LAUNCH CANADA
2025 CHALLENGE

TMU's LIQUID ROCKETRY TEAM

LC2025 Design Report for

SPRINT (Small-scale Prototyping for Rapid Iteration & Testing)

Competing Team [03]

Revision History

Revision	Description	Date
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Acknowledgements

MACH is reliant on external support to continue what we're doing and take on even bigger projects. We would like to acknowledge and thank all our sponsors for making this possible.

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Abstract

MACH, TMU's liquid-rocketry design team, is competing in the technology development category of Launch Canada 2025 with SPRINT, a modular, rapidly iterative bipropellant liquid-rocket engine fueled by ethanol and nitrous oxide. SPRINT's architecture enables quick configuration changes and active thrust variation. In a live static-fire demonstration, MACH will validate engine performance, safety systems, and the ability to throttle thrust, laying the groundwork for future flight-weight propulsion systems.

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Abbreviations & Nomenclature

AIAA	American Institute of Aeronautics and Astronautics
ADC	Analog to Digital Converter
APCP	Ammonium Perchlorate Composite Propellant
M&L	Media and Logistics
BPVC	Boiler and Pressure Vessel Code
CEA	Chemical Equilibrium with Applications
CONOPS	Concept of Operations
COTS	Commercial Off-The-Shelf
CD	Combustion Dynamics
Cv	Valve Flow Coefficient
DAQ	Data Acquisition Unit
EthaNOS	Ethanol & Nitrous Oxide
FEA	Finite Element Analysis
GAR-E	Garolite Ablative Rocket-Engine
GSE	Ground Support Equipment
GUI	Graphical User Interface
I_{sp}	Specific Impulse
LOV	Loss of Vehicle
LRE	Liquid Rocket Engine
MACH	Metropolitan Aerospace Combustion Hub
MEOP	Maximum Expected Operating Pressure
MFV	Main Fuel Valve
MOV	Main Oxidizer Valve
MPV	Main Pressurant Valve
N_2	Nitrogen
N_2O	Nitrous Oxide
NASA	National Aeronautics and Space Administration
P&ID	Piping & Instrumentation Diagram
PM	Propellent Management
PCB	Printed Circuit Board
PLC	Programmable Logic Controller
PPE	Personal Protective Equipment
PRA	Probabilistic Risk Assessment
PSR	Probable Severity Rating
R#	Revision # (of this report)
RMS	Risk Management System
RPG	Ryerson Propulsion Group
SERM	Safety & Emergency Response Manual
SOP	Standard Operating Procedure
SRAD	Student Researched And Developed
SSR	Solid State Relay
STEM	Science, Technology, Engineering, & Math
T&C	Telemetry & Control
TMU	Toronto Metropolitan University
UTS	Ultimate Tensile Strength

1.0 Introduction

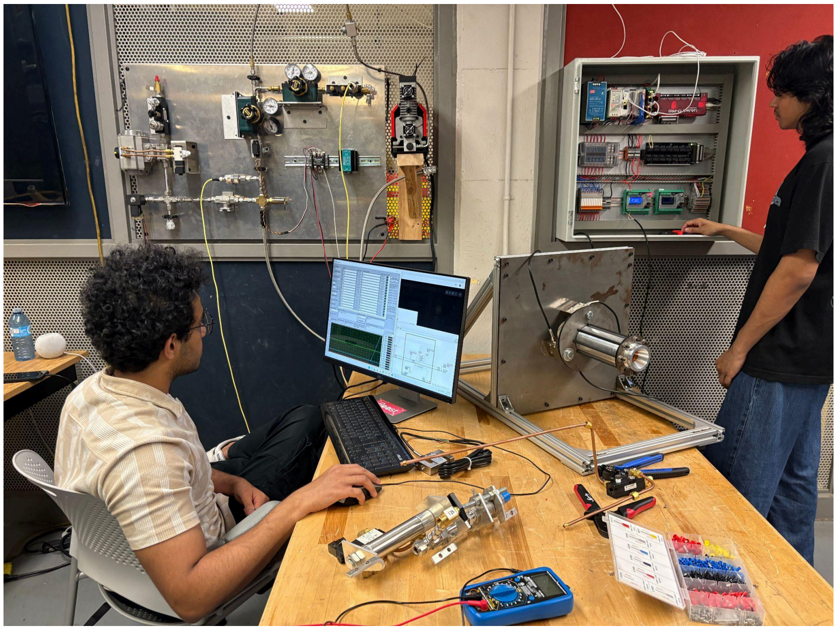


Figure 1.0.1*: GSE And Engine Test Stand.*

MACH is a student organization working out of Toronto Metropolitan University. MACH's mission is to design, build, and test liquid bipropellant rocket engines. Through focusing on the development of liquid propulsion systems, MACH hopes to provide its members with hands-on experience with high pressure fluid systems, engineering design, and experimental rocketry.

SPRINT is a piston tank, bipropellant, heat sink liquid rocket engine, inspired by the Half-Cat Mojave Sphinx [7]. It is a static test engine, collecting data and providing operational experience for design validation and future development. The engine is designed with large safety margins and high manufacturability, but can be easily optimized into flightweight designs with material removal and aerostructure integration features.

SPRINT runs on ethanol (C_2H_5OH) and nitrous oxide (N_2O), a combination the team has been calling "EthaNOS" for short. The engine, fluid, electronics, and supporting systems are designed with high safety factors and overheads to accommodate larger, higher thrust, and longer burning engines in the future.

The propellant system is built with safety and reliability as the top priority, with fail-safe isolation and vent valves for all fluid, pressurization, and fill lines. The system was also designed with modularity, able to test different propellant tanks, engine designs, and delivery rates with minor modifications.

The SPRINT system aims to test out as many configurations as possible in a short time span to verify which would be best for launching. It also has the goal of being modular with the possibility of adding cavitation venturis, and other apparatus shortly after. This will serve as a stepping stone to our flight weight rocket in 2026.

The engine telemetry includes an in-chamber pressure transmitter and load cell integrated into the thrust plate, and the fluid systems contains a large suite of pressure and temperature sensors, collecting data for and control and analysis. These are used in an electronic control system to safely perform hot-fire tests with minimal manual intervention. A robust data acquisition, control, and telemetry system ensures and safe operation of the engine and propellant system.

Figure 1.0.2*: MACH Launch Canada 2024.*

1.1 Team History

MACH was founded in 2017 as the Ryerson Propulsion Group, with the goal of designing, manufacturing, and testing a bipropellant liquid rocket engine. With limited expertise in rocket propulsion and material support available on campus, the team's knowledge was built from the ground up using reference materials and external mentorship.

With the renaming to Metropolitan Aerospace and Combustion Hub in 2022, the team has refined its focus towards practical engineering, novel research, and community collaboration. Safety and learning remain the team's cornerstones, offering unique and challenging opportunities for Canadian students in one of the most difficult fields in engineering. Despite severe material and budgetary limitations for a project of this scope, MACH strives to use industry standard components and practices to maintain safety and integrity. This is achieved by intently pursuing sponsorships, industry feedback, and novel engineering solutions without compromising safety or our mission.

1.2 Team Organization

MACH is divided into three technical subteams and two administrative subteams. The technical side is composed of the Propulsion, and Telemetry and Control (T&C) subteams. Propulsion is responsible for the design, iteration, and manufacturing of the combustion chamber, nozzle, injector, and cooling systems. Propulsion also is responsible for the design, assembly, and testing of the propellant, pressurization, pneumatic, and ground support systems. T&C is responsible for the development, integration, and testing of data acquisition, telemetry, control, and communication systems. Technical leads are also the de-facto integration team.

The administrative side comprises the Media & Logistics team. The team's responsibilities include risk assessment, team safety training, hazard communication, regulatory compliance, inventory, and logistics. The team is also responsible for sponsorships, recruitment, finances, and outreach activities such as social media and web presence.

Each subteam has dedicated Leads, who report to the Team Captain Lead-in-Training positions were created to better prepare future Leads and improve continuance of technical and organizational knowledge. After these positions are general team members, many of whom take on temporary roles of Task Leads for specific, often inter-subteam projects of varying scope. The required LC roles [2] are listed in Table 1.3.1.

Table 1.3.1: *Leadership Roster.*

Role	Name
Team Captain	Zeul Mordasiewicz
Chief Engineer	Audrey Abergel-Preston
Chief Safety Officer	Dmitry Leminov
Faculty Advisor	Dr. Ahmet Emre Karataş

Figure 1.3.2: *Weekly Town Hall Meeting.*

As of the date of publication, MACH consists of active members spanning a variety of disciplines, years of study, backgrounds, identities, and specializations. Though the majority of the team are expectedly from aerospace engineering, we also have significant membership from other engineering and non-engineering disciplines, as well as several members from outside the TMU student body. Some of the various TMU student body members are students from photography, architecture and even various design backgrounds.

1.3 Outreach & Activities

One of MACH's priorities is recognizing the valuable support provided by our sponsors and strengthening our collaborative relationships. Our partners have been instrumental in bolstering our organization's capabilities and success. They have extended substantial operational funding and offered in-kind donations of parts, equipment, tools, raw materials, manufacturing support, and workspace access. Additionally, industry expertise and design reviews have significantly improved the work of our team.

As a token of appreciation and recognition for their support, sponsor logos are prominently displayed on our team apparel. This celebrates our partnerships, raises brand visibility, and creates a sense of shared achievement. The initiative not only showcases our partners on the merchandise but also extends recognition through our webpage, marketing materials, and social media channels. This multichannel approach ensures our sponsors receive valuable exposure to our growing audience.

Figure 1.4.1: *Finalized T-Shirt Design.*

Figure 1.4.2: *Upcoming Merch for the 2025-2026 Year.*

Furthermore, after MACH underwent a successful rebranding process, we recognized the immense potential to leverage this fresh identity and breathe new life into our group. The rebranding not only gave us a renewed sense of purpose and direction but also created a unique opportunity to connect with our members and followers in a more meaningful way. To capitalize on this momentum, we decided to design new merchandise that truly embodied our updated vision, values, and aesthetics. By doing so, we aimed to not only bolster team spirit but also offer our supporters and sponsors a tangible representation of our growth and evolution.

1.4 Social Media Presence

MACH has been actively working to expand its social media presence as a key strategy for recruitment, outreach, and public engagement. By consistently sharing project updates, testing footage, behind-the-scenes content, and member highlights, we aim to attract new students to join the team while raising awareness about our mission to develop liquid bipropellant rocket engines.

Figure 1.5.1: *Revitalization of MACH Instagram Account.*

Our platforms, including Instagram, LinkedIn, and YouTube, serve as tools to communicate technical milestones, celebrate team achievements, and showcase the educational value of student rocketry. This effort not only helps build community support but also enhances visibility to sponsors and potential collaborators. As we continue to grow, social media will remain an important tool for documenting progress and connecting with the broader aerospace and rocketry community across Canada.

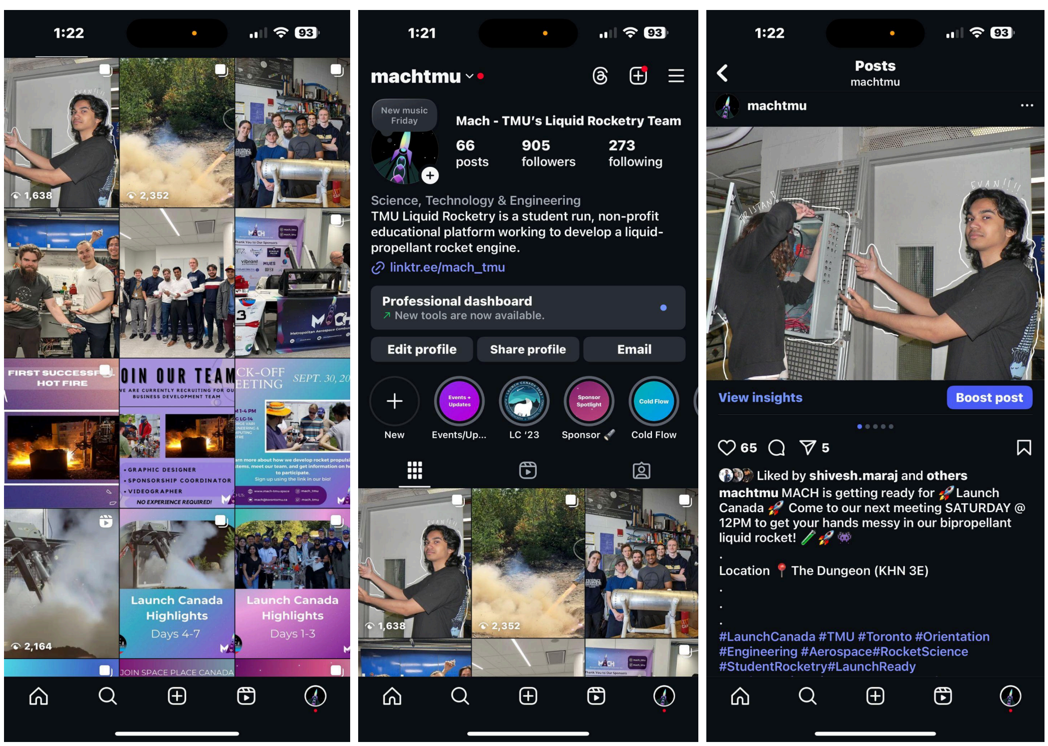


Figure 1.5.2: *Revitalization of MACH Instagram Account.*

2.0 Business Case Analysis

2.1 Academic And Business Goals

The MACH team's primary goals are academic, focused on learning through hands-on experience in liquid bipropellant engine design, testing, and system integration. Our current project, SPRINT, is not purely theoretical. It is a hardware-intensive, modular static-test engine intended to validate design assumptions and prepare the team for a future flight-weight rocket system in 2026. This educational objective is closely tied to advancing the team's knowledge in propulsion subsystems, high-pressure fluid dynamics, electronic controls, and system safety. Our team structure is built for continuity and self-sustainability. Each subteam is led by a dedicated Lead who reports to the Team Captain. We have also implemented Lead-in-Training roles to foster knowledge transfer and leadership development. This structure helps train members not only in technical design and manufacturing but also in collaborative project management across engineering disciplines. While SPRINT is primarily educational, it incorporates modular components and scalable design features such as interchangeable tanks and data systems. These could potentially be developed into commercial research tools, such as lab-scale test stands or modular GSE kits for other rocketry teams or research institutions. At this stage, commercialization is not an immediate goal, but the system's reliability and modularity keep the door open to future productization.

Key Performance Indicators (KPIs) we use to track our goals include:

- Educational growth: Number of trained members transitioning into Lead roles and skill development through task assignments
- Technical milestones: Number of successful static tests, sensor reliability, data accuracy, and modular integration performance
- Team sustainability: Member retention rate, active participation across subteams, and the effectiveness of our Lead-in-Training model

Through SPRINT, MACH aims to foster a strong and evolving environment for rocketry education while building a technical foundation for future launch-capable systems.

2.2 Value Proposition

The SPRINT project brings meaningful value to Canada's aerospace and rocketry sectors by contributing to the development of technical expertise and workforce readiness in liquid propulsion, a field that remains relatively underdeveloped in student rocketry. Through the design and testing of a static bipropellant engine, our team is gaining direct experience with high-pressure fluid systems, electronic controls, and propulsion testing. These are skills that directly transfer to both academic research and industry positions.

SPRINT also supports the growth of Canada's student rocketry ecosystem by acting as a stepping stone toward a future flight-weight vehicle. The modularity of the system allows MACH to iterate quickly and safely, accelerating design validation cycles and lowering barriers for future development. We hope these test frameworks can inform future Canadian student teams pursuing liquid propulsion, an area often considered too complex and inaccessible. Additionally, the structure of MACH's team emphasizes sustainability and leadership training, ensuring that knowledge is retained and passed down. This continuous training model produces highly capable graduates who are familiar with real engineering workflows, safety protocols, and collaborative development. All of these benefit Canada's growing aerospace sector in both academic and commercial contexts.

By investing in scalable, modular infrastructure and building a strong knowledge base in propulsion systems, MACH (through SPRINT) enhances Canada's capacity for advanced rocketry research and strengthens the talent pipeline feeding into the national space and defense industries.

2.3 Financial Analysis

For the 2024–2025 cycle, MACH operated with a total revenue of $13,159, consisting of a $5,659 roll-over from the previous year, $5,000 in external sponsorships, and $2,500 in SIF funding. Our total projected expenses were $44,530, resulting in a budget deficit of approximately $37,030. To address this, MACH requested $45,000 in funding for the 2024–2025 fiscal year, split evenly between the Fall and Winter terms.

Projected expenses totaled $18,300, primarily supporting:

- Propulsion: $6,000 for SRAD tank and ignitor development, engine stock, liner casting materials, and testing operations
- Structures: $5,000 for ground support equipment and airframe development
- Telemetry & Control: $4,800 for PCB outsourcing, avionics hardware, surveillance network, and tools
- General Equipment: $1,500 for a mini lathe and $1,000 for team merchandise

Projected expenses increased to $26,230, covering:

- Propulsion: $10,000 for system testing, pneumatics, propellant subsystems, and SRAD machining
- Structures: $2,500 for composite airframe skins and structural reinforcement
- Telemetry & Control: $4,800 for new SCADA systems, telemetry upgrades, and a mission control Toughbook

- General Team Needs: Conference fees, off-grid equipment, toolkits, safety supplies, and branding/merchandise

While MACH does not generate profit, we closely track all expenses to ensure responsible spending and continued sponsor confidence. Our team also actively seeks funding through sponsorships, university grants, and fundraising initiatives to maintain long-term viability.

3.0 Requirements

Based on the mission requirements of performing a 5 second static engine test with a 250 lbf thrust on startup, logical decomposition of the subsystems was performed. Identification of the subsystems served as an important step for deriving subsequent subsystem requirements. Each subsystem requirement was carefully revised to ensure that it was verifiable.

To ensure that SPRINT meets its mission objectives and complies with Launch Canada rules (see Appendix I: Launch Canada Compliance Requirements), we have defined a hierarchical set of requirements. High-level system requirements are decomposed into subsystem requirements that drive detailed design and verification.

Table 4.1: SPRINT Liquid Engine Subsystem Requirement.

Req. #	Requirement
1.1 Tank	
1.1.1	The tank shall be proofed to a pressure up to 1.5× the MEOP without yielding.
1.1.2	The tank shall have a burst factor of safety of at least 2 at the MEOP.
1.2 Tank Relief Valve	
1.2.1	The tank relief valve shall open at a pressure above the tank's working pressure and below the MEOP.
1.2.2	The tank pressure at the fully open relief valve position shall be used to define the tank's MEOP.
2.1 Ox Tank Fill Vent	
2.1.1	The oxidizer tank fill vent shall be capable of operating in low temperature environments with no impact of valve operation and performance.
2.1.2	The oxidizer tank fill vent shall be a normally closed valve.
2.1.3	The oxidizer tank fill vent shall be capable of being operated remotely.
2.2 Oxidizer Tank Dump Valve	
2.2.1	The oxidizer tank dump valve shall be positioned below the tank to ensure it drains liquid nitrous rather than gas.
2.2.2	The oxidizer tank dump valve shall have an orifice size that is sufficiently large to allow a fully loaded oxidizer tank to be emptied in less than 30 minutes.
2.2.3	The oxidizer tank dump valve shall fail in the open position to ensure that the oxidizer tank contents are dumped if communication is lost with the test stand.
2.3 Oxidizer Tank Section	

2.3.1	The oxidizer tank volume shall be sufficient to accommodate the expected liquid volume and gas ullage according to filling ratios defined in standards for safe handling of nitrous oxide.
3.1 Main Oxidizer Valve	
3.1.1	The main oxidizer valve orifice size shall be large enough to ensure that the flow is not cavitated and choked at the main valve.
3.1.2	The main oxidizer valve shall be actuated to the fully open position in less than 1s at the MEWP.
3.1.3	The wetted materials in the main oxidizer valve shall be compatible with nitrous oxide.
3.1.4	The main oxidizer valve shall be servo actuated ball valve, capable of remote actuation.
3.2 Main Fuel Valve	
3.2.1	The main fuel valve orifice size shall be large enough to ensure that the flow is not cavitated and choked at the main valve.
3.2.2	The main fuel valve shall be actuated to the fully open position in less than 1s at the MEWP.
3.2.3	The wetted materials in the main fuel valve shall be compatible with ethanol.
3.2.4	The main fuel valve shall be servo actuated ball valve, capable of remote actuation.
3.4 Ethanol Tank Fill Valve	
3.3.1	The ethanol tank fill valve shall have a pressure rating that exceeds the MEOP of the ethanol tank.
3.3.2	The ethanol tank fill valve shall be opened and closed manually during fill.
3.3.3	The ethanol tank fill valve shall be located above the fuel tank.
4.1 Chamber Casing	
4.1.1	The combustion chamber casing shall have a yield FOS of greater than 1.5 at the maximum expected operating pressure.
4.2 Injector	
4.2.1	The injector orifices shall be sized such that a minimum stiffness of 10% is achieved for the entirety of the burn duration.
4.2.1	The injector material shall be compatible with both ethanol and nitrous oxide.
4.2.1	The injector material shall retain its structural integrity at the maximum expected operating temperature during the burn.
4.3 Graphite Crush Gasket	
4.31	The graphite insert shall not crack or become dislodged at any point during the hotfire test. It should be replaced upon reassembly.

4.4 Ignition System	
4.4.1	The ignition system shall be capable of being activated remotely at mission control.
4.4.2	The injector face ignitor shall remain fixed until stable self-sustained combustion is attained.
4.4.3	The ignition system shall provide sufficient activation energy to vaporize and combust the mixed propellants during startup.
4.4.4	The ignitor burn duration shall last the duration of the hotfire.
4.4.5	The ignitor shall produce thick, visible smoke that can be seen using the camera system.
5.1.1 GSE Pressurization Control Valves	
5.1.1.1	The pressurization control valves shall be remotely actuated.
5.1.1.2	The control valves for the GSE pressurant panel shall be configured to ensure that the N2 cylinder contents are NOT passively vented.
5.1.1.3	The GSE pressurant control valves shall have a pressure rating that exceeds the MEOP of the pressurant tank.
5.1.1.4	The GSE pressurant control panel shall contain a relief valve that passively vents pressurant in the event of pressure excursions above the maximum expected working pressure.
5.1.2 GSE Purge Regulator	
5.1.2.1	The Purge regulator shall be hand-loaded.
5.1.2.2	The GSE pressurization control regulator shall have an inlet pressure rating that exceeds the supply pressure from a 6K nitrogen supply cylinder.
5.1.3 GSE Pressurization Vent Valve	
5.1.3.1	The pressurization panel on the GSE subassembly shall passively vent pressurant contained within isolated portions of plumbing if control is lost.
5.2.1 Oxidizer Fill Valve	
5.2.1.1	The oxidizer fill valve shall have a pressure rating that exceeds the MEOP of the nitrous supply cylinder.
5.2.1.2	The oxidizer fill valve shall be actuated remotely to allow for remote fill capabilities.
5.2.1.3	The wetted components of the oxidizer fill valve shall be compatible with nitrous oxide.
5.2.1.4	The oxidizer fill valve shall be actuated pneumatically.
5.3.2 GSE Pneumatic Regulator	
5.3.2.1	The GSE pneumatic regulator shall allow for precise control of the outlet pressure, ensuring that the pneumatic pressure is maintained to 100 psi +/- 5 psi.

5.3.2.2	The GSE pneumatic regulator shall have an inlet pressure rating that exceeds the expected supply pressure range from a T nitrogen supply cylinder.
5.4.1 Thrust Mount and Tripod	
5.4.1.1	The thrust assembly shall be capable of static operation of the engine.
5.4.1.2	The thrust assembly shall be capable of withstanding the maximum expected thrust (250 lbf) with a yield safety factor of at least 3.
5.4.1.3	The thrust assembly shall be capable of measuring engine thrust in the static engine configuration.
5.4.1.4	The tripod shall be capable of handling up to 3x the weight of the tank.
5.4.1.5	The tripod structure shall have load cells for measuring the propellant feed system during fill and drain.
5.4.2 GSE Structure/Blast shield	
5.4.2.1	The GSE structure shall provide support for the GSE plumbing, and electronics enclosure.
5.4.2.2	The GSE structure shall be anchored to the ground such that no movement is possible at any point during the hotfire test of the engine.
6.1 GSE Electronics	
6.1.1	The electronics shall be water/dust proof up to IP65.
6.1.2	The electronics shall be expandable up to 12 24V outputs, 6 thermocouple inputs, 8 pressure transducers inputs, 6 load cell inputs (two amplifier/junction boxes), and 3 PWM outputs
6.1.3	Computers at mission control shall use Labview for all operations
6.1.4	Ladder logic on the PLC shall work in tandem with the LabJack as a back up to auto abort the system under non nominal circumstances.

4.0 System Architecture Overview

SPRINT is a fully-integrated, ground-support-equipment (GSE) and liquid-rocket-engine (LRE) system designed for rapid iteration, safe hot-fire testing, and minimal manual intervention. The assembled test stand consists of:

- **Ground Support Frame & Enclosure** (IP65-rated electronics cabinet, barrier mounts)
- **Propellant Supply & Pressurization** (modular ethanol and N_2O feed tanks with quick-disconnects, N_2 pressurant circuits, relief and isolation valves)
- **Engine Assembly** (piston-tank feed, impinging injector, regeneratively cooled chamber, ablative nozzle)
- **Thrust Measurement** (load cells integrated into thrust plate)
- **Telemetry & Control** (LabJack T7-Pro and PLC within GSE, high-speed Ethernet, Labview)

Below is a flow chart of all systems:

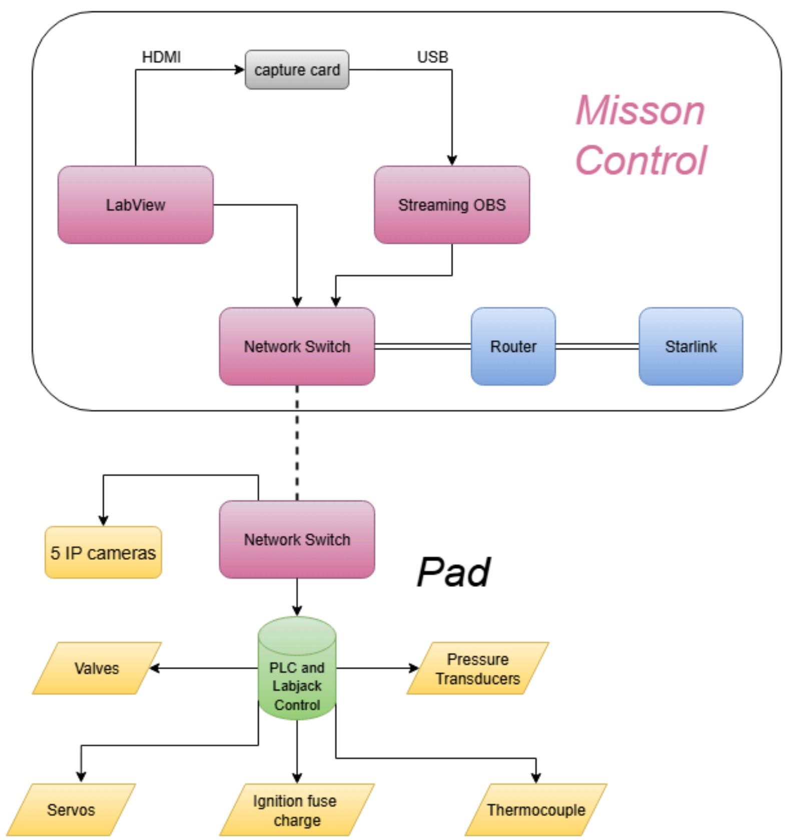


Figure 4.0.1: *Overview of All Systems.*

4.1 Structural Design

The structural backbone is a steel frame supporting the propellant tanks, engine thrust stand, and electronics enclosure. Quick-release pins and 3D-printed PETG coupler allow tool-free disassembly in under 10 minutes. All load-bearing joints are configured in pure compression. Anti-splay steel cables maintain tripod leg geometry under static thrust loads (up to 250 lbf with a FOS ≥ 3).

4.2 Engine

General properties of the engine are listed in Table 4.2.1 and the engine assembly is shown in Figures 4.2.1.

Table 4.2.1: *SPRINT Rocket-Engine Properties*

Parameter	Value
Propellants	Ethanol ,N_2O
Total Impulse	5560.3 Ns
Nominal Burn Duration	5 s
Designed Thrust	1112.06 N (250 lbf)
O/F Ratio	2.1
Tank Pressure (25C)	819.72 psig
Chamber Pressure	250 psig
Cooling System	Heat Sink
Injector, Chamber & Nozzle Material	6061 Aluminum
Throat Material	Copper
Retainer Material	Steel

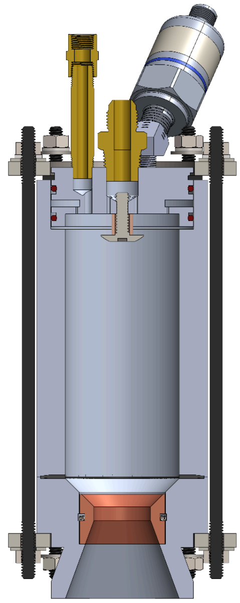


Figure 4.2.1: *Thrust Chamber Assembly.*

SPRINT's bipropellant system runs on ethanol and nitrous oxide ("EthaNOS"). Key updates from MACH's previous GAR-E system include:

- **Injector:** Switched from simple orifice plate to a "Half-Cat" style Mojave Sphinx [7] screw in pintle, improving atomization and chamber stability.
- **Piston-Tank Feed:** Ethanol is no longer pressurized by nitrogen, but rather by the pressurization of nitrous through a piston
- **Isolation Valves:** Servo-actuated ball valves are now able to throttle fuel and oxidizer.
- GSE (Figure 4.2.2) has been overhauled to allow for filling of an SRAD tank.

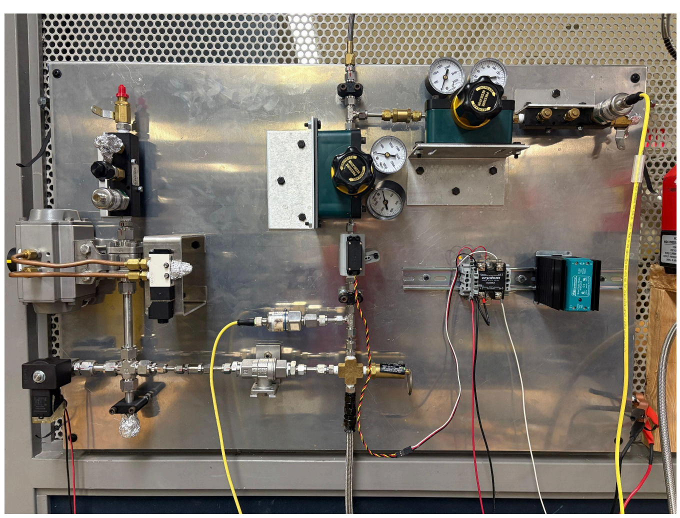


Figure 4.2.2: *GSE Plumbing.*

4.3 Electronics

All control electronics are housed in an IP65‑rated enclosure mounted on the GSE frame. The LabJack T7‑Pro handles analog I/O (pressure, temperature, thrust), while a CLICK PLUS PLC manages digital I/O (valve drives, E‑stop). Ethernet connectivity replaces USB to improve noise immunity. Manual overrides (mechanical E‑stop and lock‑out key) are integrated at pad control.

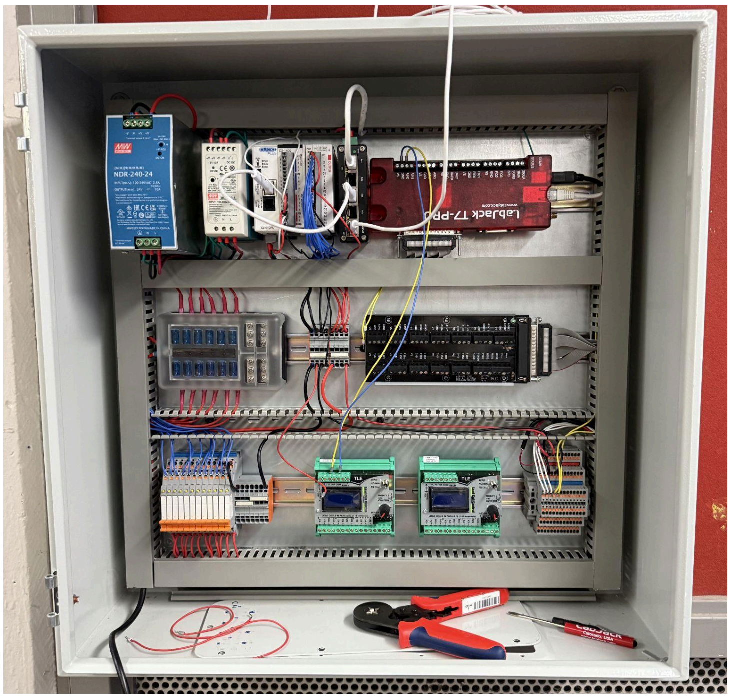


Figure 4.3.1: *Electronics enclosure.*

4.4 Data Analysis Plan

Telemetry is streamed at 100 Hz via LJStreamM into csv files, with simultaneous local and USB‑stick backups. Post‑test, MATLAB scripts parse headers to extract:

- **Chamber Pressure & Temperature** (in‑chamber transducer)
- **Thrust Data**
- **Valve Actuation Timing** (DIO timestamps)

Automated scripts compute mean/max pressures, response delays, and ISP estimates before exporting CSV summaries for team review. Configuration files ensure repeatable setups across test campaigns.

5.0 Mission Concept of Operations Overview

An overview of the nominal Mission Concept of Operations (CONOPS) is shown in Figure 5.0.1, followed by detailed descriptions for each phase.

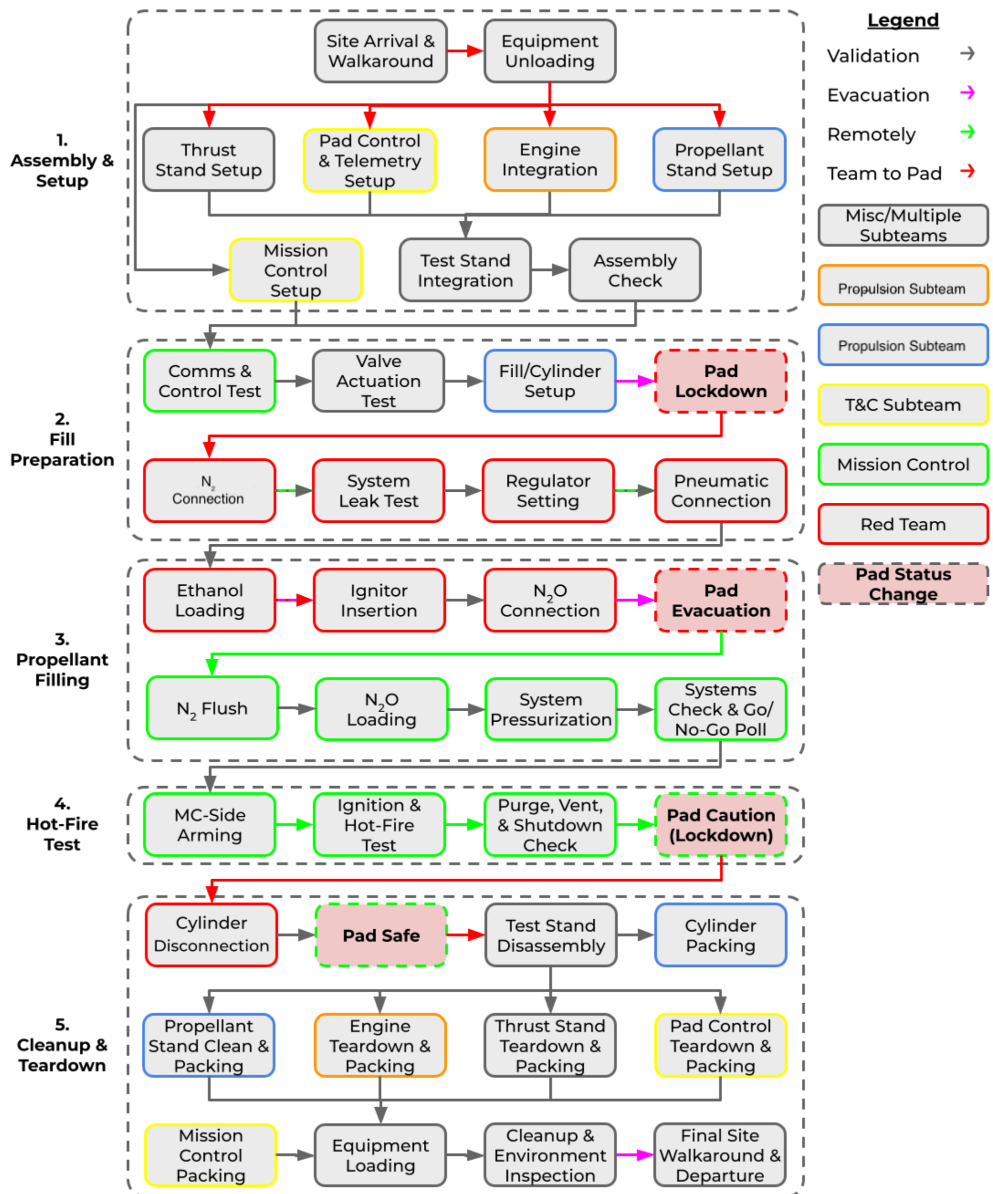


Figure 5.0.1: *Nominal CONOPS for Hot-Fire Testing.*

5.1 Overview of all tests

1. **Baseline Characterization**
- Perform a series of low scale leak tests of each system of plumbing to verify plumbing, performance and data acquisition.
- Execute two hot-fire tests at nominal operating conditions to confirm thrust, chamber pressure and mixture-ratio control.
- Execute a hot-fire test while throttling MOV and MFV and validate a controlled and predicted drop in thrust a.

5.2 Hot Fire Test Overview

1. **Assembly & Setup**

Start: Equipment & personnel arrive at the test site.

End: All equipment fully assembled and ready for testing.

- Perform initial inspection of site & unload equipment.
- Set up mission control & support equipment to pad (power, comms, etc).
- Set up and secure thrust stand, prepare site (flame trench, defoliation, etc).
- Assemble propellant stand, engine & thrust assembly, electronics at pad.
- Integrate all subsystems into test stands & perform assembly checks.

2. **Fill Preparation**

Start: System testing begins.

End: All testing passed and system ready for propellant loading.

- Perform communications, control, E-stop, and valve actuation testing.
- Set up N_2 pressurant and N_2O oxidizer cylinders, prepare ethanol fill setup.
- Pad "Lockdown" declared and off limits except to Red Team personnel.
- Connect N_2 pressurant cylinder and perform pneumatic leak testing.
- N_2 inert gas flush performed & system depressurized after passing leak tests.
- Main pressurant & propellant valves disarmed at pad.

3. **Propellant Filling**

Start: Ethanol filling begins.

End: Final systems checks completed and go/no-go poll passed.

- Perform Ethanol filling procedure*.
- Switch Red Team personnel and perform N_2O connection procedure.

- Arm main pressurant, propellant, & fill valves.
- Connect ignitor power. Arm ignitor and evacuate pad**.
- Pad "Evacuation" status declared and off limits to all personnel.
- Perform remote N_2O loading and propellant pressurization procedures*.
- Perform final systems check and go/no-go poll.

4. Hot-Fire Test

Start: Mission control side arming procedure.

- Select engine sequence profile, either nominal operations, or throttled operations.
    - In the case of throttled operation, the MOV and MFV will be open fully upon igniter confirmation, then after 2.5 seconds will be throttled to 70% of open.

End: No oxidizer and/or fuel remains in the system, "Caution" pad state declared.

- Perform mission control side arming procedure.
- Send ignition command (engine computer automatic control initiated).
- *Engine control system ignition, hot-fire, shutdown, & purge operations*:*
    - Initiate E-match, await detection of APCP ignition.
        - Return to standby if APCP ignition is not detected.
    - Open propellant valves, await detection of propellant ignition.
        - Abort and purge if main ignition is not detected.
    - Perform abort if any preset parameters are exceeded during firing*.
        - Controlled (automatic or manual) abort shuts down fuel and oxidizer main & isolation valves in sequence, initiates purge sequence, and opens all vent valves.
        - Emergency manual abort cuts power to valve control, returning the system to safe state & initiating uncontrolled shutdown.
            - Vents open, depressurizing all lines & venting oxidizer.
    - After 5s, initiate nominal shutdown, purge, and vent sequence.
        - Close fuel line isolation valves and open purge bypass valves.
        - Initiate purge sequence with remaining pressurant, flushing residual fuel via bypass line & oxidizer directly through the run tank.
        - Close all isolation valves and open all vents.
- Monitor hot-fire & perform manual or emergency abort if necessary.
- Follow appropriate contingency procedures if necessary.

5. Cleanup & Teardown

Start: "Safe" pad state declared after a five-minute fire watch.

End: All equipment & personnel leave the site.

- Red Team returns to the pad to disconnect N_2 & N_2O cylinders.
- Fully disarm both mission control and pad side systems.
- Drain remaining ethanol & perform field-clean of sensitive systems.
- Disassemble test stand into component systems, remove & check cylinders.
- Teardown & pack propellant stand, engine & thrust assembly, & electronics.
- Teardown & pack mission control & support equipment.
- Inventory & load equipment for transportation.
- Perform site cleanup & inspection; take soil samples for analysis [5].
- Perform final site walkaround before departure.

6.0 Structural Design

The structures consist of the tripod and the engine stand.

6.1 Tank Tripod Structure

The tank tripod consists of a center carrier, three legs, and anti-splay cables. Each leg section is press-fit into the carrier, and a quick-release pin is inserted through each leg to prevent it from falling out when the tripod is moved. These pins carry no structural loads. Anti-splay cables are installed at the base of the tripod in order to prevent the legs from splaying and loading the carrier in tension. These cables connect each leg to a steel ring at the center of the base of the tripod, effectively preventing the "feet" of the legs from sliding apart.

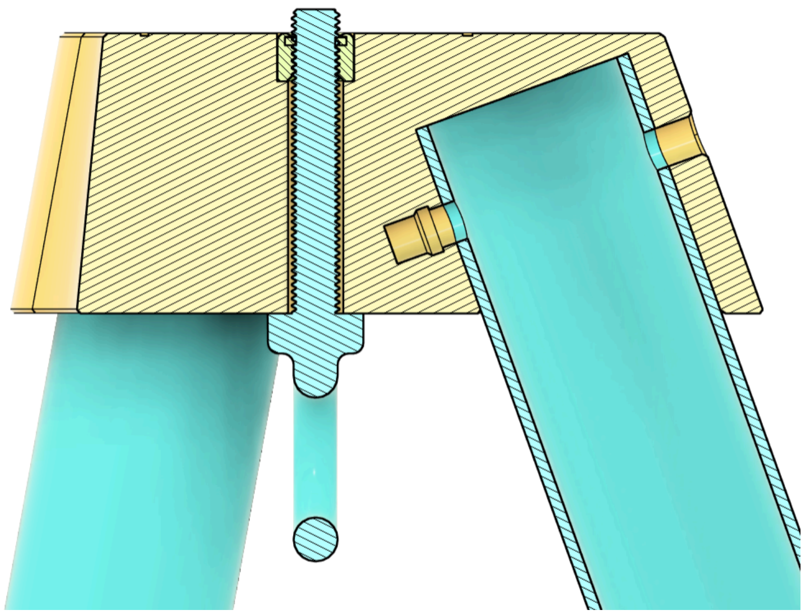


Figure 6.1.1: *Cross Section Tank Tripod Structure.*

Each leg section is press-fit into the carrier, and a quick-release pin is inserted through each leg to prevent it from falling out when the tripod is moved. These pins carry no structural loads. Anti-splay cables are installed at the base of the tripod in order to prevent the legs from splaying and loading the carrier in tension. These cables connect each leg to a steel ring at the center of the base of the tripod, effectively preventing the "feet" of the legs from sliding apart. The load cell and tank hang from an M12 eye bolt installed through the geometric center of the tripod legs. All carabiners, etc are human-rated.

1. Manufacturing Process
    a. The legs of the tank tripod consist of 2" galvanized steel pipe cut to length with a bandsaw. Holes for fixation to the carrier were drilled, guided by a 3D-printed

hole cutting jig. The carrier was 3D printed in PETG with parameters adjusted to maximize inter-layer adhesion.

2. Analysis
    a. All components of the tank tripod are overbuilt to the extent that analysis is not necessary. All 3D printed components are loaded purely compressively, such that a failure would require extruding the legs through the top of the 3D printed carrier, or breaking steel aircraft cables. The tank tripod will never experience such loads.
3. Testing and Validation
    a. The tripod was validated with 3x the expected weight.

6.2 Test Stand

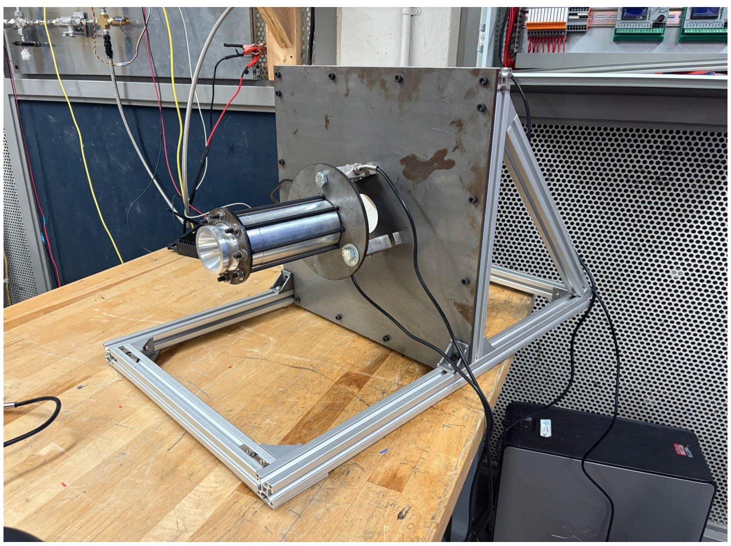


Figure 6.2.1: *Test Stand Completed.*

e

Detailed Design

The SPRINT test stand is built from off-the-shelf aluminum extrusion and a heavy-gauge steel backplate, providing a lightweight, base that resists both thrust loads during engine tests:

- **Base Frame:**
    - **Profile:** (80/20 series) T-slot aluminum extrusions assembled into a 600 × 400 mm rectangle.
    - **Bracing:** Diagonal extrusion gussets at each corner, plus a central cross-brace tying the two long sides to prevent racking.

- **Backplate:**
  - **Material:** ¼ inch thick mild steel, from send cut send with holes matching the extrusion pattern.
  - **Attachment:** Socket-head screws into drop-in T-nuts in the extrusions.

- **Engine Mount & Thrust Reaction:**
  - **Thrust Plate:** ¼ inch thick mild steel bolted to the backplate via three load cells.

Manufacturing Process

1. **Extrusion Cut & Assembly:**
   - Cut all aluminum profiles to length using a precision miter saw.
   - Deburr T-slots to ensure smooth T-nut insertion.
   - Assemble frame with corner gusset plates bolts.

2. **Backplate Fabrication:**
   - Order back plate from send cut send.

3. **Final Assembly:**
   - Install load cells onto thrust-plate brackets; torque all flange bolts to spec.

Analysis

Testing and Validation

1. **Proof Load Test:**
   - Applied 500 lbf (2× nominal) via a calibrated hydraulic ram at the engine flange.

2. **Bolt-Torque Verification:**
   - All M8 T-slot and M10 flange bolts torqued, then re-checked after 10 load cycles (0→250 lbf); no loosening observed.

3. **Vibration Shake-Down:**
   - Subjected stand to a 5–100 Hz sweep at up to 1 g on a portable shaker plate.
   - Post-test inspection confirmed no fastener loosening, no permanent deformation in extrusions or backplate.

These tests confirm the stand's suitability for repeated static and dynamic loading during hot-fire campaigns, with ample safety margins and reliable, tool-free serviceability.

6.3 Tank

The SPRINT tank is a stacked piston tank with nitrous on the bottom and ethanol on the top. A downcomer along the outside of the tank gives a pathway for the ethanol to flow upon opening the main valves.

Figure 6.3.1: *SPRINT Tank.*

6.3.1 Pressure calculations

The set proof pressure defined as 1.5x MEOP as per the LC requirements is determined to be: 1335psi.

From simulations such as the Half Cat Sim [26], the overpressurization failure mode was determined to be due to screw tear out.

6.3.1.1 Definitions and Objective

- MEOP was defined as per the highest pressure nitrous would be on the hottest possible allowable day, which is 28.8°C. At this temperature N2O would be 890 psi [25].
- From simulations[26], the overpressurization failure mode was determined to be due to screw tear out.

Objective:

Determine the tear-out stress, the corresponding Margin of Safety (MoS), and the tear-out failure pressure for screws at MEOP.

Table 6.3.1.1: Tank Parameters

Parameters		Units
MEOP	890	psi
Outside Diameter	4	in.
Wall Thickness W	0.125	in.
Inside Diameter	3.75	in.
# of Screws	8	
Bolt	1/4-20	
Center-Edge Distance D_{CE}	0.5	in.
Screw Hole Diameter D_s	0.3125	in.
Internal Area A_i	11.04	in^2

Force on tank bulkhead

1. Total clamping (separating) force at 890 psi

$$F_{tot} = P_{op} \times A_i = 890\,psi \times 11.04in^2 = 9825.6 \text{ lbf} \tag{6.1}$$

2. Force carried by each of the 8 screws

$$F_{screw} = \frac{F_{tot}}{8} = \frac{9825.6}{8} = 1228.2 \text{ lbf} \quad (6.2)$$

3. Effective shear area:

$$C_{CE} - \frac{D_s}{2} \times 2 \times W = \frac{0.5 - 0.343}{2} \times 2 \times 0.125 = 0.0821\, in^2 \quad (6.3)$$

4. Tear-out stress in the aluminum

$$\text{ToS} = \frac{F}{A} = 14962\, psi \quad (6.4)$$

5. Screw Tear-out MoS

$$MoS = \frac{Ss}{ToS} - 1 = \frac{30000}{14962} - 1 = 1.0051 \quad (6.5)$$

6. Yield pressure

$$\text{YS} = (MoS + 1) \times MEOP = (1.0051 + 1) \times 890 = 1784.59\, psi \quad (6.6)$$

Therefore the burst pressure is $1784.59\, psi$ which is just over 2x MEOP, and the proof pressure will be 1.5x 890 is 1335psi

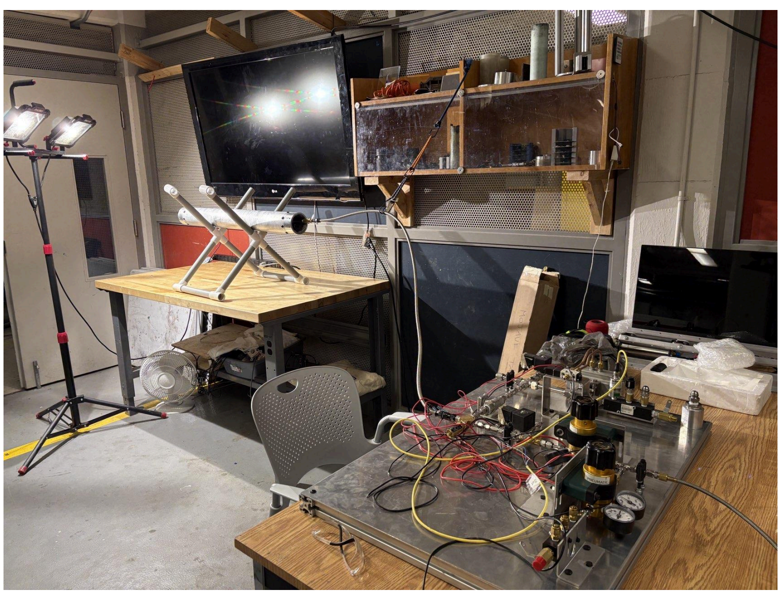


Figure 6.3.2: *Hydrostatic Testing.*

6.3.2 Overview and Requirements

The SPRINT tank is a custom two-section, piston vessel fabricated from 6061-T6 aluminum to store ethanol and nitrous oxide separately while maintaining a common wall. The lower chamber contains liquid N_2O, and the upper chamber holds ethanol. The piston assembly, sealed with

O-rings, isolates the two fluids and transfers piston forces via a downcomer tube to ensure consistent propellant feed.

- **MEOP (WP):** 890psig
- **Proof Pressure:** 1.5 × WP = 1335 psig
- **Burst Pressure:** ≥ 2 × WP ≈ 1784 psig

All wetted surfaces are compatible with ethanol and nitrous oxide, and the tank includes a normally open relief valve and pressure transducer ports for telemetry.

Detailed Design

- **Piston Assembly:** Precision-turned 6061-T6 piston with two PTFE O-rings in dedicated grooves, guided by a downcomer tube that runs outside the pressure boundary to transfer volumetric displacement.
- **Ports & Fittings:**
    - Fill/drain ports: 1/4 in NPT female with quick-disconnects for ethanol (top) and N_2O (bottom).
    - Relief valve port: 1/2 in NPT for a commercial burst disk rated > 2× MEOP.
    - Sensor port: 1/4 in NPT tapped for a pressure transmitter
- **Seals & Cleanliness:** All seals and hardware are ultrasonic cleaned, ports capped when not in use to maintain cleanliness.

Manufacturing Process

1. **Cylinder Fabrication:**
    - Bought a 36” extruded piece of aluminum stock from local metal supplier
    - Hand drilled end retainer screws holes used a 3D printed jig.
2. **Piston & Downcomer:**
    - Piston turned and grooved on CNC lathe; PTFE O-rings installed.
3. **Assembly & Inspection:**
    - Components ultrasonically cleaned, dried in a sealed.
    - Fasteners torqued with a calibrated torque wrench.

Analysis

- **Thermal Considerations:** Ambient temperature range (–10 °C to +40 °C) produces < 1 % change in seal compression; piston seals remain within operational envelope.

Testing and Validation

1. **Functional Piston Verification:**
    - Pressurized to 800 psig behind piston to verify holds pressure.

7.0 Propulsion System

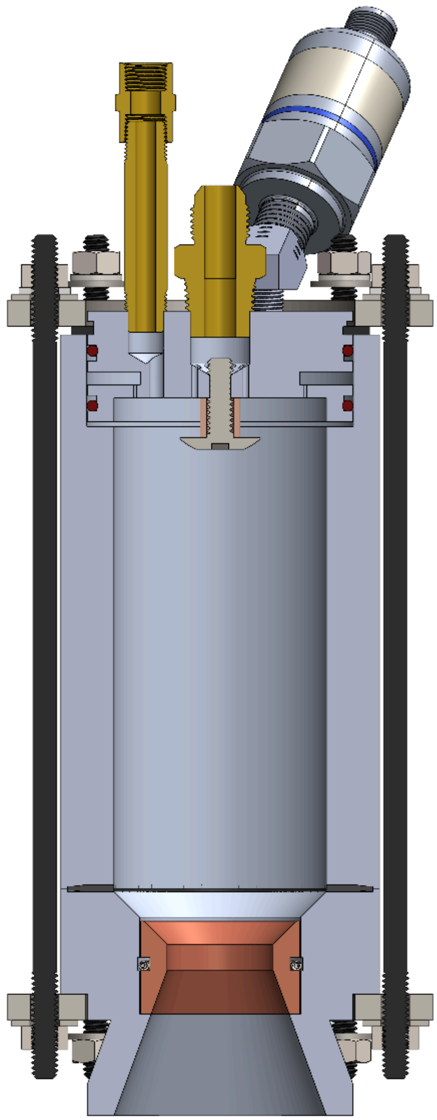


Figure 7.1.1: *Thrust Chamber Assembly.*

7.1 Combustion Chamber And Nozzle

As shown in figure 7.1.1, the combustion chamber is made out of a piece of stock 6061 aluminum T6. The throat is made out of copper which helps with erosion due to its higher heat conductivity.

Figure 7.1.2: *Machined Combustion Chamber Components.*

Originally, we wanted to use the school's lathe, but due to lack of access and permission, we opted for ordering the parts from JLC CNC. The engine passively cools itself though being a heatsink. The outer temperature is not expected to exceed 200deg C. The combustion chamber will undergo hydrostatic testing to ensure it can hold 1.5 its MEOP.

7.2 Injector

The injector was manufactured with a lathe, then a 3 axis CNC. There's a fuel volute for the ethanol and the Nitrous comes down the middle, then gets deflected off a screw radially.

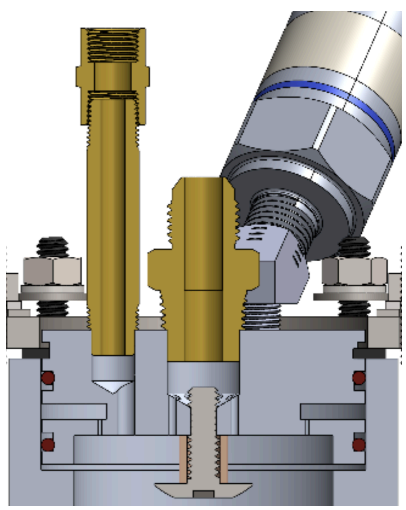


Figure 7.2.1: *Injector.*

NPT ports were manually tapped (***Figure 7.2.2)***.

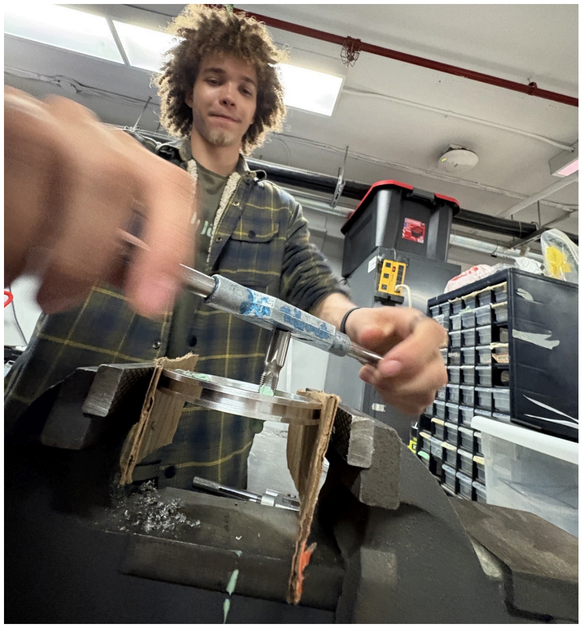


Figure 7.2.2: *Manual Tapping.*

7.3 Ground Support Plumbing

The ground support plumbing supplies oxidizer to the main propulsion system. As shown in Figure 7.3.1, Significant changes have been made since the original cad.

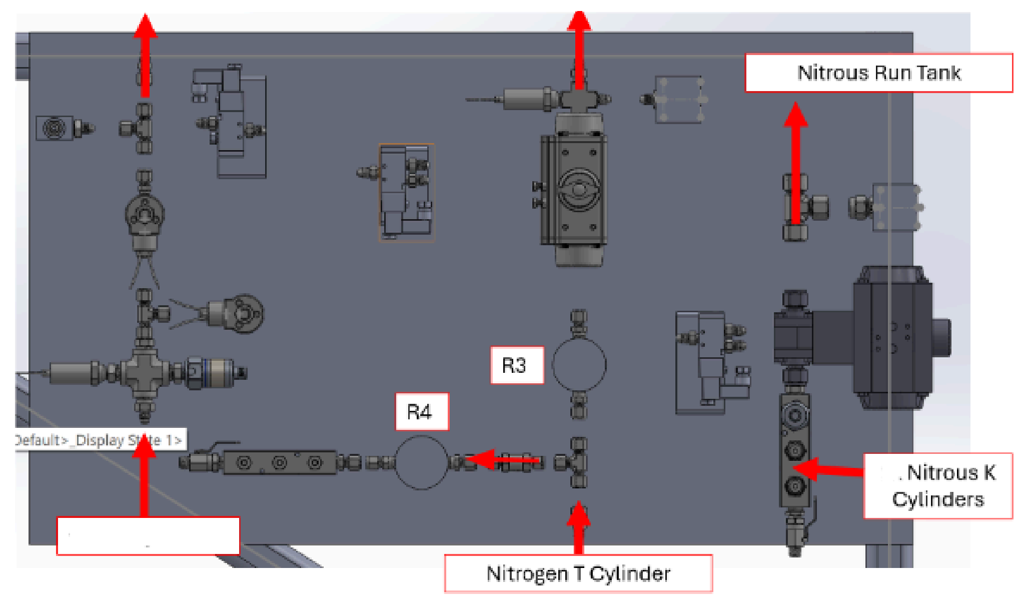


Figure 7.3.1: GSE Plumbing CAD.

As can be seen in the preceding figure, the GSE plumbing components are to be mounted on a common panel. Pneumatic pressure supply to the pneumatic valves is supplied from a tap-off from the N2. The current assembled state of the GSE panel of plumbing has been presented in Figure 7.3.2.

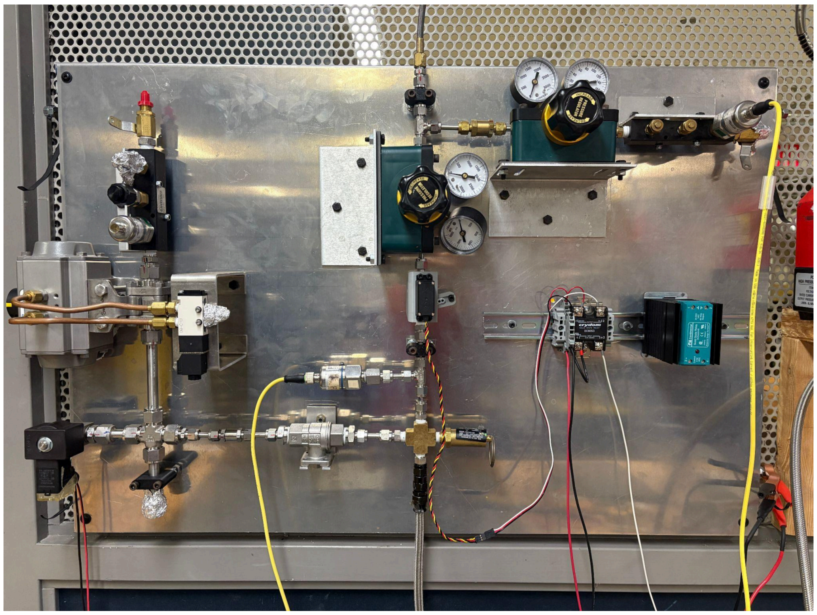


Figure 7.3.2: *GSE Plumbing.*

Our P&ID (*Figure 7.3.3)* begins at the supply side, where both the nitrogen pressurant and nitrous-oxide cylinders are fitted with quick-disconnect couplings. Downstream of each bottle, a pressure regulator maintains the desired pressurization, and a high-capacity solenoid vent valve provides automated over-pressure relief. A secondary manual vent valve offers a redundant failsafe, and a linear-actuated valve in the nitrous feed line enables precise remote shutoff. Upstream of the nitrous-oxide, an interstitial purge valve connects the N_2 and N_2O circuits allowing us to flush the oxidizer plumbing with inert gas before and after testing. Ethanol is introduced manually via a hand-pump into the fuel side of the piston tank. Finally, four pressure transducers, strategically placed across the combustion chamber and feed lines provide real-time data for system monitoring and post-test analysis.

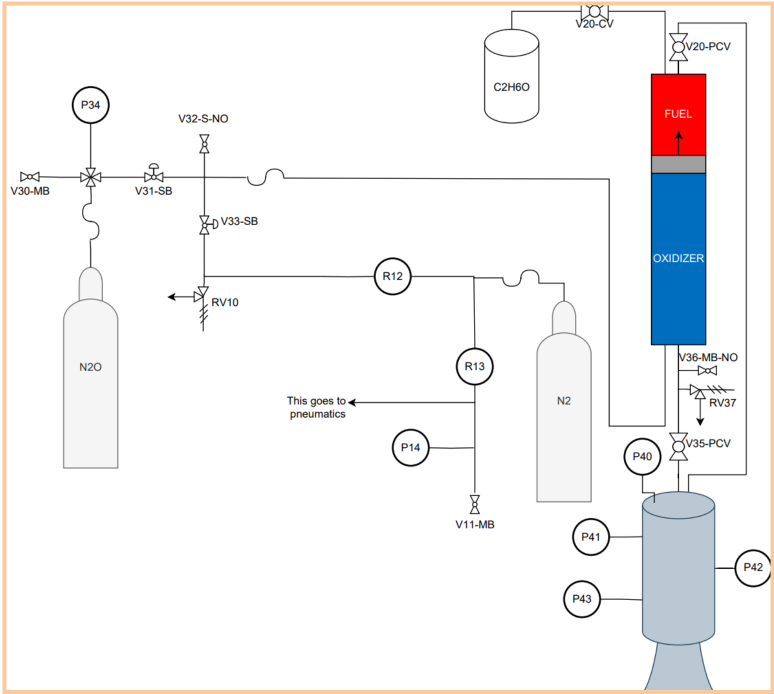


Figure 7.3.3: *System P&ID.*

7.4 Ignition System

A cartridge igniter attached to the face of the injector was employed. The igniter is lit by an E match that goes through the nozzle of the engine. Only upon visual confirmation of smoke though a camera are the MOV and MFV opened.

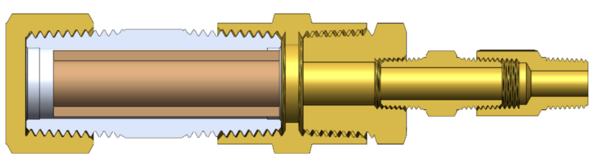


Figure 7.4.1: *Cartridge Igniter.*

Requirements and Design

The SPRINT ignition system employs a single-use pyrotechnic cartridge igniter, energized by a low-energy electric match (E-match). Key requirements are: remote activation from mission control, positive confirmation of igniter burn prior to propellant valve actuation, secure mounting to the injector face, and a through-bore to direct hot combustion gases into the chamber. Prior to opening fuel and oxidizer valves, the system's LabVIEW VI monitors a dedicated thermocouple and a camera verify a sustained igniter burn (≥ 50 ms) before enabling the "ignition" interlock.

Testing and Validation

Each lot of igniters undergoes a two-stage qualification:

1. **Cold‑Fire Compatibility Test**
   - A dummy igniter with thermocouple is fired against a steel block. Temperature rise and burn duration (> 50 ms) will be verified.

2. **Live‑Fire Chamber Dry‑Run**
   - On a dedicated test stand, the igniter is mounted to the injector face with propellant lines disconnected. The E‑match is fired, and the camera and thermocouple signals are recorded. Successful tests require ≥ 95 % sensor agreement on burn detection and no structural distortion of the igniter body.

8.0 Electronics

8.1 Hardware

The hardware system is designed to collect accurate telemetry and enable precise control over the bi-propellant liquid rocket while providing maximum possible safety. The system utilizes various instrumentation and control electronics to enable seamless and reliable control over the liquid rocket. The Labjack T7-Pro is the primary device utilized for instrumentation and control over the analog measurement devices. Moreover, the digital relays and servos are controlled by the CLICK PLUS C2-01CPU programmable logic controller. These systems are designed to be primarily operated on software, and are thus routed through the Ethernet Hub and then controlled remotely. Nonetheless, the control systems still include fail-safe contingencies and manual override capabilities.

The ground station enclosure (GSE) houses all critical hardware, as such it is IP65 rated and can thus protect the electronics from the harsh conditions experienced on the launch pad. The GSE capabilities consist of analog measurement devices, PWM-controlled servo and mechanical relays. To ensure electrical performance and reliability the connectors utilized were IP67 rated. The capabilities of the system listed below:

Table 8.1: Connectors.

Components	Amount Supported	Connector	Purposes
Thermocouple	6	K-Type Connector	Measure temperature at critical points through the rocket for thermal monitoring

Pressure Transducers	8	M12 3 Pin Connector	Monitor pressure throughout the propellant system to ensure functionality
Load Cells	6	M12 5 Pin Connector	Measure engine thrust
Servo	3	M12 3 Pin Connector	Perform mechanical actuation
Solenoids Valves	11	M12 2 Pin Connector	Control pneumatic and mechanical valves on board the rocket
E-Match	1	M12 2 Pin Connector	Trigger ignition of solid propellant through a controlled electric discharge

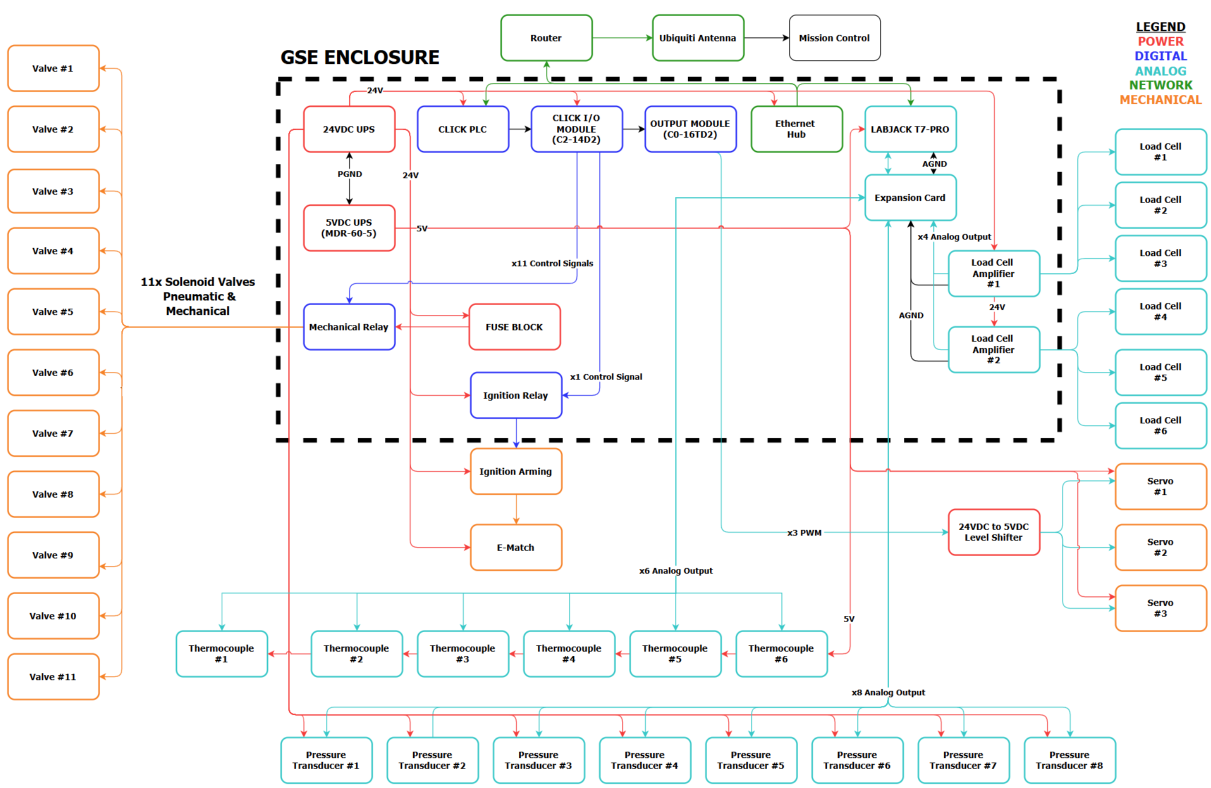


Figure 8.1 GSE Flow Chart.

8.2 Data Analysis And Software

This section outlines the full scope of software and data management for the SPRINT system. It focuses on how telemetry, control systems, data logging, and post-test analysis are implemented and integrated. All software components align with the standards outlined in the Launch Canada Rules and Requirements Guide. We detail how LabVIEW interfaces with the LabJack T7-Pro via Ethernet, and how data from various sensors and actuators is streamed, stored, and processed.

8.2.1 Software Architecture

Our system architecture is centered around LabVIEW Community Edition, which operates from the ground station. LabVIEW communicates with the LabJack T7-Pro over an Ethernet connection using the LJM (LabJack Management) driver. This setup allows for fast and reliable data transmission without relying on USB connections, which are more sensitive to noise and disconnection.

The connection is initiated using the LJM_OpenS() function. This function takes three arguments: device type, connection type, and identifier. In our case, the syntax is:

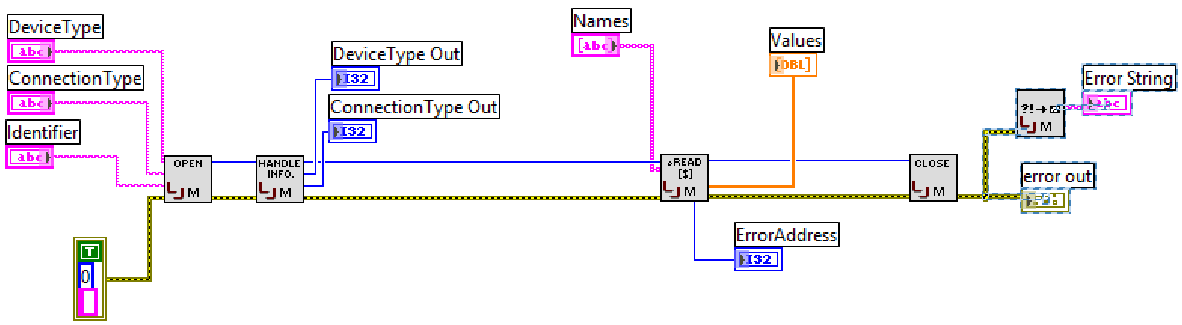
• LJM_OpenS("T7", "ETHERNET", "", handle)

This command opens a connection with the T7 device over Ethernet. If the IP is known, it targets a specific unit; otherwise, the function can be configured to connect to any available device. Once the connection is established, the system uses LJM_eReadNames, and LJM_eWriteNames functions to perform individual or batch reads and writes. These functions allow real-time monitoring and control of digital and analog channels on the T7-Pro.

For high-speed applications like propulsion testing, we use the LJStreamM application. LJStreamM operates in stream mode acquisition. Unlike LJLogM, which uses a slower command-response mode, LJStreamM pulls blocks of scan data from the T7-Pro at regular intervals. Specifically, it collects about 0.5 seconds worth of data per iteration based on the user-defined scan rate.

The scan rate is configurable and multiplied by the number of channels to determine the sample rate. LJStreamM also provides a built-in front panel for graphing values, viewing raw and scaled data, and logging files. We configure all of this via the Configuration Panel, where parameters like channel count, scaling equations, and log file prefixes are saved and reused across sessions.

The LabVIEW VI (Virtual Instrument) used for our internal control process much of what LJStreamM does but is customized for valve actuation logic, safety checks, and hardware-specific feedback. The VI reads analog inputs from pressure transducers, thermocouples, and load cells. It reads digital inputs and outputs as well, controlling solenoid valves and PWM-based servo-actuated valves using appropriate DIO and DIO-EF registers. This VI continuously updates the front panel in real time, allowing operators to monitor and react to system behavior during tests.



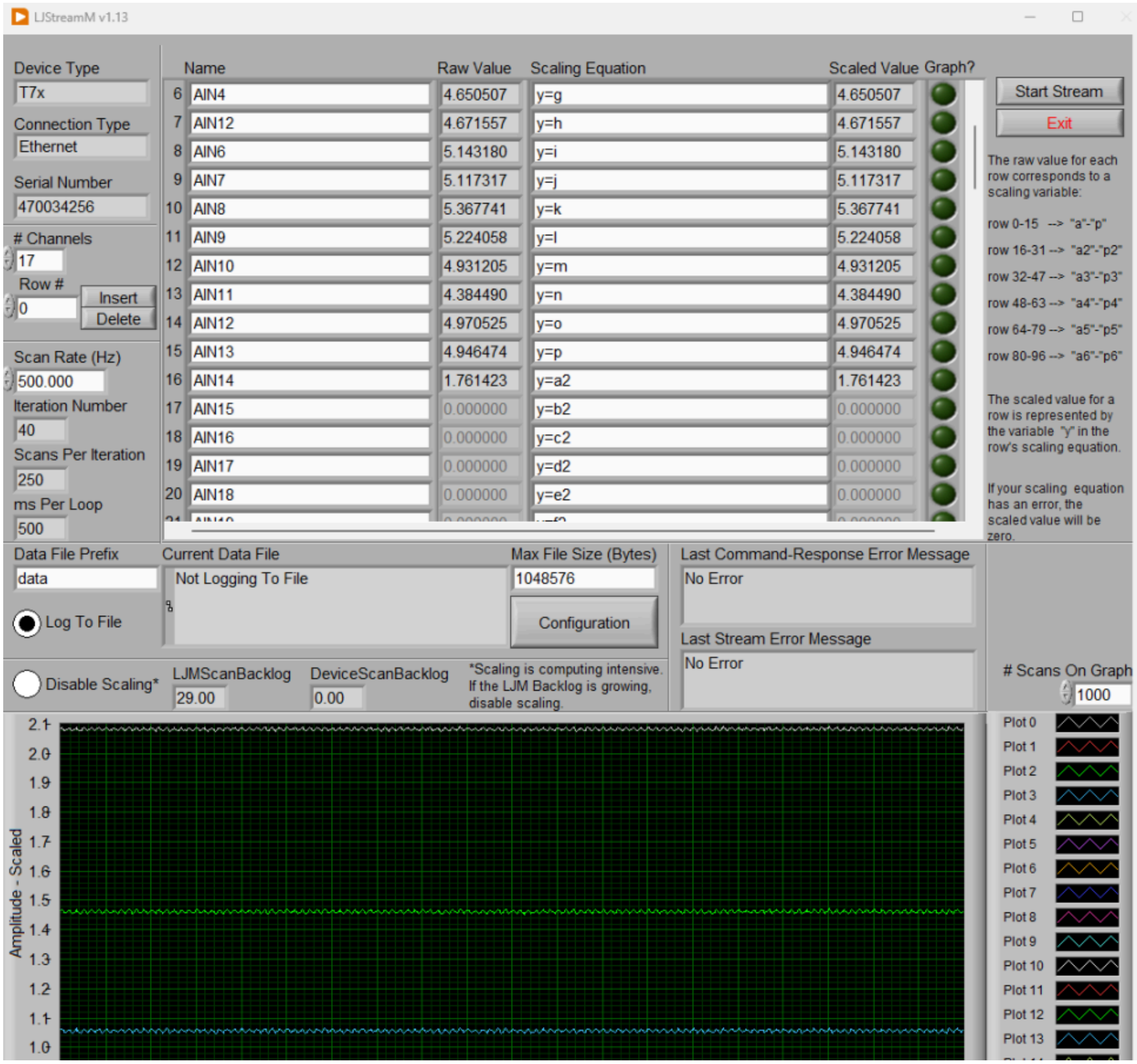
8.2.2 Data Logging

All telemetry data is logged in real time using LabVIEW's Write to Measurement File VI or via LJStreamM's built-in logging. In LabVIEW, the logging is within a dedicated loop that appends new data rows at each iteration. Each logged entry includes:

- Timestamp in UTC
- Raw analog values (from pressure, temperature, and force sensors)
- Digital output states representing valve status
- PWM duty cycle values representing servo positions

We selected the LVM (LabVIEW Measurement) file format for LabVIEW-based logs for its compatibility with both LabVIEW and third-party tools. LJStreamM writes its own DAT-format files, which are plain text and tab-delimited. These files include a header with time stamps and channel names, making them easy to parse. Each row logs a set of readings taken at a given timestamp, and file sizes are automatically managed based on a user-defined byte limit.

LJStreamM saves configuration files such as LJStreamM.cfg and LJStreamM_open.cfg, which preserve logging and device settings between sessions. These configurations help avoid repeated manual setup and ensure consistency in testing environments.



8.2.3 Data Processing And Review

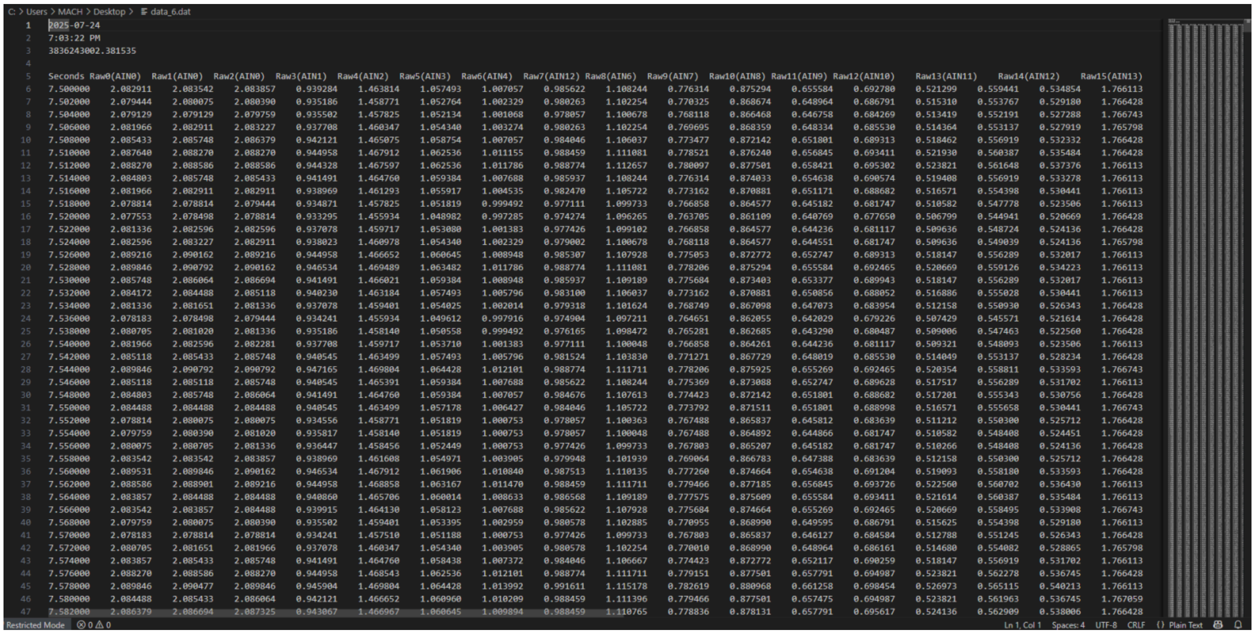
After each static or cold-flow test, the recorded .DAT files are transferred and analyzed using MATLAB or Excel. The files are parsed based on the channel headers to identify each signal. We generate time-series plots of all sensor channels and use visual inspection to confirm that valve events align with the expected pressure or temperature responses.

We apply basic scripts and formulas to compute key test metrics, including:

- Mean and maximum pressures across each transducer
- Temperature gradients and peak thermal loads
- Actuation delay and duration for each valve command

The processed results are exported to .CSV format and used in team reports and safety reviews.

Raw .DAT files are archived for traceability and potential reanalysis. This approach supports quick feedback loops during test campaigns while ensuring traceable and well-documented data history.



2025-07-24
7:03:22 PM
3836243002.381535

Seconds	Raw0(AIN0)	Raw1(AIN0)	Raw2(AIN0)	Raw3(AIN1)	Raw4(AIN2)	Raw5(AIN3)	Raw6(AIN4)	Raw7(AIN12)	Raw8(AIN6)	Raw9(AIN7)	Raw10(AIN8)	Raw11(AIN9)	Raw12(AIN10)	Raw13(AIN11)	Raw14(AIN12)	Raw15(AIN13)
7.500000	2.082911	2.083542	2.083857	0.939284	1.463814	1.057493	1.007057	0.985622	1.108244	0.776314	0.875294	0.655584	0.692780	0.521299	0.559441	0.534854	1.766113
7.502000	2.079444	2.080075	2.080390	0.935186	1.458771	1.052764	1.002329	0.980263	1.102254	0.770325	0.868674	0.648964	0.686791	0.515310	0.553767	0.529180	1.766428
7.504000	2.079129	2.079129	2.079759	0.935502	1.457825	1.052134	1.001068	0.978057	1.100678	0.768118	0.866468	0.646758	0.684269	0.513419	0.552191	0.527288	1.766743
7.506000	2.081966	2.082911	2.083227	0.937708	1.460347	1.054340	1.003274	0.980263	1.102254	0.769695	0.868359	0.648334	0.685530	0.514364	0.553137	0.527919	1.765798
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7.510000	2.087640	2.088270	2.088270	0.944958	1.467912	1.062536	1.011155	0.988459	1.111081	0.778521	0.876240	0.656845	0.693411	0.521930	0.560387	0.535484	1.766428
7.512000	2.088270	2.088586	2.088586	0.944328	1.467597	1.062536	1.011786	0.988774	1.112657	0.780097	0.877501	0.658421	0.695302	0.523821	0.561648	0.537376	1.766113
7.514000	2.084803	2.085748	2.085433	0.941491	1.464760	1.059384	1.007688	0.985937	1.108244	0.776314	0.874033	0.654638	0.690574	0.519408	0.556919	0.533278	1.766113
7.516000	2.081966	2.082911	2.082911	0.938969	1.461293	1.055917	1.004535	0.982470	1.105722	0.773162	0.870881	0.651171	0.688682	0.516571	0.554398	0.530441	1.766113
7.518000	2.078814	2.078814	2.079444	0.934871	1.457825	1.051819	0.999492	0.977111	1.099733	0.766858	0.864577	0.645182	0.681747	0.510582	0.547778	0.523506	1.766113
7.520000	2.077553	2.078498	2.078814	0.933295	1.455934	1.048982	0.997285	0.974274	1.096265	0.763705	0.861109	0.640769	0.677650	0.506799	0.544941	0.520669	1.766428
7.522000	2.081336	2.082596	2.082596	0.937078	1.459717	1.053080	1.001383	0.977426	1.099102	0.766858	0.864577	0.644236	0.681117	0.509636	0.548724	0.524136	1.766428
7.524000	2.082596	2.083227	2.082911	0.938023	1.460978	1.054340	1.002329	0.979002	1.100678	0.768118	0.864577	0.644551	0.681747	0.509636	0.549039	0.524136	1.765798
7.526000	2.089216	2.090162	2.089216	0.944958	1.466652	1.060645	1.008948	0.985307	1.107928	0.775053	0.872772	0.652747	0.689313	0.518147	0.556289	0.532017	1.766113
7.528000	2.089846	2.090792	2.090162	0.946534	1.469489	1.063482	1.011786	0.988774	1.111081	0.778206	0.875294	0.655584	0.692465	0.520669	0.559126	0.534223	1.766113
7.530000	2.085748	2.086064	2.086694	0.941491	1.466021	1.059384	1.008948	0.985937	1.109189	0.775684	0.873403	0.653377	0.689943	0.518147	0.556289	0.532017	1.766113
7.532000	2.084172	2.084488	2.085118	0.940230	1.463184	1.057493	1.005796	0.983100	1.106037	0.773162	0.870881	0.650856	0.688052	0.516886	0.555028	0.530441	1.766113
7.534000	2.081336	2.081651	2.081336	0.937078	1.459401	1.054025	1.002014	0.979318	1.101624	0.768749	0.867098	0.647073	0.683954	0.512158	0.550930	0.526343	1.766428
7.536000	2.078183	2.078498	2.079444	0.934241	1.455934	1.049612	0.997916	0.974904	1.097211	0.764651	0.862055	0.642029	0.679226	0.507429	0.545571	0.521614	1.766428
7.538000	2.080705	2.081020	2.081336	0.935186	1.458140	1.050558	0.999492	0.976165	1.098472	0.765281	0.862685	0.643290	0.680487	0.509006	0.547463	0.522560	1.766428
7.540000	2.081966	2.082596	2.082281	0.937708	1.459717	1.053710	1.001383	0.977111	1.100048	0.766858	0.864261	0.644236	0.681117	0.509321	0.548093	0.523506	1.766113
7.542000	2.085118	2.085433	2.085748	0.940545	1.463499	1.057493	1.005796	0.981524	1.103830	0.771271	0.867729	0.648019	0.685530	0.514049	0.553137	0.528234	1.766428
7.544000	2.089846	2.090792	2.090792	0.947165	1.469804	1.064428	1.012101	0.988774	1.111711	0.778206	0.875925	0.655269	0.692465	0.520354	0.558811	0.533593	1.766743
7.546000	2.085118	2.085118	2.085748	0.940545	1.465391	1.059384	1.007688	0.985622	1.108244	0.775369	0.873088	0.652747	0.689628	0.517517	0.556289	0.531702	1.766113
7.548000	2.084803	2.085748	2.086064	0.941491	1.464760	1.059384	1.007057	0.984676	1.107613	0.774423	0.872142	0.651801	0.688682	0.517201	0.555343	0.530756	1.766428
7.550000	2.084488	2.084488	2.084488	0.940545	1.463499	1.057178	1.006427	0.984046	1.105722	0.773792	0.871511	0.651801	0.688998	0.516571	0.555658	0.530441	1.766743
7.552000	2.078814	2.080075	2.080075	0.934556	1.458771	1.051819	1.000753	0.978057	1.100363	0.767488	0.865837	0.645812	0.683639	0.511212	0.550300	0.525712	1.766428
7.554000	2.079759	2.080390	2.081020	0.935817	1.458140	1.051819	1.000753	0.978057	1.100048	0.767488	0.864892	0.644866	0.681747	0.510582	0.548408	0.524451	1.766428
7.556000	2.080075	2.080705	2.081336	0.936447	1.458456	1.052449	1.000753	0.977426	1.099733	0.767803	0.865207	0.645182	0.681747	0.510266	0.548408	0.524136	1.766428
7.558000	2.083542	2.083542	2.083857	0.938969	1.461608	1.054971	1.003905	0.979948	1.101939	0.769064	0.866783	0.647388	0.683639	0.512158	0.550300	0.525712	1.766428
7.560000	2.089531	2.089846	2.090162	0.946534	1.467912	1.061906	1.010840	0.987513	1.110135	0.777260	0.874664	0.654638	0.691204	0.519093	0.558180	0.533593	1.766428
7.562000	2.088586	2.088901	2.089216	0.944958	1.468858	1.063167	1.011470	0.988459	1.111711	0.779466	0.877185	0.656845	0.693726	0.522560	0.560702	0.536430	1.766113
7.564000	2.083857	2.084488	2.084488	0.940860	1.465706	1.060014	1.008633	0.986568	1.109189	0.777575	0.875609	0.655584	0.693411	0.521614	0.560387	0.535484	1.766113
7.566000	2.083542	2.083857	2.084488	0.939915	1.464130	1.058123	1.007688	0.985622	1.107928	0.775684	0.874664	0.655269	0.692465	0.520669	0.558495	0.533908	1.766743
7.568000	2.079759	2.080075	2.080390	0.935502	1.459401	1.053395	1.002959	0.980578	1.102885	0.770955	0.868990	0.649595	0.686791	0.515625	0.554398	0.529180	1.766113
7.570000	2.078183	2.078814	2.078814	0.934241	1.457510	1.051188	1.000753	0.977426	1.099733	0.767803	0.865837	0.646127	0.684584	0.512788	0.551245	0.526343	1.766428
7.572000	2.080705	2.081651	2.081966	0.937078	1.460347	1.054340	1.003905	0.980578	1.102254	0.770010	0.868990	0.648964	0.686161	0.514680	0.554082	0.528865	1.765798
7.574000	2.083857	2.085433	2.085748	0.941491	1.464760	1.058438	1.007372	0.984046	1.106667	0.774423	0.872772	0.652117	0.690259	0.518147	0.556919	0.531702	1.766113
7.576000	2.088270	2.088586	2.088270	0.944958	1.468543	1.062536	1.012101	0.988774	1.111711	0.779151	0.877501	0.657791	0.694987	0.523821	0.562278	0.536745	1.766428
7.578000	2.089846	2.090477	2.089846	0.945904	1.469804	1.064428	1.013992	0.991611	1.115178	0.782619	0.880968	0.661258	0.698454	0.526973	0.565115	0.540213	1.766113
7.580000	2.084488	2.085433	2.086064	0.942121	1.466652	1.060960	1.010209	0.988459	1.111396	0.779466	0.877501	0.657475	0.694987	0.523821	0.561963	0.536745	1.767059
7.582000	2.086379	2.086694	2.087325	0.943067	1.466967	1.060645	1.009894	0.988459	1.110765	0.778836	0.878131	0.657791	0.695617	0.524136	0.562909	0.538006	1.766428

8.2.4 Testing And Validation

To ensure reliable data capture, we validate the entire software system before each live test. Dry runs are conducted with simulated signals or disconnected sensors. During these trials, we verify:

- That all configured channels match their expected inputs and outputs
- That the streaming rate is stable, typically around 100 Hz
- That no data loss or corruption occurs over long durations (tested up to 1 hour)

Any configuration errors or dropped frames are logged and addressed before proceeding to full system tests. We maintain consistent settings and versioning for all test types, including ignition, cold-flow, and full engine firings.

8.2.5 Compliance, Redundancy, And Safety

Our software system meets all relevant requirements outlined in the Launch Canada telemetry standards. To increase reliability, errors are catched and made sure the valve states arent changed if software disconnects. This monitors the logging loop and automatically restarts the stream if a timeout or failure is detected.

Redundant data storage is implemented using dual local and USB backups. The system writes log errors and warnings to a separate error file for review. Operators are alerted on-screen in case of stream interruption, allowing manual override when needed.

Future versions of the system will explore integrating cloud-based backups and remote monitoring dashboards. For now, the existing software design provides a robust, field-tested framework for data acquisition, monitoring, and analysis.

9.0 Range Safety

Health of all personnel and interested parties is of the utmost importance, to ensure that we need clear safety distances, PPE(Personal Protective Equipment), closed sections and SOP(Standard Operating Procedures). The TNT equivalence shows our total propellant load yields power of 5.19kg of TNT. Safe distance is 61.78 meters, glass shatters at 27.47 meters, injury threshold is 12.37 meters, and shrapnel could possibly fly out to 635.3 meters. Using concrete to close off the area we reduce the safe area to 61.78 meters. so this concludes the mission control to be held at around 62-70 meters from pad control which is 10 meters form pad. These precautions will ensure the safety of all interested parties in the vicinity of the test area.

Formula 1: Scaled Distance (Used to find Overpressure [Ps])

$$Z = \frac{R}{\sqrt[3]{W}} \tag{10.0}$$

R = Stand-off distance
W = TNT equivalent
*Note: Z is sometimes used to calculate safe distances, where R is replaced with some factor relating to risk tolerance.

Formula 2: TNT equivalence

$$W = M_c \cdot \left(\frac{H_c}{1155}\right) \cdot Y \tag{10.1}$$

M_{cETH} = Mass Ethanol = 1.57(kg)[1]
M_{cN2O} = Mass Nitrous Oxide = 4.75(kg)
H_{cETH} = Heat of combustion of Ethanol = 7086 [kcal/kg]
H_{cN2O} = Heat of combustion of Nitrous = 445 [kcal/kg]
Y = Yield of combustion[2] = 1

$$W_{ETH} = 1.57 \cdot \left(\frac{7086}{1155}\right) \cdot 1 = 9.62[lbs] \tag{10.2}$$

$$W_{N2O} = 4.75 \cdot \left(\frac{445}{1155}\right) \cdot 1 = 1.83[lbs] \tag{10.3}$$

[1] Masses are equal to engine tank volume. Nitrous is assumed to be fully liquid.

[2] Yield of combustion, where the worst case scenario is assumed, results in a yield factor of 1. Where all the ethanol is reacted with all the Nitrous Oxide and full combustion is achieved.

Formula 1.1: Stand-off Distance from Milestone Scale Distances

$$Z\sqrt[3]{W} = R \tag{10.4}$$

By using values of Z from Figure 9.1, the non-scaled distances of interest overpressure 0.4psi, 1 psi, and 3.5psi can be calculated. The engine has a TNT equivalent of 11.45(lbs) or 5.19(kg).

9.1 Calculated Safe Distances

Table 9.1: Calculated Overpressure distances based on TNT_{eqiv}

Overpressure (psi)	Distance from Origin (m)
0.4 (Safe)	61.78
1 (Shatters Glass)	27.47
3.5 (Serious Injury)	12.37

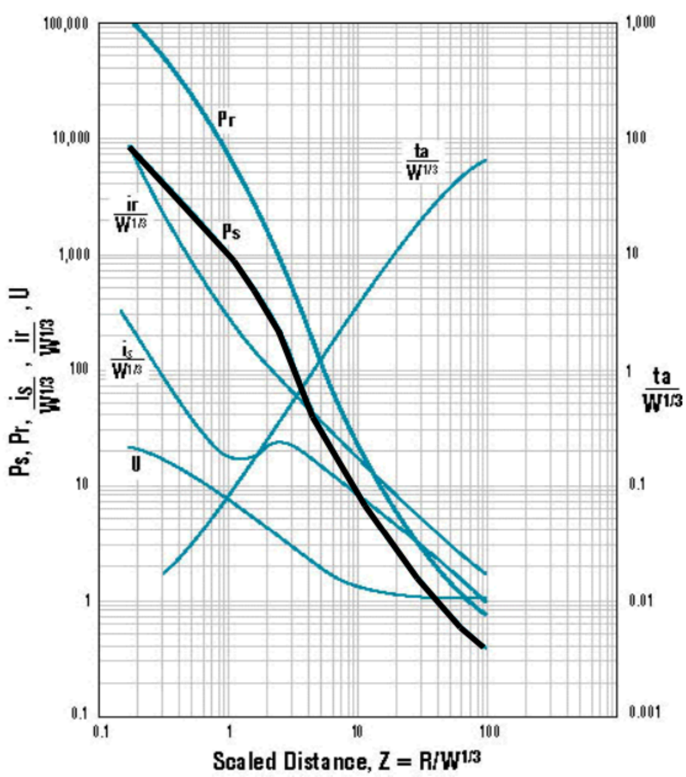

Figure 9.1: Scaled Distance to Peak Positive Incident Overpressure (Ps) Graph [25]

Using the UN Explosion Danger Area Calculator for bare explosives equaling our calculated

TNT equivalent, our estimated safe distance with no protective solutions is 635.3m (2084.3176ft). MACH should request a barricade, human made or natural, or shielding that can contain explosions of MACH's TNT equivalent of 5.19(kg). Providing protection against shrapnel would decrease our safe distance to the overpressure safe distance of 61.78(m) or 202.69029(ft) which is comparable to the conditions of the Simple Path Farms site.

10.0 Hazard and Risk Assessment

10.1 Safety and Operational Risks

Safety and operational risks are important considerations in the design and execution of the SPRINT engine project. These risks encompass hazards associated with propulsion system failures, structural integrity issues, and personnel safety. Ensuring proper mitigation strategies is essential to prevent catastrophic failures and maintain operational efficiency. This section outlines the primary risks, categorized into propulsion system risks, structural risks, and personnel safety risks.

Table 10.1: Summary of Key Safety and Operational Risks

Risk Category	Key Risks
Propulsion System Risks	Nitrous Oxide Thermal Decomposition, Pressure Vessel Failure, Premature Ignition, Valve Sequencing Errors, Flow Control Issues
Structural Risks	Support Tower Failure, Engine Mount Failure
Personnel Safety Risks	Chemical Exposure, High Pressure Systems, Fire/Explosion Hazards, Mechanical Hazards

Propulsion Systems Risks

The propulsion system represents the core operational element of the SPRINT engine and incorporates multiple subsystems working in concert, each with associated failure modes. Analysis of these failure modes reveals several critical risk categories requiring systematic evaluation and mitigation.

Nitrous Oxide Thermal Decomposition

Nitrous oxide decomposition presents a primary risk due to the oxidizer's inherent chemical instability. The decomposition reaction follows an autocatalytic pathway, where the heat released accelerates the reaction rate. This behavior can manifest under two conditions: elevated temperatures or exposure to catalytic contaminants. The resulting rapid pressure rise can exceed the pressure vessel's structural limits within milliseconds.

Current Mitigation Strategies

To mitigate risks of nitrous oxide thermal decomposition, the team has implemented several strategies. Temperature control is critical during operations. The team will carefully monitor temperatures to prevent conditions that could trigger thermal decomposition All components in the propellant feed system have been selected for chemical compatibility with nitrous oxide. This reduces the potential for chemical interactions that could destabilize the oxidizer. Relief devices onboard the GSE are installed to manage pressure changes. These mechanisms allow controlled pressure release if unexpected conditions arise. An emergency dump system has been designed to quickly evacuate the oxidizer if critical risks are detected. This provides an additional safety mechanism during the operational sequence. These mitigation strategies aim to manage the inherent risks of nitrous oxide handling through careful design and operational protocols.

Additional Recommendations

To further enhance safety and reduce the risk of nitrous oxide thermal decomposition, the team recommends two additional strategies. First, implement a comprehensive monitoring system that continuously tracks temperature and pressure thresholds for the nitrous oxide system. This real-time monitoring will allow for early detection of potentially hazardous conditions that could lead to thermal decomposition. Second, apply thermal insulation around the oxidizer tanks to minimize external temperature variations and reduce the risk of uncontrolled temperature-driven pressure changes. Proper insulation can help maintain a more stable thermal environment for the nitrous oxide, further mitigating decomposition risks.

10.2 Structural Risks

The structural integrity of the SPRINT engine and its support systems is crucial to ensuring successful operation. Failures in structural components can lead to uncontrolled collapse, loss of system stability, and severe damage to the propulsion unit. Key structural risks are as follows:

Support Failure

A potential structural failure could lead to a catastrophic collapse, posing significant risks to equipment, personnel, and the overall testing process. To mitigate these risks, the team has implemented several strategic approaches: High-strength steel components have been selected for the support tower construction. These materials provide enhanced structural reliability and load-bearing capacity compared to standard structural materials. Comprehensive load analysis has been conducted using two complementary methods: finite element modeling (FEM) and detailed analytical calculations. These analytical approaches allow for a thorough assessment of potential stress points, load distributions, and structural performance under various operational conditions. A robust anchoring system has been designed to ensure the support tower's stability. These anchoring mechanisms are engineered to minimize movement and provide additional structural reinforcement, reducing the risk of unexpected tower displacement or failure.

Engine Mount Failure

The engine mount interfaces the propulsion system and its support structure, serving as the main connection point that maintains the entire system's stability during testing and operation. High-strength fasteners have been strategically selected and reinforced at all mounting points. These specialized components are engineered to withstand extreme loads and provide superior structural integrity compared to standard mounting hardware. By using advanced materials and precise manufacturing techniques, the team ensures that each connection point can resist the substantial forces generated during engine operation. Finite Element Method (FEM) analysis has been conducted to validate the load-bearing capacity of the mounting system. This computational approach allows engineers to simulate and analyze complex stress distributions, identifying potential weak points before they can become critical failure modes.

Injector Performance

Suboptimal injector characteristics such as inadequate propellant atomization or uneven fuel and oxidizer distribution can significantly compromise engine performance, potentially resulting in reduced thrust output and combustion instabilities. To mitigate these potential risks, the team has implemented a multi-faceted approach to injector design and validation. Analytical models are employed to optimize the injector geometry, as well as standardized assumptions are made to model and predict propellant mixing and spray characteristics before physical fabrication. These computational models help refine the injector design to ensure optimal propellant atomization and distribution. Complementing the initial analysis, the team conducts experimental cold flow testing to empirically verify the predicted spray patterns. These tests use inert fluids to simulate actual propellant behavior, providing direct experimental validation of the injector's performance characteristics. Additionally, the team emphasizes precision manufacturing techniques for the injector orifices, ensuring consistent and accurate geometries that meet the stringent requirements for propellant mixing and combustion efficiency.

Combustion Instability

The potential for combustion instability is an important consideration in rocket engine design, characterized by potentially destructive pressure oscillations within the combustion chamber. These oscillations can arise from complex interactions between the combustion process, chamber geometry, and propellant injection dynamics.

For the SPRINT engine, the team preliminarily assesses that combustion instability risks are mitigated by the engine's relatively small size. The compact dimensions and carefully designed injector geometry - which features a like-like impinging design with specific orifice characteristics - reduce the likelihood of significant pressure oscillations.

Ignition Reliability

Unreliable ignition can result in failed engine start sequences or incomplete combustion, affecting performance. To enhance reliability, the team has developed a custom pyrotechnic initiator system as a baseline ignition method. This backup system provides an additional layer of confidence for test day operations, ensuring that even if the primary torch igniter encounters issues, an alternative ignition mechanism is available. Laboratory testing rigorously validates the ignition system's performance, examining critical parameters such as burn duration, peak temperature, and consistent ignition characteristics. The remote activation capability further enhances operational safety, allowing precise control of the ignition sequence.

10.3 Control System Risks

The control system is responsible for engine telemetry, actuation of valves, and real-time adjustments to maintain stability. Failures in this system can compromise mission objectives.

Sensor Failure

Failures in pressure, temperature, or position sensors can result in inaccurate data readings, leading to compromised decision-making. To mitigate these risks, current strategies include deploying redundant sensors for critical measurements, conducting regular calibration and validation of sensor outputs, and utilizing industrial-grade sensors designed to withstand extreme environments.

Data Acquisition Issues

Data loss or corruption can impede performance assessments and real-time decision-making. To mitigate these risks, strategies include high-speed data acquisition with redundant storage to ensure data reliability, the use of shielded cabling to minimize electromagnetic interference, and regular system integrity checks to maintain system performance and accuracy.

Communication Loss

Loss of telemetry signals can prevent monitoring and control of the engine during tests, posing significant risks. To mitigate this, current strategies include implementing multiple communication channels for redundancy, real-time telemetry monitoring to detect signal degradation, and hardwired fail-safe triggers for emergency shutdowns to ensure safety and reliability.

Software Malfunctions

Bugs or failures in control algorithms can cause incorrect valve actuation or unstable flight control, leading to potential system failures. To mitigate these risks, current strategies include software-in-the-loop testing for all control algorithms, implementing manual override capabilities for unexpected behavior, and conducting regular updates and bug fixes through iterative testing.

10.4 Manufacturing Risks

Component Procurement Delays

Delays in procuring critical components can disrupt assembly and testing schedules, impacting project timelines. To mitigate this risk, strategies include early identification and ordering of long lead-time items, establishing multiple supplier agreements to reduce dependency on a single vendor, and maintaining a buffer stock of critical components to ensure availability when needed.

Machine Shop Availability

Limited access to machine shop facilities can delay the fabrication of key components, impacting overall project timelines. To mitigate this risk, strategies include pre-scheduling machining time well in advance, identifying backup machining facilities for overflow work, and prioritizing in-house machining for critical components to ensure timely production.

Quality Control Issues

Inconsistent quality in manufactured components can result in failures during testing and delays in project progress. To mitigate this risk, strategies include strict adherence to quality assurance protocols, conducting pre- and post-manufacturing inspections of critical components, and implementing standardized testing procedures to ensure reliability and performance.

Assembly Integration Challenges

Complex assemblies require precise coordination to ensure smooth integration and avoid delays. To mitigate this risk, strategies include developing detailed assembly procedures and checklists, conducting mock assembly testing before final integration, and assigning a dedicated integration team to oversee the process and address any issues in real-time.

10.5 Testing Program Risks

Delays in testing can impact overall project timelines and prevent timely identification of technical issues.

Test Site Availability

Limited test site availability can cause delays in scheduled firings and system evaluations, impacting project timelines. To mitigate this risk, strategies include advanced booking of test sites with built-in schedule flexibility, establishing backup test locations, and coordinating with regulatory agencies to streamline site approvals.

Weather Constraints

Adverse weather conditions can disrupt outdoor testing and transportation schedules, leading to potential delays. To mitigate this risk, strategies include scheduling tests during seasons with historically stable weather, developing indoor testing setups for critical subsystems, and implementing weather monitoring systems to anticipate and plan for potential delays.

Equipment Availability

Limited access to necessary testing equipment can hinder validation efforts and delay project progress. To mitigate this risk, strategies include maintaining an updated list of required test equipment, partnering with universities and research institutions for shared access, and renting equipment when purchasing is not a viable option.

Test Schedule Delays

Unexpected issues during testing can lead to setbacks in the overall project timeline, affecting development milestones. To mitigate this risk, strategies include developing contingency schedules with built-in buffer time, conducting thorough pre-test checklists to minimize unexpected failures, and parallelizing test activities where possible to maximize efficiency. Additional recommendations include implementing automated testing procedures to streamline validation efforts and conducting regular risk assessments to proactively identify and address potential delays.

10.6 Competition Timeline Risks

The project must meet specific deadlines to ensure successful participation in the Launch Canada competition. Regulatory and logistical constraints must be considered.

Regulatory Approval Delay

Failure to obtain required permits and approvals can significantly halt project progress. To mitigate this risk, current strategies include early engagement with regulatory authorities to fully understand compliance requirements, assigning a dedicated compliance officer to track approvals, and maintaining detailed documentation to streamline the approval process.

Documentation Requirements

Failure to submit required documentation on time or with complete accuracy can result in disqualification or project hold-ups. To mitigate this risk, current strategies include establishing a centralized documentation repository for organized record-keeping, assigning team members to track and compile necessary reports, and conducting periodic audits to ensure compliance with submission requirements.

Transportation Logistics

Transporting the propulsion system, test equipment, and support structures to the competition site presents significant logistical challenges. To mitigate these risks, current strategies include detailed transport planning with pre-shipment inspections to ensure all components are secure, partnering with logistics companies for reliable and timely delivery, and designing modular components to simplify transportation and assembly at the site.

Resource Allocation Issues

Competing demands for funding, personnel, and material resources can create bottlenecks that hinder project progress. To mitigate these challenges, current strategies include regular financial tracking and forecasting to ensure efficient budget management, prioritizing resource allocation based on critical project milestones, and actively seeking external sponsorships and funding opportunities to supplement available resources.

11.0 Team Development

11.1 Succession Planning

To ensure continuity and leadership growth, MACH has implemented a structured succession framework:

- **Lead-in-Training Roles:** Each Subteam Lead recruits and mentors a Lead-in-Training.
- **Mentorship Pairing:** New members are paired with experienced mentors from their subteam. Mentors guide them through onboarding tasks, project standards, and tooling best practices, providing feedback during weekly 1:1 check-ins.
- **Transition Workshops:** Prior to semester end, outgoing Leads will host hands-on workshops covering team processes, design review practices, and safety protocols.
- **Role Rotation:** Key tasks such as test-stand assembly, hydrostatic testing, and data analysis rotate among members each campaign. This cross-training prepares multiple individuals to step into leadership or specialist roles if required.

11.2 Knowledge Retention

To prevent institutional knowledge loss as members graduate, MACH maintains robust documentation and archival practices:

- **Centralized Knowledge Repository:** All technical documents, CAD models, test data, and scripts are version-controlled in a shared GitHub organization. Each deliverable includes a README with setup and usage instructions.
- **Exit Interviews & Handover Checklists:** Departing members complete an exit interview and fill a handover checklist that highlights ongoing tasks, contact lists for sponsors, and unresolved action items. This ensures incoming Leads can quickly pick up work in progress.

12.0 References

[1] Aqua Environment, "873-D High Flow Dome Loaded Reducing Regulators," Aqua Environment, [Online]. Available: https://valvesandregulators.aquaenvironment.com/viewitems/high-flow-reducing-regulators-2/873-d-high-flow-dome-loaded-reducing-regulators. [Accessed: 31-Jan-2025].

[2] Launch Canada, *Design, Test & Evaluation Guide,* Revision 3, Launch Canada, Jul. 25, 2025.

[3] Asia Industrial Gases Association (AIGA), *Safe Practices for Storage and Handling of Nitrous Oxide*, AIGA 081/20, Rev. of AIGA 081/16, Nov. 2020. [Online]. Available: http://www.asiaiga.org. [Accessed: 01-Feb-2025].

[4] Swagelok Pittsburgh, "What is Fluid System Creep?" Swagelok Pittsburgh, [Online]. Available: https://pittsburgh.swagelok.com/en/about-us/blog/news-item-35-what-is-fluid-system-creep. [Accessed: 31-Jan-2025]

[5] Zook Enterprises, LLC, "PB Rupture Disk," Zook, [Online]. Available: https://zookdisk.com/products/pb-rupture-disk/. [Accessed: 31-Jan-2025].

[6] Aqua Environment, "1094 Open/Close Valves," Aqua Environment, [Online]. Available: https://valvesandregulators.aquaenvironment.com/viewitems/high-flow-open-close-valves-2/1094-open-close-valves. [Accessed: 31-Jan-2025].

[7] Half Cat Rocketry, "Mojave Sphinx," Half Cat Rocketry, [Online]. Available: https://www.halfcatrocketry.com/mojave-sphinx. [Accessed: 31-Jan-2025].

[8] M. A. K. A. Kul, Y. Seymen, M. E. Yıldız, and S. M. Köroğlu, (PDF) preliminary design, basic simulation and optimization of Liquid Rocket Engines,

https://www.researchgate.net/publication/317841320_Preliminary_Design_Basic_Simulation_a nd_Optimization_of_Liquid_Rocket_Engines (accessed Nov. 10, 2024).

[9] M. Lazzarin, N. Bellomo, F. Barato, and A. Bettella, (PDF) testing and CFD simulation of diaphragm hybrid rocket motors, https://www.researchgate.net/publication/262033007_Testing_and_CFD_Simulation_of_Diaphragm_Hybrid_Rocket_Motors (accessed Nov. 10, 2024).

[10] Falk, A. Y. Space Storable Propellant Performance--Gas/Liquid Like-Doublet Injector Characterization, Final Report, R-8973 (NASA CR-120935), Rocketdyne, a division of Rockwell International, Canoga Park, California, October 1972

[11] W. J. Carter and B. E. Ball, ASME Section VIII Div. 1, Pressure Vessels. McGraw-Hill Professional Publishing, 2023.

[12] D. R. Batha, M. D. Carey, J. G. Campbell, C. D. Coulbert, and M. E. Goodhart, *Thrust Chamber Cooling Techniques For Spacecraft Engines*. 1963, p. 17.

[13] "CHAMBERSAFE," *Half Cat Rocketry*. https://www.halfcatrocketry.com/chambersafe

[14] Parker Hannifin Corporation, *Parker O-Ring Handbook*, ORD 5700, Parker Hannifin Corporation. [Online]. Available: https://www.parker.com/content/dam/Parker-com/Literature/O-Ring-Division-Literature/ORD-5700.pdf. [Accessed: 31-Jan-2025].

[15] E. R. Stepp, *Thrust Vector Control Load Predictions*, NASA Technical Report, ER63, Rev. 05, 2024. [Online]. Available: https://ntrs.nasa.gov/api/citations/20240010637/downloads/Stepp_ER63_TVC_Load_Predictions_rev05.pdf. [Accessed: 01-Feb-2025].

[16] G. P. Sutton and O. Biblarz , "Rocket Propulsion Elements, 9th edition," Wiley.com, https://www.wiley.com/en-au/Rocket+Propulsion+Elements%2C+9th+Edition-p-97811187536 51 (accessed Nov. 10, 2024).

[17] Half Cat Rocketry, "PV Design," Half Cat Rocketry, [Online]. Available: https://www.halfcatrocketry.com/pv-design. [Accessed: 31-Jan-2025].

[18] MatWeb, "ASM Material Data Sheet: 6061-T6 Aluminum," MatWeb, [Online]. Available: https://asm.matweb.com/search/specificmaterial.asp?bassnum=ma6061t6. [Accessed: 31-Jan-2025].

[19] M. C. Louwerse, M. N. W. Groenendijk, H. V. Jansen, and M. C. Elwenspoek, (PDF) nozzle fabrication for Micropropulsion of a microsatellite, https://www.researchgate.net/publication/231136007_Nozzle_fabrication_for_micropropulsion_of_a_microsatellite (accessed Nov. 10, 2024).

[20] E. A. R. and K. B., Jr. R., "Solid rocket motor nozzles - NASA technical reports server (NTRS)," NASA, https://ntrs.nasa.gov/citations/19760013126 (accessed Nov. 10, 2024).

[21] G. V. R. Rao, Exhaust Nozzle Contour for Optimum Thrust, https://arc.aiaa.org/doi/abs/10.2514/8.7324?journalCode=jjp (accessed Nov. 10, 2024).

[22] A. Khan, S. Kumar, H. Chowdary, and S. Sharath, (PDF) design of a supersonic nozzle using method of characteristics, https://www.researchgate.net/publication/281029694_Design_of_a_Supersonic_Nozzle_using_Method_of_Characteristics (accessed Nov. 10, 2024).

[23] P. K. Bahumanyam, Y. D. Dwivedi, and N. K. Mishra, (PDF) design of Supersonic Wind Tunnel using method of characteristics, https://www.researchgate.net/publication/273460548_Design_of_supersonic_wind_tunnel_usin g_method_of_characteristics (accessed Nov. 10, 2024).

[24] J. Singh, L. E. Zerpa, B. Partington, and J. Gamboa, "Effect of nozzle geometry on critical-subcritical flow transitions," Heliyon, https://www.sciencedirect.com/science/article/pii/S2405844018374164 (accessed Nov. 10,2024).

[25] Friends of Amateur Rocketry, "Liquid Nitrous Oxide – Temperature-Pressure-Density," Friends of Amateur Rocketry, Nov. 2023. [Online]. Available: https://friendsofamateurrocketry.org/wp-content/uploads/2023/11/Liquid-Nitrous-Oxide.pdf. [Accessed: 26-Jul-2025].

[26] Half Cat Rocketry, HalfCatSim v1.3.10, [Online]. Available: https://www.halfcatrocketry.com/halfcatsim. [Accessed: 26-Jul-2025].

Appendix I: Launch Canada Compliance Requirements

A.1 System Requirements

A.1.1 Pressurized Fluid Systems

Table A.1.1: Launch Canada Compliance Requirements

No	Description	Notes (If required)
2.0	**Propulsion Systems**	The SRAD engine will use pressurized liquid propellants. Cold-flow tests will be carried out using water and liquid carbon dioxide.
R2.1.1	**All SRAD motors shall be static fired, well characterized and tested before arrival at the competition, per Section 2.5. No second-party motors (i.e., those that are not COTS and not developed by the participating team) are permitted.**	MACH will only static fire, so does not need to meet this requirement
R2.1.2	**The total impulse for a rocket made with COTS components and entered into the Basic category shall not exceed 40,960 Newton-seconds (9,208 pounds-seconds, i.e., “O” impulse motor).**	N/A, due to not being in basic category
R2.1.3	**Non-Toxic Propellants** Launch vehicles entered in the LC Challenge shall use non-toxic propellants.	The propellants for this engine design are: Fuel: Ethanol Oxidizer: Nitrous Oxide Pressurant: Nitrogen Safety Data Sheets from propellant suppliers.
	2.2.1.2 Sealed Systems	
2.2.1.1	**Pressure Definitions**	All pressures will be defined according to 2.2.1.1. Eg. MEOP = 1.2x WP.
R2.2.1	**Any sealed system or segment shall have a pressure relief device.**	
	2.2.1.3 Operational Envelope	

R2.2.2	**Teams shall define the operational ranges their engines can launch under in terms of fill percentage and oxidizer pressure.**	N/A
2.2.1.4 Design Standards		
R2.2.3	**Any system, subsystem or component that will be pressurized with personnel in proximity shall comply with a recognized standard for the design and safe operation of such systems.**	
R2.2.4	**Any system, subsystem or component that will be transported while pressurized shall comply with the applicable Transport Canada and US Department of Transportation (DoT) standards**	MACH will not transport pressurized vessels
2.2.1.5 Wetted Materials		
R2.2.5	**All wetted materials (i.e., those exposed to a fluid) employed in a rocket's fluid systems shall be compatible with the fluid(s) and conditions (e.g., temperature, pressure, shock, vibration) to which they will be exposed.**	
R2.2.6	**Any materials in a fluid system or component that would not normally be directly exposed to a given fluid but could be exposed during a credible failure or by migrating downstream shall similarly be compatible with that fluid.**	
2.2.1.6 General Cleanliness		
R2.2.8	**Caps, plugs or other protective covers shall be used on all ports and openings in fluid systems to prevent contamination when not in use.**	
2.2.1.7 Oxidizer System Cleanliness		
R2.2.9	**No hydrocarbons shall be employed in any oxidizer system component, or in wetted components upstream of an oxidizer system.**	
R2.2.10	**All oxidizer system hardware (valves, plumbing, etc.) shall be thoroughly cleaned to an acceptable standard for oxygen service.**	All plumbing will be ultrasonic cleaned ✓
R2.2.11	**After cleaning, components shall be thoroughly dried in such a way that contamination is not introduced.**	A custom sealed clean drying container will be used
R2.2.12	**Cleaned components shall be maintained in that condition. This is typically done by capping / plugging all ports, and then further protecting the part by bagging.**	
R2.2.13	**All caps, plugs, bags or other protective material that will be used with an oxidizer system shall themselves be cleaned for oxygen service to avoid re-contamination**	

R2.2.14	**All components shall be presumed contaminated unless all the following are satisfied:** **• They were supplied in an oxygen clean condition, or were known to have been cleaned to an acceptable standard, AND** **• They have been constantly maintained in that condition, for example by capping, double bagging, etc.**	
2.2.2.1 Metallic Pressure Vessels		
R2.2.15	**Vehicle propellant tanks shall not have a burst pressure of less than 1.5 times the maximum expected operating pressure, and other pressure vessels shall not have a burst pressure of less than 2.0 times the maximum expected operating pressure. Maximum operating pressure is the maximum pressure expected at any point during pre-launch, flight, and recovery operations.**	
R2.2.16	**If a propellant tank is designed with a burst pressure of less than 2.0 times the maximum expected operating pressure, hydrostatic burst testing shall be performed to demonstrate that the design and manufacturing process actually achieved or exceeded the design burst pressure.**	
R2.2.17 - R2.2.23 are not applicable		
2.2.2.3 SRAD Pressure Vessel Testing		
R2.2.24	**Teams shall comply with all rules, regulations, and best practices imposed by the authorities at** **their chosen test location(s).**	
R2.2.25	**Prior to use, pressure vessels intended for static testing or flight shall be proof tested.**	
R2.2.26	**Proof pressure shall be selected such that the gross stress level in the tank during the proof test does not exceed 95% of the yield strength of the material and does not exceed 75% of the ultimate strength of the material.**	
R2.2.27	**The tank shall be designed such that the above requirement can be met with a proof pressure** **not less than 1.5 times the maximum expected operating pressure.**	

R2.2.28	**The proof pressure shall be held for not less than twice the maximum expected system working time.**	Working time shall not be more than 1 minute, therefore we will test for 2 minutes.
R2.2.29	**Proof testing shall always be performed with an incompressible fluid such as water - NEVER with gas.**	
2.2.2.3.2 Burst Testing applicable for: - **Any metallic pressure vessels with a design burst pressure of less than 2.0 times the maximum expected operating pressure;** - **Any composite pressure vessel.**		Burst testing will not be done.
2.2.3.1 Remote Operation		
R2.2.32	**Any experimental pressure vessel, system or component thereof with a burst pressure less than 4.0 times the maximum expected operating pressure (i.e., factor of safety of 4.0) shall only be pressurized and de-pressurized remotely.**	The only manual actuation will be opening the globe valve of our supply tanks. This ensures the only section under pressure when personnel are nearby are rated above a FOS of 4. All venting will be done remotely.
R2.2.33	**Experimental pressure vessels shall never be approached by personnel while pressurized to more than 25% of its burst pressure.**	
R2.2.34	**Commercial pressure vessels pressurized above their rated pressure shall only be remotely pressurized and depressurized.**	N/A We will not be pressurizing using COTS vessels rated above their rated pressure.
R2.2.35	**Commercial pressure vessels pressurized above their rated pressure shall never be approached by personnel while pressurized above its rated pressure.**	N/A
R2.2.36	**Experimental pressure vessels shall incorporate electronic pressure measurement and telemetry to allow tank pressures to be monitored remotely.**	Pressure transmitters on nitrous and ethanol sides will be employed
R2.2.37	**Commercial pressure vessels pressurized above their rated pressure shall have electronic pressure measurement and telemetry to allow pressure vessels to be monitored remotely.**	N/A
2.2.3.2 Overpressure Protection		

R2.2.38	**Pressure relief devices or features shall be incorporated on all systems having a pressure source which can exceed the maximum allowable pressure of the system, or where the malfunction /failure of any component can cause the maximum allowable pressure to be exceeded.**	
R2.2.39	**Relief devices shall be sized based on the worst credible failure that would cause the pressure to rise to a hazardous level**	
R2.2.40	**Under no circumstances shall the pressure in the system exceed 110% MEOP. Relief devices shall be used where necessary to satisfy this requirement.**	
R2.2.41	**All pressure relief devices shall be sized to provide relief at full flow capacity at the pressure specified above, or lower.**	
R2.2.42	**Only commercial burst disks shall be utilized to satisfy these requirements.**	
	R2.2.42, R2.2.43 are not applicable	
2.2.3.3 Filling, Draining & Venting		
R2.2.45	**Propellant tanks shall be filled and drained from the bottom of the tank, near the top of the main propellant valves.**	This requirement is satisfied for nitrous, however our ethanol section will be breaking this rule and filled and drained from the top. It is up to LC to determine if we can break this rule.
R2.2.46	**If a propellant has a high vapour pressure (i.e., above 40 psia) and its propellant tank is not a certified vessel with a safety factor of 4.0 or greater, the system shall be designed to allow remote filling and draining of the propellant.**	
R2.2.47	**Vents shall be routed to minimize the hazard they pose to personnel.**	
	R2.2.48 - R2.2.51 are not applicable	
R2.2.52	**The average oxidizer flow rate during abort shall be measured in testing, and data of this test shall be provided to LC staff.**	

R2.2.53	**The effective orifice of any plumbing used for draining the tank shall be in excess of the area of a single ⅛" diameter orifice for oxidizer tanks over 100 mL, ¼" for oxidizer tanks over 2 L, ⅜" for oxidizer tanks over than 10 L, ½" for oxidizer tanks over 25 L commensurate with a discharge coefficient of at least 0.3.**	The tank vent will be a normally open solenoid valve
R2.2.54	**For an engine test stand, fuel and oxidizer vents shall be kept separate to preclude the potential mixing of vented propellants.**	
R2.2.55	**For vehicles, fuel and oxidizer vents shall be routed to opposite sides of the vehicle.**	
2.2.3.4 Failure Considerations **2.2.3.4.1 Failsafe Remote Venting**		
R2.2.56	**Pressurized systems shall be designed to ensure that there is no credible failure case that would cause the loss of the ability to remotely depressurize the system. This requirement applies to all high-pressure sources on a vehicle or static test stand: propellant tanks, pressurant tanks, etc.**	
R2.2.57	**A rocket or engine test stand shall implement an emergency vent capability to relieve pressure to a safe level (less than 689 kPa (150 psig)) for all the pressurant and propellant tanks that is independent of the nominal control system.**	
R2.2.58	**Liquid and gaseous propellants having vapor pressures greater than 150 psig (e.g., N2O) shall implement remote offloading for these propellants.**	
2.2.3.4.1 Propellant Mixing		
R2.2.59	**A rocket or engine static test stand that incorporates both a fuel and an oxidizer shall be designed such that a single malfunction of either the oxidizer or the fuel subsystems cannot result in the mixing of fuel and oxidizer.**	
2.2.3.4.1 Leakage		
R2.2.60	**Any separable fluid fitting is prone to leakage. Propellant systems shall be designed to ensure, as far as possible, that simultaneous leaks in fuel and oxidizer plumbing do not result in the propellants leaking to the same place and mixing.**	
2.2.3.4.1 Use of Check Valves		
R2.2.61	**Check valves shall not be used as flow restrictors, especially on high flow lines.**	
R2.2.62	**Check valves shall not be used as flame flashback arrestors.**	

R2.2.63	**Check valves shall not be used to seal the fill line after umbilical retraction unless the valve is inline with and actuatable through the connector.**	
R2.2.64	**Check valves shall not be placed downstream of a 90° elbow/bend.**	
R2.2.65	**Under no scenario shall a team use two check valves in a row.**	
	R2.2.66 and R2.2.67 are not applicable	
2.2.3.4.1 Valves		
R2.2.68	**Piloted valves shall abort in the depressurized state.**	
R2.2.69	**Control valves which provide the pressure to operate piloted valves shall depressurize the pilot line when the control valve is de-energized.**	
R2.2.70	**Dump and Vent Valves shall have a duty cycle 3 times the abort time or operational time whichever is more. Fill valves shall have a duty cycle 2 times the fill time or operational time whichever is more.**	
R2.2.71	**SRAD valves for use in a remotely operated system shall have a demonstrated probability of failure less than 5% over at least 20 tests using the same starting conditions, preparation and lubrication.**	Our servo actuated ball valves will undergo rigorous testing
	R2.2.72 and R2.2.73 are not applicable	
2.2.3.4.1 Nitrous Line Filters		
R2.2.74	**Nitrous line filters shall not be used in-line with any nitrous flow pathway between the mother/ supply bottle and the engine**	
R2.2.75 - R2.2.81 are not applicable		

A.1.2 Ignition

Table A.1.2: Launch Canada Compliance Requirements

No	Requirement	Notes (If required)
R2.3.1	**The action that arms the igniter shall be independent of the action that fires it.**	Labview, with a PLC, a mechanical relay, and a remote lock out will be used as an ignition system.
R2.3.2	**All ground-started propulsion system ignition circuits/sequences shall not be "armed" until all personnel**	

	are at least 15 m (50 ft) away from the launch vehicle.	
R2.3.3	**The engine igniter shall be both physically and electrically isolated from the power source by a minimum of two independent inhibits.**	
R2.3.4	**The engine igniter shall be electrically isolated by switches in both the power and return legs.**	
R2.3.5	**The igniter shall be locked out to prevent any sort of ignition event when personnel are in the vicinity, and this lockout shall short and ground the igniter leads.**	
R2.3.6	**If pyrotechnic or otherwise electromagnetic interference (EMI) sensitive igniters are employed, the igniter wiring shall be in a separate cable, which is twisted, shielded, double insulated, and independent of all other systems.**	
R2.3.7	**Protection of igniter wiring by use of physical barriers or by physical location of components shall be employed such that short circuits to other power systems are impossible, even assuming loose or broken wires.**	
2.3.3 Propellant Valve Interlock		
R2.3.8	**The system shall incorporate features that prevent the main propellant valve(s) from opening until confirmation of nominal igniter operation has been received**	A camera will watch for smoke, then upon visual confirmation we will open the MFV and MOV. A thermocouple will also be installed to verify it.
R2.3.9	**Systems that employ a fully automated open-loop start sequence that automatically opens the propellant valve(s) after firing the igniter, without any confirmation that the igniter is actually operating nominally, are deemed to be a safety hazard and shall not be used**	

A.1.3 Engine Controls & Function

Table A.1.3: Launch Canada Compliance Requirements

No	Requirement	Notes (If required)
R2.4.1	**The main pressurant valve open command shall be considered a hazardous command.**	
R2.4.2	**The main pressurant valve close command shall be considered a safety critical command.**	

R2.4.3	**The main pressurant valves shall be actuated remotely.**	
R2.4.4	**The main fuel and oxidizer propellant valve open command shall be considered a hazardous command.**	
R2.4.5	**The main fuel and oxidizer propellant valve close command shall be considered a safety critical command.**	
R2.4.6	**The main fuel and oxidizer propellant valves shall be actuated remotely**	
R2.4.7	**The fuel and oxidizer propellant tank vent valve open commands shall be considered a safety critical command.**	
R2.4.8	**The fuel and oxidizer propellant tank vent valves shall be actuated remotely**	
R2.4.9	**If vent valves are controlled by a computer-based system, they shall be operable independently of the computer, in case of a software, power or control system failure.**	
R2.4.10	**Not applicable**	
R2.4.11	**When the pad controller is in the “lock out” condition, the control point shall be capable of commanding safety critical commands (vent valves open for the pressurant and propellant tanks).**	
R2.4.12	**When the pad controller is in the “lock out” condition, the control point shall be capable of monitoring safety critical measurements (pressurant and propellant tank pressures and temperatures).**	
R2.4.13	**When the rocket or static test stand pressurant or propellant loading operations are in progress, the pressurant and propellant tank pressures and temperatures shall be continuously monitored at the control point.**	
R2.4.14	**When the rocket or static test stand pressurant or propellant tank pressures and temperatures are at unsafe levels, the control point shall:** **• Warn the pad personnel to immediately stop loading pressurant or propellants into the rocket or static firing test stand.** **• Warn the pad personnel to immediately evacuate the area around the rocket or static firing test stand.** **• Command the pressurant and propellant tank vent valves open to vent the tank to safe levels**	

R2.4.15	**The rocket or static test stand shall protect safety critical command, hazardous command, and safety critical measurement wiring and pneumatic controls from fire during a launch or static firing.**	

R2.4.20 - R2.4.23 are not applicable

A.1.4 Propulsion System Testing

Table A.1.4: Launch Canada Compliance Requirements

No	Requirement	Notes (If required)
R2.5.1	**Teams shall comply with all rules, regulations, and best practices imposed by the authorities at their chosen test location(s).**	
R2.5.2	**The following test shall be performed before firing a rocket engine:** **• Rocket Engine Combustion Chamber Test**	
R2.5.3	**The following tests shall be performed before each rocket or rocket engine test:** **• Function Verification Test** **• Leak Test**	
R2.5.4	**The following tests shall be performed as part of a rocket engine static firing:** **• Rocket Engine Test Stand Propellant Fill and Drain Test** **• Rocket Engine Test Stand Propellant Cold Flow Test** **• Rocket Engine Static Test Firing**	
	R2.5.5 is not applicable	
2.5.1 Combustion Chamber Pressure Testing		
R2.5.6	**SRAD and modified COTS propulsion system combustion chambers shall be designed and tested according to the SRAD pressure vessel requirements.**	
2.5.1 Leak Testing		
R2.5.7	**Leak testing shall be performed on fluid systems prior to operation, and any time a change to the system that could impact leak-tightness has occurred.**	
R2.5.8	**Air from a compressor shall not be used for leak testing an oxidizer system, as it is highly prone to contaminating the system with moisture or oil.**	

R2.5.9	**Leak testing shall be performed at pressures well below MEOP: typically, less than 150 psig, and not more than 25% of normal operating pressure.**	
R2.5.10	**Leaks shall be tested with soap solution, a leak detection fluid such as Swagelok "Snoop", or a suitable leak detector.**	
R2.5.11	**Leak testing shall be performed on all fitting and line joints, valve stems and flanges.**	
R2.5.12	**My leak detecting fluid used on an oxidizer system shall be compatible with the oxidizer to avoid a fire or explosion hazard in case the fluid leaks into the system, or the oxidizer leaks out.**	
2.5.3 Propellant Fill & Drain Test		
R2.5.13	**Rockets or rocket engine test stands employing SRAD or modified COTS propulsion systems using liquid propellant(s) shall successfully complete a propellant fill and drain test in their final configuration without any anomalies that would prevent test completion or compromise safety**	
R2.5.14	**Any anomalies encountered during a test shall be documented and provided to Launch Canada upon completion of the test.**	
R2.5.15	**If a proxy fluid is used, the system shall be disassembled, cleaned and dried as necessary to prevent contamination of the propellant.**	
R2.5.16	**Under no circumstances shall a hydrocarbon-containing test fluid be used in an oxidizer system.**	
R2.5.17	**A full fill and drain or full abort test shall be conducted after a ten-minute hold or a quoted maximum hold time which if less than 10 minutes will not be allowed to exceed 10 minutes.**	
2.5.4 COLD FLOW TESTING		
R2.5.18	**During development of a SRAD propulsion system employing one or more liquid propellants, cold flow testing shall be performed prior to progressing to hot-fire testing.**	
R2.5.19	**A cold flow test shall be performed on both rocket engine test stands and the rocket vehicles prior to first firing.**	

R2.5.20	**For cold flow tests performed without a thrust chamber, you shall ensure that the discharge does not present a hazard to personnel and equipment via the impact energy of the flow.**	
R2.5.21	**Cold flow tests shall provide the same pressure drop as the injector and combustion chamber and develop the same volumetric flowrate of the proxy fluid as would be expected with the real propellant.**	
R2.5.22	**If a cold flow test will involve release of propellants or test fluids to the environment, those fluids shall pose no hazard of environmental contamination.**	
R2.5.23	**If a fluid other than the propellant is used, the system shall be disassembled, cleaned and dried as necessary to prevent contamination of the propellant.**	
R2.5.24	**Under no circumstances shall a hydrocarbon-containing fluid be used in an oxidizer system**	
R2.5.25	**For any propulsion system where emptying a propellant tank by dumping a propellant through the combustion chamber is part of the abort procedure, or an option, the thrust generated by that action shall be determined**	
2.5.5 Static Hot-Fire Testing		
R2.5.26 is not applicable		
R2.5.27	**Prior to hot fire testing, the team shall submit their test stand design and procedures for a safety review per the Launch Canada Requirements for Static Test Firing Approval.**	
2.5.5 Engine Test Stands		
R2.5.28	**Final testing for all deliverables including cold flow, hot fire and abort testing shall be performed on the flight hardware with all systems available on the flight vehicle present.**	
R2.5.29	**If a test stand is used with liquid propellants, it shall employ materials that are tolerant of propellant spills and minimize the chance of a fire occurring or spreading.**	
R2.5.30	**The test stand shall be firmly anchored to the ground in such a way that it cannot move or slide under at least 2x the maximum load to which it will be exposed.**	
R2.5.31 - R11.2.5 are not applicable		

Appendix II: Proposed Site Layouts (Timmins)

Based on the prior parameters and limitations, MACH proposes two layouts that would be best suited for our testing at the Timmins site.

Case 1

In case 1, mission control is next to Space Concordia's MC. While using large barriers to shield MACH's MC, Pad Control, and Space Concordia's MC. Figure A2-1b shows an overview of the most preferable location based on satellite images. This is within the safe distance for overpressure while, in theory, not interfering with Space Concordia and vice versa.

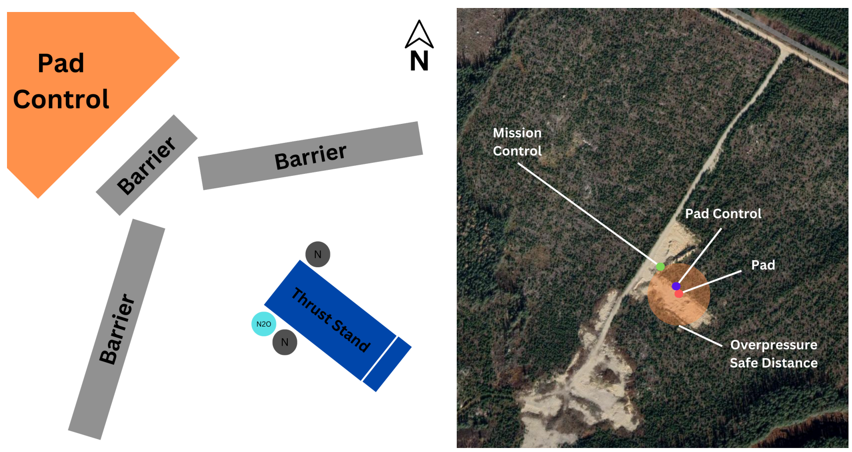

Figure A2-1: Case 1 Pad Layout a: Close-up. b: Proposed Location

Case 2

In case 2, large barriers are placed in such a manner that Space Concordia and MACH work alongside each other while offering protection for both teams' projects. The downside is that if one team goes on lock down the other team is forced off Pad. There is also the risk with case 2 that should a critical failure occur, then overpressure or debris shot straight up could cause damage to the other team's engine. The upside is less barriers and far more flexible pad placement where the side designated as the common area is always facing Space Concordia's MC. That being said, the location chosen matters significantly for MACH and should be placed in such a way that allows our MC to be straight behind the common area and clear of obstacles.

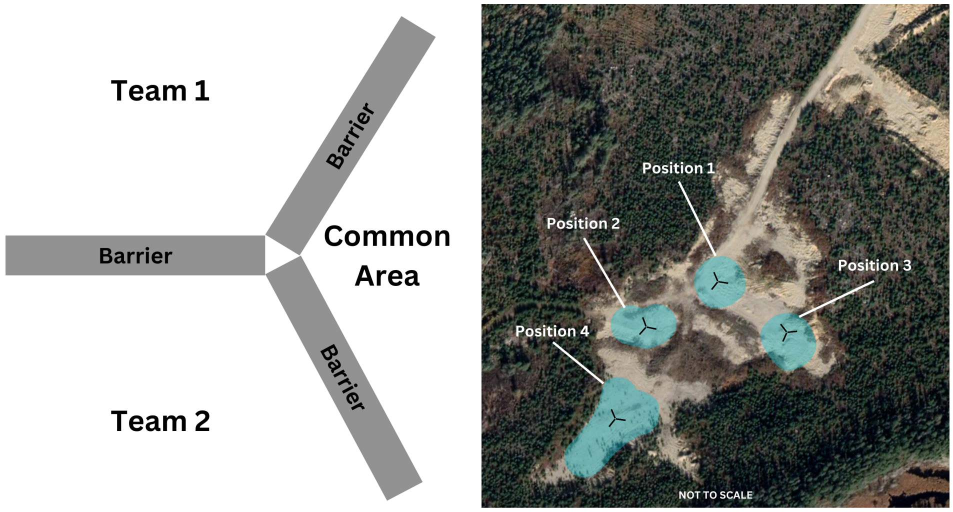

Figure A2-2: Case 2 Pad Layout a: Close-up. b: Proposed Locations

In conclusion, our team asks that Launch Canada adhere to specific requests for MACH's Site Design based on cable length limitations and Safe distances. The critical points of Mission Control, Pad Control, and Pad must be strategically placed within the specified distance limits. By implementing these requirements, we aim to create a safe and efficient site that fosters successful testing while prioritizing the safety of all team members and spectators.