*. Publisher Not Identified, 2018.

USF SOAR

Cleaning Procedures

Plumbing Hardware

Materials	
Item	**Quantity x Size**
Klean-Strip Acetone	1 x Quart
Distilled Water	3 x Gallons
Air Compressor	1 x
Air Comprssor hose	1 x
Air Compressor fittings	1 x
Denatured Alcohol	1 x
Paper Towels	1x
PPE	1x

Tube Cleaning Procedures	
1	Fully disassemble the Swagelok fittings from each tubing section.
2	With an acetone bath, fully submerge the steel tubing and agitate within the bath.
3	Place the tubing on a paper towel to dry and evaporate any residual fluids.
4	Submerge the Swagelok-NPT adapters from the tubing assembly into the acetone bath and agitate.
5	Place the adapters on the same paper towel as the tubing previously cleaned.
6	After 10 to 15 minutes, reassemble the tubing section assembly.
7	Apply flash tape over the opening of the tubing section assembly to prevent particle contamination.
8	Label the tubing section with respect to which instrument on the P&ID it will connect to.

Valve/Component Cleaning Procedures	
1	If a valve or component has additional fittings or adapters on it, remove them entirely.
2	Submerge the valve in the acetone bath and agitate it.
3	Place the valve on a paper towel to dry.
4	After 10 to 15 minutes, attempt to soak up any residual fluids in the threads with a clean rag.
5	Once the valve has dried, apply flash tape over the opening to prevent particle contamination.

Tank Cleaning Procedures	
1	Plug bottom port of tank, removing adapters if still attached
2	Decant approximately 50 mL of acetone into the tank
3	Cover top port, agitating tank in order to rinse all interior surfaces with acetone
4	Discard acetone inside tank, and allow remaining liquid to evaporate from open tank for 10 to 15 minutes
5	Apply flash tape over openings to prevent particle contamination

Injector Cleaning Procedures	
1	Gently clean the injectoro-rings with an acetone-soaked paper towel, and rid any excess lubricant.
2	Clean the internal surfaces of the injector with acetone as well, ridding any excess lubricant or particles especially around the orifices.
3	Agitate the entire injector manifold in an acetone bath.
4	Allow to dry for 10 to 15 minutes.
5	Apply flash tape on the injector orifices, only on the external surface exposed to the chamber.

FUEL SIDE LEAK TESTING		
ENSURE all **FUEL LINE MANUAL VALVES** are **CLOSED** by being perpendicular to the flow		
	FMV0	
	FMV1	
	FMV2	
	FMV3	
	FMV4	
ENSURE FUEL pressure regulatator is **CLOSED** by being turned all the way **COUNTER-CLOCKWISE**		
OPEN main gate valve on **FUEL LINE NITROGEN TANK**		
SLOWLY turn the knob on the **FUEL SIDE** pressure regulator a **QUATER-TURN CLOCKWISE** to **INCREASE** the outlet pressure		
READ the pressure gauge on the outlet side. **REPEAT** last step until pressure is set to **LEAK TESTING** pressure		
	PRESSURE READING	**50 psi**
OPEN FMV1		
Ensure test stand operators move away from test stand		
OPEN FSV1		
Ensure **FUEL** propellent tank is holding **STEADY PRESSURE**		
If pressure is not maintained, close FSV1 then tighten connection where leak exists		
CLOSE FSV1		
OPEN FSV2 to **DEPRESSURIZE** the fuel propellent tank		
Ensure **FUEL** propellent tank **SENSORS** are reading **ZERO** pressure		
CLOSE FSV2		
CLOSE FMV1		

FUEL LOADING PROCEDURES	
OPEN FMV2	
Connect fuel hand pump to **FMV3**	
OPEN FMV3	
Hand pump fuel from parent tank to propellent tank	
CLOSE FMV3	
CLOSE FMV2	
Disconnect fuel pump	

FUEL TANK PRIMING/PRESSURE SET		
OPEN FMV1		
Ensure test stand operators move away from test stand		
OPEN FSV1		
Ensure **FUEL PROPELLENT TANK** holds a steady pressure of **50 PSI**		
CLOSE FSV1		
OPEN FMV4		
CLOSE FMV1		
SLOWLY turn the knob on the **FUEL SIDE** pressure regulator a **QUATER-TURN CLOCKWISE** to **INCREASE** the outlet pressure		
READ the pressure gauge on the outlet side. **REPEAT** last step until pressure is set to desired **OPERATING** pressure		
	PRESSURE READING	
MOVE FUEL PARENT TANK BACK TO BUNKER LOCATION		

OXIDIZER SIDE LEAK TESTING		
Ensure test stand operators wheel **OXIDIZER PARENT TANK** to **HOT ZONE**		
ENSURE all **OXIDIZER LINE MANUAL VALVES** are **CLOSED** by being perpendicular to the flow		
	OMV0	
	OMV1	
	OMV2	
	OMV3	
	OMV4	
ENSURE OXIDIZER pressure regulatator is **CLOSED** by being turned all the way **COUNTER-CLOCKWISE**		
OPEN main gate valve on **OXIDIZER LINE NITROGEN TANK**		
SLOWLY turn the knob on the **OXIDIZER SIDE** pressure regulator a **QUATER-TURN CLOCKWISE** to **INCREASE** the outlet pressure		
READ the pressure gauge on the outlet side. **REPEAT** last step until pressure is set to **LEAK TESTING** pressure		
	PRESSURE READING	**100 PSI**
OPEN OMV1		
Ensure test stand operators take a step back		
OPEN OSV1		
Ensure **OXIDIZER** propellent tank is holding **STEADY PRESSURE**		
If pressure is not maintained, close OSV1 then tighten connection where leak exists		
CLOSE OSV1		
OPEN OSV2 to **DEPRESSURIZE** the oxidizer propellent tanks		
Ensure **OXIDIZER** propellent tank **SENSORS** are reading **ZERO** pressure		
CLOSE OSV2		
CLOSE OMV1		

OXIDIZER LOADING PROCEDURES	
OPEN OMV2	
Connect oxidizer parent tank hose to **OMV3**	
OPEN OMV3	
SLOWLY OPEN main valve on **OXIDIZER** parent tank	
ENSURE OXIDIZER PROPELLENT TANK is filled with liquid **OXIDIZER**	
CLOSE OMV2	
CLOSE OMV3	
CLOSE main valve on **OXIDIZER** parent tank	
VENT OXIDIZER hose line from **PARENT TANK**	
DISCONNECT OXIDIZER parent tank hose line	

OXIDIZER PRESSURE SET		
SLOWLY turn the knob on the **OXIDIZER SIDE** pressure regulator a **QUATER-TURN CLOCKWISE** to **INCREASE** the outlet pressure		
READ the pressure gauge on the outlet side. **REPEAT** last step until pressure is set to desired **OPERATING** pressure		
	PRESSURE READING	

OPEN OMV1	
OPEN FMV1	
ARM IGNITION SWITCH	
ENSURE ALL TEST STAND OPERATORS LEAVE THE AREA WITH OXIDIZER PARENT TANK	
SYSTEM IS ARMED	

PROPELLANT FLOW AND SYSTEM SAFING	
SOUND THE TESTING ALARM	
OPEN FSV1	
ENSURE tank **TEMPERATURE** are **STEADY**	
ENSURE tank **PRESSURE** is **STEADY**	
OPEN OSV1	
ENSURE tank **PRESSURE** is **STEADY**	
ENSURE tank **TEMPERATURE** is **STEADY**	
IF TEMPERATURE OR PRESSURE NOT MAINTAINED PAUSE AND LOOK FOR LEAKS WITH BINOCULARS	
TURN ON LabVIEW **DATA LOGGING SWITCH**	
SOUND THE TESTING ALARM	
ARM MASTER FLOW SWITCH	
COUNTDOWN from T-10 seconds	
FLIP MASTER FLOW SWITCH	
Allow system to flow for **AT LEAST 30 SECONDS** then **TURN OFF TANK PRESSURIZATION** switch	
Ensure **FUEL** propellent tank pressure reads zero pressure	
Ensure **OXIDIZER** propellent tank pressure reads zero pressure	
TURN OFF Master FLOW SWITCH	
Remote operator yells **ALL CLEAR**	
Have test stand operators approach test stand	
DISARM IGNITION SWITCH	
CLOSE main gate valve on **FUEL** Nitrogen tanks	
CLOSE main gate valve on **OXIDIZER** Nitrogen tanks	
Have test stand operators take a step back	
TURN ON tank pressurization switch	
Ensure **FUEL** propellent tank pressure sensors reads **ZERO**	
Ensure **OXIDIZER** propellent tank pressure sensors reads **ZERO**	
TURN OFF tank pressurization switch	
Turn off LabVIEW	

SYSTEM IS SAFED

Post-Pressurization Abort Procedure	
OPEN OSV2 to vent off oxidizer	
Ensure **OXIDIZER** propellent tank reads **ZERO** pressure	
OPEN OSV1 to purge any excess **OXIDIZER GAS**	
After about 10-15 seconds **CLOSE OSV1**	
CLOSE OSV2	
OPEN FSV2	
Ensure **FUEL** propellent tank ullage reads **ZERO** pressure	
CLOSE FSV1	
Remote operator yells **ALL CLEAR**	
Have test stand operators approach test stand	
CLOSE main gate valve on **FUEL** Nitrogen tanks	
CLOSE main gate valve on **OXIDIZER** Nitrogen tanks	
OPEN FMV2	
Connect fuel hand pump to **FMV3**	
OPEN FMV3	
Hand pump fuel from propellent tank to parent tank	
CLOSE FMV3	
CLOSE FMV2	
Disconnect fuel pump	
MOVE FUEL PARENT TANK BACK TO BUNKER LOCATION	
TURN ON tank pressurization switch	
Ensure **FUEL** propellent tank pressure sensors reads **ZERO**	
Ensure **OXIDIZER** propellent tank pressure sensors reads **ZERO**	
TURN OFF tank pressurization switch	
Turn off LabVIEW	
SYSTEM IS SAFED	

AIG AEROSPACE INSURANCE SERVICES, INC.

CERTIFICATE OF COMMERCIAL LIABILITY INSURANCE

This certificate is issued for informational purposes only. It certifies that the policies listed in this document have been issued to the Named Insured. It does not grant any rights to any party nor can it be used, in any way, to modify coverage provided by such policies. alteration of this certificate does not change the terms, exclusions or conditions of such policies. Coverage is subject to the provisions of the policies, including any exclusions or conditions, regardless of the provisions of any other contract, such as between the certificate holder and the Named Insured. The limits shown below are the limits provided at the policy inception. Subsequent paid claims may reduce these limits.

Producer:	Named Insured:
ARTHUR J.GALLAGHER & CO., INC. 8333 NW 53RD STREET, SUITE 600 MIAMI, FL 33166	UNIVERSITY OF SOUTH FLORIDA BOARD OF TRUSTEES 4202 E. FOWLER AVE., OPM100 TAMPA, FL 33620-6980

General Liability

Insurer Name: NATIONAL UNION FIRE INSURANCE COMPANY OF PITTSBURGH, PA

Policy Number: AP 081151226-01

Policy Effective Date: December 21, 2018 Policy Expiration Date: December 21, 2019

Limits of Insurance	$ 2,000,000.	Each Occurrence Limit
	$ 50,000.	Damage To Premises Rented To You Limit (any one premises)
	$ 3,000.	Medical Expense Limit (any one person)
	$ 2,000,000.	Personal & Advertising Injury Aggregate Limit
	$ NOT APPLICABLE	General Aggregate Limit
	$ 2,000,000.	Products/Completed Operations Aggregate Limit
		Hangarkeepers Limit
	$ NOT COVERED	Each Aircraft Limit
	$ NOT COVERED	Each Loss Limit
	$ NOT APPLICABLE	Hangarkeepers Deductible (each aircraft)

General Aggregate Limit applies per: [X] Policy [ ] Project [ ] Location

Description of Operations/Locations/Endorsements/Special Provisions

ADDITIONAL INSURED(S) SUBJECT TO FORM CGL191 ATTACHED TO THIS POLICY.

Additional Insured Status YES

THIS CERTIFICATE DOES NOT GRANT ANY COVERAGE OR RIGHTS TO THE CERTIFICATE HOLDER.
IF THIS CERTIFICATE INDICATES THAT THE CERTIFICATE HOLDER IS AN ADDITIONAL INSURED, THE POLICY(IES) MUST EITHER BE ENDORSED OR CONTAIN SPECIFIC LANGUAGE PROVIDING THE CERTIFICATE HOLDER WITH ADDITIONAL INSURED STATUS. THE CERTIFICATE HOLDER IS AN ADDITIONAL INSURED ONLY TO THE EXTENT INDICATED IN SUCH POLICY LANGUAGE OR ENDORSEMENT.

Cancellation

In the event of cancellation of any policy described above, the insurer will attempt to mail 30 days written notice to the certificate holder prior to the effective date of cancellation. However, failure to do so will not impose duty or liability upon the insurer, its agents or representatives, nor will it delay cancellation.

Certificate Holder: SOCIETY OF AERONAUTICS AND ROCKETRY AT USF	Certificate No. 1
Authorized Representative: D.W. Baker	December 20, 2018 AT Date of Issue

CGL309 (3/05)

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ADDITIONAL INSURED - DESIGNATED PERSON OR ORGANIZATION

This endorsement modifies insurance provided under the following:

COMMERCIAL GENERAL LIABILITY COVERAGE FORM

SCHEDULE

Name of Additional Insured Person(s) or Organization(s):
SOCIETY OF AERONAUTICS AND ROCKETRY AT USF
Information required to complete this Schedule, if not shown above, will be shown in the Declarations.

SECTION II - WHO IS AN INSURED is amended to include as an additional Insured the person(s) or organization(s) shown in the Schedule, but only with respect to liability for "bodily injury", "property damage" or "personal and advertising injury" caused, in whole or in part, by your acts or omissions or the acts or omissions of those acting on your behalf:

A. In the performance of your ongoing operations; or

B. In connection with your premises owned by or rented to you.

All other provisions of this policy remain the same.

This endorsement becomes effective December 21, 2018 to be attached to and hereby made a part of Policy No. AP 081151226-01 issued to UNIVERSITY OF SOUTH FLORIDA BOARD OF TRUSTEES
By NATIONAL UNION FIRE INSURANCE COMPANY OF PITTSBURGH, PA

Endorsement No. TBD

Date of Issue December 20, 2018 AT

By ______ (Authorized Representative)

CGL191 (3/05)

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