Liquid Fuel Engine Test Stand (LFETS) Design Document

Last modified: 2019/11/29

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1 Executive Summary

The Portland State Aerospace Society (PSAS) is an interdisciplinary student group at Portland State University. PSAS is participating in the Base 11 Space Challenge, a university rocketry team competition to build a liquid bi-propellant rocket that reaches an altitude of 100km. Our technology development philosophy is "incremental progress", where systems are designed, built, tested, broken, and iterated. Thus our first foray into liquid fuel engine design is a fully functional, robust, and safe liquid fuel engine test stand we'll use to iterate our liquid fuel engine system.

This document is an overview of the design of the Liquid Fuel Engine Test Stand (LFETS). It includes the Piping and Instrumentation Diagram (P&ID), a design discussion around each critical component, and a safety analysis of the system as recorded in the attached hazard and operability (HAZOP) report. It also shows progress made to date on LFETS subsystems.

2 Design Requirements

2.1 Launch Vehicle No. 4 - 100 km Vehicle Requirements

LV4 will utilize a modular composite airframe consisting of layers of carbon fiber with Nomex honeycomb between them. Although more intensive to manufacture, the composite has higher strength than aluminum with a fraction of its weight. Using a composite airframe reduces weight and therefore lowers propellant requirements letting us to build a smaller and less expensive rocket. The fact that the rocket is modular rather than a single rigid body allows us to modify and rearrange subsystems to best fit our needs without a total redesign of the airframe. The rocket will be powered by an 6kN, Aluminum Silicate, 3D printed, engine.

LV4 must have both a sufficiently powerful engine and enough propellant to reach the 100 km apogee design goal. Constraints on engine design and the incentive to minimize gross lift-off weight cause tensions with our mission requirements, so to solve this complex problem we have utilized an iterative optimization scheme.

We start with the constraints that our future electric feed system and composite structures requires our engine have no more than 6 kN of thrust at sea-level. The variables that we then optimize for are total propellant mass, total mass flow rate, and exit pressure of the engine, thus determining our rocket design and its simulated trajectory which is used for evaluation.

The results of our Multidisciplinary Design Optimization (MDO) efforts inform subsystem design and engineering, which feeds back into the next iteration of optimizations as our designs become higher fidelity. As such, our mass flow rates and exit pressures are not calculated *per se*, but are indicative of the most feasible design we have available. For more information, please refer to our MDO document.

Our most current flight simulations from our MDO design show a vehicle with a gross lift-off weight (GLOW) of 220 kg, roughly 30 cm (12 in) outer diameter, and an apogee of 121 km.

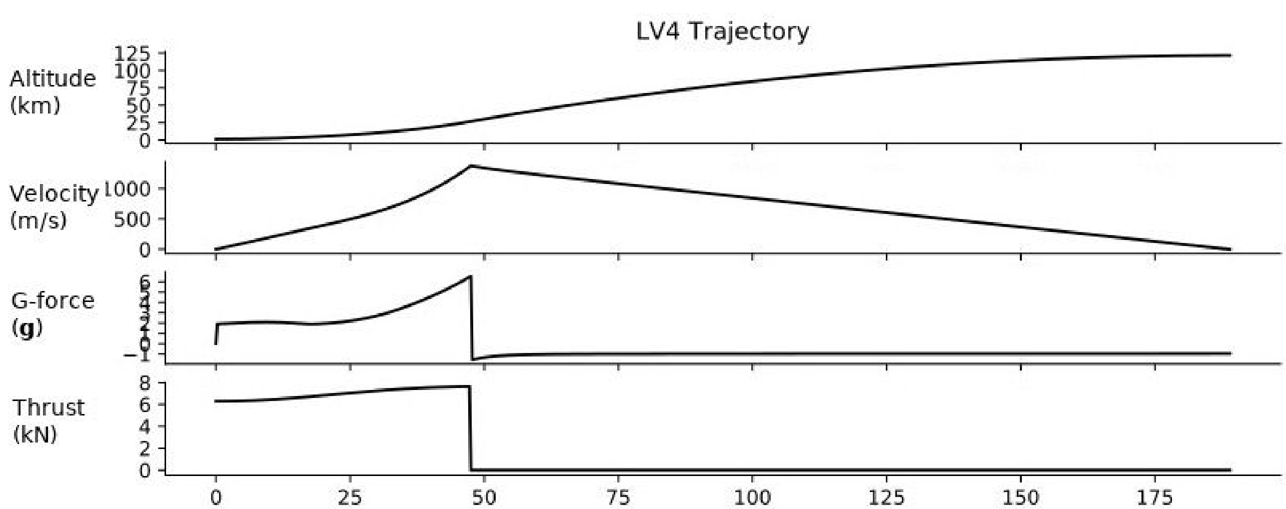


Figure 1 *- LV4 (100 km rocket) vehicle simulation*

2.2 Fuel Choice - LOX and IPA

After considering all of the possible propellants, and judging them based on safety, ease of acquisition, ease of use, and performance, we chose liquid oxygen (LOX) and Isopropyl alcohol (IPA) as our bi-propellant. Both are relatively inexpensive, readily available, safe compared to other bi-propellants, burn cleanly, and safely evaporate in the event of a spill. IPA was also chosen for its miscibility with water and correspondingly high heat capacity, ease of handling, and relatively low coking characteristics compared to kerosene. Our current bi-propellant is 64.8% IPA and 35.2% H_2O by mass, with a 1.3:1 oxidizer to fuel ratio. This corresponds to a 70% by volume isopropyl alcohol fuel.

2.3 Liquid Fuel Engine Design

Although the current design for the flight-ready Liquid Fuel Engine (LFE) is a 6 kN regeneratively cooled engine, our first test fires will be on a ⅓-scale 2.2 kN (500 lb) 3D printed regeneratively cooled engine and injector. (see Figure 2 for a diagram and Table 1 for performance numbers). We chose a LOX centered pintle injector design; the fuel inlet is at the nozzle and runs through the walls to the base of the housing where the propellants are metered into the combustion chamber (see Figure 2). The fuel absorbs combustion heat and returns it to the combustion chamber by passing through an annular metering orifice created by the gap between the pintle outer diameter and the combustion slot as seen in Figure 2**3** The LOX flows through the center of the pintle injector and is metered through orifices located radially about the tip. The two flows impinge to create an atomizing spray with a cone angle of 45 degrees.

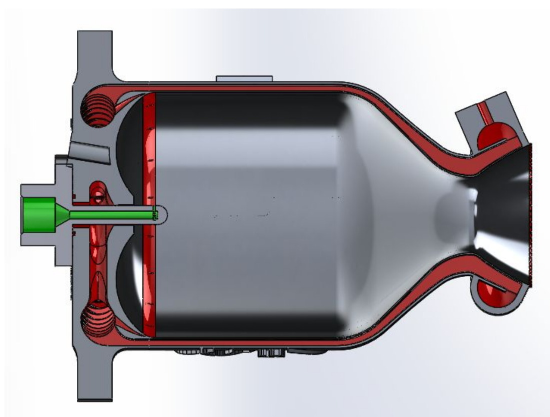


Figure 2: *Cross section of 2.2 kN engine. Fuel flow path shown in red, LOX flow path shown in green.*

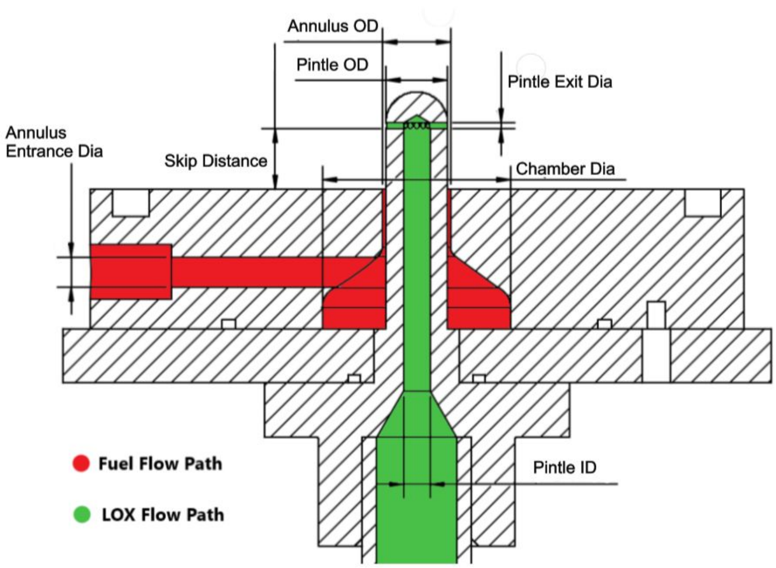


Figure 3: *Cross section of pintle injector. LOX flow path*

Once a valid 2.2 kN design is successfully tested, work will begin on scaling up the design to become the flight-ready 6 kN engine with optimizations stemming from observations and lessons learned during the 2.2kN test fires.

Parameter (unit)	**Value**
Chamber Pressure (psi)	350
Effective Exhaust Velocity (ft/s)	7800
Mass Flow Rate (lb/s)	2.06
LOX Mass Flow Rate (lb/s)	1.13
IPA Mass Flow Rate (lb/s)	0.94
Specific Impulse (s)	242

Table 1: *Various Parameters calculated for the ⅓ scaled, 2.2kN prototype.*

2.4 Test Stand Design Limits

In order to generate a set of maximum engine thrust and flow rates, we used a set of engine design Python scripts available on the PSAS Github here. Flow rates listed below in Table 2 include the ⅓-scale 2.2 kN demonstration engine, the last output from the LV4 optimization program for a 100km design engine of roughly 6 kN, and the worst-case maximum engine design of 10 kN.

Parameter (unit)	Demonstration	Current Proposed Flight Engine	Max Test Stand Design
	2.2kN (500lbf)	**6.28kN (1310lbf)**	**10kN (2250lbf)**
Chamber Pressure (psi)	350	350	350
Mass Flow Rate (lb/s)	2.06	5.78	8.23
LOX Mass Flow Rate (lb/s)	1.13	3.27	4.65
IPA Mass Flow Rate (lb/s)	0.94	2.51	3.58

Table 2: *Engine flow rates and test stand design requirement*

2.5 Safety Requirements

As per the Base 11 Safety Guidelines we have designed our test stand with safety in mind. A key aspect of this is that all of our test stand components must undergo a HAZOPS (Hazards and Operability Study) and pass a design review with industry advisors. Additionally all designs must conform to the following regulations and standards:

- ASTM MNL36-2nd Safe Use of Oxygen and Oxygen Systems
- ASME B31.3 Process Piping
- ASME Boiler and Pressure Vessel Code
- NASA NSS 1740.15 Safety Standard for Oxygen and Oxygen Systems
- NASA LPR 1710.40 Langley Research Center Pressure Systems Handbook
- PNNL 18696 Pressure Systems Stored-Energy Threshold Risk Analysis

The test stand and all components must be designed for safe operability and use. Specific training and operating procedures have been written out for each relevant subsystem of the test stand.

3 Design Overview

In order to accommodate future PSAS LFE designs, we chose to design a test stand that is capable of safely test firing and collecting performance data from a range of liquid fuel engines, with thrusts (and matching flow rates) up 10 kN.

Our design is a portable, horizontally firing, pressure-fed test stand with a completely automated control and data acquisition system called the Test Stand Automation and Regulation (TSAR). TSAR controls and automatically sequences the entire test fire procedure. Compressed Nitrogen pressurizes the LOX and IPA tanks through a series of valves. A blow-torch igniter ignites the propellent stream.

Most importantly, LFETS was designed from the ground up for safety. All systems are operated remotely and require no operators present. All systems are designed to “fail safe”. Hazard and Operability (HAZOP) study was performed on each portion of the system to identify possible failure modes and key component specifications. Each system is designed reviewed, and standard operating procedures (SOPs) are written for system operation.

Figure 4 shows the current LFETS CAD model. Figure 5 and 6 shows the current Pressure and Instrumentation Diagram (P&ID).

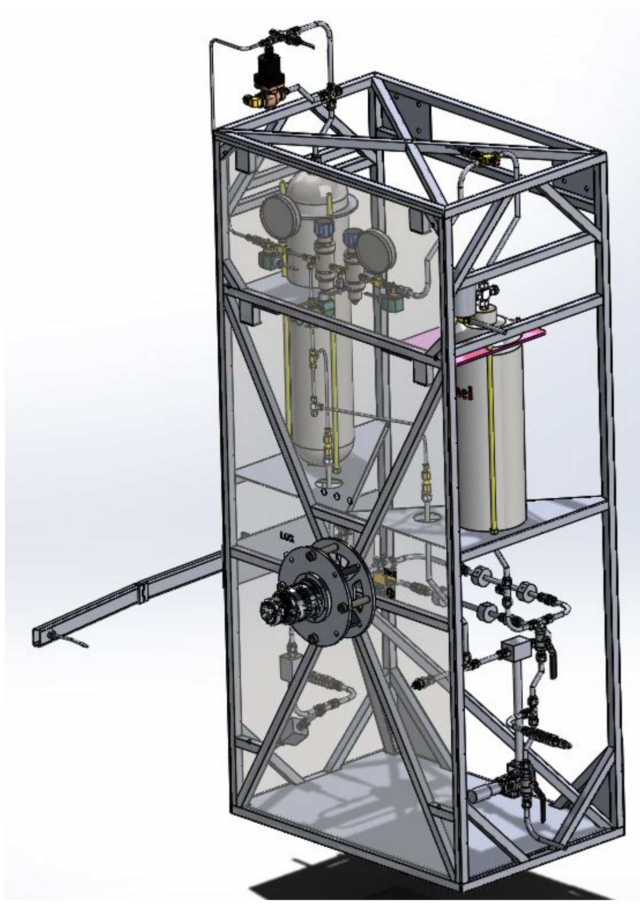


Figure 4: *Current CAD model of the test stand.*

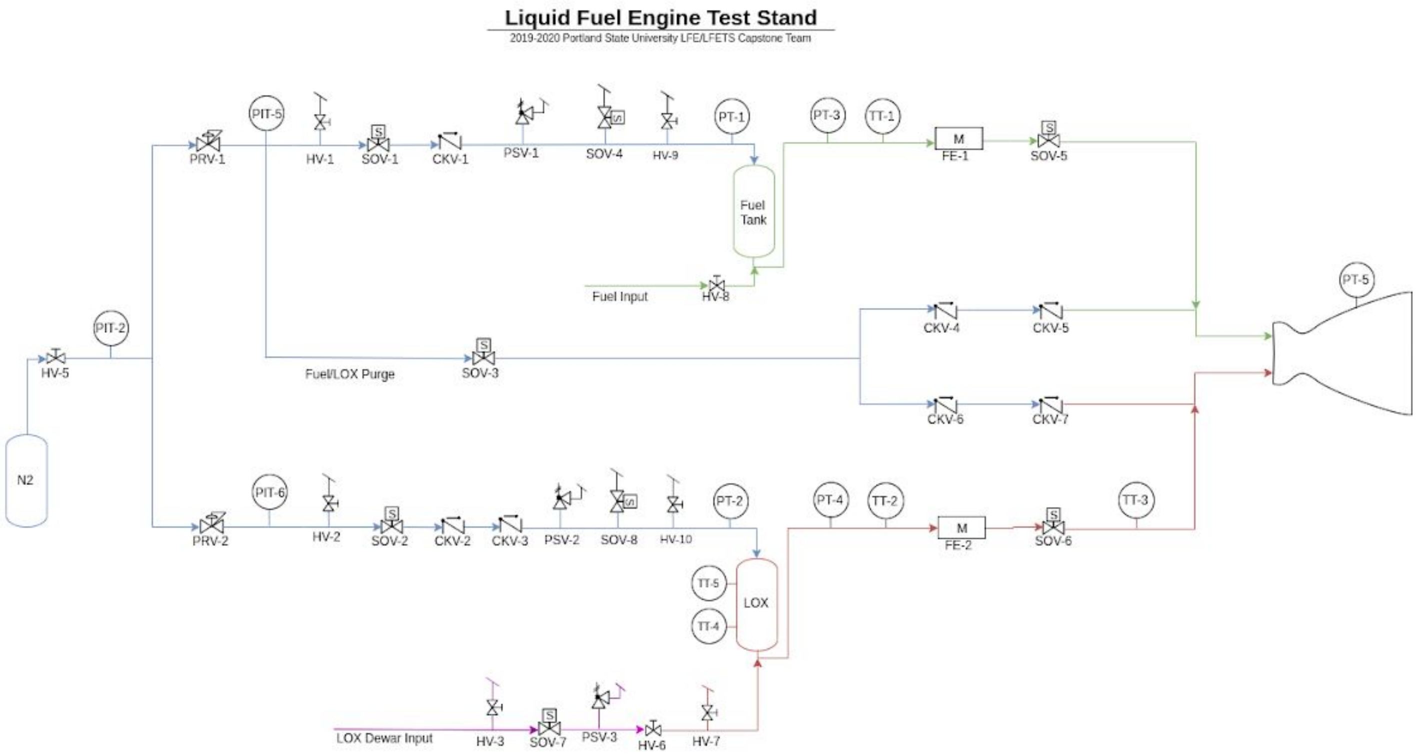


Figure 5: *Pressure and Instrumentation Diagram (1/2)*

Symbol	Acronym	Detail
N2	N/A	Nitrogen Pressure Vessle
Fuel Tank	N/A	Isopropyl Alcohol Pressure Vessle
LOX	N/A	Liquid Oxygen Pressure Vessle
	N/A	Liquid Fuel Rocket Engine
PIT N2	N/A	Pressure Indicator and Transducer
PIT-0	N/A	Pressure Indicator and Transducer
PT-1	N/A	Pressure Transducer
TT-1	N/A	Temperature Transducer
M	FE-0	Mass Flow Meter and Regulator
	HV-0	Hand Turn Valve, Vented to Atmosphere
	HV-0	Hand Turn Valve
	PRV-0	Pressure Relief Valve
S	SOV-0	Solenoid Operated Valve ,Vent to Atmosphere
S	SOV-0	Solenoid Operated Valve
	PSV-0	Pressure Safety Valve
	CKV-0	Check Valve

Figure 6: *Pressure and Instrumentation Diagram (2/2)*

4 Operational Overview

The test stand as a system operates as an automated system. During a test firing, the opening and closing of the valves is conducted remotely via the test stand automation system. The operator will be able to see all current valves states, pressures and temperatures. To make the test stand do something, the operator will enter a command into the system.

The test stand operation will proceed following the very broad outline:

- Setup and Wiring SOPs
    - Setup and check systems for damage, connect data and power connections according to SOPs
    - Includes visual inspection and test operation of all valves
    - Inspection and setup of ignition system
- Fuel and Nitrogen Loading SOPs
    - Processes to load high pressure nitrogen and fuel into the test stand
    - The test stand will be powered but locked out to prevent arming
- Liquid Oxygen Loading SOPs
    - Semi-automated process to fill liquid oxygen and chill the lines
    - Technicians will attach a dewar and set hand valves into their fill positions, then withdraw from the test stand
    - Filling and engine chill will be conducted with automated subroutines, using a series of temperature sensors to determine when chill is complete and tank is full
    - Technicians will then return, reset hand valves to their standby position and remove the dewar
- Test Firing SOPs
    - After the pad is cleared, the arming lockout will be removed and the operator will step through a series of predefined states (See Figure 7) to conduct the fire
    - The rough order of system states include:
        - Arm
        - Chilldown
        - Ready
        - Pressurized
        - Staged ignition states
        - Firing
        - Purge
        - Shutdown
- Emergency Stop
    - The test stand includes a physical emergency off button on the test stand and at the control station which overrides any functions in progress
        - The pressing of this button at any time immediately puts all valves into their standby/safety state
        - This closes the main fuel/oxidizer valves, closes the nitrogen valves and depressurizes the entire system
    - The test stand automation system also contains software acceptable ranges for pressure gauges, and will trigger a shutdown if any monitored pressures go outside of the acceptable limits.
- Lockout Provisions

    - The test stand includes an arming key at the control center. Without this key, the igniter cannot be powered, and the system contains a software interlock to return an error if the system is attempted to be armed.
        - In order to arm the system, the arming key must be interested into the lock and the system turned to arm.
    - The test stand also includes a lock that accepts the same arming key. Whenever personnel are at the test stand, they will carry the arming key with them, and insert it into the test stand and turn it to the “safe” position. In the safe position, valves cannot be moved from the safety state and the igniter cannot be powered.
        - When procedures dictate moving automated valves, personnel must clear the area and take the arming key with them.
- Breakdown and Cleanup
    - Liquid oxygen will be allowed to boil off after operations are complete
    - Fuel will be drained manually
    - Nitrogen will be manually disconnected
    - Test stand power and data connections will be manually disconnected and packed up

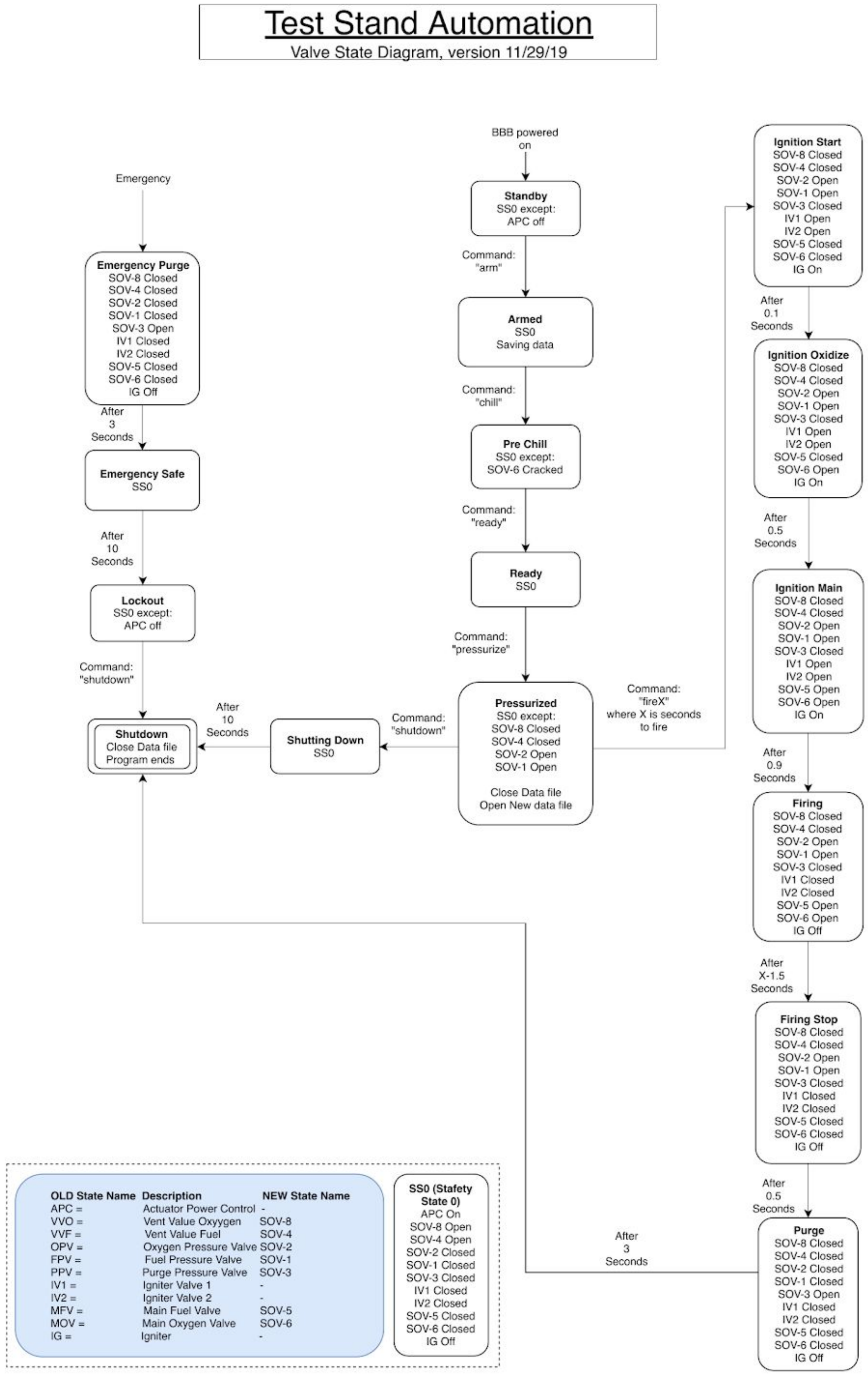


Figure 7: Test fire flow chart

5 LFETS Detailed Mechanical Design

Test stand components are being tested to meet all operational and safety requirements. Individual tanks will be rated and tested, and all components have been designed to operate within their working pressures. In the case where a failure could result in operation outside of maximum allowable pressures, pressure relief valves are located to protect those components. While this section is a general discussion, also please see:

- See Appendix B for the HAZOP analysis of each of these systems.
- See Appendix F for the LFETs

5.1 Filling and Operation Principles

Our test stand is designed to minimize human interaction by providing pressurization, firing, and purging operations remotely. As designed, operators will move fuel and oxidizer to the stand, then the stand will be loaded using a hand pump for fuel and autogenous pressure for the oxidizer. The fuel will be measured ahead of time. We will load fuel first, allowing the overflow to evaporate. The oxidizer will then be filled utilizing a top-level temperature sensor to determine when the oxidizer has reached the top of the tank. The system will then allow for a remote engine chill.

Figure 8: *Physical test construction of the stand with a mock-plywood pressure panel. Note: not all components in photo are updated. Please refer to the P&ID and appendices for current specs.*

5.2 Pressure Testing

All pressure components are first pressurized to low positive pressures. Leaks are checked for by spraying hardware and suspect locations with a soapy water mixture. The system is depressurized and leaks are fixed. The system is then pressurized to some fraction of operational pressure checked for leaks again. The process is repeated, pressurize, leak check, depressurize, until the system has been tested to a factor of safety (FS) of 1.5 per [FAA AC43.13-1B](#).

5.3 LOX Compatibility

All seals, metals, seats, and other valve or plumbing components from the outlet of the pressure regulator on the oxygen side of the system to the pintle are chosen for LOX compatibility. Stainless Steel (SS304 or SS316) is used for hardware and plumbing. PTFE or equivalent material replaces all non-metal components. Valves are specifically chosen for LOX compatibility and must show ability to cycle in the worst case scenario even with the formation of water ice.

5.4 Structure and Anchoring

The main frame of the test stand is constructed of welded 1” square steel tubing. The test stand frame is designed to withstand engines with up to 10kN of thrust. To ensure this requirement could be met, a finite element analysis was performed using Abaqus (Figure 9). Since the analysis has been performed, the structure of the test stand has been altered by welding a hexagonal mounting ring to where the cross-members meet. The purpose of this change is to allow propellant piping to enter the back of the engine directly rather than be blocked by the crossing members. Because of these changes, we will rerun an analysis of the updated design before we begin testing.

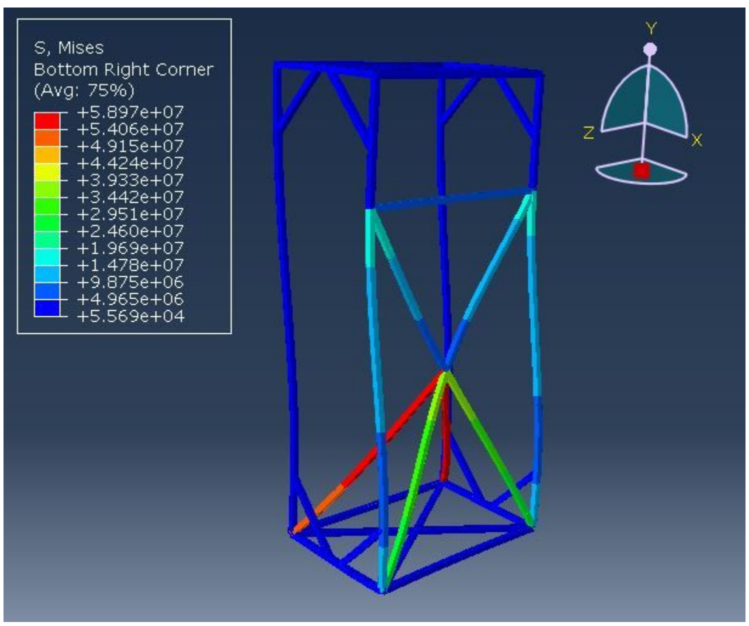


Figure 9 *Test stand structural Finite Element Stress Analysis.*

An additional design requirement of our test stand was that we wanted it to be transportable in the back of a pickup truck. To make this happen, we settled on the upright table design seen above. The challenge created by this type of design is that it is possible to tip the stand over. In order to anchor the stand, we plan on ground anchoring with guy wires. We will update our CAD and analysis when we have selected a test fire site and can properly model our anchoring method.

5.5 Actuated Components

Active components on the test stand includes solenoid valves used to control nitrogen pressure and venting. All solenoid valves will be 12V or 24V DC and be rated for working pressures above that of commercially available N_2 gas. We will use pressure sensors located in the lines to confirm the valves have actuated.

The P&ID (see Figure 5) identifies valves SOV-5 and SOV-6 as solenoid valves, although they are currently motor operated values. These are the main fuel and oxidizer valves, respectively. This design utilizes a high-torque 12V DC motor and bent sheet metal brackets fabricated to fit the ball valves. The advantages of this design includes the use of low-cost components and the inclusion of a magnetic absolute position sensor.

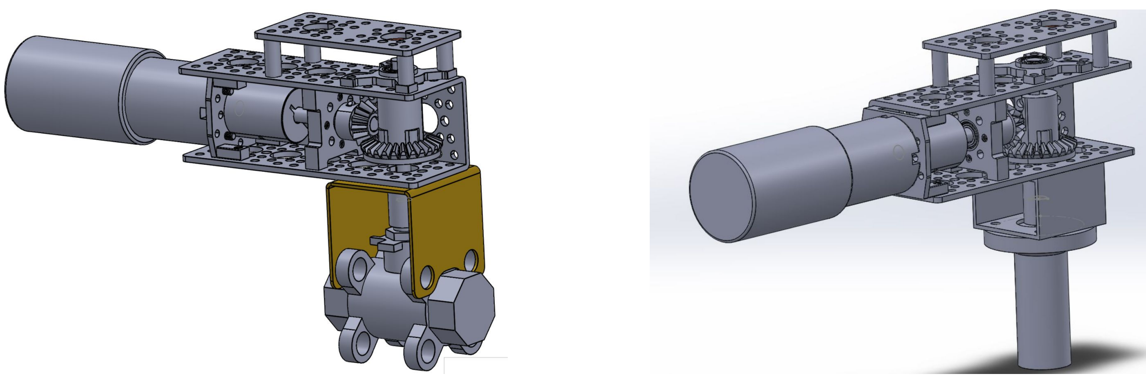


Figure 10: *Main fuel valve, SOV-5. (left) and Main LOX valve, SOV-6. (right)*

The challenges with this design is that although the prototype does actuate both fuel and oxidizer valves while providing live position sensing, the design will not close under power failure conditions. Through consultation with industry experts, we have become aware of the need to encase the cryogenic valves in a dry environment to prevent moisture buildup and freezing of the valve

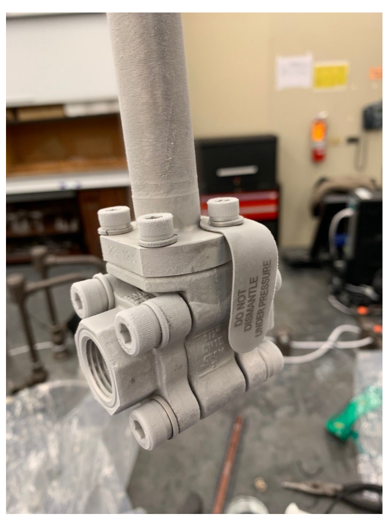


Figure 11: *Frost buildup on LOX valve during liquid nitrogen testing.*

5.6 Pressure Regulators

The stand uses two primary pressure regulators to control gas pressure to the tanks. One regulator provides pressure to the fuel and purge lines, and the other regulator provides pressure to the oxidizer line. The regulators are adjustable, allowing us to use different pressures on the fuel and oxidizer systems as required by the pintle injector design. Each regulator will be located above the liquid tanks and protected from liquid by check valves. Currently spec'd regulators have a maximum downstream working pressure of 500psi, so we may replace the existing regulators if we choose to experiment with engine pressures above the current design.

One additional design change we made with regard to the pressure regulation system was incorporating manual valves HV-1 and HV-2 on the P&ID into the system just downstream of the regulators. These will be used as bleed valves that will allow us to vent N2 manually to adjust the regulator outlet pressure without opening the entire system.

5.7 Pressure Relief Valves

To protect the test stand from over pressure failures, the design includes three pressure relief valves: one on the fuel line, one on the oxidizer line, and one on the dewar fill line. The fuel and oxidizer relief valves will be physically mounted above the tanks and open at preset pressures above operating pressure. The valves are currently specified to open at 650psi on the LOX line and 850psi on the fuel line. We are reviewing these values and may replace these components if the pressure requirements change.

5.8 Pressure Vessels

The primary pressure vessels in the test stand include the N_2 tank, the liquid oxygen tank and the fuel tank. All pressure vessels are and will be DOT-rated pressure vessels. We are still evaluating our N_2 pressure options; at this time we plan to use the compressed nitrogen cylinder delivered by a gas supplier, either one by itself (or several manifolded together depending on our expected nitrogen usage).

The liquid oxygen tank is a Hoke 4-gallon (15L) stainless steel sample cylinder. This tank is manufactured with threading on both ends and is rated up to 1800 psi, well above the pressure relief valve on the oxygen lines. The capacity of this cylinder should allow for approximately a 10-second test of the ⅓-scale 2.2kN design.

The fuel tank seen in Figure 8 is a Luxfer aluminum CO2 tank. This tank is sufficiently rated, and we will purchase a second sample cylinder to match the liquid oxygen tank.

5.9 Check Valves

Our design specifies single check valves on the fuel side and double check valves on the liquid oxygen (LOX) side. Double check valves are recommended by most industry professionals with cryogenic experience. This is especially helpful when considering LOX systems which must be sealed using relatively hard PTFE O-rings. One concern with the cryogenic check valves is water ice buildup from condensed moisture. We will use inert purging before filling the system to help alleviate this concern by replacing the air in the lines with N_2.

5.10 O-rings and Seals

Most seals are Commercial Off The Shelf (COTS) parts that can be replaced easily with PTFE seals of the same type. It should be noted that PTFE will not seal as well as the original, which is taken into account by careful construction and component de-rating.

5.11 Ignition System

The ignition system is an external blow torch on a passively actuated arm. The arm is intended to hold the ignition source in the correct position until engine ignition, at which point the arm will be moved away from the engine by the exhaust flow. The igniter is controlled by the Test Stand Automation and Regulation (TSAR) system, which requires a key system to fire. The system is enabled by key in ARM position, and disabled by the key in the SAFE position. A CAD mockup of the arm design is shown below.

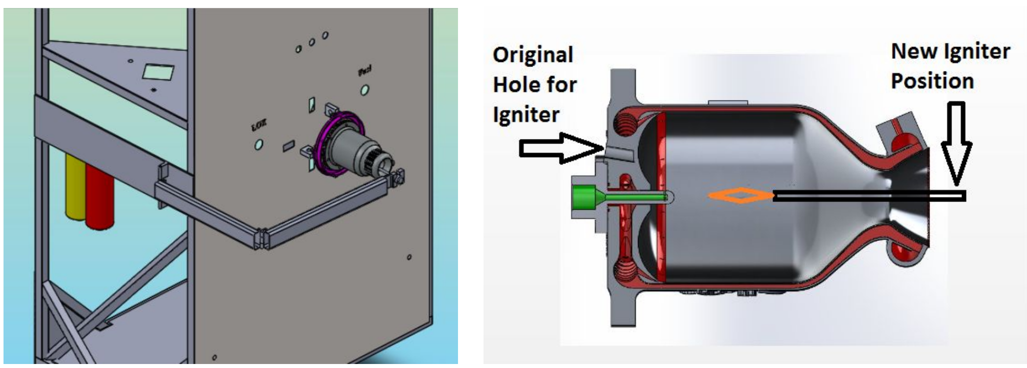


Figure 12: *Solidworks model of new igniter system attached to the test stand model (left). Igniter position change in the engine (right).*

We completed a prototype of the arm mechanism in the spring, however the torch components have not yet been tested. We are reviewing our options and may elect to replace the spark torch system with external fuel/oxidizer as shown in the CAD.

5.12 Test Stand Materials Selection

Base Materials

The test stand currently uses Aluminum, brass, and stainless steel for its components. The frame of the test stand is made from 1" square steel tubing with a painted coating. The materials used to support plumbing on the test stand are generally anodized Aluminum, stainless steel, or Teflon. These materials were chosen for accessibility and are not intended to interact directly with liquid oxygen. All liquid oxygen-contact components will be specified as cryogenic and LOX-compatible. This will include primarily stainless steel and brass components.

Stainless Steel (304/316)

Stainless steel will be used wherever economically feasible. Eventually the team would like to replace all piping, fittings and components with stainless steel, however this is cost prohibitive. At this time only the piping, fittings and valves on the liquid oxygen lines are stainless steel. We will replace or upgrade the fuel and gas systems with stainless steel components as we are able over the next year. One potential challenge with stainless components is a tendency to experience galling. Anti-seize compounds will be used between stainless fittings to help reduce galling of the threads.

Aluminum (any series)

Aluminum was chosen for its ease of use and compatibility with the fuel mixture of IPA and water. One challenge with aluminum is that it presents the largest corrosion risk especially when mated with dissimilar metals. We are in the process of designing storage processes to mitigate the types of corrosion issues experienced by other teams mixing aluminum and brass components. Aluminum fittings are also much cheaper than stainless steel fittings at about 15-20% of the cost. Aluminum is significantly less likely to seize than SS but anti-seize compound should still be used.

Brass (any series)

Brass was chosen for many components due to it’s LOX compatibility and high availability. It’s also significantly cheaper than the same components made of SS. Brass is unlikely to experience galling but does present a corrosion risk when mixed with aluminum components. We also currently have a number of swagelok fittings on the gas system which presents a cross-threading risk. Mitigation of cross threading is a matter of simply taking care with alignment when getting the first few turns in on the shoulder nut.

Sealants and Anti-Galling

For components not in contact with oxygen, we use a generic Permatex anti-seize component. This is primarily used for AN type shoulder nut threads. Where components are part of the LOX system, Krytox TS4 is used. This is a “thread sealant” that also acts as an anti-galling compound. Ideally the anti-seize on the SS (AN style) shoulder nuts should never experience a high oxygen environment but cryogenics are notorious for leaking, so it is possible that contact will occur.

For pipe threads in contact with oxygen, oxygen compatible thread tape is used (Federal Process GT90). Other pipe-threads are sealed with regular PTFE or other base pipe tapes.

6 Detailed Electrical Design

6.1 Major Subsystems

The Test Stand Automation and Regulation (TSAR) system is split up into six major subsystems:

1. **Command & Control** is the remote interface, consisting of the User Interface laptop which allows operators to command test fire, monitor pressure and temperature, and safely store data. The command and control laptop is located a minimum safe distance from the test stand.
2. **Central Manager** is the Linux-based computer and software that implements and manages the firing sequence and receives, records, and retransmits all test data from the sensors.
3. **Actuator Controller** is under the Central Manager and is a safety-critical microcontroller-based system responsible for directly managing all actuators.
4. **Actuation** consists of all TSAR subsystems that control test stand propellant actuators, such as the main fuel valve, lox valve, and solenoid pressurant valves.
5. **Sensing** consists of all TSAR subsystems that have pressure, temperatures, or state sensors (see Pressure and Instrumentation Diagram) and perform data acquisition.
6. **Power Management** powers and controls all of the TSAR subsystems.
7. **Data Backup** is a Linux-based client listening to the retransmitted data from the central manager and acts as a data backup.

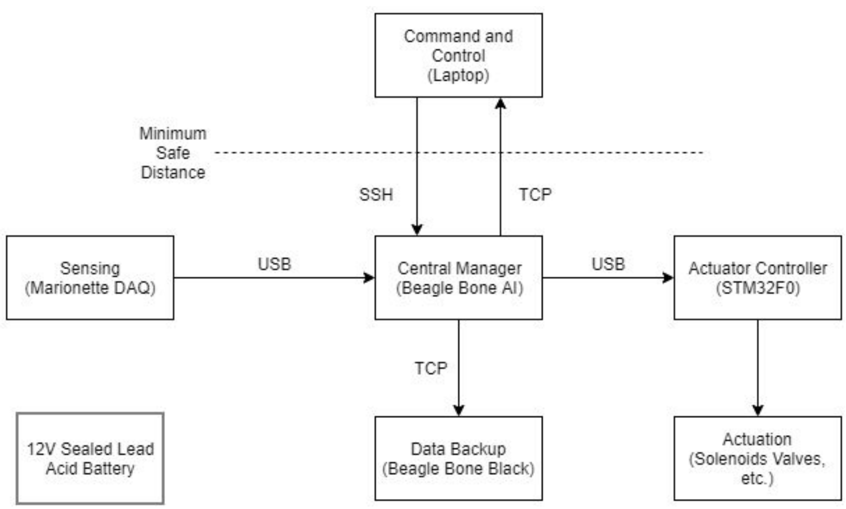


Figure 13: *TSAR high-level system block diagram.*

6.2 TSAR Control Architecture

To ensure safe and consistent operation of the engine, any abnormalities (loss of communication, abnormal sensor data, etc.) will result in the safe shutdown mode being initiated.

All actuation control is done via the Actuator controller, a simple single-threaded microcontroller running bare-metal C code. The Actuator Controller will reliably relay control instructions from the Central Manager, while also monitoring the Central Manager (via a heartbeat signal) for failure. The TSAR state machine will be implemented on the Actuator Controller, with the Central Manager providing the state transition signal. The TSAR state machine includes the safest emergency shutdown procedure for each point of a test fire. The Central Manager can send the command for an emergency stop, or—in the event of a loss of signal from the Central Manager—the Actuator Controller will automatically engage the emergency stop.

The Central Manager is designed to be a dedicated, high-level orchestrator for test-fires. It is implemented on a BeagleBone AI running Linux and has direct access to all sensor data from throughout the system, and handles and signal processing, while also providing the signal for state transitions to the Actuator Controller. It observes, collects, saves, and transmits all sensor data to Command & Control from Sensing subsystems. The Central Manager accepts very basic high-level commands from Command & Control, such as "Start Test Fire", or "Range Safety Officer confirms personnel have left the area", or "Emergency Stop". However, outside of these commands, the Central Manager is completely independent of Command & Control. Connection loss or abnormal sensor data results in an automatic emergency shutdown code being sent to the Actuator Controller, which shuts the engine down and locks the entire system out until full shutdown.

Command & Control serves as a remote user interface allowing test stand operators to easily enter high-level commands from a large distance, view sensor readouts. It consists of a laptop (connected over ethernet) and safety enable system that controls power to TSAR systems.

Data Backup systems consist of a single TCP client listening to transmitted data sent from the Central Manager and storing the data on a local SD card. There will always be at least one Data Backup system (often integrated with the Command and Control system), but multiple Data Backup systems are preferred for data redundancy.

6.3 TSAR Power Architecture

The Test Stand Automation and Regulation (TSAR) system includes several safety systems, an emergency stop, and a lock-out tag-out box. The system is powered by two 12V Lead-Acid batteries located at the command center. TSAR's Power Management has a large number of redundant lockouts. First, power is sourced from two 12V Lead-Acid batteries. This power is passed through an on-stand fuse, emergency stop, and power key switch located at minimum safe distance for operators from the stand, and is then passed to the Remote Electrical Lockout Panel, as well as the Control & Sensing relay. The Control & Sensing Relay defaults to open, and its gate is driven by an emergency stop, power key switch, and in-line shorter bar receptacle. Once power passes the Control & Sensing relay, it is delivered to the Control & Sensing power subsystem. There is a shorter bar present across the supply and ground rails for Control & Sensing power.

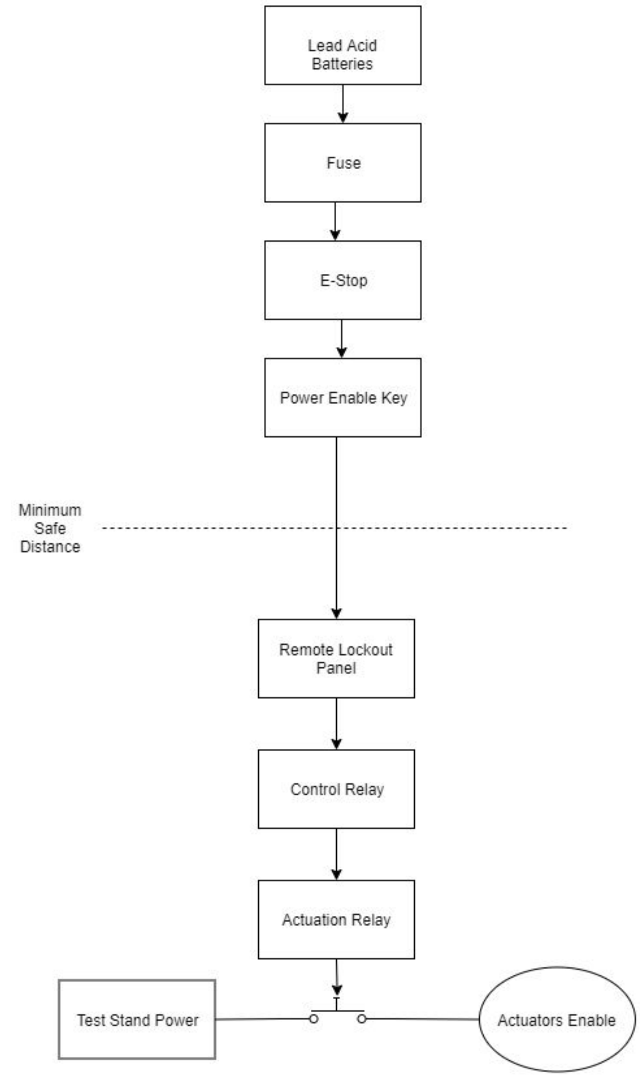


Figure 14: *TSAR Power Enable Architecture.*

Control & Sensing power boots the Actuator Controller, Central Manager, and all sensing subsystems, but does not power any actuators.

Power from Control & Sensing is also passed off to the Actuation Manual Relay, which once again defaults to open, and has its gate driven by a power key switch and in-line shorter bar receptacle on the Remote Electrical Lockout Panel.

This power is immediately passed off to the Actuation Automatic Relay, which defaults to open, and is directly managed by the Actuator Controller. In this way, both the Actuator Controller, and operators at Command & Control must sign off on power delivery to Actuation before it occurs. This power is then finally delivered to all actuators in the system.

Finally, just after the Actuation Automatic Relay, there is another shorter bar across the supply and ground rails for Actuation power.

The end result is that, in order for a test to successfully occur, the following steps must be observed:

1. Disengage shorter bar on sensing & control power before the test begins.
2. Turn on-site power key, and check on-site emergency stop disengaged.
3. Insert the shorter bar into the sensing & control shorter-bar receptacle
4. Personnel turn Sensing & Control power key at the Remote Electrical Lockout Panel and ensure the emergency stop is not engaged.
5. Personnel launch Command & Control client, connect to Central Manager, and initiate test fire.
6. Personnel disengage actuation shorter bar, leave test area, insert the bar into the receptacle for actuator power, and confirm personnel no longer near stand on Command & Control.
7. Personnel engage Actuation power key on Remote Electrical Lockout Panel, tell Command & Control to begin the firing.
8. Actuator Controller engages Actuator power, test fire begins.

The shorter-bars ensure that when a subsystem is not supposed to be engaged, if it is ever accidentally engaged it immediately blows a fuse. The in-line receptacles at the Remote Electrical Lockout Panel also guarantee that a system cannot be powered on until it's shorter bar is removed. The shorter-bars are different sizes to guarantee they are never swapped by accident. The emergency stops ensure that on-site and remote personnel can immediately kill all system power at any time.

6.4 TSAR Software Architecture

TSAR top-level control is handled by FRESHMEN, (Forward Range Engine System Hotfire Management and Emergency Notification). This software presents a heads-up display for test fire status and sensor data, and a simplified command interface for generating high-level commands to be sent off to the Central Manager. FRESHMEN connects to the Central Manager using JSON over TCP, with physical layer being Ethernet.

The Central Manager is responsible for coordinating all test fire operations. It has direct access to all sensor data, and has explicit control over all actuators, and actuator power itself. While the Central Manager is directly connected to most sensors, it does not directly control any actuators. Instead, all actuation is accomplished by sending commands to the Actuator Controller. The central manager must handle saving and retransmission of all engine test data. The Central Manager program has black box regions dedicated to sensor hardware interface and communication with the Actuator Controller.

The Actuator Controller is the central pathway for all control over actuators. It serves as a final defense against system failure. Its programming is kept as simple as possible, and is focussed solely on producing reliable control signals for all actuators on the test stand. The Actuator Controller requires a consistent heartbeat an emergency response code corresponding to the currently most appropriate way to detect and handle emergency indicators, such as connection loss. If for some reason this heartbeat stops, or any other emergency indicator is tripped, the Actuator Controller will execute an emergency shutdown routine in accordance with the emergency response code most recently sent.

Appendix A - Links to CAD and Technical Drawings

All drawings, CAD files, and project documentation are located on the PSAS Github page and on Google Drive. The specific repositories and drive folder can be found at:

- Repositories
  - https://github.com/psas/liquid-engine-test-stand
  - https://github.com/psas/liquid-propellant-engine
  - https://github.com/psas/pintle-injector
- Links to included drawings
  - Piping & Instrumentation Diagram (P&ID)
  - Test Stand Automation and Regulation (TSAR)

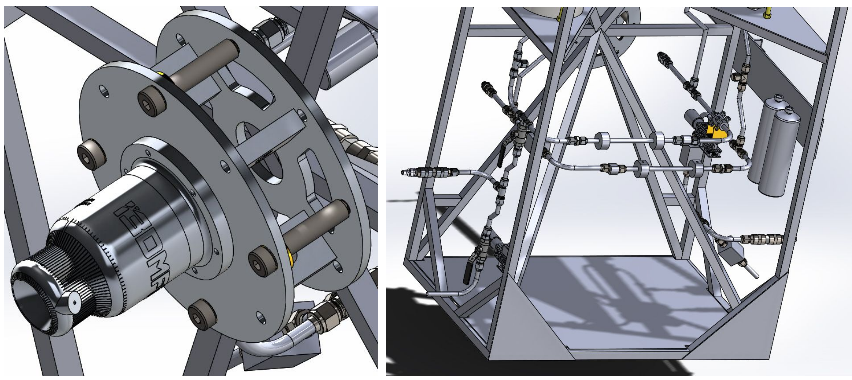


Figure 14: *Pictures of the test stand Solidworks model showing the engine on the thrust plate (left) and the lower fuel and LOX sections (right).*

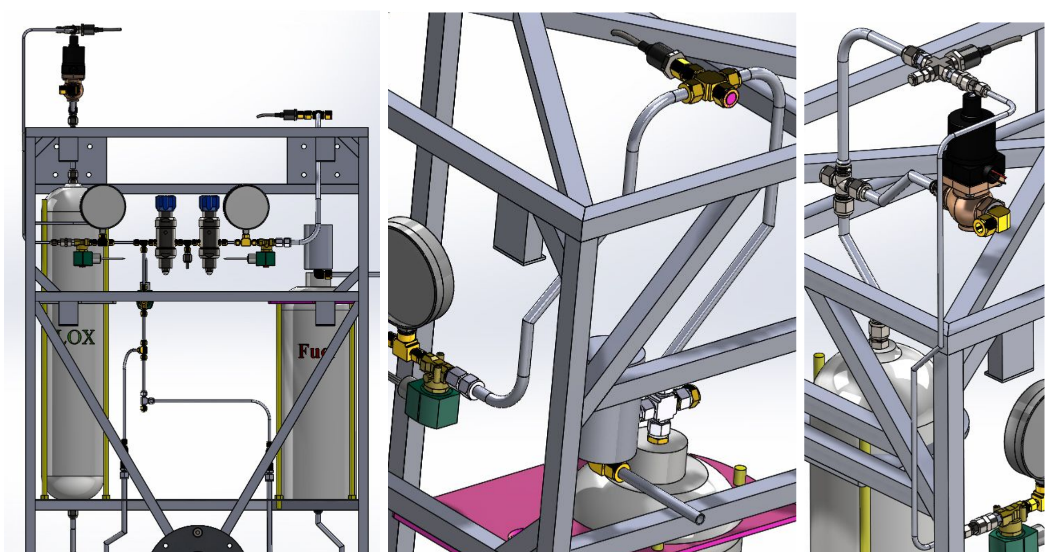
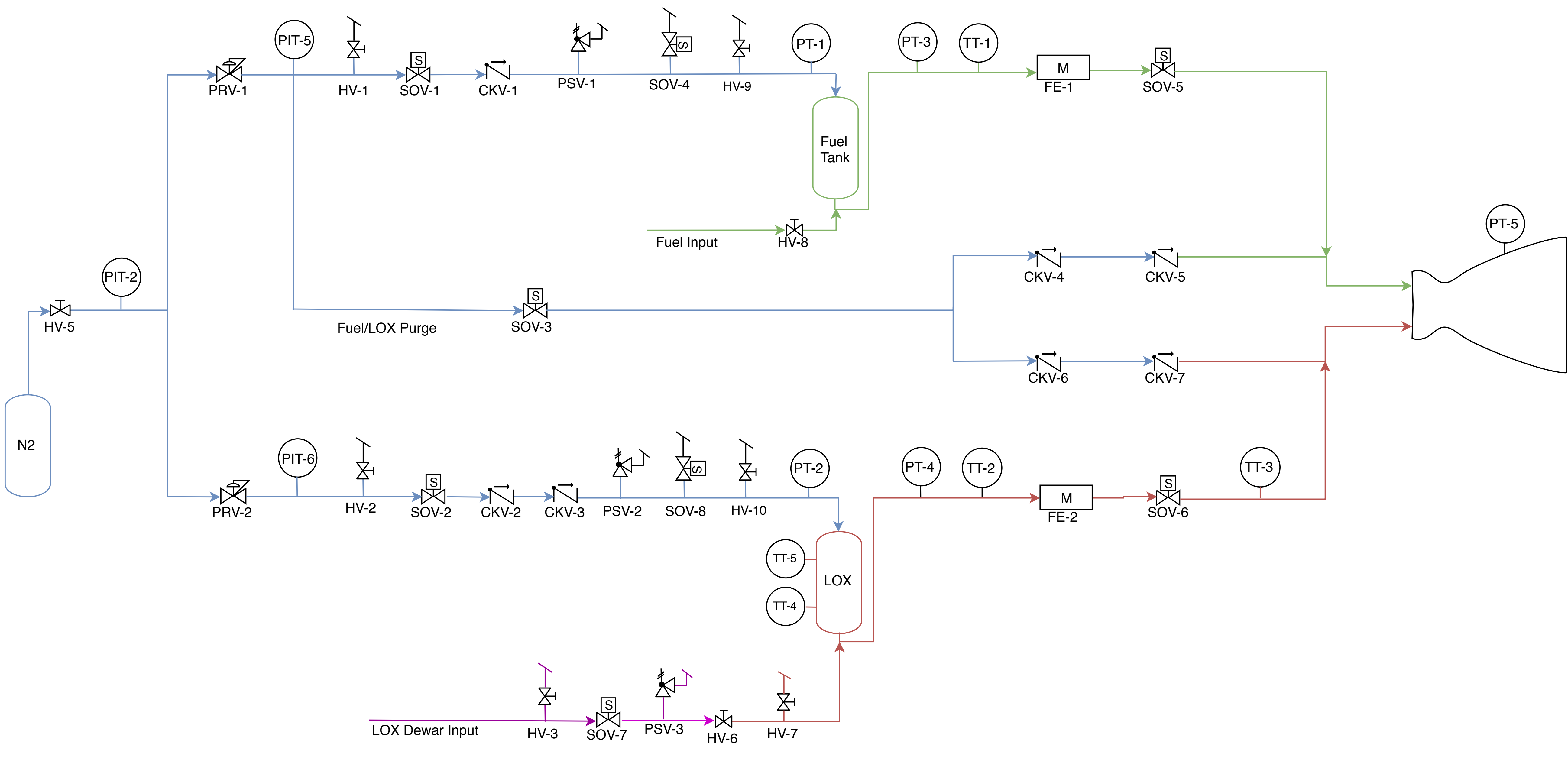


Figure 15: *Pictures of the test stand Solidworks model showing the pressure section (left), the upper fuel section (middle), and upper LOX section (right).*

Symbol	Acronym	Detail
N2	N/A	Nitrogen Pressure Vessle
Fuel Tank	N/A	Isopropyl Alcohol Pressure Vessle
LOX	N/A	Liquid Oxygen Pressure Vessle
	N/A	Liquid Fuel Rocket Engine
PIT N2	N/A	Pressure Indicator and Transducer
PIT-0	N/A	Pressure Indicator and Transducer
PT-1	N/A	Pressure Transducer
TT-1	N/A	Temperature Transducer
M	FE-0	Mass Flow Meter and Regulator
	HV-0	Hand Turn Valve, Vented to Atmosphere
	HV-0	Hand Turn Valve
	PRV-0	Pressure Relief Valve
S	SOV-0	Solenoid Operated Valve ,Vent to Atmosphere
S	SOV-0	Solenoid Operated Valve
	PSV-0	Pressure Safety Valve
	CKV-0	Check Valve

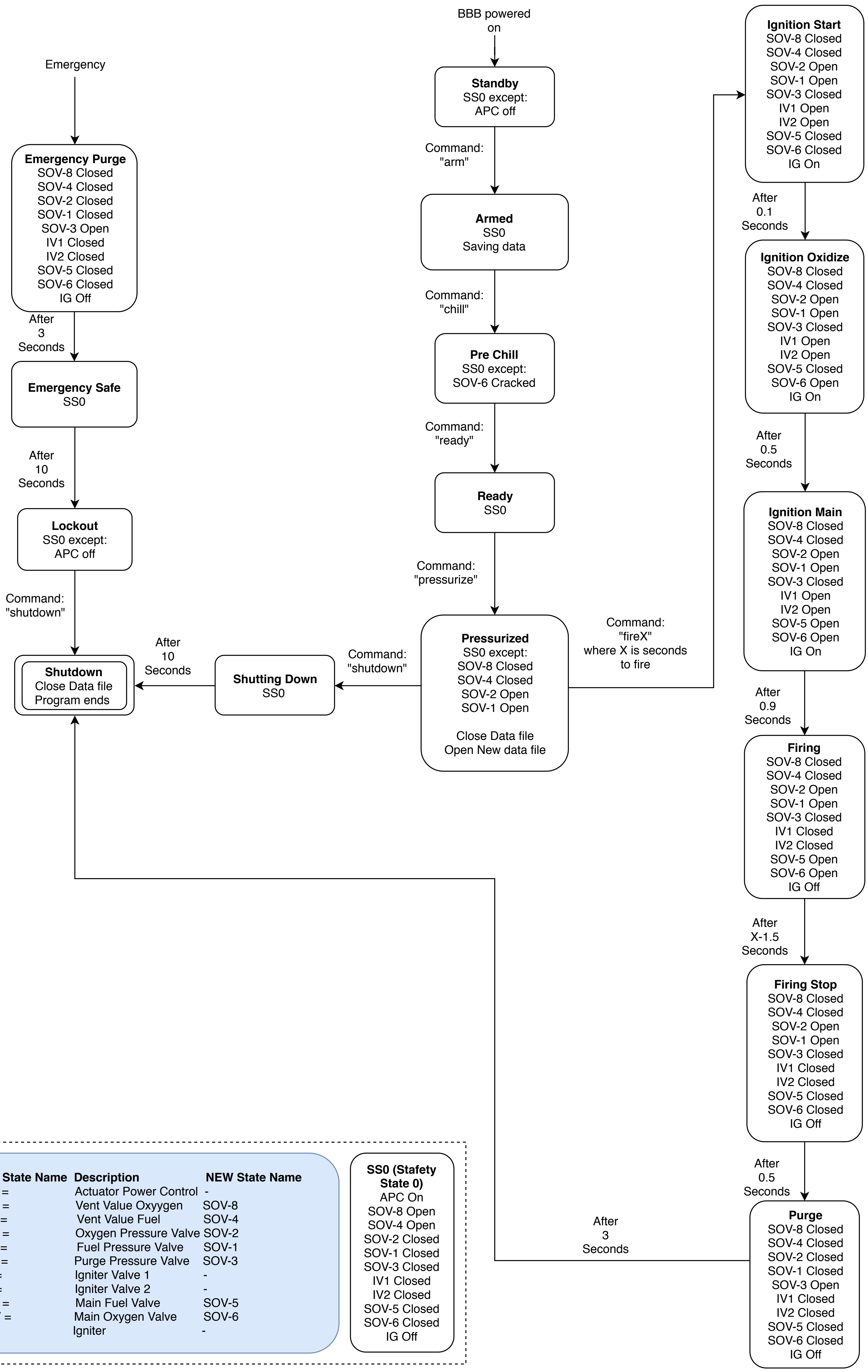
Liquid Fuel Engine Test Stand

2019-2020 Portland State University LFE/LFETS Capstone Team



Test Stand Automation

Valve State Diagram, version 11/29/19



OLD State Name	**Description**	**NEW State Name**
APC =	Actuator Power Control	-
VVO =	Vent Value Oxyygen	SOV-8
VVF =	Vent Value Fuel	SOV-4
OPV =	Oxygen Pressure Valve	SOV-2
FPV =	Fuel Pressure Valve	SOV-1
PPV =	Purge Pressure Valve	SOV-3
IV1 =	Igniter Valve 1	-
IV2 =	Igniter Valve 2	-
MFV =	Main Fuel Valve	SOV-5
MOV =	Main Oxygen Valve	SOV-6
IG =	Igniter	-

SS0 (Stafety State 0)
APC On
SOV-8 Open
SOV-4 Open
SOV-2 Closed
SOV-1 Closed
SOV-3 Closed
IV1 Closed
IV2 Closed
SOV-5 Closed
SOV-6 Closed
IG Off

Appendix B - Hazard and Operability (HAZOP) Study

A hazard and operability study (HAZOP) was conducted for the liquid fuel engine test stand (LFETS) to review the piping and instrumentation (PID) for safety and common failure modes. This document can be found on the Portland State Aerospace Society Google Drive (link).

HAZOP Report

Liquid Fuel Rocket Engine Test Stand

November 2019

TABLE OF CONTENTS

EXECUTIVE SUMMARY

A hazard and operability study (HAZOP) was conducted for the liquid fuel engine test stand (LFETS) to review the piping and instrumentation (PID) for safety and common failure modes.

This HAZOP study reviews the following portions of the PID, later referred to as nodes:

1) Liquid oxygen oxidizer system.
2) Isopropyl alcohol fuel system.
3) Pressurized nitrogen purge system.
4) Filling Liquid oxygen tank.

The system was studied to determine whether potential hazards or operation concerns were present under high/low temperature, high/low pressure or high/low flow conditions. When potential issues were identified, the proposed design was assessed to determine if it adequately mitigated the concern. In cases where the design did not include a way of addressing the concern, additional components were modified or electronic interlocks were proposed to mitigate the hazard.

Overall the pre-existing design was able to address most concerns through physical components selection, however two common themes from the meeting were an emphasis on more detailed specification for components in each section of the system based on the maximum possible pressure or flow rates they could experience under failure conditions, and ensuring that components in the LOX node are rated for cryogenic and oxygen conditions. Many components of the system will need to be tested, retested or replaced based on the results of this HAZOP report.

The report below documents the meeting, the PID nodes and recommendations from the group for changes that need to be made to the design. The HAZOP identified 44 potential issues and made 11 recommendations to mitigate these problems. The following report is split by deviation and node and follows the structure of the meeting.

1 HAZOP MEETING

Meeting Location: Portland State University, Portland Oregon
Meeting Date: November 12, 2019
Meeting Days: 1

Site: Engineering Building
Room: EB 450

Leader: Mike Mckenzie
Scribe: Solomon Reid

2 INTRODUCTION

2.1 Purpose of Study

A HAZOP study is conducted to identify potential hazards that can occur in the liquid fuel engine test stand system. The HAZOP specifically considered the following conditions:

- High pressure
- Low pressure
- High temperature
- Low temperature
- High flow
- Low flow

2.2 Scope of Study

The scope of the HAZOP study includes the liquid fuel engine test stand system and its associated utilities. This includes the portions of the system handling high-pressure nitrogen, liquid oxygen and isopropyl alcohol.

The table below include drawings that were used in the HAZOP study.

Table 2-1 - Drawings Used in the Analysis

Type	Number	Title	Revision	Revision Date
Drawing	PID-001	Liquid Fuel Engine Test Stand	001	11-12-2019

3 HAZOP METHODOLOGY

3.1 Hazard Analysis Method

The HAZOP study is a qualitative means of identifying hazards and began by breaking the system into nodes. The team then identified all deviations from the way each node is intended to function (high temperature, high pressure, etc). The team next proceeded stepwise through each component in the system for each deviation and identified hazards. Once a hazard was identified, the team noted a recommendation for improvements or safeguards to prevent the issue identified.

3.2 Participants

The HAZOP study was conducted by the senior capstone team. The members of the team are listed in the table below:

Table 3-1 - Team Members

First Name	Last Name
Curtis	Palmer
Michael	McKenzie
Steven	Doyle
Zachary	Reed
Jacob	Evans
Allen	Zhu
Marc	Wasserman
Solomon	Reid

3.3 Study Sections

The HAZOP study for the liquid fuel engine test stand system is divided into 4 nodes:

Table 3-2 - List of Nodes

No	Method	Type	Name	Description	Design Intent	Highlight
1	HAZOP	Line/Pipe	Isopropyl Alcohol (IPA)	Pressurized N_2 feed IPA from tank to engine.	Draft	Green
2	HAZOP	Line/Pipe	Nitrogen Purge	N_2 discharges excess LOX/IPA out to engine.	Draft	Blue

3	HAZOP	Line/Pipe	Liquid Oxygen (LOX)	Pressurized N_2 feed LOX from tank to engine.	Draft	Red
4	HAZOP	Tank	LOX Tank Fill	Liquid Oxygen Tank Fill from commercial dewar	Draft	Purple

3.4 Documentation

The HAZOP study was documented in the HAZOP worksheets which can be found below in Appendix 2. Additionally, recommendations for modifications stemming from the meeting can be found below in Appendix 1.

Appendix 1: Recommendations/Action Items

Deviation	Node	Action	Reference
1 - High Pressure	1	Investigate additional regulator at N2 tank outlet. Add PIT-2 at N2 tank	1.1 High pressure - Pressurized N2 feed IPA from tank to engine.
		PI-5 changed to PIT-5 (added visual indicator) and HV-1 added to manually relieve pressure in line upstream of SOV-1	1.1 High pressure - Pressurized N2 feed IPA from tank to engine.
	2	SOV-5 and SOV-6 should be closed during N2 1st purge	2.1 High Pressure - N2 discharges excess LOX/IPA out to engine.
	4	Determine PSV-3 set pressure	4.1 High Pressure - Liquid Oxygen Tank Fill
2 - High Temperature	1	Verify max. wide open flow rate of N2 pressurizing line. IPA auto-ignition at 400C, temperature not expected to be reached	1.3 High temperature (> design temp = 150F) - Pressurized N2 feed IPA from tank to engine.
		Investigate addition on TT at N2 tank	1.3 High temperature (> design temp = 150F) - Pressurized N2 feed IPA from tank to engine.
	4	Add TT-5 to LOX tank for LOX headspace and liquid temperature monitoring	4.3 High temperature (> design temp = 150F) - Liquid Oxygen Tank Fill.
3 - Low Temperature	1	Verify max. N2 flowrate based on expected fuel flow rate during firing, calculate cooling. No issue	1.4 Low temperature - Pressurized N2 feed IPA from tank to engine.

		anticipated due to low fuel freezing point and low Cp on N2	
	3	Verify max. N2 flowrate based on expected LOX flow rate during firing, calculate cooling. No issue anticipated due to lower LOX temperature and low Cp on N2	3.4 Low temperature - Pressurized N2 feed LOX from tank to engine.
4 - High Flow	1	Verify solubility of N2 in fuel	1.5 High flow - Pressurized N2 feed IPA from tank to engine.
5 - Low Flow	4	Add check valve in LOX fill system	4.5 Low Flow - Liquid Oxygen Tank Fill

Appendix 2: HAZOP Worksheet

Node 1	**Fuel (IPA) line**				
Item	**Deviation**	**Cause**	**Consequence**	**Safeguard(s)**	**Action Item(s)**
1.1	High pressure	1.1.1. SOV-1 is closed and PRV-1 failed open	Piping sees full pressure from N2 tank to SOV-1, SOV-3, and HV-1. SOV-1 and SOV-3 see full N2 pressure	MAWP for SOV-1, SOV-3,HV-1 greater than max. N2 tank pressure (3000 psig). Line between N2 tank, SOV-1, SOV-3 rated greater than max. N2 tank pressure. HV-1 also need to be set to N2 tank pressure (3000psig)	Investigate additional regulator at N2 tank outlet. Add PIT-2 at N2 tank
		1.1.2. PRV-1 failed open and SOV-1 open	Excess pressure downstream of SOV-1	PT-5 set @ 550 psig detects high pressure, commands SOV-4 to open. PSV-1 set @ 850 psig. Fuel tank MAOP greater than 850 psig. CKV-1 MAOP (Maximum Allowable Operating Pressure) > 850 psig.	
		1.1.3. PIT-5 fails high (sends high pressure signal)	Incorrect feedback on actual pressure in fuel system	Fuel system vents via SOV-4, even if actual high pressure state	

				not present	
		1.1.4. High pressure in fuel system, SOV-4 does not operate	Pressure in line up to PSV-1 operating point (850 psig)	Line between N2 tank and engine rated greater than PSV-1 operating point (850 psig)	
		1.1.5. SOV-5 stuck closed	Pressure in fuel line maintained by N2 supply	SOV-4 may operate to relieve pressure in fuel line based on signal from PIT-5, PT-1, or PT-3	
		1.1.6. PRV-1 set to incorrect setting	Downstream subject to high pressure	If SOV-1 open, PT-1 or PT-3 signal SOV-4 to operate. If SOV-1 and SOV-3 closed, high pressure state in line upstream of SOV-1 and SOV-3 & HV-4 detected by PIT-5. Line between N2 tank and SOV-1 and SOV-3 rate for full N2 tank pressure	PI-5 changed to PIT-5 (added visual indicator) and HV-1 added to manually relieve pressure in line upstream of SOV-1
1.2	Low pressure	1.2.1			*Item removed upon review*
		1.2.2. Leak upstream of CKV-1	CKV-1 subject to pressure difference of up to 850 psig	CKV-1 rated w/ MAOP (delta P) of 850 psig	
		1.2.3. PRV-1 fails closed	Low pressure downstream of PRV-1, insufficient fuel flow to engine	PT-1 or PT-3 read low pressure, signal emergency shutdown if during firing, otherwise engage firing interlock	
		1.2.4. SOV-1 fails closed during firing	Low pressure downstream of SOV-1, insufficient fuel flow to engine	PT-1 or PT-3 read low pressure, signal emergency shutdown if during firing, otherwise engage firing interlock	

1.3	High temperature (> design temp = 150F)	1.3.1. Fuel line rapidly pressurized by N2	Adiabatic heating of fuel line components, auto-ignition of fuel	Inert purge line via nitrogen purge prior to startup	Verify max. wide open flow rate of N2 pressurizing line. IPA auto-ignition at 400C, temperature not expected to be reached
		1.3.2. N2 tank heated externally e.g. by solar radiation	Increase in N2 pressure due to increased N2 temperature	PIT-2 detects increased pressure (greater than 3000 psig), signals to SOV-3 to open and vent N2 to atmosphere through purge line	Investigate addition of TT at N2 tank
		1.3.3. High line temperature	fuel pressure increases	TT-1 detects high temperature, signals emergency shutdown	
1.4	Low temperature	1.4.1. N2 pressurizing line cooled by N2 regulated down from tank pressure	Ice formation on outside of line. Fuel freezing?	None	Verify max. N2 flowrate based on expected fuel flow rate during firing, calculate cooling. No issue anticipated due to low fuel freezing point and low Cp on N2
1.5	High flow	~~1.5.1. Incorrect setting of PRV-1~~	~~N2 dissolves in fuel tank?~~	~~None~~	*Item removed upon review*
1.6	Low flow	1.6.1. Low pressure	low fuel supply to engine if during firing	same safeguards as for 1.2 (low pressure)	
		1.6.2. Leak or obstruction in pressurizing line	low fuel supply to engine if during firing	same safeguards as for 1.2 (low pressure)	
		1.6.3 Low IPA flow and 1st N2 purge in progress	N2 flow into IPA system downstream of fuel tank	Interlock SOV-3 and SOV-6, SOV-5. If SOV-3 open, then SOV-5 closed and if SOV-5 open, then SOV-3 closed	Follow up with TSAR team to implement interlock
Node 2	**N2 purge line**				
Item	**Deviation**	**Cause**	**Consequence**	**Safeguard(s)**	**Action Item(s)**

2.1	High pressure	2.1.1. PRV-1 fails open and SOV-3 closed	SOV-3 sees full pressure from N2 tank if N2 not regulated upstream of PRV-1	SOV-3 rated for full N2 tank pressure (3000 psig)	
		2.1.2. PRV-1 fails open and SOV-3 open	CKV-4, CKV-5, CKV-6, CKV-7 see full N2 tank pressure, vent N2 to atmosphere through engine	All check valves rated for N2 tank pressure. Purge line rated for N2 tank pressure	SOV-5 and SOV-6 should be closed during N2 1st purge
2.2	Low pressure	2.2.1. Low N2 tank pressure or incorrect PRV-1 setting or line blockage	line potentially susceptible to fuel or LOX backflow	double check valves (CKV-4/CKV-5 and CKV-6/CKV-7) prevent backflow	
2.3	High temperatur e	2.3.1. Out of control fire around test stand	Multiple, unknown	Stand-back distance, on-site barriers	
2.4	Low temperatur e	2.4.1. Contact with LOX in LOX line	CKV-7 freezes open/shut	CKV-7 and CKV-6 rated for LOX line temperatures (cryo-rated)	
Node 3	**Oxidizer (LOX) Line**				
Item	**Deviation**	**Cause**	**Consequence**	**Safeguard(s)**	**Action Item(s)**
3.1	High pressure	~~3.1.1. N2 tank regulator fails open/set incorrectly if present~~	~~PRV-2 sees full N2 tank pressure~~	~~PRV-2 rated for max. N2 tank pressure (> 3000 psig)~~	*Item removed upon review*
		3.1.2. PRV-2 fails open	components and line downsteam of PRV-2 see full N2 tank pressure	SOV-2, CKV-2, CKV-3 rated for N2 tank pressure. PSV-2 set at 650 psig. SOV-5 set at 500 psig, actuated by high pressure signal from PT-2 or PT-4	
		3.1.3. PT-2 failed	High pressure state in LOX line	PT-4 also has control of SOV-8. PSV-2 set at 650 psig. PT-4 connected to emergency shutdown	

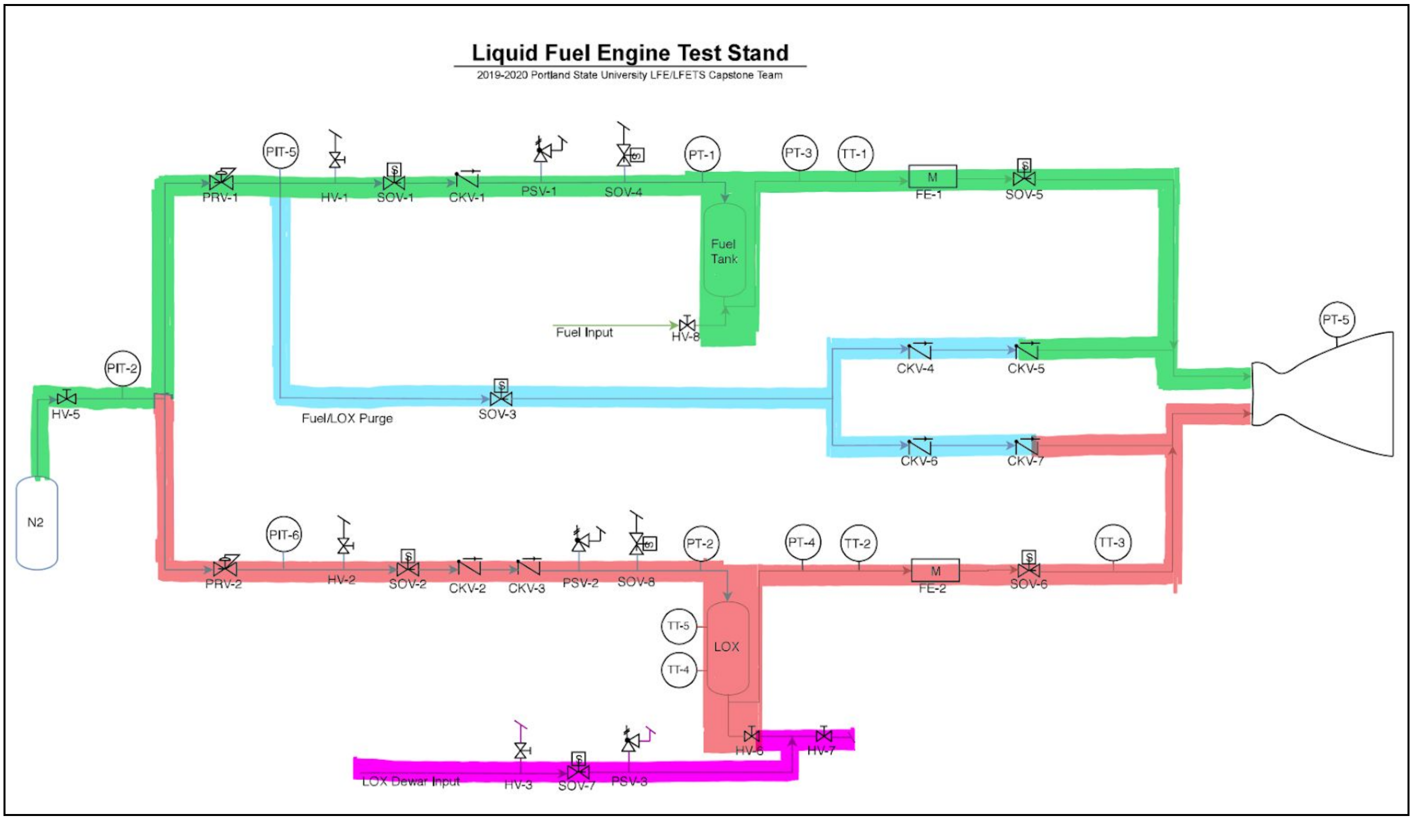
				system	
		3.1.4. PT-4 failed	High pressure state in LOX line	PT-2 also has control of SOV-8. PSV-2 set at 650 psig. PT-2 connected to emergency shutdown system	
		3.1.5. High pressure state and SOV-4 failed	LOX lines and LOX tank see pressure greater than SOV-8 set	LOX tanked and LOX line rated greater than PSV-2 setpoint (> 650 psig)	
		3.1.6. LOX boiling in tank	High pressure in LOX line	PT-4 detects high pressure, actuates SOV-8, PSV-2 setpoint at 650psi, also add PSV-3	
3.2	Low pressure	3.2.1. Low N2 pressurization supply or low LOX	Low pressure in LOX line, low LOX supply to engine	PT-4 detects low pressure, signals emergency shutdown	
		3.2.2. PIT-6 fails	Low pressure state in LOX line, low LOX supply to engine during firing	PT-2 or PT-4 detects low pressure state, signals emergency shutdown	
3.3	High temperature	3.3.1. High temperature in N2 tank	Increased line LOX line temperature, increased LOX boiloff rate	PT-2 monitor LOX tank headspaces pressure, actuates SOV-8 to vent pressure. PT-4 monitors pressure downstream of LOX tank, actuates SOV-8 at setpoint 550psi	
		3.3.2. LOX line heated externally (e.g. solar)	Increased line LOX line temperature, increased LOX line pressure	LOX line insulated (cryogel)	
		3.3.3. Fire	Fire-case temperatures. Increased pressure due to boiling LOX	PSV-2 rated for fire-case flow rate/temperature	

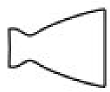
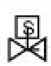
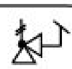
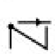
3.4	Low temperature	3.4.1. N2 pressurizing line cooled by N2 regulated down from tank pressure	Ice formation on outside of line	None	Verify max. N2 flowrate based on expected LOX flow rate during firing, calculate cooling. No issue anticipated due to lower LOX temperature and low Cp(specific heat) on N2
		3.4.2. LOX inherently low temperature	Components frozen due to frozen condensation or frozen internals	All LOX line components cryo-rated (PSV-2, CKV-2, CKV-3, FE-2, SOV-6, SOV-8 all pipes and fittings)	Investigate, environmental chamber for SOV-6
3.5	High flow	3.5.1. PRV-2 fails open	~~LOX boiloff rate increases,~~ increased pressure in LOX line	PSV-2 rated for N2 wide open flow	Verify PSV-2 max. flow rate
		3.5.2. Test stand catches fire	PSV-2 sees on-fire temperature due to high LOX boiloff rate	PSV-2 rated for LOX on-fire boiloff flow rate	Verify PSV-2 max. flow rate
		~~3.5.3. FE-2 fails open, does not regulate flow~~	~~Increased LOX flow to engine~~	~~Unclear~~	*Item removed upon review*
3.6	Low flow	3.6.1. Low N2 supply	Low LOX supply to engine during firing	PIT-6 detects low pressure, signals emergecy shutdown	
		3.6.2. Low LOX level and 1st N2 purge in progress	N2 flow into LOX system downstream of LOX tank	Interlock SOV-3 and SOV-6, SOV-5. If SOV-3 open, then SOV-6 closed and if SOV-6 open, then SOV-3 closed	Follow up with TSAR team to implement interlock
Node 4	**LOX fill line**				
Item	**Deviation**	**Cause**	**Consequence**	**Safeguard(s)**	**Action Item(s)**
4.1	High pressure	4.1.1. Excessive headspace pressure in LOX dewar	High pressure in LOX fill line	PSV-3, vent stack outlet at distance from test stand manual controls	Determine PSV-3 set pressure
					Design vent stacks

4.2	Low pressure	4.2.1. Low dewar headspace pressure, low LOX	LOX tank does not fill	PT-2 or PT-4 detect low pressure, alert operator	
4.3	High temperature	4.3.1. External heating of LOX line/LOX fill line	High LOX boiloff rate, high pressure in LOX line	See item 3.3, LOX line high pressure, PSV-3 relieves pressure in line	Add TT-5 to LOX tank for LOX headspace and liquid temperature monitoring
		4.3.2. LOX fill line not pre-chilled	LOX line fittings leak due to thermal contraction	System to open SOV-8 during LOX filling to vent tank as part of filling procedure	Spec a small valve for SOV-7 to fill tank slowly
4.4	High flow	4.4.1. Excessive headspace pressure in LOX dewar	LOX filling system fills rapidly	PSV-3 routed to vent stack at distance for test stand manual controls	
4.5	Low flow	4.5.1. Low pressure in LOX dewar	possible LOX backflow in filling system	Interlock w/ PT-2 signal. If PT-2 reads high pressure in LOX system, SOV-7 must close and will not open	Add check valve in LOX fill system

Appendix 3: PID Drawing with Nodes

Name	Revision	Title
PID-001	2019-01	Liquid Fuel Engine Test Stand
PID-Legend	001	Test Stand Legend



Symbol	Acronym	Detail
N2	N/A	Nitrogen Pressure Vessle
Fuel Tank	N/A	Isopropyl Alcohol Pressure Vessle
LOX	N/A	Liquid Oxygen Pressure Vessle
	N/A	Liquid Fuel Rocket Engine
PIT N2	N/A	Pressure Indicator and Transducer
PIT-0	N/A	Pressure Indicator and Transducer
PT-1	N/A	Pressure Transducer
TT-1	N/A	Temperature Transducer
M	FE-0	Mass Flow Meter and Regulator
	HV-0	Hand Turn Valve, Vented to Atmosphere
	HV-0	Hand Turn Valve
	PRV-0	Pressure Relief Valve
	SOV-0	Solenoid Operated Valve ,Vent to Atmosphere
	SOV-0	Solenoid Operated Valve
	PSV-0	Pressure Safety Valve
	CKV-0	Check Valve

Appendix C - Pressure Testing Procedure

This procedure is followed after Liquid Fuel Engine Test Stand (LFETS) assembly to test the maximum static pressure that the system can withstand.

(link)

STANDARD OPERATING PROCEDURE FOR STRENGTH TESTING

November 2019

1 Table of Contents

2 Purpose and Scope of Document

2.1 Purpose

The Liquid Fuel Engine Test Stand (LFETS) system is comprised of stainless steel tubing fabricated for standard and cryogenic temperatures. Once the tubing and components are assembled, they shall be strength tested for the standard operating pressure of 500psig. To obtain a valid strength test, the test stand shall be tested to 1.5x the design pressure of the system, or 750psig.

2.2 Scope

This document will outline the necessary precautions, safety measures and calculations required to perform the strength test using water as the test medium.

3 Personal Protective Equipment & Clothing

3.1 PPE

Due to the inherent physical safety risks associated with elevated pressure, all persons involved in the strength testing procedure shall employ the Personal Protective Equipment described in the following sections.

3.1.1 Safety Glasses

The eyes are the most vulnerable part of the body to the extreme cold temperatures of cryogenic liquids and vapors. Safety glasses must always be worn by any person in contact with or in the vicinity of liquid oxygen.

3.1.2 Hearing Protection

A test failure may produce loud noises during the release of pressure. Pressurizing and depressurizing the test assembly may also generate elevated noise levels. Thus, ear plugs or earmuffs shall be required during strength testing procedures.

3.2 Clothing

All persons involved in strength testing must wear suitable clothing for the task, in addition to the PPE outlined above. This includes long-sleeved shirt and full length.

3.2.1 Footwear

Footwear must be close-toed and non-absorbent with non-slip soles. Additionally, footwear should extend far enough up the ankle area such that the trousers are worn over the footwear to prevent any liquid oxygen entering the shoe in the event of a spill.

4 Test Stand Preparation for Strength Testing

4.1 Preparation

Test stand shall be assembled and fittings torqued to manufacturer specifications. Ball valves shall be set to 1/2 turn so that seats are not subjected to test forces. All components shall be verified to be capable of the maximum hydrotest pressure.

4.2 Test Components

Testing shall be performed using water as the test medium, and a calibrated hand-pump to pressurize the system. A certified gauge shall be used to record the test pressure, and a recording medium utilized to record test pressure at intervals. Allowances shall be made to record test fluid temperature during the test to measure the effects of ambient or solar heating on the test fluid.

5 Test Design

5.1 Calculations for maximum test pressure are taken from ASME B31.3 Section 304.

$t=PD2(SEW+PY)$ (design wall thickness for tubing)

$P=2tSEW(D-2tY)$ (design pressure for tubing)

P = Design pressure (psig) (B31.3 304.1.1)
S = Yield strength (psi), specified by ASME B31.3 Table A-1 (B31.3 304.1.1)

(S values in table A-1 vary with temperature)
t = Nominal wall thickness (in.), specified by manufacturer (B31.3 304.1.1)
D = Nominal outside diameter (in.), specified by manufacturer (B31.3 304.1.1)
W = Weld joint strength reduction factor, from table B31.3 302.3.5 (B31.3 304.1.1)
E = Quality factor from B31.3 A-1A or A-1B (B31.3 304.1.1)
(E=1.00 for ASTM A53/53M, ASTM A106, and API 5L)
(E varies for NON-seamless tubing)
Y = Coefficient from Table 304.1.1 in B31.3 (B31.3 304.1.1)
(Valid for t < D / 6)

5.2 Design Documentation

Test documentation shall be created to record test design for each unique section of tubing. A design document shall be created for each unique diameter of tubing showing calculated maximum design pressure, test pressure and record thickness, diameter, yield and allowable strength, ASTM standard and Purchase Order for the tubing.

6 Test Procedures

6.1 Filling and Purging the system with Water

Connect a clean, filtered water source to the system and fully charge the system with water. Utilize a procedure to purge gas vapor from the system so that the entire system is fully purged with water. Once a full purge is completed, connect the hand pump and calibrated gauge to begin test. Verify all valves are at a half turn so that valve seats are not loaded during the test.

6.2 Strength Test

Using the hand pump, pressurize the system to a pressure between the minimum test pressure and the maximum test pressure. Record the rise from zero to the test pressure, and the test fluid temperature. Record the pressure and temperature at 10 minute intervals for 1 hour.

If at any time during the test a leak is discovered, depressurize the system and repair the leak. Repeat test procedure once the leak is confirmed repaired.

Once the test is complete, drain the water to a suitable storage vessel. Purge and dry the system using clean dry gaseous nitrogen.

7 Checklist

1. Verify that all test stand components are assembled correctly for testing.
2. Remove PRV-1, PRV-2, PSV-1, PSV-2 and PSV-3 from service (these components do not require pressure testing as they carry a pressure rating.
3. Open and cap the outlet to HV-1, HV-2, HV-3 and HV-7.
4. Open SOV-1, SOV-2, SOV-3, SOV-5, SOV-6 and SOV-7.

5. Cap the LOX Dewar connection, LOX engine outlet and Fuel engine outlet with a purge valve rated to the maximum test pressure and plug.

6. Connect the water source to HV-5 and fill the system with water. Use high-point vents HV-1, HV-2, HV-7 to vent air or gas from the system.

7. Pressurize the system with a hand pump to a pressure between the minimum and maximum test pressure. Record the test pressure and test fluid temperature.

8. Record test pressure and temperature at 10 minute intervals for a minimum of 1 hour.

9. Once test is complete, close depressurize the system with the hand valves temporarily installed on the fuel and liquid oxygen engine outlets. Close HV-5 and disconnect the water source. Install a N2 source at HV-5 and purge and dry the system with nitrogen through the high point vents and the engine fuel and oxidizer outlets.

10. Close the nitrogen cylinder and blow the test stand system down to zero (0) psig. Remove the nitrogen cylinder and safe the system.

8 References

(2018). ASME B31.3-2018 edition: Process piping. New York: American Society of Mechanical Engineering,

Appendix D - Component and Material Specifications

This document calls out the specifications for each component in the Liquid Fuel Engine Test Stand (LFETS).

(link)

Portland State Aerospace Society
Material Specification | Pressure Component

Equipment Tag	**PRV-1**	
Description	1/4" Nitrogen to Fuel Inlet Regulator	
Manufacturer	Swagelok	
Model Number	**KCY1JRA412A20000**	
Material Specification	316 Stainless Steel	
Pressure Class	3600psig	
Max. Allowable Operating Pressure (MAOP)	3600psig (inlet) 500psig (outlet)	248 bar (inlet) 34.5 bar (outlet)
Max. Allowable Working Temperature (MAWT)	176F	80C
Min. Design Metal Temperature (MDMT)	N/A	N/A

PN: KCY1JRA412A20000
1 = 316SS
J = 0 to 500psig pressure control range
R = 3600psig maximum inlet pressure
A
4 = 1/4" Female NPT Ports
1 = PCTFE Seats
2 = 0.06 Flow Coefficient
A = Alloy X-750 diaphragm, no vent
2 = Knob handle
0 = no isolation or relief valves
0 = no cylinder connections
0 = no gauges
0 = no options

Portland State Aerospace Society
Material Specification | Pressure Component

Equipment Tag	**HV-1**	
Description	Fuel side blowdown valve upstream of SOV-1	
Manufacturer	McMaster Carr	
Model Number	**4040T61**	
Material Specification	316 Stainless Steel	
Pressure Class	ANSI 900	
Max. Allowable Operating Pressure (MAOP)	2000psig	131.8bar
Max. Allowable Working Temperature (MAWT)	450F	232C
Min. Design Metal Temperature (MDMT)	-20F	-28C

PN: KCY1JRA412A20000
1 = 316SS
J = 0 to 500psig pressure control range
R = 3600psig maximum inlet pressure
A
4 = 1/4" Female NPT Ports
1 = PCTFE Seats
2 = 0.06 Flow Coefficient
A = Alloy X-750 diaphragm, no vent
2 = Knob handle
0 = no isolation or relief valves
0 = no cylinder connections
0 = no gauges
0 = no options

Portland State Aerospace Society
Material Specification | Pressure Component

Equipment Tag	**SOV-1**	
Description	1/2" Nitrogen Inlet to Fuel System	
Manufacturer	Clark Cooper	
Model Number	**EH40-08-D024-OX**	
Material Specification	Stainless Steel	
Pressure Class	3600psig	
Max. Allowable Operating Pressure (MAOP)	3600psig	248bar
Max. Allowable Working Temperature (MAWT)	225F	107C
Min. Design Metal Temperature (MDMT)	-50F	-45C

PN: KCY1JRA412A20000
1 = 316SS
J = 0 to 500psig pressure control range
R = 3600psig maximum inlet pressure
A
4 = 1/4" Female NPT Ports
1 = PCTFE Seats
2 = 0.06 Flow Coefficient
A = Alloy X-750 diaphragm, no vent
2 = Knob handle
0 = no isolation or relief valves
0 = no cylinder connections
0 = no gauges
0 = no options

Portland State Aerospace Society
Material Specification | Pressure Component

Equipment Tag	**CKV-1**	
Description	N2 to Fuel Inlet Check Valve	
Manufacturer	Swagelok	
Model Number	**SS-4C4-1**	
Material Specification		
Pressure Class	3000psig	
Max. Allowable Operating Pressure (MAOP)	3000psig	206bar
Max. Allowable Working Temperature (MAWT)	375F	190C
Min. Design Metal Temperature (MDMT)	-10F	-23C

PN: KCY1JRA412A20000
1 = 316SS
J = 0 to 500psig pressure control range
R = 3600psig maximum inlet pressure
A
4 = 1/4" Female NPT Ports
1 = PCTFE Seats
2 = 0.06 Flow Coefficient
A = Alloy X-750 diaphragm, no vent
2 = Knob handle
0 = no isolation or relief valves
0 = no cylinder connections
0 = no gauges
0 = no options

Portland State Aerospace Society
Material Specification | Pressure Component

Equipment Tag	**PSV-1**	
Description	1/2" Brass high-pressure relief valve	
Manufacturer	Generant	
Model Number	**HPRV-500B-S-850**	
Material Specification	Brass	
Pressure Class	ANSI 900	
Max. Allowable Operating Pressure (MAOP)	850psig	58.6bar
Max. Allowable Working Temperature (MAWT)	250F	121C
Min. Design Metal Temperature (MDMT)	-40F	-40C

PN: KCY1JRA412A20000
1 = 316SS
J = 0 to 500psig pressure control range
R = 3600psig maximum inlet pressure
A
4 = 1/4" Female NPT Ports
1 = PCTFE Seats
2 = 0.06 Flow Coefficient
A = Alloy X-750 diaphragm, no vent
2 = Knob handle
0 = no isolation or relief valves
0 = no cylinder connections
0 = no gauges
0 = no options

Portland State Aerospace Society
Material Specification | Pressure Component

Equipment Tag	**SOV-4**	
Description	1/2" Fuel Vent Valve	
Manufacturer	Clark Cooper	
Model Number	**EH40-08-D024-OX**	
Material Specification	Stainless Steel	
Pressure Class	3600psig	
Max. Allowable Operating Pressure (MAOP)	3600psig	248bar
Max. Allowable Working Temperature (MAWT)	225F	107C
Min. Design Metal Temperature (MDMT)	-50F	-45C

PN: KCY1JRA412A20000
1 = 316SS
J = 0 to 500psig pressure control range
R = 3600psig maximum inlet pressure
A
4 = 1/4" Female NPT Ports
1 = PCTFE Seats
2 = 0.06 Flow Coefficient
A = Alloy X-750 diaphragm, no vent
2 = Knob handle
0 = no isolation or relief valves
0 = no cylinder connections
0 = no gauges
0 = no options

Portland State Aerospace Society

Material Specification | Pressure Component

Equipment Tag	**SOV-5**	
Description	MAIN FUEL VALVE	
Manufacturer	Sharpe	
Model Number	**3/4" 80-6666KIT-TE**	
Material Specification	CF8M, Stainless Steel	
Pressure Class	ANSI 600	
Max. Allowable Operating Pressure (MAOP)	1480psig	102.1bar
Max. Allowable Working Temperature (MAWT)	392F	200C
Min. Design Metal Temperature (MDMT)	-452F	-269C

PN: KCY1JRA412A20000

1 = 316SS

J = 0 to 500psig pressure control range

R = 3600psig maximum inlet pressure

A

4 = 1/4" Female NPT Ports

1 = PCTFE Seats

2 = 0.06 Flow Coefficient

A = Alloy X-750 diaphragm, no vent

2 = Knob handle

0 = no isolation or relief valves

0 = no cylinder connections

0 = no gauges

0 = no options

Portland State Aerospace Society
Material Specification | Pressure Component

Equipment Tag	**HV-8**	
Description	Fuel tank fill valve	
Manufacturer	McMaster Carr	
Model Number	**4040T63**	
Material Specification	316 Stainless Steel	
Pressure Class	ANSI 900	
Max. Allowable Operating Pressure (MAOP)	2000psig	131.8bar
Max. Allowable Working Temperature (MAWT)	450F	232C
Min. Design Metal Temperature (MDMT)	-20F	-28C

PN: KCY1JRA412A20000
1 = 316SS
J = 0 to 500psig pressure control range
R = 3600psig maximum inlet pressure
A
4 = 1/4" Female NPT Ports
1 = PCTFE Seats
2 = 0.06 Flow Coefficient
A = Alloy X-750 diaphragm, no vent
2 = Knob handle
0 = no isolation or relief valves
0 = no cylinder connections
0 = no gauges
0 = no options

Portland State Aerospace Society

Material Specification | Pressure Component

Equipment Tag	**HV-9**	
Description	Fuel tank manual vent valve	
Manufacturer	McMaster Carr	
Model Number	**4040T63**	
Material Specification	316 Stainless Steel	
Pressure Class	ANSI 900	
Max. Allowable Operating Pressure (MAOP)	2000psig	131.8bar
Max. Allowable Working Temperature (MAWT)	450F	232C
Min. Design Metal Temperature (MDMT)	-20F	-28C

PN: KCY1JRA412A20000
1 = 316SS
J = 0 to 500psig pressure control range
R = 3600psig maximum inlet pressure
A
4 = 1/4" Female NPT Ports
1 = PCTFE Seats
2 = 0.06 Flow Coefficient
A = Alloy X-750 diaphragm, no vent
2 = Knob handle
0 = no isolation or relief valves
0 = no cylinder connections
0 = no gauges
0 = no options

Portland State Aerospace Society
Material Specification | Pressure Component

Equipment Tag	**PRV-2**	
Description	1/4" Nitrogen to LOX Inlet Regulator	
Manufacturer	Swagelok	
Model Number	**KCY1JRA412A20000**	
Material Specification	316 Stainless Steel	
Pressure Class	3600psig	
Max. Allowable Operating Pressure (MAOP)	3600psig (inlet) 500psig (outlet)	248 bar (inlet) 34.5 bar (outlet)
Max. Allowable Working Temperature (MAWT)	176F	80C
Min. Design Metal Temperature (MDMT)	N/A	N/A

PN: KCY1JRA412A20000
1 = 316SS
J = 0 to 500psig pressure control range
R = 3600psig maximum inlet pressure
A
4 = 1/4" Female NPT Ports
1 = PCTFE Seats
2 = 0.06 Flow Coefficient
A = Alloy X-750 diaphragm, no vent
2 = Knob handle
0 = no isolation or relief valves
0 = no cylinder connections
0 = no gauges
0 = no options

Portland State Aerospace Society
Material Specification | Pressure Component

Equipment Tag	**HV-2**	
Description	LOX side blowdown valve upstream of SOV-2	
Manufacturer	McMaster Carr	
Model Number	**4040T61**	
Material Specification	316 Stainless Steel	
Pressure Class	ANSI 900	
Max. Allowable Operating Pressure (MAOP)	2000psig	131.8bar
Max. Allowable Working Temperature (MAWT)	450F	232C
Min. Design Metal Temperature (MDMT)	-20F	-28C

PN: KCY1JRA412A20000
1 = 316SS
J = 0 to 500psig pressure control range
R = 3600psig maximum inlet pressure
A
4 = 1/4" Female NPT Ports
1 = PCTFE Seats
2 = 0.06 Flow Coefficient
A = Alloy X-750 diaphragm, no vent
2 = Knob handle
0 = no isolation or relief valves
0 = no cylinder connections
0 = no gauges
0 = no options

Portland State Aerospace Society
Material Specification | Pressure Component

Equipment Tag	**SOV-2**	
Description	1/2" Nitrogen Inlet to Oxidizer System	
Manufacturer	Clark Cooper	
Model Number	**EH40-08-D024-OX**	
Material Specification	Stainless Steel	
Pressure Class	3600psig	
Max. Allowable Operating Pressure (MAOP)	3600psig	248bar
Max. Allowable Working Temperature (MAWT)	225F	107C
Min. Design Metal Temperature (MDMT)	-50F	-45C

PN: KCY1JRA412A20000
1 = 316SS
J = 0 to 500psig pressure control range
R = 3600psig maximum inlet pressure
A
4 = 1/4" Female NPT Ports
1 = PCTFE Seats
2 = 0.06 Flow Coefficient
A = Alloy X-750 diaphragm, no vent
2 = Knob handle
0 = no isolation or relief valves
0 = no cylinder connections
0 = no gauges
0 = no options

Portland State Aerospace Society
Material Specification | Pressure Component

Equipment Tag	**CKV-2**	
Description	N2 to Oxidizer Inlet Check Valve (pair-upstream)	
Manufacturer	Rego	
Model Number	**CG250SS**	
Material Specification	Stainless Steel	
Pressure Class	600psig CWP	
Max. Allowable Operating Pressure (MAOP)	5000psig	344bar
Max. Allowable Working Temperature (MAWT)	165F	74C
Min. Design Metal Temperature (MDMT)	-320F	-195C

PN: KCY1JRA412A20000
1 = 316SS
J = 0 to 500psig pressure control range
R = 3600psig maximum inlet pressure
A
4 = 1/4" Female NPT Ports
1 = PCTFE Seats
2 = 0.06 Flow Coefficient
A = Alloy X-750 diaphragm, no vent
2 = Knob handle
0 = no isolation or relief valves
0 = no cylinder connections
0 = no gauges
0 = no options

Portland State Aerospace Society
Material Specification | Pressure Component

Equipment Tag	**CKV-3**	
Description	N2 to Oxidizer Inlet Check Valve (pair-downstream)	
Manufacturer	Rego	
Model Number	**CG250SS**	
Material Specification	Stainless Steel	
Pressure Class	600psig CWP	
Max. Allowable Operating Pressure (MAOP)	5000psig	344bar
Max. Allowable Working Temperature (MAWT)	165F	74C
Min. Design Metal Temperature (MDMT)	-320F	-195C

PN: KCY1JRA412A20000
1 = 316SS
J = 0 to 500psig pressure control range
R = 3600psig maximum inlet pressure
A
4 = 1/4" Female NPT Ports
1 = PCTFE Seats
2 = 0.06 Flow Coefficient
A = Alloy X-750 diaphragm, no vent
2 = Knob handle
0 = no isolation or relief valves
0 = no cylinder connections
0 = no gauges
0 = no options

Portland State Aerospace Society

Material Specification | Pressure Component

Equipment Tag	**PSV-2**	
Description	1/2" LOX-side pressure safety valve	
Manufacturer	Generant	
Model Number	**HPRV-500B-T-650X**	
Material Specification	Brass	
Pressure Class	ANSI 900	
Max. Allowable Operating Pressure (MAOP)	650psig	44.82bar
Max. Allowable Working Temperature (MAWT)	400F	204.44
Min. Design Metal Temperature (MDMT)	-320F	-195C

PN: KCY1JRA412A20000
1 = 316SS
J = 0 to 500psig pressure control range
R = 3600psig maximum inlet pressure
A
4 = 1/4" Female NPT Ports
1 = PCTFE Seats
2 = 0.06 Flow Coefficient
A = Alloy X-750 diaphragm, no vent
2 = Knob handle
0 = no isolation or relief valves
0 = no cylinder connections
0 = no gauges
0 = no options

Portland State Aerospace Society

Material Specification | Pressure Component

Equipment Tag	**SOV-8**	
Description	LOX System Vent Valve	
Manufacturer	Magnatrol	
Model Number	**E29LR62**	
Material Specification	Bronze	
Pressure Class	500psig	
Max. Allowable Operating Pressure (MAOP)	500psig	34.5bar
Max. Allowable Working Temperature (MAWT)	400F	204C
Min. Design Metal Temperature (MDMT)	-350F	-212C

PN: KCY1JRA412A20000
1 = 316SS
J = 0 to 500psig pressure control range
R = 3600psig maximum inlet pressure
A
4 = 1/4" Female NPT Ports
1 = PCTFE Seats
2 = 0.06 Flow Coefficient
A = Alloy X-750 diaphragm, no vent
2 = Knob handle
0 = no isolation or relief valves
0 = no cylinder connections
0 = no gauges
0 = no options

Portland State Aerospace Society

Material Specification | Pressure Component

Equipment Tag	**HV-10**	
Description	LOX Tank Manual Vent Valve	
Manufacturer	Habonim	
Model Number	**05-C47C-6666AT/NPT**	
Material Specification	CF8M, Stainless Steel	
Pressure Class	ANSI 600	
Max. Allowable Operating Pressure (MAOP)	1480psig	102bar
Max. Allowable Working Temperature (MAWT)	392F	200C
Min. Design Metal Temperature (MDMT)	-452F	-269C

PN: KCY1JRA412A20000
1 = 316SS
J = 0 to 500psig pressure control range
R = 3600psig maximum inlet pressure
A
4 = 1/4" Female NPT Ports
1 = PCTFE Seats
2 = 0.06 Flow Coefficient
A = Alloy X-750 diaphragm, no vent
2 = Knob handle
0 = no isolation or relief valves
0 = no cylinder connections
0 = no gauges
0 = no options

Portland State Aerospace Society
Material Specification | Pressure Component

Equipment Tag	**SOV-6**	
Description	MAIN LOX VALVE	
Manufacturer	Sharpe	
Model Number	**3/4" C80-6666KIT-TE**	
Material Specification	CF8M, Stainless Steel	
Pressure Class	ANSI 600	
Max. Allowable Operating Pressure (MAOP)	1480psig	102.1bar
Max. Allowable Working Temperature (MAWT)	392F	200C
Min. Design Metal Temperature (MDMT)	-452F	-269C

PN: KCY1JRA412A20000
1 = 316SS
J = 0 to 500psig pressure control range
R = 3600psig maximum inlet pressure
A
4 = 1/4" Female NPT Ports
1 = PCTFE Seats
2 = 0.06 Flow Coefficient
A = Alloy X-750 diaphragm, no vent
2 = Knob handle
0 = no isolation or relief valves
0 = no cylinder connections
0 = no gauges
0 = no options

Portland State Aerospace Society
Material Specification | Pressure Component

Equipment Tag	**HV-5**	
Description	Nitrogen Tank Isolation Valve	
Manufacturer	N/A	
Model Number		
Material Specification	DOT 3AA2400 / 2400psig Size 300 N2 Cylinder	
Pressure Class	2400psig	
Max. Allowable Operating Pressure (MAOP)	2400psig	165.5bar
Max. Allowable Working Temperature (MAWT)		
Min. Design Metal Temperature (MDMT)		

PN: KCY1JRA412A20000
1 = 316SS
J = 0 to 500psig pressure control range
R = 3600psig maximum inlet pressure
A
4 = 1/4" Female NPT Ports
1 = PCTFE Seats
2 = 0.06 Flow Coefficient
A = Alloy X-750 diaphragm, no vent
2 = Knob handle
0 = no isolation or relief valves
0 = no cylinder connections
0 = no gauges
0 = no options

Portland State Aerospace Society

Material Specification | Pressure Component

Equipment Tag	**CKV-4**	
Description	Fuel purge check valve (pair-upstream)	
Manufacturer	Swagelock	
Model Number	**B-4C4-1**	
Material Specification	Brass 360 ASTM B16	
Pressure Class	ANSI 900	
Max. Allowable Operating Pressure (MAOP)	3000psig	206bar
Max. Allowable Working Temperature (MAWT)	250F	121C
Min. Design Metal Temperature (MDMT)	-10F	-23C

PN: KCY1JRA412A20000

1 = 316SS

J = 0 to 500psig pressure control range

R = 3600psig maximum inlet pressure

A

4 = 1/4" Female NPT Ports

1 = PCTFE Seats

2 = 0.06 Flow Coefficient

A = Alloy X-750 diaphragm, no vent

2 = Knob handle

0 = no isolation or relief valves

0 = no cylinder connections

0 = no gauges

0 = no options

Portland State Aerospace Society
Material Specification | Pressure Component

Equipment Tag	**CKV-5**	
Description	Fuel purge check valve (pair-downstream)	
Manufacturer	Swagelock	
Model Number	**B-4C4-1**	
Material Specification	Brass 360 ASTM B16	
Pressure Class	ANSI 900	
Max. Allowable Operating Pressure (MAOP)	3000psig	206bar
Max. Allowable Working Temperature (MAWT)	250F	121C
Min. Design Metal Temperature (MDMT)	-10F	-23C

PN: KCY1JRA412A20000
1 = 316SS
J = 0 to 500psig pressure control range
R = 3600psig maximum inlet pressure
A
4 = 1/4" Female NPT Ports
1 = PCTFE Seats
2 = 0.06 Flow Coefficient
A = Alloy X-750 diaphragm, no vent
2 = Knob handle
0 = no isolation or relief valves
0 = no cylinder connections
0 = no gauges
0 = no options

Portland State Aerospace Society
Material Specification | Pressure Component

Equipment Tag	**CKV-6**	
Description	Oxidizer purge check valve (pair-upstream)	
Manufacturer	Rego	
Model Number	**CG250SS**	
Material Specification	Stainless Steel	
Pressure Class	600psig CWP	
Max. Allowable Operating Pressure (MAOP)	5000psig	344bar
Max. Allowable Working Temperature (MAWT)	165F	74C
Min. Design Metal Temperature (MDMT)	-320F	-195C

PN: KCY1JRA412A20000
1 = 316SS
J = 0 to 500psig pressure control range
R = 3600psig maximum inlet pressure
A
4 = 1/4" Female NPT Ports
1 = PCTFE Seats
2 = 0.06 Flow Coefficient
A = Alloy X-750 diaphragm, no vent
2 = Knob handle
0 = no isolation or relief valves
0 = no cylinder connections
0 = no gauges
0 = no options

Portland State Aerospace Society

Material Specification | Pressure Component

Equipment Tag	**CKV-7**	
Description	Oxidizer purge check valve (pair-downstream)	
Manufacturer	Rego	
Model Number	**CG250SS**	
Material Specification	Stainless Steel	
Pressure Class	600psig CWP	
Max. Allowable Operating Pressure (MAOP)	5000psig	344bar
Max. Allowable Working Temperature (MAWT)	165F	74C
Min. Design Metal Temperature (MDMT)	-320F	-195C

PN: KCY1JRA412A20000
1 = 316SS
J = 0 to 500psig pressure control range
R = 3600psig maximum inlet pressure
A
4 = 1/4" Female NPT Ports
1 = PCTFE Seats
2 = 0.06 Flow Coefficient
A = Alloy X-750 diaphragm, no vent
2 = Knob handle
0 = no isolation or relief valves
0 = no cylinder connections
0 = no gauges
0 = no options

Portland State Aerospace Society
Material Specification | Pressure Component

Equipment Tag	**HV-3**	
Description	LOX Dewar Vent Valve	
Manufacturer	Habonim	
Model Number	**05-C47C-6666AT/NPT**	
Material Specification	CF8M, Stainless Steel	
Pressure Class	ANSI 600	
Max. Allowable Operating Pressure (MAOP)	1480psig	102bar
Max. Allowable Working Temperature (MAWT)	392F	200C
Min. Design Metal Temperature (MDMT)	-452F	-269C

PN: KCY1JRA412A20000
1 = 316SS
J = 0 to 500psig pressure control range
R = 3600psig maximum inlet pressure
A
4 = 1/4" Female NPT Ports
1 = PCTFE Seats
2 = 0.06 Flow Coefficient
A = Alloy X-750 diaphragm, no vent
2 = Knob handle
0 = no isolation or relief valves
0 = no cylinder connections
0 = no gauges
0 = no options

Portland State Aerospace Society
Material Specification | Pressure Component

Equipment Tag	**HV-6**	
Description	LOX Tank Drain Valve 1	
Manufacturer	Habonim	
Model Number	**05-C47C-6666AT/NPT**	
Material Specification	CF8M, Stainless Steel	
Pressure Class	ANSI 600	
Max. Allowable Operating Pressure (MAOP)	1480psig	102bar
Max. Allowable Working Temperature (MAWT)	392F	200C
Min. Design Metal Temperature (MDMT)	-452F	-269C

PN: KCY1JRA412A20000
1 = 316SS
J = 0 to 500psig pressure control range
R = 3600psig maximum inlet pressure
A
4 = 1/4" Female NPT Ports
1 = PCTFE Seats
2 = 0.06 Flow Coefficient
A = Alloy X-750 diaphragm, no vent
2 = Knob handle
0 = no isolation or relief valves
0 = no cylinder connections
0 = no gauges
0 = no options

Portland State Aerospace Society

Material Specification | Pressure Component

Equipment Tag	**HV-7**	
Description	LOX Tank Drain Valve 2	
Manufacturer	Habonim	
Model Number	**05-C47C-6666AT/NPT**	
Material Specification	CF8M, Stainless Steel	
Pressure Class	ANSI 600	
Max. Allowable Operating Pressure (MAOP)	1480psig	102bar
Max. Allowable Working Temperature (MAWT)	392F	200C
Min. Design Metal Temperature (MDMT)	-452F	-269C

PN: KCY1JRA412A20000

1 = 316SS

J = 0 to 500psig pressure control range

R = 3600psig maximum inlet pressure

A

4 = 1/4" Female NPT Ports

1 = PCTFE Seats

2 = 0.06 Flow Coefficient

A = Alloy X-750 diaphragm, no vent

2 = Knob handle

0 = no isolation or relief valves

0 = no cylinder connections

0 = no gauges

0 = no options

Portland State Aerospace Society

Material Specification | Pressure Component

Equipment Tag	**PSV-3**	
Description	1/2" LOX-fill pressure safety valve (thermal relief)	
Manufacturer	Generant	
Model Number	**HPRV-500B-T-650X**	
Material Specification	Brass	
Pressure Class	ANSI 900	
Max. Allowable Operating Pressure (MAOP)	650psig	44.82bar
Max. Allowable Working Temperature (MAWT)	400F	204.44
Min. Design Metal Temperature (MDMT)	-320F	-195C

PN: KCY1JRA412A20000

1 = 316SS

J = 0 to 500psig pressure control range

R = 3600psig maximum inlet pressure

A

4 = 1/4" Female NPT Ports

1 = PCTFE Seats

2 = 0.06 Flow Coefficient

A = Alloy X-750 diaphragm, no vent

2 = Knob handle

0 = no isolation or relief valves

0 = no cylinder connections

0 = no gauges

0 = no options

Portland State Aerospace Society

Material Specification | Pressure Component

Equipment Tag	**SOV-7**	
Description	LOX Fill Valve	
Manufacturer	Sharpe	
Model Number	**3/4" C80-6666KIT-TE**	
Material Specification	CF8M, Stainless Steel	
Pressure Class	ANSI 600	
Max. Allowable Operating Pressure (MAOP)	1480psig	102.1bar
Max. Allowable Working Temperature (MAWT)	392F	200C
Min. Design Metal Temperature (MDMT)	-452F	-269C

PN: KCY1JRA412A20000

1 = 316SS

J = 0 to 500psig pressure control range

R = 3600psig maximum inlet pressure

A

4 = 1/4" Female NPT Ports

1 = PCTFE Seats

2 = 0.06 Flow Coefficient

A = Alloy X-750 diaphragm, no vent

2 = Knob handle

0 = no isolation or relief valves

0 = no cylinder connections

0 = no gauges

0 = no options

Appendix E - Propellant and Pressurant MSDS

Material safety data sheets for Liquid Oxygen, Isopropyl alcohol, and Nitrogen gas.

- LOX
- IPA
- N2

SAFETY DATA SHEET

Oxygen, Refrigerated Liquid

Section 1. Identification

GHS product identifier : Oxygen, Refrigerated Liquid

Chemical name : Oxygen Refrigerated Liquid

Other means of identification : Liquid Oxygen; LOX; Liquid Oxygen USP

Product type : Liquefied gas

Product use : Synthetic/Analytical chemistry.

Synonym : Liquid Oxygen; LOX; Liquid Oxygen USP

SDS # : 001190

Supplier's details : Airgas USA, LLC and its affiliates
259 North Radnor-Chester Road
Suite 100
Radnor, PA 19087-5283
1-610-687-5253

24-hour telephone : 1-866-734-3438

Section 2. Hazards identification

OSHA/HCS status : This material is considered hazardous by the OSHA Hazard Communication Standard (29 CFR 1910.1200).

Classification of the substance or mixture : OXIDIZING GASES - Category 1
GASES UNDER PRESSURE - Refrigerated liquefied gas

GHS label elements

Hazard pictograms :

Signal word : Danger

Hazard statements : May cause or intensify fire; oxidizer.
Contains refrigerated gas; may cause cryogenic burns or injury.
May cause frostbite.
Combustibles in contact with Liquid Oxygen may explode on ignition or impact.

Precautionary statements

General : Read and follow all Safety Data Sheets (SDS'S) before use. Read label before use. Keep out of reach of children. If medical advice is needed, have product container or label at hand. Close valve after each use and when empty. Use equipment rated for cylinder pressure. Do not open valve until connected to equipment prepared for use. Use a back flow preventative device in the piping. Use only equipment of compatible materials of construction. Open valve slowly. Use only with equipment cleaned for Oxygen service. Always keep container in upright position. Do not change or force fit connections. Avoid spills. Do not walk or roll equipment over spills.

Prevention : Wear cold insulating gloves and face shield. Keep away from clothing, incompatible materials and combustible materials. Keep reduction valves free from grease and oil. Use and store only outdoors or in a well ventilated place.

Response : Thaw frosted parts with lukewarm water. Do not rub affected area. Get immediate medical advice/attention. In case of fire: Stop leak if safe to do so.

Storage : Store in a well-ventilated place.

Disposal : Not applicable.

Hazards not otherwise classified : Liquid can cause burns similar to frostbite.

Section 3. Composition/information on ingredients

Substance/mixture : Substance

Chemical name : Oxygen Refrigerated Liquid

Other means of identification : Liquid Oxygen; LOX; Liquid Oxygen USP

Product code : 001190

CAS number/other identifiers

CAS number : 7782-44-7

Ingredient name	%	CAS number
Oxygen Refrigerated Liquid	100	7782-44-7

Any concentration shown as a range is to protect confidentiality or is due to batch variation.

There are no additional ingredients present which, within the current knowledge of the supplier and in the concentrations applicable, are classified as hazardous to health or the environment and hence require reporting in this section.

Occupational exposure limits, if available, are listed in Section 8.

Section 4. First aid measures

Description of necessary first aid measures

Eye contact : Immediately flush eyes with plenty of water, occasionally lifting the upper and lower eyelids. Check for and remove any contact lenses. Continue to rinse for at least 10 minutes. Get medical attention.

Inhalation : Remove victim to fresh air and keep at rest in a position comfortable for breathing. If not breathing, if breathing is irregular or if respiratory arrest occurs, provide artificial respiration or oxygen by trained personnel. It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation. Get medical attention if adverse health effects persist or are severe. If unconscious, place in recovery position and get medical attention immediately. Maintain an open airway. Loosen tight clothing such as a collar, tie, belt or waistband.

Skin contact : Flush contaminated skin with plenty of water. Remove contaminated clothing and shoes. Get medical attention if symptoms occur. In case of contact with liquid, warm frozen tissues slowly with lukewarm water and get medical attention. Do not rub affected area. Wash clothing before reuse. Clean shoes thoroughly before reuse.

Ingestion : Remove victim to fresh air and keep at rest in a position comfortable for breathing. Get medical attention if adverse health effects persist or are severe. Ingestion of liquid can cause burns similar to frostbite. If frostbite occurs, get medical attention. Never give anything by mouth to an unconscious person. If unconscious, place in recovery position and get medical attention immediately. Maintain an open airway. Loosen tight clothing such as a collar, tie, belt or waistband. As this product rapidly becomes a gas when released, refer to the inhalation section.

Most important symptoms/effects, acute and delayed

Potential acute health effects

Eye contact : Extremely cold material. Liquid can cause burns similar to frostbite.

Inhalation : No known significant effects or critical hazards.

Skin contact : Extremely cold material. Dermal contact with rapidly evaporating liquid could result in freezing of the tissues or frostbite.

Frostbite : Try to warm up the frozen tissues and seek medical attention.

Ingestion : Ingestion of liquid can cause burns similar to frostbite.

Over-exposure signs/symptoms

Eye contact : Adverse symptoms may include the following:, frostbite

Inhalation : No specific data.

Skin contact : Adverse symptoms may include the following:, frostbite

Ingestion : Adverse symptoms may include the following:, frostbite

Section 4. First aid measures

Indication of immediate medical attention and special treatment needed, if necessary

Notes to physician : Treat symptomatically. Contact poison treatment specialist immediately if large quantities have been ingested or inhaled.

Specific treatments : No specific treatment.

Protection of first-aiders : No action shall be taken involving any personal risk or without suitable training. It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation.

See toxicological information (Section 11)

Section 5. Fire-fighting measures

Extinguishing media

Suitable extinguishing media : Use an extinguishing agent suitable for the surrounding fire.

Unsuitable extinguishing media : None known.

Specific hazards arising from the chemical : Contains gas under pressure. Contains refrigerated gas. Oxidizing material. This material increases the risk of fire and may aid combustion. Contact with combustible material may cause fire. In a fire or if heated, a pressure increase will occur and the container may burst or explode.

Hazardous thermal decomposition products : No specific data.

Special protective actions for fire-fighters : Promptly isolate the scene by removing all persons from the vicinity of the incident if there is a fire. No action shall be taken involving any personal risk or without suitable training. Contact supplier immediately for specialist advice. Move containers from fire area if this can be done without risk. Use water spray to keep fire-exposed containers cool.

Special protective equipment for fire-fighters : Fire-fighters should wear appropriate protective equipment and self-contained breathing apparatus (SCBA) with a full face-piece operated in positive pressure mode. For incidents involving large quantities, thermally insulated undergarments and thick textile or leather gloves should be worn.

Section 6. Accidental release measures

Personal precautions, protective equipment and emergency procedures

For non-emergency personnel : No action shall be taken involving any personal risk or without suitable training. Evacuate surrounding areas. Keep unnecessary and unprotected personnel from entering. Do not touch or walk through spilled material. Shut off all ignition sources. No flares, smoking or flames in hazard area. Avoid breathing gas. Provide adequate ventilation. Wear appropriate respirator when ventilation is inadequate. Put on appropriate personal protective equipment.

For emergency responders : If specialized clothing is required to deal with the spillage, take note of any information in Section 8 on suitable and unsuitable materials. See also the information in "For non-emergency personnel".

Environmental precautions : Ensure emergency procedures to deal with accidental gas releases are in place to avoid contamination of the environment. Avoid dispersal of spilled material and runoff and contact with soil, waterways, drains and sewers. Inform the relevant authorities if the product has caused environmental pollution (sewers, waterways, soil or air).

Methods and materials for containment and cleaning up

Small spill : Immediately contact emergency personnel. Stop leak if without risk. Use spark-proof tools and explosion-proof equipment.

Section 6. Accidental release measures

Large spill : Immediately contact emergency personnel. Stop leak if without risk. Use spark-proof tools and explosion-proof equipment. Note: see Section 1 for emergency contact information and Section 13 for waste disposal.

Section 7. Handling and storage

Precautions for safe handling

Protective measures : Put on appropriate personal protective equipment (see Section 8). Contains gas under pressure. Contains refrigerated gas. Do not get in eyes or on skin or clothing. Avoid breathing gas. Do not puncture or incinerate container. Use equipment rated for cylinder pressure. Close valve after each use and when empty. Protect cylinders from physical damage; do not drag, roll, slide, or drop. Use a suitable hand truck for cylinder movement.
Never allow any unprotected part of the body to touch uninsulated pipes or vessels that contain cryogenic liquids. Prevent entrapment of liquid in closed systems or piping without pressure relief devices. Some materials may become brittle at low temperatures and will easily fracture. Empty containers retain product residue and can be hazardous. Keep away from clothing, incompatible materials and combustible materials. Keep reduction valves free from grease and oil.

Advice on general occupational hygiene : Eating, drinking and smoking should be prohibited in areas where this material is handled, stored and processed. Workers should wash hands and face before eating, drinking and smoking. Remove contaminated clothing and protective equipment before entering eating areas. See also Section 8 for additional information on hygiene measures.

Conditions for safe storage, including any incompatibilities : Store in accordance with local regulations. Store in a segregated and approved area. Store in a dry, cool and well-ventilated area, away from incompatible materials (see Section 10). Cylinders should be stored upright, with valve protection cap in place, and firmly secured to prevent falling or being knocked over. Cylinder temperatures should not exceed 52 °C (125 °F). Separate from reducing agents and combustible materials. Store away from grease and oil. Keep container tightly closed and sealed until ready for use. See Section 10 for incompatible materials before handling or use.

Section 8. Exposure controls/personal protection

Control parameters

Occupational exposure limits

Ingredient name	Exposure limits
Oxygen Refrigerated Liquid	None.

Appropriate engineering controls : Good general ventilation should be sufficient to control worker exposure to airborne contaminants.

Environmental exposure controls : Emissions from ventilation or work process equipment should be checked to ensure they comply with the requirements of environmental protection legislation. In some cases, fume scrubbers, filters or engineering modifications to the process equipment will be necessary to reduce emissions to acceptable levels.

Individual protection measures

Hygiene measures : Wash hands, forearms and face thoroughly after handling chemical products, before eating, smoking and using the lavatory and at the end of the working period. Appropriate techniques should be used to remove potentially contaminated clothing. Wash contaminated clothing before reusing. Ensure that eyewash stations and safety showers are close to the workstation location.

Eye/face protection : Safety eyewear complying with an approved standard should be used when a risk assessment indicates this is necessary to avoid exposure to liquid splashes, mists, gases or dusts. If contact is possible, the following protection should be worn, unless the assessment indicates a higher degree of protection: safety glasses with side-shields.

Skin protection

Section 8. Exposure controls/personal protection

Hand protection	:	Chemical-resistant, impervious gloves complying with an approved standard should be worn at all times when handling chemical products if a risk assessment indicates this is necessary. If contact with the liquid is possible, insulated gloves suitable for low temperatures should be worn. Considering the parameters specified by the glove manufacturer, check during use that the gloves are still retaining their protective properties. It should be noted that the time to breakthrough for any glove material may be different for different glove manufacturers. In the case of mixtures, consisting of several substances, the protection time of the gloves cannot be accurately estimated.
Body protection	:	Personal protective equipment for the body should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product.
Other skin protection	:	Appropriate footwear and any additional skin protection measures should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product.
Respiratory protection	:	Based on the hazard and potential for exposure, select a respirator that meets the appropriate standard or certification. Respirators must be used according to a respiratory protection program to ensure proper fitting, training, and other important aspects of use.
Thermal hazards	:	If there is a risk of contact with the liquid, all protective equipment worn should be suitable for use with extremely low temperature materials.

Section 9. Physical and chemical properties

Appearance

Physical state	:	Cryogenic Liquid
Color	:	Colorless. Blue.
Odor	:	Odorless.
Odor threshold	:	Not available.
pH	:	Not available.
Melting point	:	-218.4°C (-361.1°F)
Boiling point	:	-183°C (-297.4°F)
Critical temperature	:	-118.15°C (-180.7°F)
Flash point	:	[Product does not sustain combustion.]
Evaporation rate	:	Not available.
Flammability (solid, gas)	:	Extremely flammable in the presence of the following materials or conditions: reducing materials, combustible materials and organic materials.
Lower and upper explosive (flammable) limits	:	Not available.
Vapor pressure	:	Not available.
Vapor density	:	1.1 (Air = 1)
Specific Volume (ft^3/lb)	:	12.0482
Gas Density (lb/ft^3)	:	0.083
Relative density	:	Not applicable.
Solubility	:	Not available.
Solubility in water	:	Not available.
Partition coefficient: n-octanol/water	:	0.65
Auto-ignition temperature	:	Not available.
Decomposition temperature	:	Not available.
Viscosity	:	Not applicable.
Flow time (ISO 2431)	:	Not available.
Molecular weight	:	32 g/mole

Section 10. Stability and reactivity

Reactivity : No specific test data related to reactivity available for this product or its ingredients.

Chemical stability : The product is stable.

Possibility of hazardous reactions : Under normal conditions of storage and use, hazardous reactions will not occur.

Conditions to avoid : No specific data.

Incompatible materials : Highly reactive or incompatible with the following materials:
combustible materials
reducing materials
grease
oil

Hazardous decomposition products : Under normal conditions of storage and use, hazardous decomposition products should not be produced.

Hazardous polymerization : Under normal conditions of storage and use, hazardous polymerization will not occur.

Section 11. Toxicological information

Information on toxicological effects

Acute toxicity

Not available.

Irritation/Corrosion

Not available.

Sensitization

Not available.

Mutagenicity

Not available.

Carcinogenicity

Not available.

Reproductive toxicity

Not available.

Teratogenicity

Not available.

Specific target organ toxicity (single exposure)

Not available.

Specific target organ toxicity (repeated exposure)

Not available.

Aspiration hazard

Not available.

Information on the likely routes of exposure : Not available.

Potential acute health effects

Section 11. Toxicological information

Eye contact : Extremely cold material. Liquid can cause burns similar to frostbite.

Inhalation : No known significant effects or critical hazards.

Skin contact : Extremely cold material. Dermal contact with rapidly evaporating liquid could result in freezing of the tissues or frostbite.

Ingestion : Ingestion of liquid can cause burns similar to frostbite.

Symptoms related to the physical, chemical and toxicological characteristics

Eye contact : Adverse symptoms may include the following:, frostbite

Inhalation : No specific data.

Skin contact : Adverse symptoms may include the following:, frostbite

Ingestion : Adverse symptoms may include the following:, frostbite

Delayed and immediate effects and also chronic effects from short and long term exposure

Short term exposure

Potential immediate effects : Not available.

Potential delayed effects : Not available.

Long term exposure

Potential immediate effects : Not available.

Potential delayed effects : Not available.

Potential chronic health effects

Not available.

General : No known significant effects or critical hazards.

Carcinogenicity : No known significant effects or critical hazards.

Mutagenicity : No known significant effects or critical hazards.

Teratogenicity : No known significant effects or critical hazards.

Developmental effects : No known significant effects or critical hazards.

Fertility effects : No known significant effects or critical hazards.

Numerical measures of toxicity

Acute toxicity estimates

Not available.

Section 12. Ecological information

Toxicity

Not available.

Persistence and degradability

Not available.

Bioaccumulative potential

Product/ingredient name	$LogP_{ow}$	BCF	Potential
Oxygen Refrigerated Liquid	0.65	-	low

Mobility in soil

Section 12. Ecological information

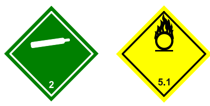
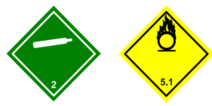
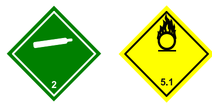
Soil/water partition coefficient (K_{OC}) : Not available.

Other adverse effects : No known significant effects or critical hazards.

Section 13. Disposal considerations

Disposal methods : The generation of waste should be avoided or minimized wherever possible. Disposal of this product, solutions and any by-products should at all times comply with the requirements of environmental protection and waste disposal legislation and any regional local authority requirements. Dispose of surplus and non-recyclable products via a licensed waste disposal contractor. Waste should not be disposed of untreated to the sewer unless fully compliant with the requirements of all authorities with jurisdiction. Empty Airgas-owned pressure vessels should be returned to Airgas. Waste packaging should be recycled. Incineration or landfill should only be considered when recycling is not feasible. This material and its container must be disposed of in a safe way. Empty containers or liners may retain some product residues. Do not puncture or incinerate container.

Section 14. Transport information

	DOT	TDG	Mexico	IMDG	IATA
UN number	UN1073	UN1073	UN1073	UN1073	UN1073
UN proper shipping name	Oxygen, Refrigerated Liquid	Oxygen, Refrigerated Liquid	Oxygen, Refrigerated Liquid	Oxygen, Refrigerated Liquid	Oxygen, Refrigerated Liquid
Transport hazard class(es)	2.2 (5.1) 	2.2 	2.2 (5.1) 	2.2 (5.1) 	2.2 (5.1) 
Packing group	-	-	-	-	-
Environmental hazards	No.	No.	No.	No.	No.

“Refer to CFR 49 (or authority having jurisdiction) to determine the information required for shipment of the product.”

Additional information

DOT Classification : **Limited quantity** Yes.
Quantity limitation Passenger aircraft/rail: 75 kg. Cargo aircraft: 150 kg.
Special provisions A52

TDG Classification : Product classified as per the following sections of the Transportation of Dangerous Goods Regulations: 2.13-2.17 (Class 2), 2.23-2.25 (Class 5).
Explosive Limit and Limited Quantity Index 0.125
ERAP Index 3000
Passenger Carrying Ship Index 50
Passenger Carrying Road or Rail Index 75
Special provisions 42

IATA : **Quantity limitation** Passenger and Cargo Aircraft: 75 kg. Cargo Aircraft Only: 150 kg.

Special precautions for user : **Transport within user’s premises:** always transport in closed containers that are upright and secure. Ensure that persons transporting the product know what to do in the event of an accident or spillage.

Section 14. Transport information

Transport in bulk according to Annex II of MARPOL and the IBC Code : Not available.

Section 15. Regulatory information

U.S. Federal regulations : **TSCA 8(a) CDR Exempt/Partial exemption**: This material is listed or exempted.

Clean Air Act Section 112 (b) Hazardous Air Pollutants (HAPs) : Not listed

Clean Air Act Section 602 Class I Substances : Not listed

Clean Air Act Section 602 Class II Substances : Not listed

DEA List I Chemicals (Precursor Chemicals) : Not listed

DEA List II Chemicals (Essential Chemicals) : Not listed

SARA 302/304

Composition/information on ingredients

No products were found.

SARA 304 RQ : Not applicable.

SARA 311/312

Classification : Refer to Section 2: Hazards Identification of this SDS for classification of substance.

State regulations

Massachusetts : This material is listed.

New York : This material is not listed.

New Jersey : This material is listed.

Pennsylvania : This material is listed.

International regulations

Chemical Weapon Convention List Schedules I, II & III Chemicals

Not listed.

Montreal Protocol (Annexes A, B, C, E)

Not listed.

Stockholm Convention on Persistent Organic Pollutants

Not listed.

Rotterdam Convention on Prior Informed Consent (PIC)

Not listed.

UNECE Aarhus Protocol on POPs and Heavy Metals

Not listed.

Inventory list

Australia : This material is listed or exempted.

Canada : This material is listed or exempted.

China : This material is listed or exempted.

Europe : This material is listed or exempted.

Japan : **Japan inventory (ENCS)**: Not determined.
Japan inventory (ISHL): Not determined.

Malaysia : Not determined.

Section 15. Regulatory information

New Zealand	:	This material is listed or exempted.
Philippines	:	This material is listed or exempted.
Republic of Korea	:	This material is listed or exempted.
Taiwan	:	This material is listed or exempted.
Thailand	:	Not determined.
Turkey	:	Not determined.
United States	:	This material is listed or exempted.
Viet Nam	:	Not determined.

Section 16. Other information

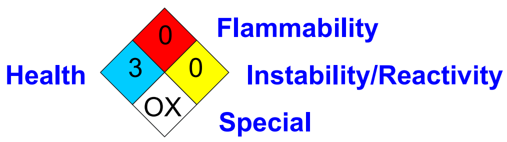
Hazardous Material Information System (U.S.A.)

Health	/	3
Flammability		0
Physical hazards		2

Caution: HMIS® ratings are based on a 0-4 rating scale, with 0 representing minimal hazards or risks, and 4 representing significant hazards or risks. Although HMIS® ratings and the associated label are not required on SDSs or products leaving a facility under 29 CFR 1910.1200, the preparer may choose to provide them. HMIS® ratings are to be used with a fully implemented HMIS® program. HMIS® is a registered trademark and service mark of the American Coatings Association, Inc.

The customer is responsible for determining the PPE code for this material. For more information on HMIS® Personal Protective Equipment (PPE) codes, consult the HMIS® Implementation Manual.

National Fire Protection Association (U.S.A.)



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Copyright ©2001, National Fire Protection Association, Quincy, MA 02269. This warning system is intended to be interpreted and applied only by properly trained individuals to identify fire, health and reactivity hazards of chemicals. The user is referred to certain limited number of chemicals with recommended classifications in NFPA 49 and NFPA 325, which would be used as a guideline only. Whether the chemicals are classified by NFPA or not, anyone using the 704 systems to classify chemicals does so at their own risk.

Procedure used to derive the classification

Classification	Justification
OXIDIZING GASES - Category 1 GASES UNDER PRESSURE - Refrigerated liquefied gas	Expert judgment Expert judgment

History

Date of printing	:	5/7/2019
Date of issue/Date of revision	:	5/7/2019
Date of previous issue	:	1/31/2018
Version	:	1

Section 16. Other information

Key to abbreviations : ATE = Acute Toxicity Estimate
BCF = Bioconcentration Factor
GHS = Globally Harmonized System of Classification and Labelling of Chemicals
IATA = International Air Transport Association
IBC = Intermediate Bulk Container
IMDG = International Maritime Dangerous Goods
LogPow = logarithm of the octanol/water partition coefficient
MARPOL = International Convention for the Prevention of Pollution From Ships, 1973 as modified by the Protocol of 1978. ("Marpol" = marine pollution)
UN = United Nations

References : Not available.

Notice to reader

To the best of our knowledge, the information contained herein is accurate. However, neither the above-named supplier, nor any of its subsidiaries, assumes any liability whatsoever for the accuracy or completeness of the information contained herein.
Final determination of suitability of any material is the sole responsibility of the user. All materials may present unknown hazards and should be used with caution. Although certain hazards are described herein, we cannot guarantee that these are the only hazards that exist.

SAFETY DATA SHEET

Version 4.6
Revision Date 05/27/2016
Print Date 10/04/2019

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name	:	Isopropanol
Product Number	:	563935
Brand	:	Sigma-Aldrich
CAS-No.	:	67-63-0

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses	:	Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company	:	Sigma-Aldrich 3050 Spruce Street SAINT LOUIS MO 63103 USA
Telephone	:	+1 800-325-5832
Fax	:	+1 800-325-5052

1.4 Emergency telephone number

Emergency Phone #	:	+1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Flammable liquids (Category 2), H225
Eye irritation (Category 2A), H319
Specific target organ toxicity - single exposure (Category 3), Central nervous system, H336

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word Danger

Hazard statement(s)

H225	Highly flammable liquid and vapour.
H319	Causes serious eye irritation.
H336	May cause drowsiness or dizziness.

Precautionary statement(s)

P210	Keep away from heat/sparks/open flames/hot surfaces. No smoking.
P233	Keep container tightly closed.
P240	Ground/bond container and receiving equipment.
P241	Use explosion-proof electrical/ ventilating/ lighting/ equipment.
P242	Use only non-sparking tools.
P243	Take precautionary measures against static discharge.
P261	Avoid breathing dust/ fume/ gas/ mist/ vapours/ spray.

P264	Wash skin thoroughly after handling.
P271	Use only outdoors or in a well-ventilated area.
P280	Wear protective gloves/ eye protection/ face protection.
P303 + P361 + P353	IF ON SKIN (or hair): Take off immediately all contaminated clothing. Rinse skin with water/shower.
P304 + P340 + P312	IF INHALED: Remove person to fresh air and keep comfortable for breathing. Call a POISON CENTER/doctor if you feel unwell.
P305 + P351 + P338	IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.
P337 + P313	If eye irritation persists: Get medical advice/ attention.
P370 + P378	In case of fire: Use dry sand, dry chemical or alcohol-resistant foam to extinguish.
P403 + P233	Store in a well-ventilated place. Keep container tightly closed.
P403 + P235	Store in a well-ventilated place. Keep cool.
P405	Store locked up.
P501	Dispose of contents/ container to an approved waste disposal plant.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS

May form explosive peroxides.

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.2 Mixtures

Synonyms : 2-Propanol solution
IPA
Isopropyl alcohol

Molecular weight : 60.1 g/mol

Hazardous components

Component		Classification	Concentration
2-Propanol			
CAS-No.	67-63-0	Flam. Liq. 2; Eye Irrit. 2A; STOT SE 3; H225, H319, H336	>= 70 - < 90 %
EC-No.	200-661-7		
Index-No.	603-117-00-0		

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice

Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled

If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact

Wash off with soap and plenty of water. Consult a physician.

In case of eye contact

Rinse thoroughly with plenty of water for at least 15 minutes and consult a physician.

If swallowed

Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed

The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed

No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
No data available

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
Use water spray to cool unopened containers.

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Use personal protective equipment. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Remove all sources of ignition. Evacuate personnel to safe areas. Beware of vapours accumulating to form explosive concentrations. Vapours can accumulate in low areas.
For personal protection see section 8.

6.2 Environmental precautions
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Contain spillage, and then collect with an electrically protected vacuum cleaner or by wet-brushing and place in container for disposal according to local regulations (see section 13).

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Avoid contact with skin and eyes. Avoid inhalation of vapour or mist.
Use explosion-proof equipment.Keep away from sources of ignition - No smoking.Take measures to prevent the build up of electrostatic charge.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place. Containers which are opened must be carefully resealed and kept upright to prevent leakage.
Storage class (TRGS 510): Flammable liquids

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters

Component	CAS-No.	Value	Control parameters	Basis
2-Propanol	67-63-0	TWA	200.000000 ppm	USA. ACGIH Threshold Limit Values (TLV)
	Remarks	Central Nervous System impairment Upper Respiratory Tract irritation Eye irritation Substances for which there is a Biological Exposure Index or Indices (see BEI® section) Not classifiable as a human carcinogen		

		TWA	200 ppm	USA. ACGIH Threshold Limit Values (TLV)
		Central Nervous System impairment Upper Respiratory Tract irritation Eye irritation Substances for which there is a Biological Exposure Index or Indices (see BEI® section) Not classifiable as a human carcinogen		
		STEL	400 ppm	USA. ACGIH Threshold Limit Values (TLV)
		Central Nervous System impairment Upper Respiratory Tract irritation Eye irritation Substances for which there is a Biological Exposure Index or Indices (see BEI® section) Not classifiable as a human carcinogen		
		STEL	400.000000 ppm	USA. ACGIH Threshold Limit Values (TLV)
		Central Nervous System impairment Upper Respiratory Tract irritation Eye irritation Substances for which there is a Biological Exposure Index or Indices (see BEI® section) Not classifiable as a human carcinogen		
		TWA	400.000000 ppm 980.000000 mg/m3	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
		The value in mg/m3 is approximate.		
		TWA	400.000000 ppm 980.000000 mg/m3	USA. NIOSH Recommended Exposure Limits
		ST	500.000000 ppm 1,225.000000 mg/m3	USA. NIOSH Recommended Exposure Limits
		PEL	400 ppm 980 mg/m3	California permissible exposure limits for chemical contaminants (Title 8, Article 107)
		STEL	500 ppm 1,225 mg/m3	California permissible exposure limits for chemical contaminants (Title 8, Article 107)

Biological occupational exposure limits

Component	CAS-No.	Parameters	Value	Biological specimen	Basis
2-Propanol	67-63-0	Acetone	40.0000 mg/l	Urine	ACGIH - Biological Exposure Indices (BEI)
	Remarks	End of shift at end of workweek			

8.2 Exposure controls

Appropriate engineering controls

Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection
Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 33 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Impervious clothing, Flame retardant antistatic protective clothing., The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face respirator with multi-purpose combination (US) or type ABEK (EN 14387) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: liquid Colour: colourless
b)	Odour	No data available
c)	Odour Threshold	No data available
d)	pH	No data available
e)	Melting point/freezing point	No data available
f)	Initial boiling point and boiling range	80.9 - 83.2 °C (177.6 - 181.8 °F)
g)	Flash point	22.2 °C (72.0 °F) - closed cup
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or explosive limits	No data available
k)	Vapour pressure	No data available
l)	Vapour density	No data available
m)	Relative density	0.858 g/cm3

n)	Water solubility	No data available
o)	Partition coefficient: n-octanol/water	No data available
p)	Auto-ignition temperature	No data available
q)	Decomposition temperature	No data available
r)	Viscosity	No data available
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information
No data available

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
Vapours may form explosive mixture with air.

10.4 Conditions to avoid
Heat, flames and sparks.

10.5 Incompatible materials
Aluminium, Acids, Oxidizing agents, Halogenated compounds, Acid anhydrides

10.6 Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - Carbon oxides
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
No data available

Inhalation: No data available

Dermal: No data available

No data available

Skin corrosion/irritation
No data available

Serious eye damage/eye irritation
No data available

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
No data available

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
No data available
No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information
RTECS: Not available

Central nervous system depression, prolonged or repeated exposure can cause:, Nausea, Dizziness, narcosis, Drowsiness, To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

Kidney - Irregularities - Based on Human Evidence
Kidney - Irregularities - Based on Human Evidence (2-Propanol)

12. ECOLOGICAL INFORMATION

12.1 Toxicity
No data available

12.2 Persistence and degradability
No data available

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects
No data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Burn in a chemical incinerator equipped with an afterburner and scrubber but exert extra care in igniting as this material is highly flammable. Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
UN number: 1219 Class: 3 Packing group: II
Proper shipping name: Isopropanol
Reportable Quantity (RQ):

Poison Inhalation Hazard: No

IMDG

UN number: 1219	Class: 3	Packing group: II	EMS-No: F-E, S-D

Proper shipping name: ISOPROPANOL

IATA

UN number: 1219	Class: 3	Packing group: II

Proper shipping name: Isopropanol

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
The following components are subject to reporting levels established by SARA Title III, Section 313:

	CAS-No.	Revision Date
2-Propanol	67-63-0	1987-01-01

SARA 311/312 Hazards
Fire Hazard, Acute Health Hazard, Chronic Health Hazard

Massachusetts Right To Know Components

	CAS-No.	Revision Date
2-Propanol	67-63-0	1987-01-01

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
2-Propanol	67-63-0	1987-01-01
Water	7732-18-5	

New Jersey Right To Know Components

	CAS-No.	Revision Date
2-Propanol	67-63-0	1987-01-01
Water	7732-18-5	

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

Eye Irrit.	Eye irritation
Flam. Liq.	Flammable liquids
H225	Highly flammable liquid and vapour.
H319	Causes serious eye irritation.
H336	May cause drowsiness or dizziness.
STOT SE	Specific target organ toxicity - single exposure

HMIS Rating

Health hazard:	2
Chronic Health Hazard:	*
Flammability:	3
Physical Hazard	0

NFPA Rating

Health hazard:	2
Fire Hazard:	3
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information

Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 4.6 Revision Date: 05/27/2016 Print Date: 10/04/2019

SAFETY DATA SHEET

Nitrogen

Section 1. Identification

GHS product identifier : Nitrogen

Chemical name : nitrogen

Other means of identification : nitrogen (dot); nitrogen gas; Nitrogen NF, Nitrogen FG

Product type : Gas.

Product use : Synthetic/Analytical chemistry.

Synonym : nitrogen (dot); nitrogen gas; Nitrogen NF, Nitrogen FG

SDS # : 001040

Supplier's details : Airgas USA, LLC and its affiliates
259 North Radnor-Chester Road
Suite 100
Radnor, PA 19087-5283
1-610-687-5253

24-hour telephone : 1-866-734-3438

Section 2. Hazards identification

OSHA/HCS status : This material is considered hazardous by the OSHA Hazard Communication Standard (29 CFR 1910.1200).

Classification of the substance or mixture : GASES UNDER PRESSURE - Compressed gas
SIMPLE ASPHYXIANTS

GHS label elements

Hazard pictograms :

Signal word : Warning

Hazard statements : Contains gas under pressure; may explode if heated.
May displace oxygen and cause rapid suffocation.

Precautionary statements

General : Read and follow all Safety Data Sheets (SDS'S) before use. Read label before use. Keep out of reach of children. If medical advice is needed, have product container or label at hand. Close valve after each use and when empty. Use equipment rated for cylinder pressure. Do not open valve until connected to equipment prepared for use. Use a back flow preventative device in the piping. Use only equipment of compatible materials of construction.

Prevention : Not applicable.

Response : Not applicable.

Storage : Protect from sunlight. Store in a well-ventilated place.

Disposal : Not applicable.

Supplemental label elements : Keep container tightly closed. Use only with adequate ventilation. Do not enter storage areas and confined spaces unless adequately ventilated.

Hazards not otherwise classified : In addition to any other important health or physical hazards, this product may displace oxygen and cause rapid suffocation.

Section 3. Composition/information on ingredients

Substance/mixture : Substance

Chemical name : nitrogen

Other means of identification : nitrogen (dot); nitrogen gas; Nitrogen NF, Nitrogen FG

Product code : 001040

CAS number/other identifiers

CAS number : 7727-37-9

Ingredient name	%	CAS number
Nitrogen	100	7727-37-9

Any concentration shown as a range is to protect confidentiality or is due to batch variation.

There are no additional ingredients present which, within the current knowledge of the supplier and in the concentrations applicable, are classified as hazardous to health or the environment and hence require reporting in this section.

Occupational exposure limits, if available, are listed in Section 8.

Section 4. First aid measures

Description of necessary first aid measures

Eye contact : Immediately flush eyes with plenty of water, occasionally lifting the upper and lower eyelids. Check for and remove any contact lenses. Continue to rinse for at least 10 minutes. Get medical attention if irritation occurs.

Inhalation : Remove victim to fresh air and keep at rest in a position comfortable for breathing. If it is suspected that fumes are still present, the rescuer should wear an appropriate mask or self-contained breathing apparatus. If not breathing, if breathing is irregular or if respiratory arrest occurs, provide artificial respiration or oxygen by trained personnel. It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation. Get medical attention if adverse health effects persist or are severe. If unconscious, place in recovery position and get medical attention immediately. Maintain an open airway. Loosen tight clothing such as a collar, tie, belt or waistband. In case of inhalation of decomposition products in a fire, symptoms may be delayed. The exposed person may need to be kept under medical surveillance for 48 hours.

Skin contact : Flush contaminated skin with plenty of water. Remove contaminated clothing and shoes. Get medical attention if symptoms occur. Wash clothing before reuse. Clean shoes thoroughly before reuse.

Ingestion : As this product is a gas, refer to the inhalation section.

Most important symptoms/effects, acute and delayed

Potential acute health effects

Eye contact : Contact with rapidly expanding gas may cause burns or frostbite.

Inhalation : At very high concentrations, can displace the normal air and cause suffocation from lack of oxygen.

Skin contact : Contact with rapidly expanding gas may cause burns or frostbite.

Frostbite : Try to warm up the frozen tissues and seek medical attention.

Ingestion : As this product is a gas, refer to the inhalation section.

Over-exposure signs/symptoms

Eye contact : No specific data.

Inhalation : No specific data.

Skin contact : No specific data.

Ingestion : No specific data.

Indication of immediate medical attention and special treatment needed, if necessary

Section 4. First aid measures

Notes to physician : In case of inhalation of decomposition products in a fire, symptoms may be delayed. The exposed person may need to be kept under medical surveillance for 48 hours.

Specific treatments : No specific treatment.

Protection of first-aiders : No action shall be taken involving any personal risk or without suitable training. If it is suspected that fumes are still present, the rescuer should wear an appropriate mask or self-contained breathing apparatus. It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation.

See toxicological information (Section 11)

Section 5. Fire-fighting measures

Extinguishing media

Suitable extinguishing media : Use an extinguishing agent suitable for the surrounding fire.

Unsuitable extinguishing media : None known.

Specific hazards arising from the chemical : Contains gas under pressure. In a fire or if heated, a pressure increase will occur and the container may burst or explode.

Hazardous thermal decomposition products : Decomposition products may include the following materials: nitrogen oxides

Special protective actions for fire-fighters : Promptly isolate the scene by removing all persons from the vicinity of the incident if there is a fire. No action shall be taken involving any personal risk or without suitable training. Contact supplier immediately for specialist advice. Move containers from fire area if this can be done without risk. Use water spray to keep fire-exposed containers cool.

Special protective equipment for fire-fighters : Fire-fighters should wear appropriate protective equipment and self-contained breathing apparatus (SCBA) with a full face-piece operated in positive pressure mode.

Section 6. Accidental release measures

Personal precautions, protective equipment and emergency procedures

For non-emergency personnel : No action shall be taken involving any personal risk or without suitable training. Evacuate surrounding areas. Keep unnecessary and unprotected personnel from entering. Avoid breathing gas. Provide adequate ventilation. Wear appropriate respirator when ventilation is inadequate. Put on appropriate personal protective equipment.

For emergency responders : If specialized clothing is required to deal with the spillage, take note of any information in Section 8 on suitable and unsuitable materials. See also the information in "For non-emergency personnel".

Environmental precautions : Ensure emergency procedures to deal with accidental gas releases are in place to avoid contamination of the environment. Inform the relevant authorities if the product has caused environmental pollution (sewers, waterways, soil or air).

Methods and materials for containment and cleaning up

Small spill : Immediately contact emergency personnel. Stop leak if without risk.

Large spill : Immediately contact emergency personnel. Stop leak if without risk. Note: see Section 1 for emergency contact information and Section 13 for waste disposal.

Section 7. Handling and storage

Precautions for safe handling

Protective measures : Put on appropriate personal protective equipment (see Section 8). Contains gas under pressure. Avoid breathing gas. Use only with adequate ventilation. Wear appropriate respirator when ventilation is inadequate. Do not puncture or incinerate container. Use equipment rated for cylinder pressure. Close valve after each use and when empty. Protect cylinders from physical damage; do not drag, roll, slide, or drop. Use a suitable hand truck for cylinder movement.
Avoid contact with eyes, skin and clothing. Empty containers retain product residue and can be hazardous.

Advice on general occupational hygiene : Eating, drinking and smoking should be prohibited in areas where this material is handled, stored and processed. Workers should wash hands and face before eating, drinking and smoking. Remove contaminated clothing and protective equipment before entering eating areas. See also Section 8 for additional information on hygiene measures.

Conditions for safe storage, including any incompatibilities : Store in accordance with local regulations. Store in a segregated and approved area. Store away from direct sunlight in a dry, cool and well-ventilated area, away from incompatible materials (see Section 10). Cylinders should be stored upright, with valve protection cap in place, and firmly secured to prevent falling or being knocked over. Cylinder temperatures should not exceed 52 °C (125 °F). Keep container tightly closed and sealed until ready for use. See Section 10 for incompatible materials before handling or use.

Section 8. Exposure controls/personal protection

Control parameters

Occupational exposure limits

Ingredient name	Exposure limits
Nitrogen	**ACGIH TLV (United States, 3/2017). Oxygen Depletion [Asphyxiant].**

Appropriate engineering controls : Use only with adequate ventilation. Use process enclosures, local exhaust ventilation or other engineering controls to keep worker exposure to airborne contaminants below any recommended or statutory limits.

Environmental exposure controls : Emissions from ventilation or work process equipment should be checked to ensure they comply with the requirements of environmental protection legislation. In some cases, fume scrubbers, filters or engineering modifications to the process equipment will be necessary to reduce emissions to acceptable levels.

Individual protection measures

Hygiene measures : Wash hands, forearms and face thoroughly after handling chemical products, before eating, smoking and using the lavatory and at the end of the working period. Appropriate techniques should be used to remove potentially contaminated clothing. Wash contaminated clothing before reusing. Ensure that eyewash stations and safety showers are close to the workstation location.

Eye/face protection : Safety eyewear complying with an approved standard should be used when a risk assessment indicates this is necessary to avoid exposure to liquid splashes, mists, gases or dusts. If contact is possible, the following protection should be worn, unless the assessment indicates a higher degree of protection: safety glasses with side-shields.

Skin protection

Hand protection : Chemical-resistant, impervious gloves complying with an approved standard should be worn at all times when handling chemical products if a risk assessment indicates this is necessary. Considering the parameters specified by the glove manufacturer, check during use that the gloves are still retaining their protective properties. It should be noted that the time to breakthrough for any glove material may be different for different glove manufacturers. In the case of mixtures, consisting of several substances, the protection time of the gloves cannot be accurately estimated.

Section 8. Exposure controls/personal protection

Body protection	:	Personal protective equipment for the body should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product.
Other skin protection	:	Appropriate footwear and any additional skin protection measures should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product.
Respiratory protection	:	The gas can cause asphyxiation without warning by replacing the oxygen in the air. Based on the hazard and potential for exposure, select a respirator that meets the appropriate standard or certification. If operating conditions cause high gas concentrations to be produced or any recommended or statutory exposure limit is exceeded, use an air-fed respirator or self-contained breathing apparatus. Respirators must be used according to a respiratory protection program to ensure proper fitting, training, and other important aspects of use. Respirator selection must be based on known or anticipated exposure levels, the hazards of the product and the safe working limits of the selected respirator.

Section 9. Physical and chemical properties

Appearance

Physical state	:	Gas. [Compressed gas.]
Color	:	Colorless.
Odor	:	Odorless.
Odor threshold	:	Not available.
pH	:	Not available.
Melting point	:	-210.01°C (-346°F)
Boiling point	:	-196°C (-320.8°F)
Critical temperature	:	-146.95°C (-232.5°F)
Flash point	:	[Product does not sustain combustion.]
Evaporation rate	:	Not available.
Flammability (solid, gas)	:	Not available.
Lower and upper explosive (flammable) limits	:	Not available.
Vapor pressure	:	Not available.
Vapor density	:	0.967 (Air = 1) Liquid Density@BP: 50.46 lb/ft3 (808.3 kg/m3)
Specific Volume (ft^3/lb)	:	13.8889
Gas Density (lb/ft^3)	:	0.072
Relative density	:	Not applicable.
Solubility	:	Not available.
Solubility in water	:	Not available.
Partition coefficient: n-octanol/water	:	0.67
Auto-ignition temperature	:	Not available.
Decomposition temperature	:	Not available.
Viscosity	:	Not applicable.
Flow time (ISO 2431)	:	Not available.
Molecular weight	:	28.02 g/mole

Section 10. Stability and reactivity

Reactivity : No specific test data related to reactivity available for this product or its ingredients.

Chemical stability : The product is stable.

Possibility of hazardous reactions : Under normal conditions of storage and use, hazardous reactions will not occur.

Conditions to avoid : Do not allow gas to accumulate in low or confined areas.

Incompatible materials : No specific data.

Hazardous decomposition products : Under normal conditions of storage and use, hazardous decomposition products should not be produced.

Hazardous polymerization : Under normal conditions of storage and use, hazardous polymerization will not occur.

Section 11. Toxicological information

Information on toxicological effects

Acute toxicity

Not available.

Irritation/Corrosion

Not available.

Sensitization

Not available.

Mutagenicity

Not available.

Carcinogenicity

Not available.

Reproductive toxicity

Not available.

Teratogenicity

Not available.

Specific target organ toxicity (single exposure)

Not available.

Specific target organ toxicity (repeated exposure)

Not available.

Aspiration hazard

Not available.

Information on the likely routes of exposure : Not available.

Potential acute health effects

Eye contact : Contact with rapidly expanding gas may cause burns or frostbite.

Inhalation : At very high concentrations, can displace the normal air and cause suffocation from lack of oxygen.

Section 11. Toxicological information

Skin contact : Contact with rapidly expanding gas may cause burns or frostbite.

Ingestion : As this product is a gas, refer to the inhalation section.

Symptoms related to the physical, chemical and toxicological characteristics

Eye contact : No specific data.

Inhalation : No specific data.

Skin contact : No specific data.

Ingestion : No specific data.

Delayed and immediate effects and also chronic effects from short and long term exposure

Short term exposure

Potential immediate effects : Not available.

Potential delayed effects : Not available.

Long term exposure

Potential immediate effects : Not available.

Potential delayed effects : Not available.

Potential chronic health effects

Not available.

General : No known significant effects or critical hazards.

Carcinogenicity : No known significant effects or critical hazards.

Mutagenicity : No known significant effects or critical hazards.

Teratogenicity : No known significant effects or critical hazards.

Developmental effects : No known significant effects or critical hazards.

Fertility effects : No known significant effects or critical hazards.

Numerical measures of toxicity

Acute toxicity estimates

Not available.

Section 12. Ecological information

Toxicity

Not available.

Persistence and degradability

Not available.

Bioaccumulative potential

Product/ingredient name	$LogP_{ow}$	BCF	Potential
Nitrogen	0.67	-	low

Mobility in soil

Soil/water partition coefficient (K_{OC}) : Not available.

Section 12. Ecological information

Other adverse effects : No known significant effects or critical hazards.

Section 13. Disposal considerations

Disposal methods : The generation of waste should be avoided or minimized wherever possible. Disposal of this product, solutions and any by-products should at all times comply with the requirements of environmental protection and waste disposal legislation and any regional local authority requirements. Dispose of surplus and non-recyclable products via a licensed waste disposal contractor. Waste should not be disposed of untreated to the sewer unless fully compliant with the requirements of all authorities with jurisdiction. Empty Airgas-owned pressure vessels should be returned to Airgas. Waste packaging should be recycled. Incineration or landfill should only be considered when recycling is not feasible. This material and its container must be disposed of in a safe way. Empty containers or liners may retain some product residues. Do not puncture or incinerate container.

Section 14. Transport information

	DOT	TDG	Mexico	IMDG	IATA
UN number	UN1066	UN1066	UN1066	UN1066	UN1066
UN proper shipping name	NITROGEN, COMPRESSED	NITROGEN, COMPRESSED	NITROGEN, COMPRESSED	NITROGEN, COMPRESSED	NITROGEN, COMPRESSED
Transport hazard class(es)	2.2 	2.2 	2.2 	2.2 	2.2 
Packing group	-	-	-	-	-
Environmental hazards	No.	No.	No.	No.	No.

"Refer to CFR 49 (or authority having jurisdiction) to determine the information required for shipment of the product."

Additional information

DOT Classification : **Limited quantity** Yes.
Quantity limitation Passenger aircraft/rail: 75 kg. Cargo aircraft: 150 kg.

TDG Classification : Product classified as per the following sections of the Transportation of Dangerous Goods Regulations: 2.13-2.17 (Class 2).
Explosive Limit and Limited Quantity Index 0.125
Passenger Carrying Road or Rail Index 75

IATA : **Quantity limitation** Passenger and Cargo Aircraft: 75 kg. Cargo Aircraft Only: 150 kg.

Special precautions for user : **Transport within user's premises:** always transport in closed containers that are upright and secure. Ensure that persons transporting the product know what to do in the event of an accident or spillage.

Transport in bulk according to Annex II of MARPOL and the IBC Code : Not available.

Section 15. Regulatory information

U.S. Federal regulations	: **TSCA 8(a) CDR Exempt/Partial exemption**: This material is listed or exempted.
Clean Air Act Section 112 (b) Hazardous Air Pollutants (HAPs)	: Not listed
Clean Air Act Section 602 Class I Substances	: Not listed
Clean Air Act Section 602 Class II Substances	: Not listed
DEA List I Chemicals (Precursor Chemicals)	: Not listed
DEA List II Chemicals (Essential Chemicals)	: Not listed

SARA 302/304

Composition/information on ingredients

No products were found.

SARA 304 RQ : Not applicable.

SARA 311/312

Classification : Refer to Section 2: Hazards Identification of this SDS for classification of substance.

State regulations

Massachusetts	: This material is listed.
New York	: This material is not listed.
New Jersey	: This material is listed.
Pennsylvania	: This material is listed.

International regulations

Chemical Weapon Convention List Schedules I, II & III Chemicals

Not listed.

Montreal Protocol (Annexes A, B, C, E)

Not listed.

Stockholm Convention on Persistent Organic Pollutants

Not listed.

Rotterdam Convention on Prior Informed Consent (PIC)

Not listed.

UNECE Aarhus Protocol on POPs and Heavy Metals

Not listed.

Inventory list

Australia	: This material is listed or exempted.
Canada	: This material is listed or exempted.
China	: This material is listed or exempted.
Europe	: This material is listed or exempted.
Japan	: **Japan inventory (ENCS)**: Not determined. **Japan inventory (ISHL)**: Not determined.
Malaysia	: Not determined.
New Zealand	: This material is listed or exempted.
Philippines	: This material is listed or exempted.
Republic of Korea	: This material is listed or exempted.

Section 15. Regulatory information

Taiwan	:	This material is listed or exempted.
Thailand	:	Not determined.
Turkey	:	Not determined.
United States	:	This material is listed or exempted.
Viet Nam	:	Not determined.

Section 16. Other information

Hazardous Material Information System (U.S.A.)

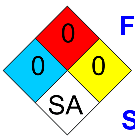
Health	/	0
Flammability		0
Physical hazards		3

Caution: HMIS® ratings are based on a 0-4 rating scale, with 0 representing minimal hazards or risks, and 4 representing significant hazards or risks. Although HMIS® ratings and the associated label are not required on SDSs or products leaving a facility under 29 CFR 1910.1200, the preparer may choose to provide them. HMIS® ratings are to be used with a fully implemented HMIS® program. HMIS® is a registered trademark and service mark of the American Coatings Association, Inc.

The customer is responsible for determining the PPE code for this material. For more information on HMIS® Personal Protective Equipment (PPE) codes, consult the HMIS® Implementation Manual.

National Fire Protection Association (U.S.A.)

Health



Flammability

Instability/Reactivity

Special

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Copyright ©2001, National Fire Protection Association, Quincy, MA 02269. This warning system is intended to be interpreted and applied only by properly trained individuals to identify fire, health and reactivity hazards of chemicals. The user is referred to certain limited number of chemicals with recommended classifications in NFPA 49 and NFPA 325, which would be used as a guideline only. Whether the chemicals are classified by NFPA or not, anyone using the 704 systems to classify chemicals does so at their own risk.

Procedure used to derive the classification

Classification	Justification
GASES UNDER PRESSURE - Compressed gas SIMPLE ASPHYXIANTS	Expert judgment Expert judgment

History

Date of printing	:	4/30/2019
Date of issue/Date of revision	:	4/30/2019
Date of previous issue	:	4/30/2019
Version	:	1.03

Key to abbreviations : ATE = Acute Toxicity Estimate
BCF = Bioconcentration Factor
GHS = Globally Harmonized System of Classification and Labelling of Chemicals
IATA = International Air Transport Association
IBC = Intermediate Bulk Container
IMDG = International Maritime Dangerous Goods
LogPow = logarithm of the octanol/water partition coefficient
MARPOL = International Convention for the Prevention of Pollution From Ships, 1973

Section 16. Other information

as modified by the Protocol of 1978. ("Marpol" = marine pollution)
UN = United Nations

References : Not available.

Notice to reader

To the best of our knowledge, the information contained herein is accurate. However, neither the above-named supplier, nor any of its subsidiaries, assumes any liability whatsoever for the accuracy or completeness of the information contained herein.
Final determination of suitability of any material is the sole responsibility of the user. All materials may present unknown hazards and should be used with caution. Although certain hazards are described herein, we cannot guarantee that these are the only hazards that exist.