RPL

ROCKET PROPULSION LABORATORY

Final Presentation

May 29th, 2020

Overview

The Concept Rocket

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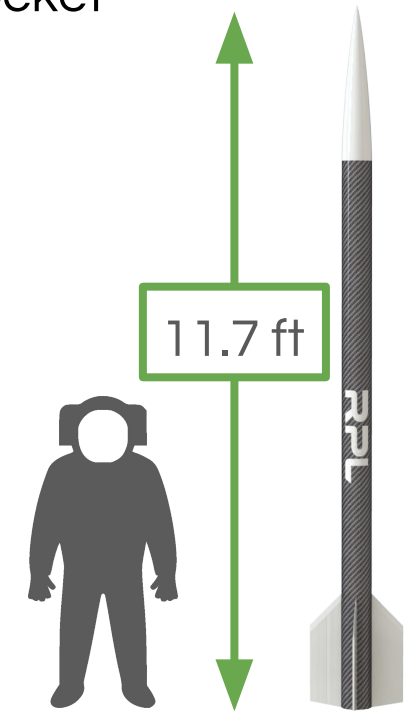
- Last year, RPL designed a concept rocket
  - Compete in FAR/Mars
  - Target apogee: 45,000 feet
  - Liquid oxygen/liquid methane

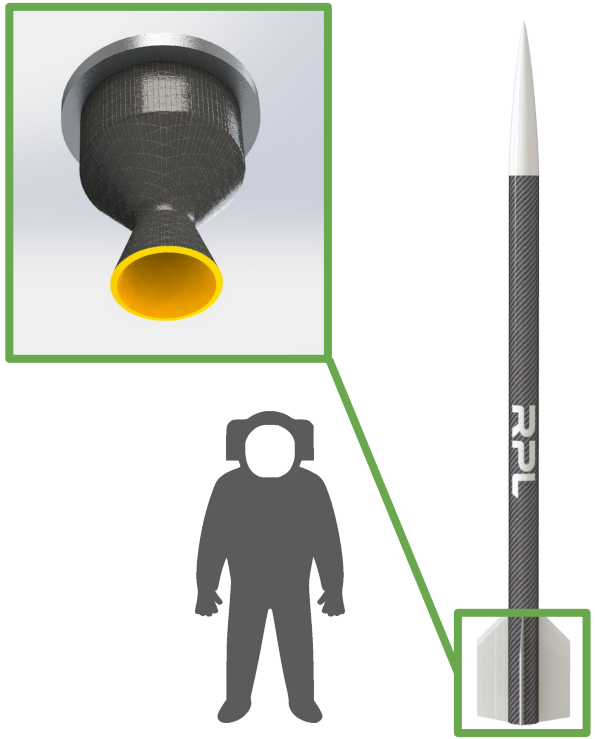
BABY COME BACK!!



The Concept Rocket

BCB's Engine

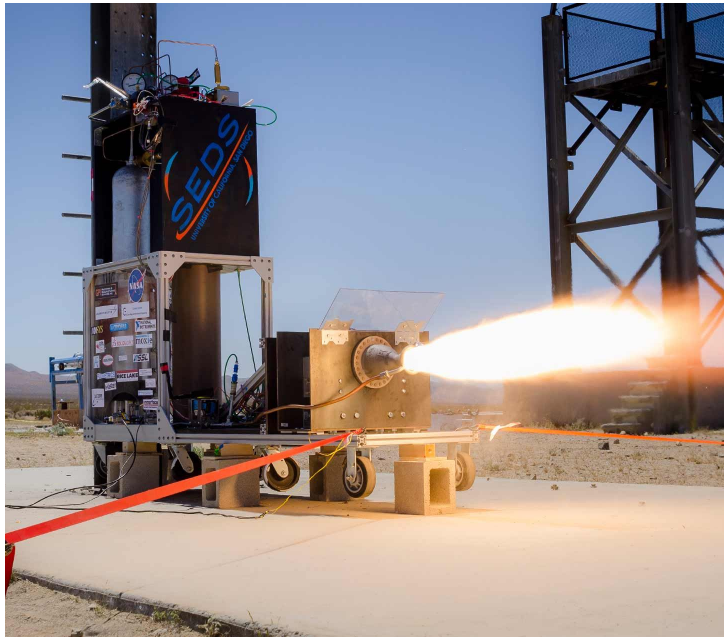
- Light, but not reusable
- Specifications
  - 350 psi
  - 700 lb thrust
- Projected apogee: 43,000 feet



REQUIRES TESTING!!

Static Fire Testing

- Run the rocket engine and propulsion system, but fixed to the ground
- Goals:
  - Make sure components work properly
  - Make sure system is up to specifications

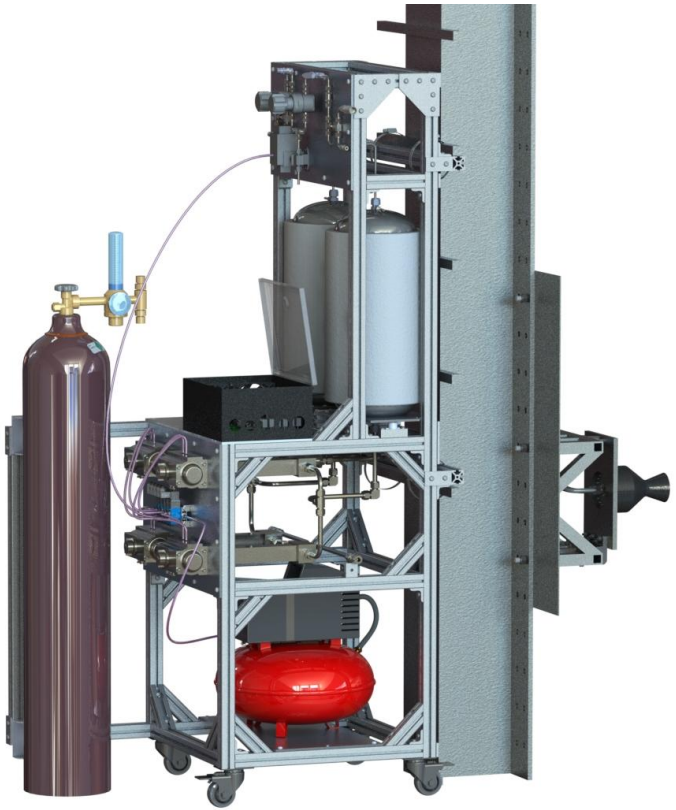


UCSD SEDS test rig in action at FAR

The Test Rig

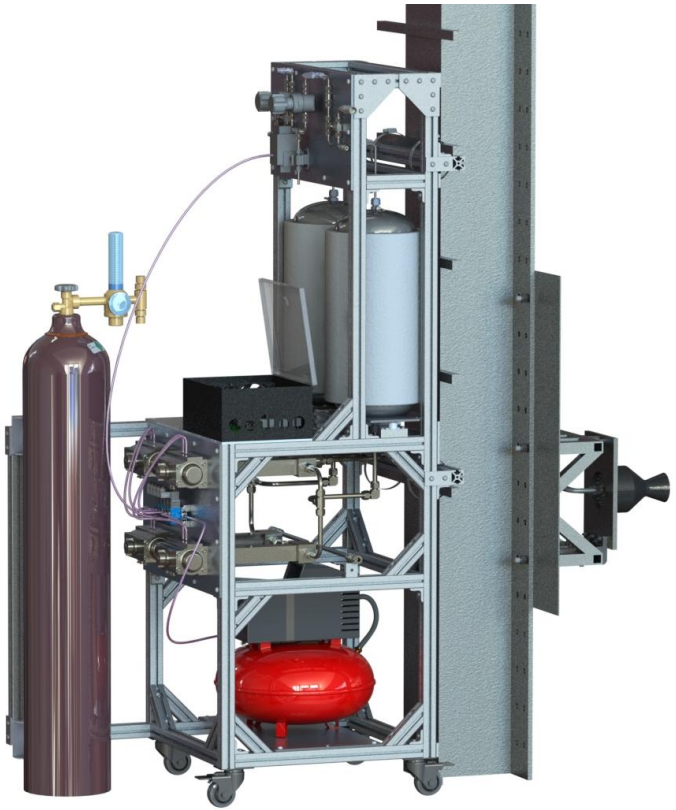
The Test Rig

- Engine fixed to load-bearing I-beam
- Propulsion system on 8020 frame
- Electronic system acquires data and provides an interface



Components

- Propulsion system
  - Engine and Injector
  - Feed system
- Structure
  - Weldment
  - 8020 frame
- Electronics
  - Sensors and actuation
  - Control box and GUI

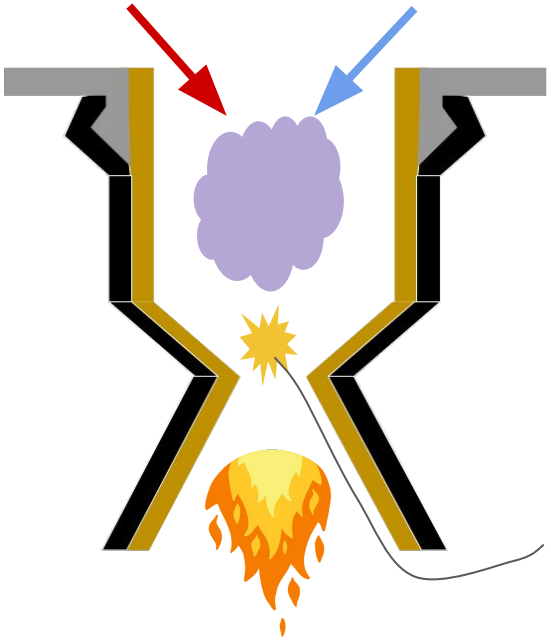


Propulsion

Engine

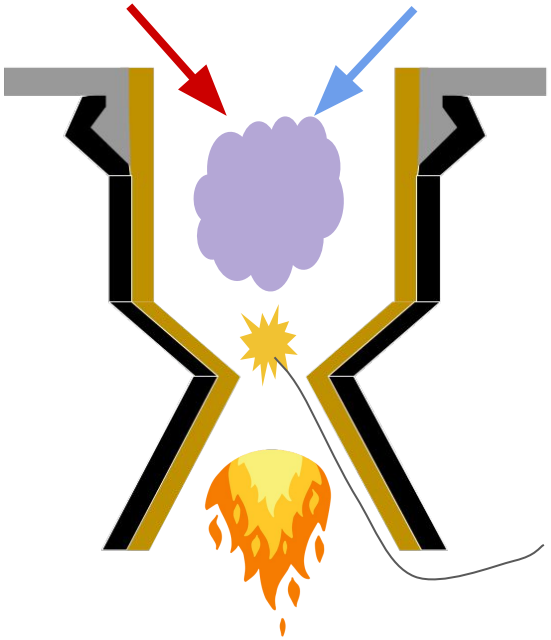
How It Works

- Fuel and oxidizer enters combustion chamber
- Combusts in presence of ignition source
- High velocity expansion through throat
- Mach 1 at throat gives faster expansion → higher thrust



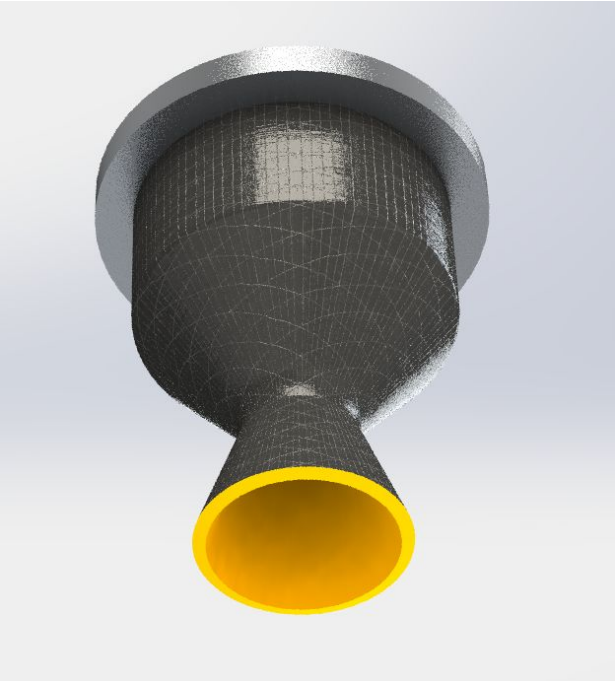
Design Specifications

- Thrust: 700 lb
- Chamber pressure: 350 psi
- Mass flow rate: 2.7 lbm/s
- Duration: 12.5 s
- Length: 7 in
- Diameter: 4 in



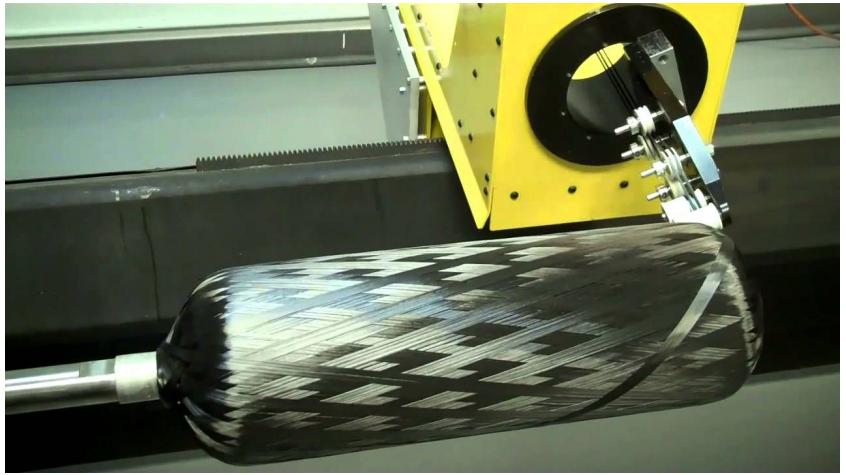
Our Engine

- Silica phenolic ablative
- Carbon fiber overwrap
- Steel flange attaches to injector and test rig
- Manufactured by Compositex



Manufacturing

- Machine flange at UCSB and send to Compositex
- Wind overwrap onto mandrel and around flange
- Layer ablative material inside engine
- Ship to UCSB and test at FAR!

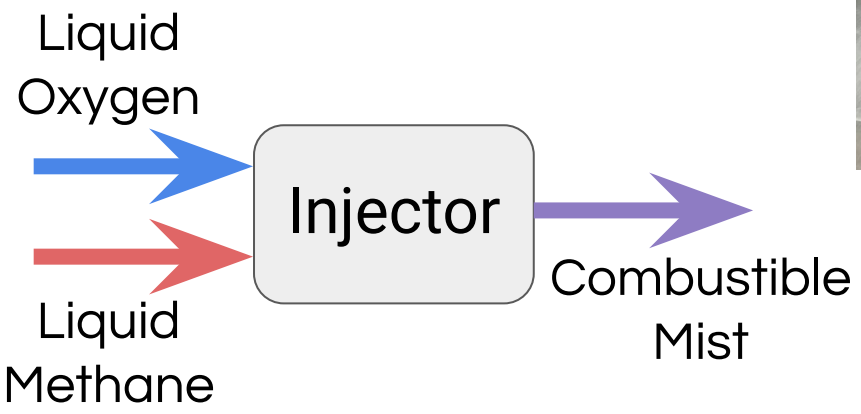


Filament winding of a pressure vessel by TCR Composites

Injector

Injector Overview

- Mixes propellants in engine
- Provides appropriate flow rates to engine



Christopher Nilsen - Purdue University's Maurice J. Zucrow Laboratories

Injector Design

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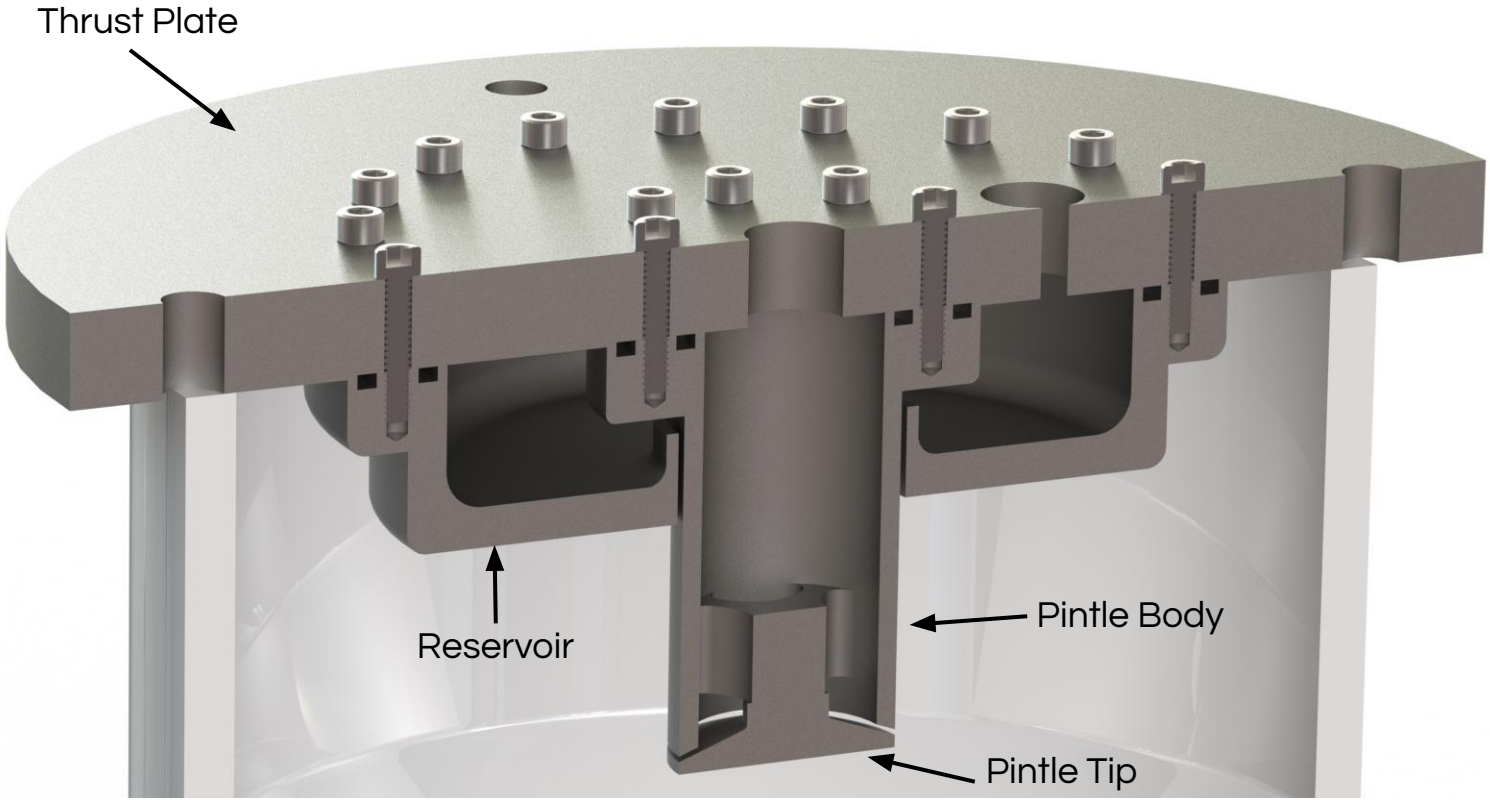
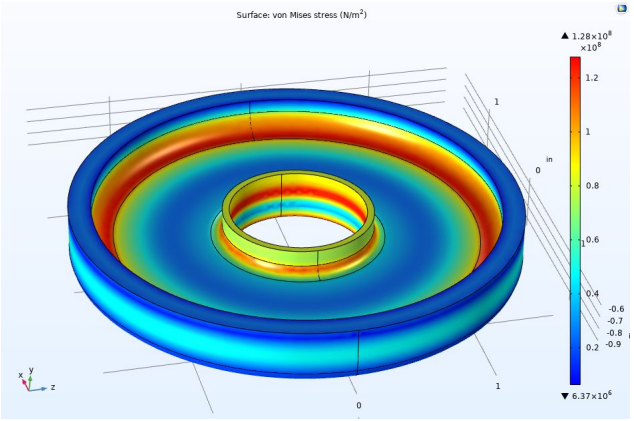
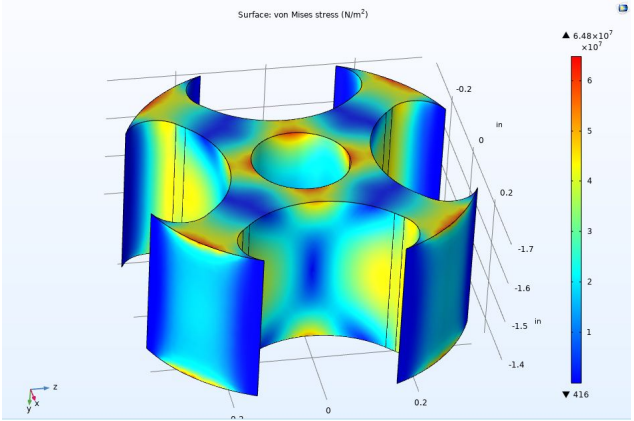
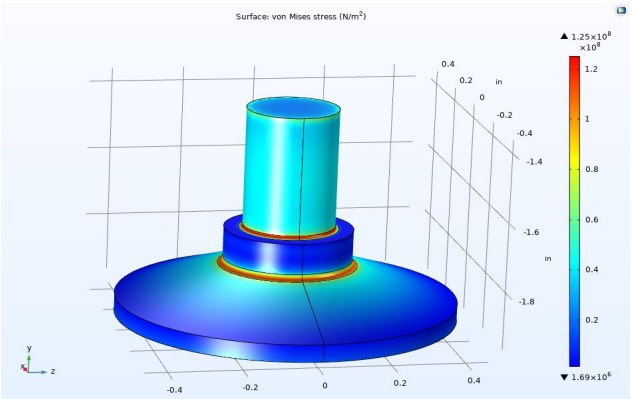
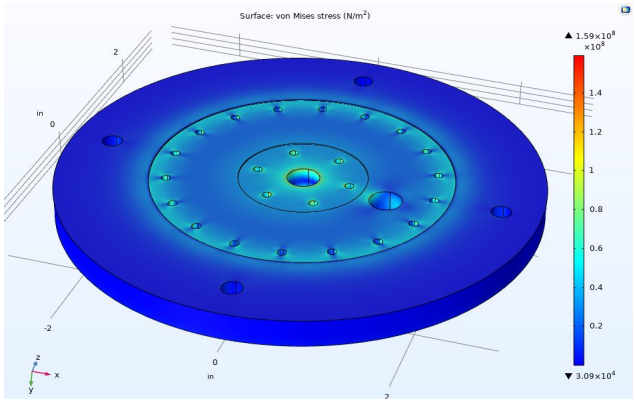


Injector Stresses









Overview

The Test Rig

<u>Propulsion</u>

Structure

Electronics

Sequencing

Next Steps

Injector Flow

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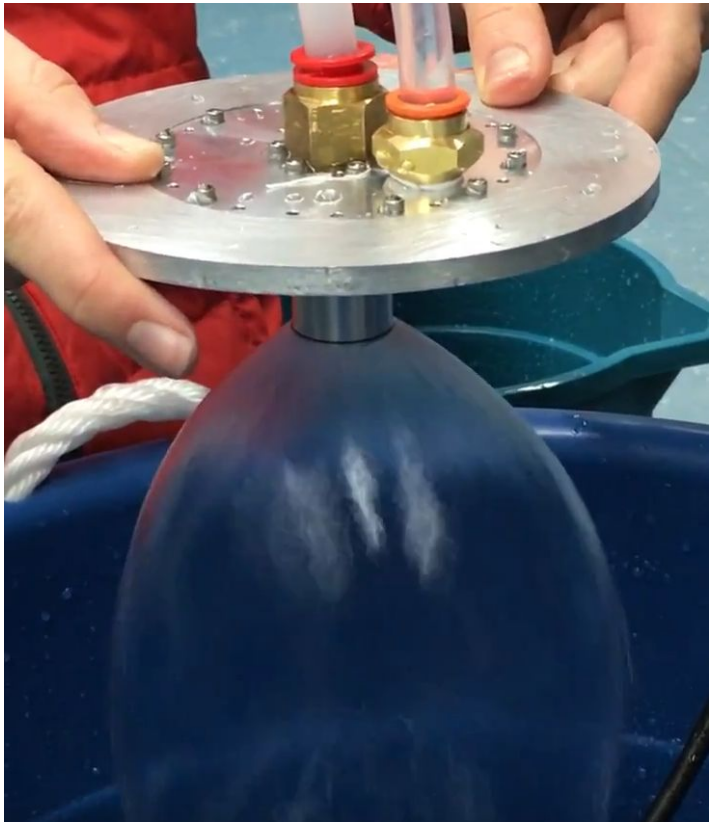
Fluid Dynamics
- Oxygen/Methane Gaps

Water flow test
- Confirm calculations
- Proved manufacturability



Feed System

Feed System Requirements

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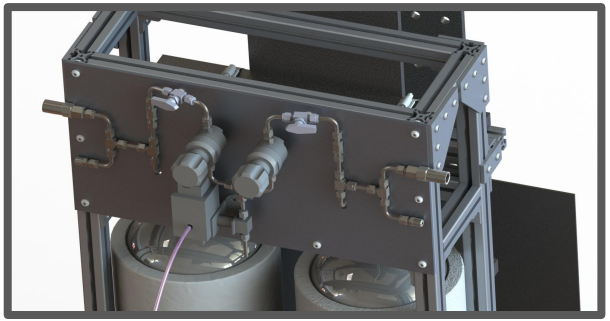
Main Requirements:

- Store Propellants Safely
- Provide flow towards Injector
- React to system failures

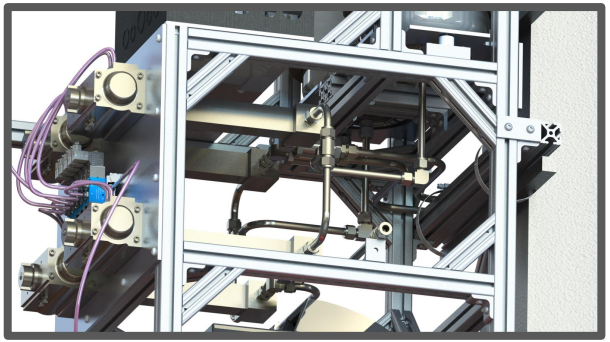
Main Components:

- Tanks
- Plumbing
- Valves
- Fittings

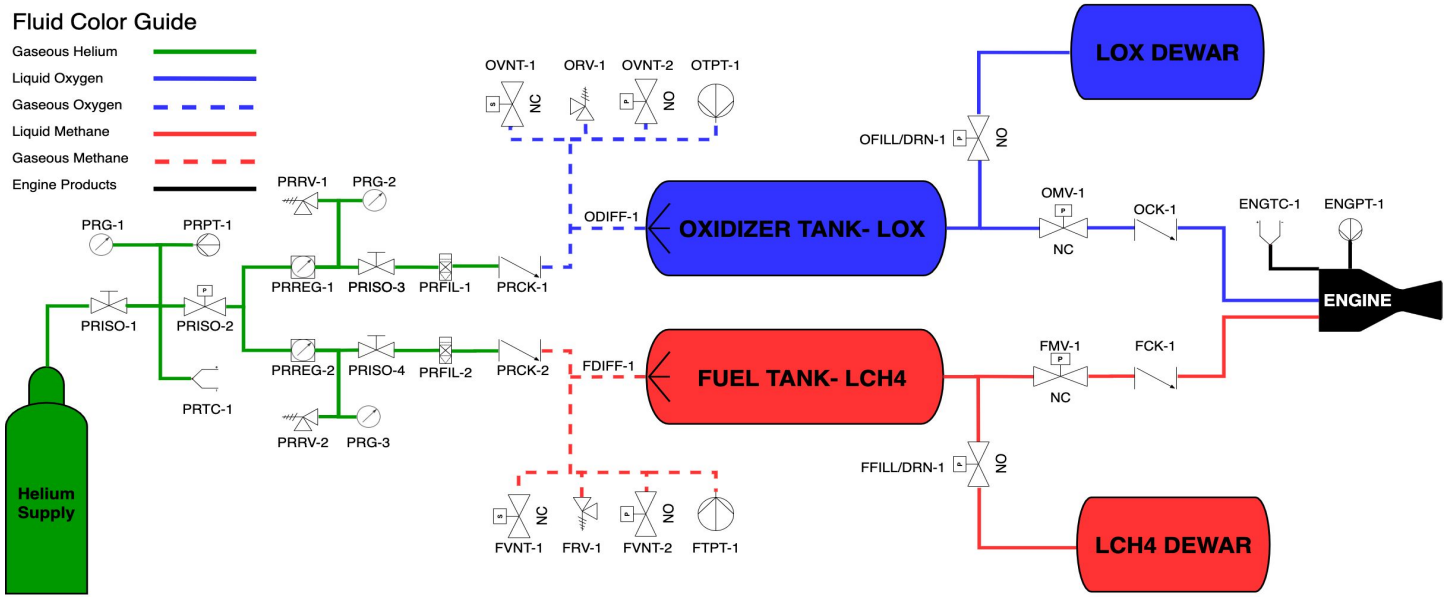
Top Plumbing



Bottom Plumbing



Piping & Instrumentation Diagram



KEY XXXXX-1

Propellant Designator:
PR: Pressurant
O: Oxidizer
F: Fuel

Function Designator:
CK: Check Valve
DIFF: Diffuser
FIL: Filter
FILL/DRN: Fill Drain Valve
G: Gauge
ISO: Isolation Valve

Function Designator:
MV: Main Valve
PT: Pressure Transducer
REG: Regulator
RV: Relief Valve
TC: Thermocouple
VNT: Vent

Numeric Designator

Valve Designator:
P: Pneumatic Actuator
S: Solenoid

Tank Pressures

Requirement/Spec	Imperial	SI
Injector Inlet Pressure	420 psi	2.9 MPa
Mass Flow Rate	0.084 slug/s	1.22 kg/s
Mixture Ratio	2.8	2.8
Oxygen Flow Rate	12.4 gpm	0.78 L/s
Methane Flow Rate	11.9 gpm	0.75 L/s
Oxygen Tank Pressure	540 ± 15 psi	3.7 ± 0.1 MPa
		3.2 ± 0.1

Tank Design

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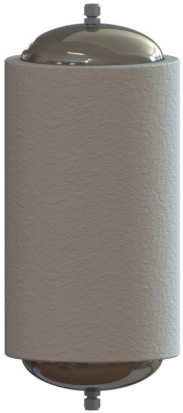
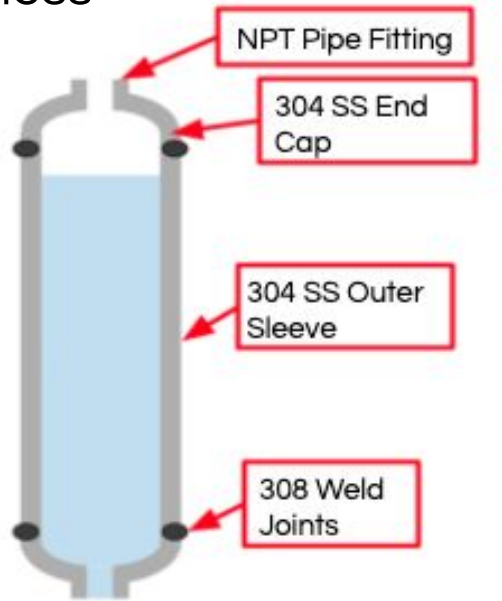
Dimensions

- Body: NPS Size 8 Sch 40 Pipe Seamless
- End Caps: 8.625” OD, 5/16” Thickness
- Material: 304 SS
- Weld: 308 Weld Joints





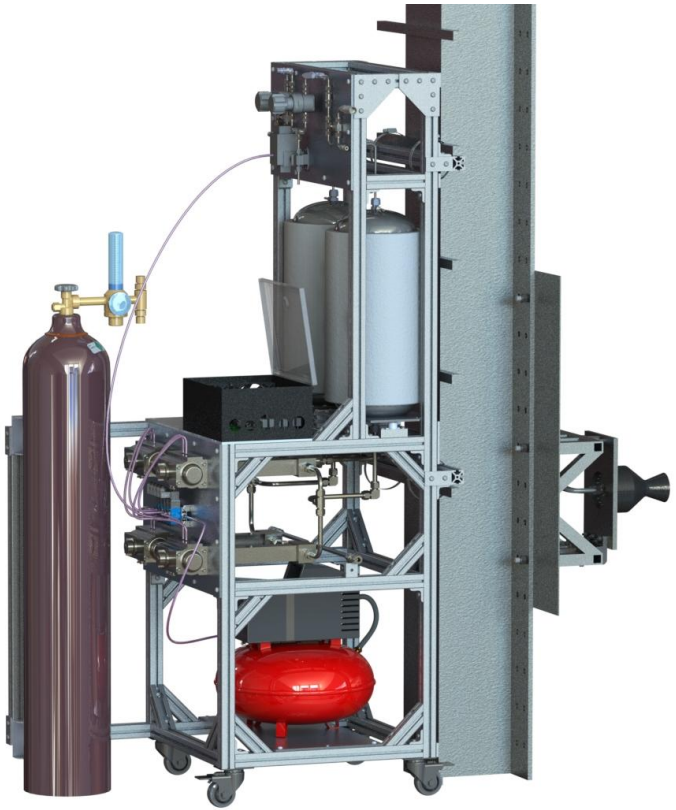
Critical Components

- Ball Valves
- Pneumatic Actuators
- Relief Valves
- Check Valves
- Pressure Regulators

Structure

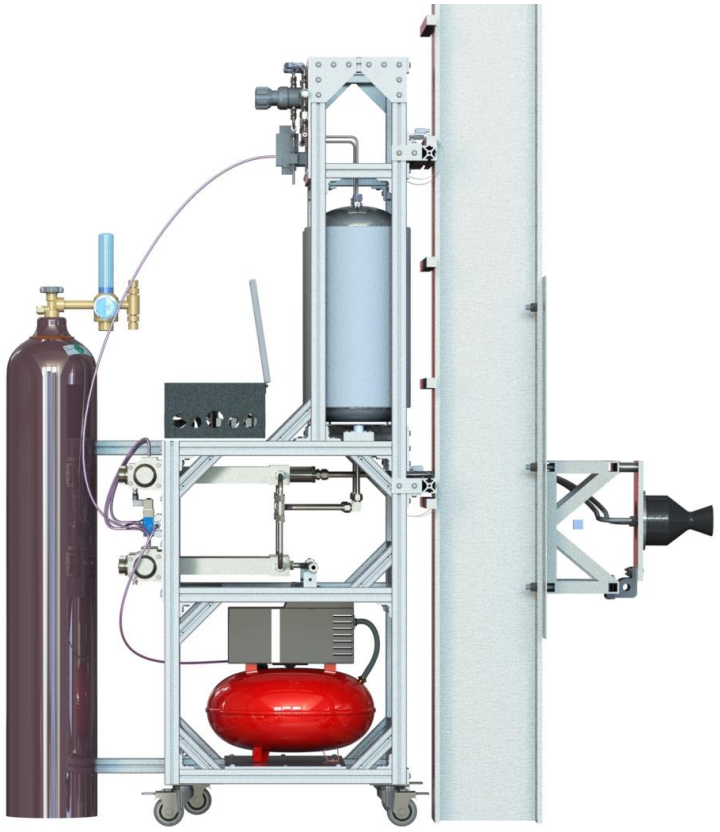
Design Specifications

- Secure to I-beam
- Withstand 1000 lbf thrust
- Measure engine thrust
- Shield rig from explosion
- Easy access to components
- Easy to transport



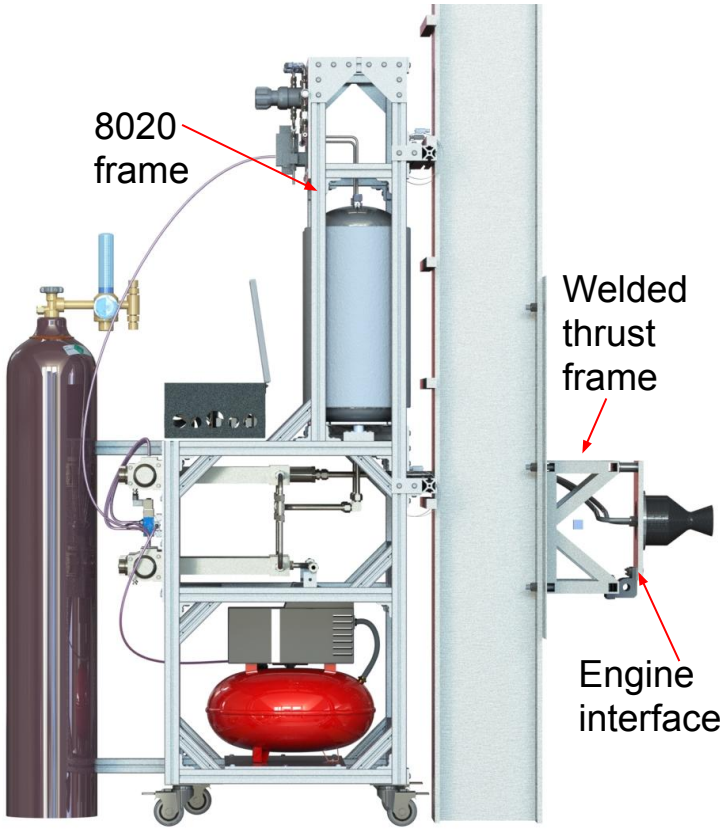
General Layout

- Tanks and engine mount on opposite sides of the I-beam
  - Ensures tanks not close to engine
  - Allows both tanks and engine to mount to I-beam



Main Components

- 8020 frame
  - Mounts tanks and feed system
- Welded thrust frame
  - Secures the engine-injector assembly to the I-beam
- Engine Interface
  - Attaches engine and injector to the welded frame



8020 Frame

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- Easy to assemble
- Easy to mount and access components
- Easy to transport
  - Caster wheels
- Sufficiently strong

8020 Frame

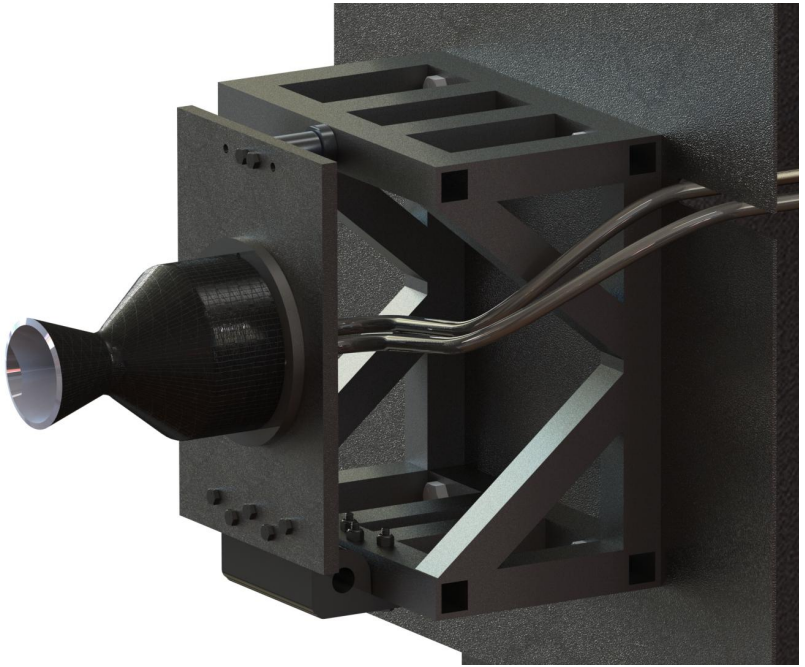
- 1.5 inch square cross section rails
- Corner braces support bending moments
- Attach to rungs on I-beam using hose clamps

8020 Frame

- Mount components on ¼ inch thick aluminum plates
  - Sufficiently strong to support weight of components
  - Lowest safety factor is 7.2 for tank mounting plates

Welded Thrust Frame

- Use rectangular low-carbon steel tubes
- Welded so can withstand engine vibrations
- Bolted to I-beam using locknuts

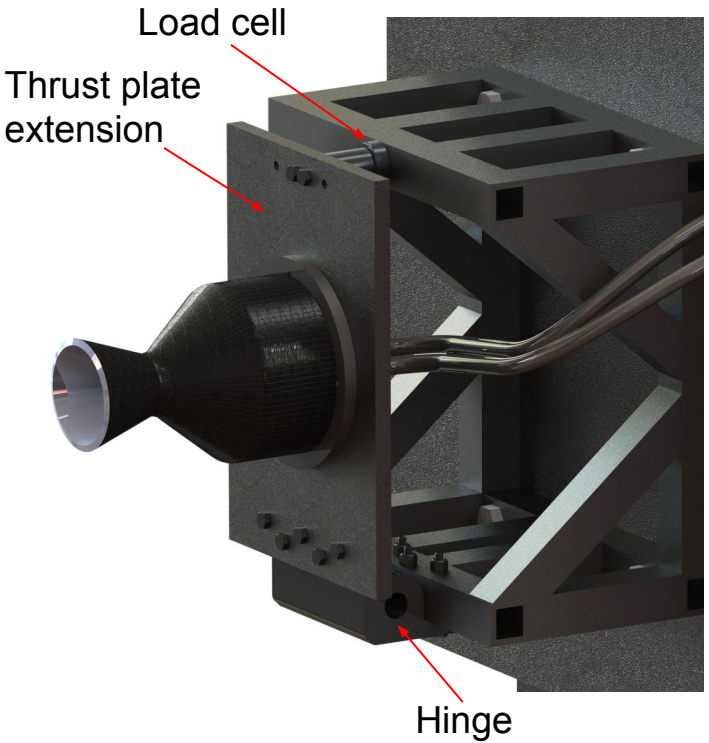


Welded Thrust Frame

- Horizontal tubes behind hinge and load cell take compressive load
- Diagonal members support bending moments
- Safety factors sufficiently large
- Blast plate between weldment and I-beam

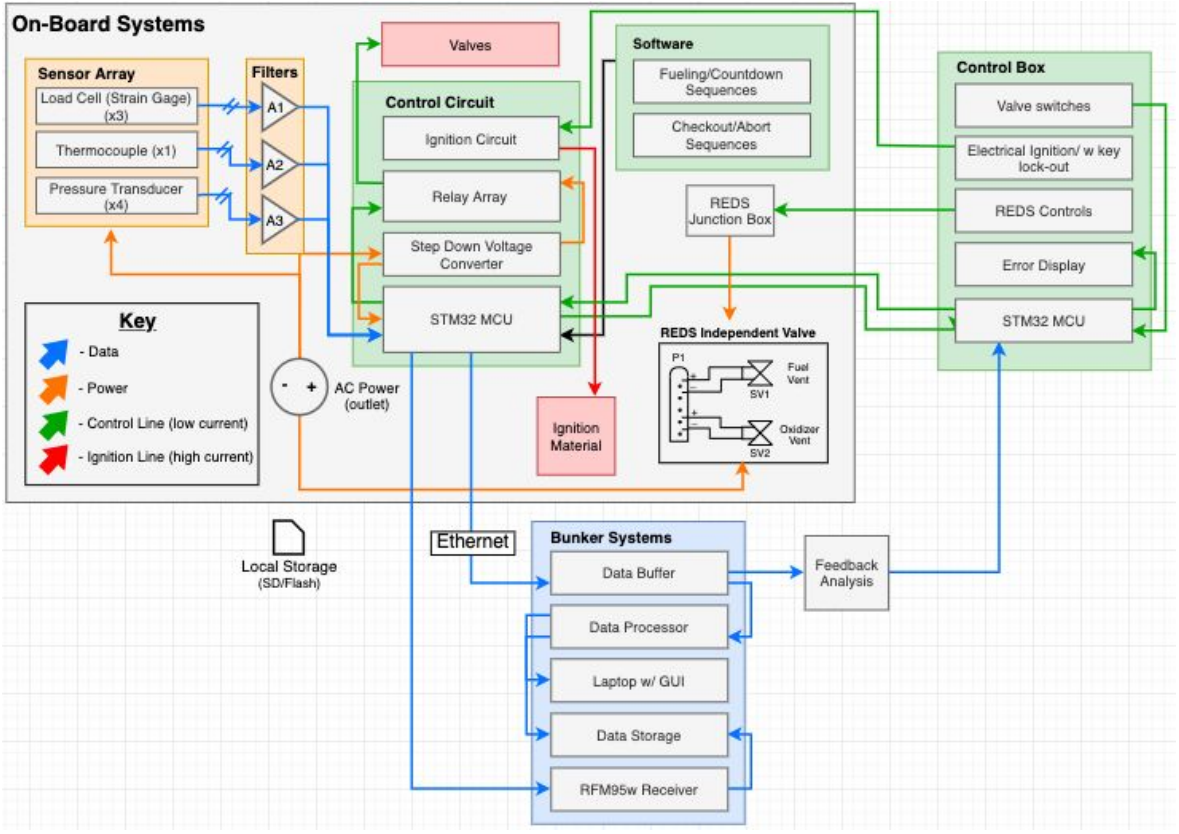
Engine Interface

- Thrust plate extension
  - Connects the hinge to the thrust plate
- Hinge
  - Connects thrust plate extension to weldment
- Load cell
  - Measures engine's thrust vs. time



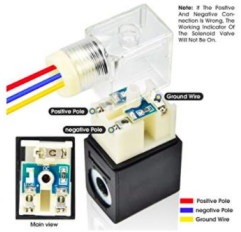
Electronics

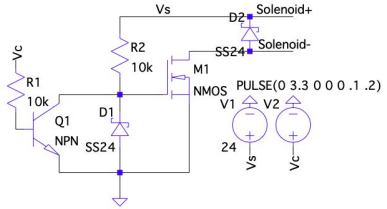
System Overview

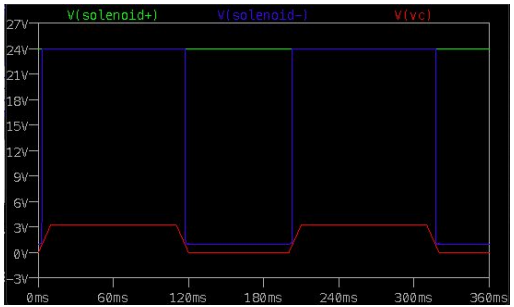


Controls

- 6 valves → electric solenoids
  - Normally open in case of power loss
- Transistor switching circuit
  - Key circuit elements:
    - High power transistors
    - Flyback diodes
    - Feedback using limit switches
- SSR (solid state relay) array
- Control signal from STM
  - Fueling, ignition, abort

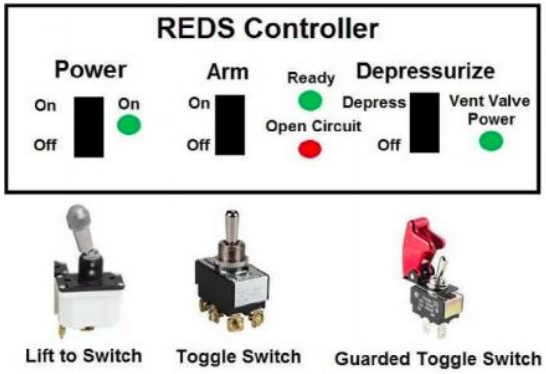


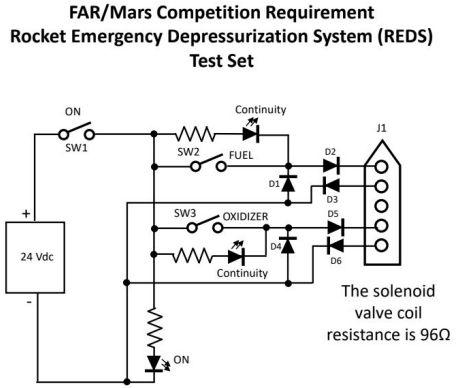


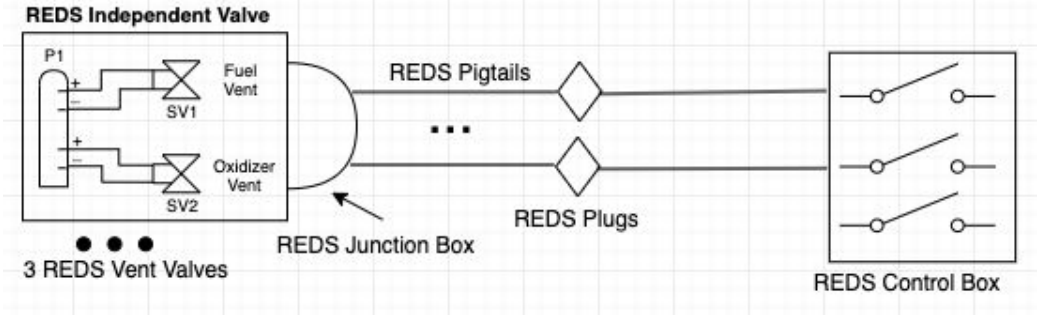


REDS

- REDS - Rocket Emergency Depressurization System

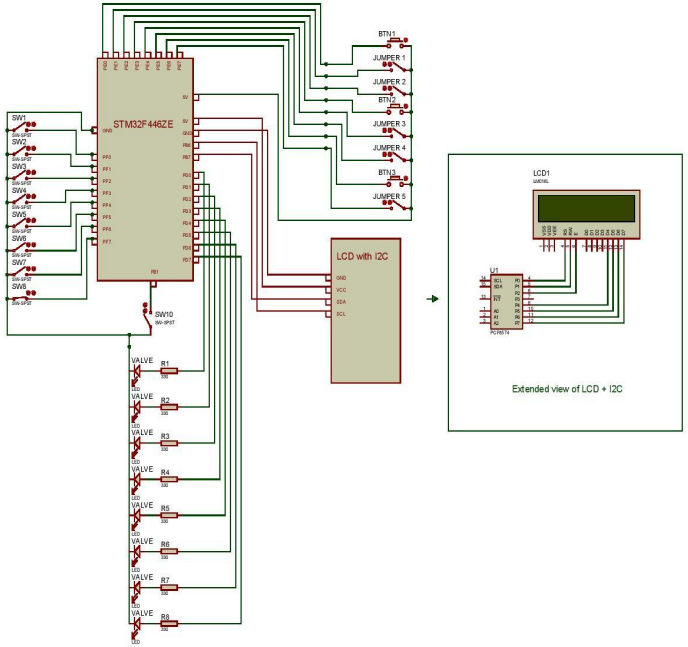






Control Box

- STM32F446ZE module
- 8 flip switches control 3 subsystems
- LCD with built-in I2C displays status and error messages
- Kill switch terminates all process when flipped



Control Box

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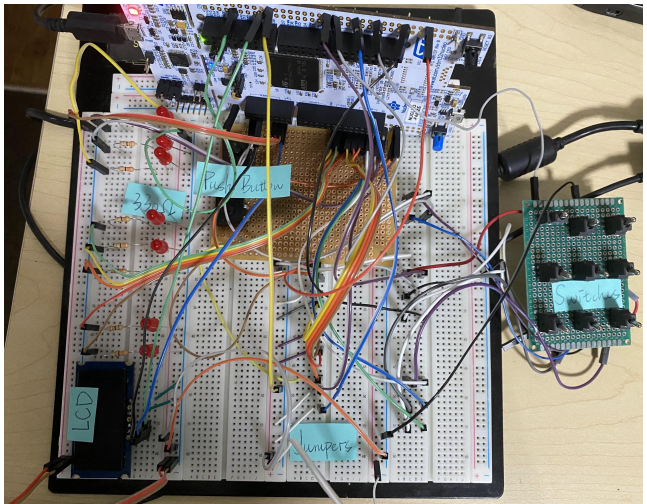
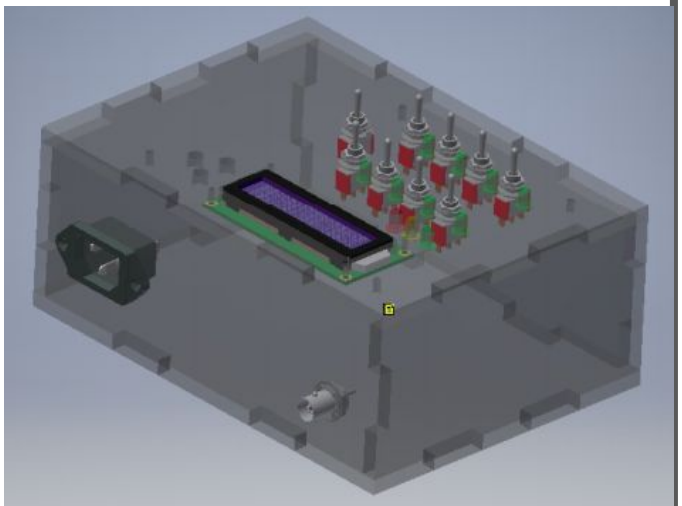
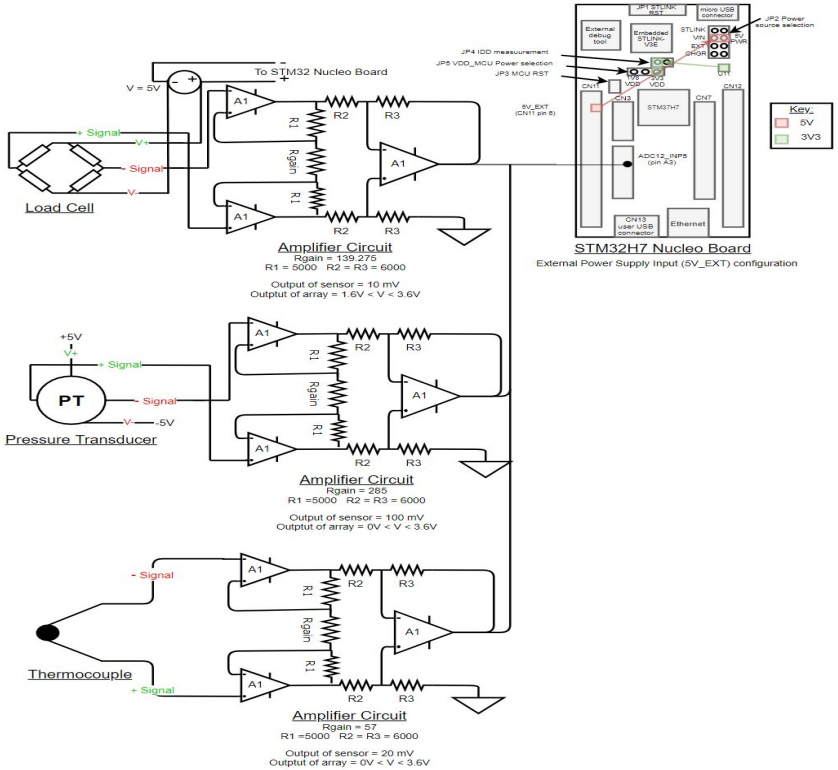
- Built to showcase the control box functionality
- Used Jumpers and pushbuttons with boolean logic to emulate real-life situations





Sensors

- Need to handle ranges given off by engine
- Analog sensors
- ADC on STM
- Instrumentation amplifiers

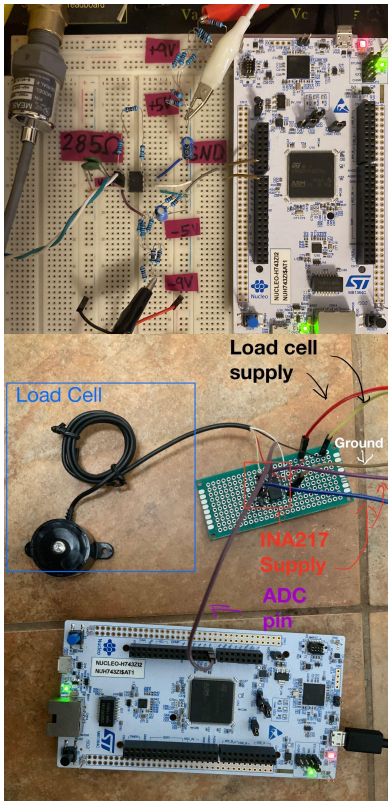


Sensors

- Data is represented graphically and recorded to .txt file
  - Data must be recorded to report to FAR
- Ethernet communication
  - Long distance
- Bunker computer reads incoming data to update GUI

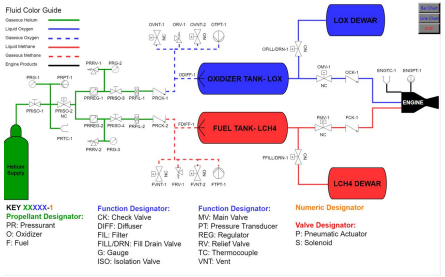
Pressure Transducer

Load Cell

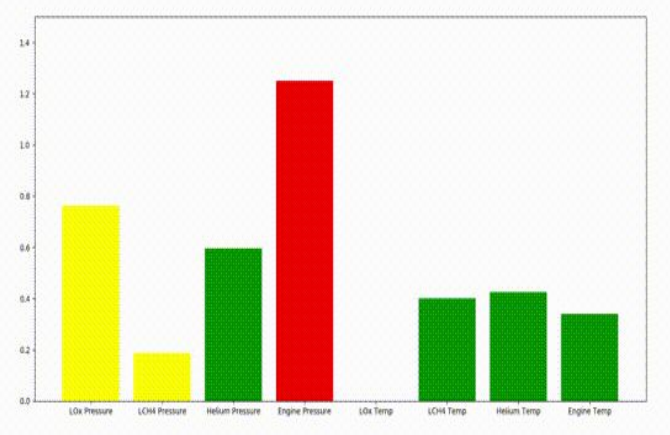


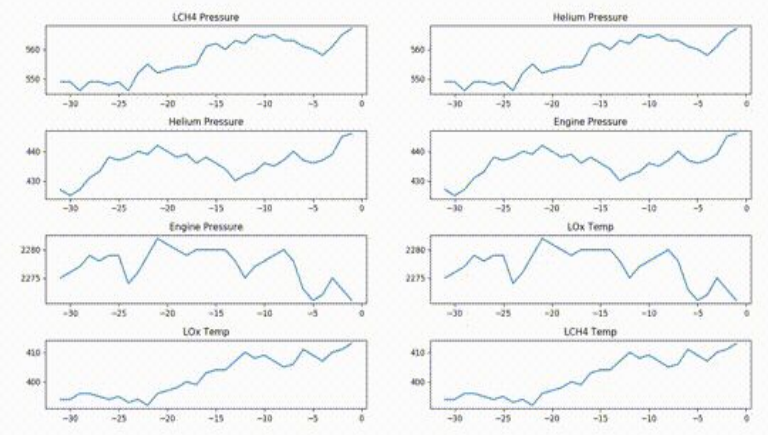
Graphic User Interface

- Main computer is connected to the rocket through ethernet. Data is transferred by TCP/IP and stored on the computer.
- GUI sets the ip address and tests connection before data transfer starts.
- GUI reads the latest recorded data from text file and updates diagram on screen.



Graphic User Interface





Sequencing

Sequencing

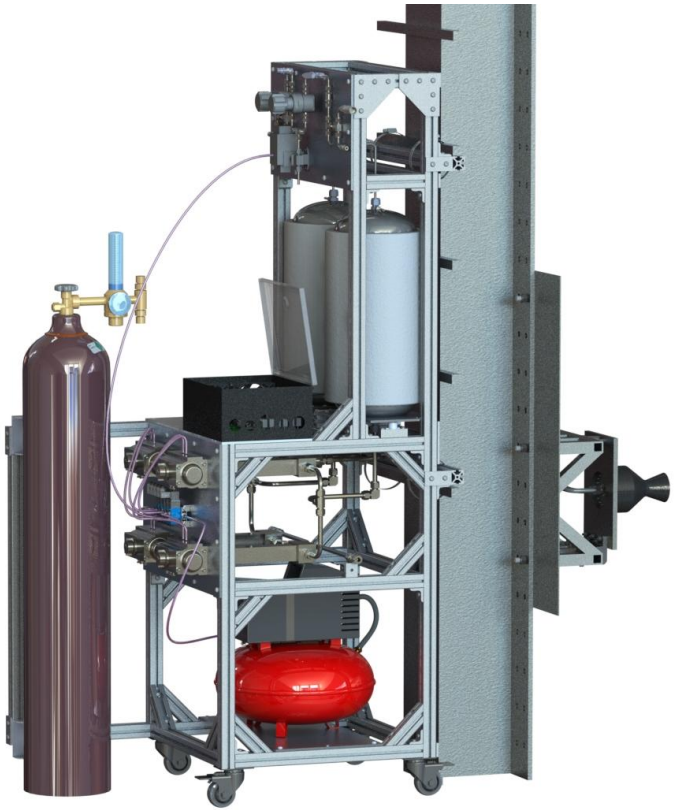
The sequence of fire consists of several stages:

1. Chill
2. Fill
3. Pressurize
4. Fire

Detailed SOPs are being produced for all stages from assembly to disassembly.

Testing Capabilities

- Component tests
  - Valve actuation
  - Tank boil-off
- Subsystem tests
  - Pressurization
  - Leak tests
- Large scale tests
  - Water flow test
  - Liquid nitrogen test
  - Static fire test



Next Steps

COVID-19

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- While work is still remote:
  - Finish SOPs
  - New Members
  - Prototyping/Assem
  - Design Packet
- In the future:
  - Resume fab and testing
  - Finish assembly
  - Run the test!

Sponsors

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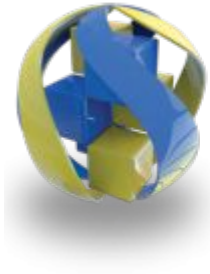
Raytheon



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Dr. Greg Dahlen

Capstone Professors

ME Technical Staff

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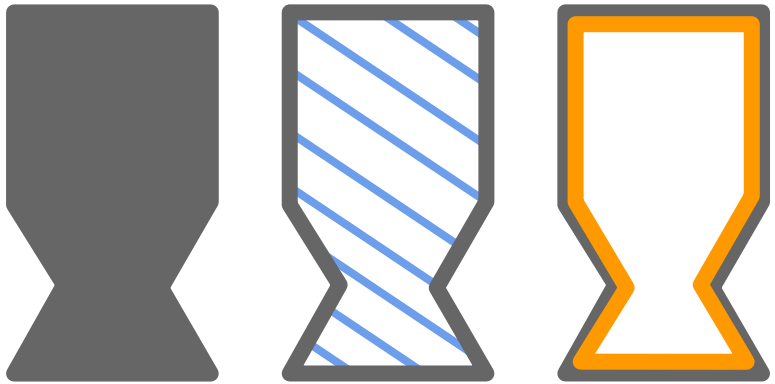
Thank you!

Backup Slides

Engine Cooling

- Rocket engines must be cooled by some means
  - Large thermal mass
  - Regenerative cooling
  - Ablative cooling



Safety/Hazards

ROCKET PROPULSION LABORATORY

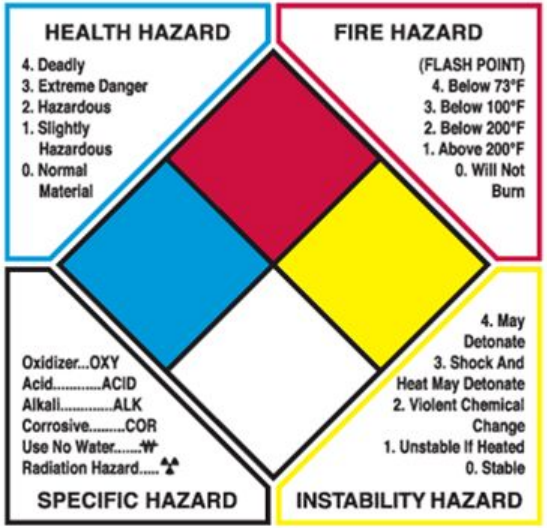
High Pressure System

- Expected: 150->2200 psi
- Ruptures, component failure, shrapnel

Cryogenics (LOx, LCH4,LN2)

- Burns/Frostbite/Expanding Vapor

Flammables (CH4 gas)



Safety/Hazards

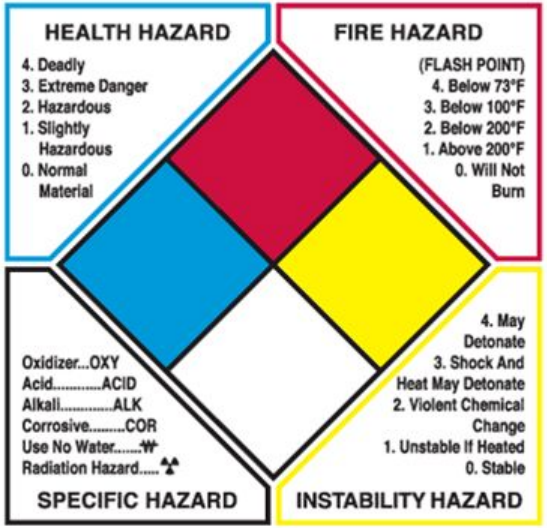
Oxidizers (LOx)

Pyrotechnics (Ignitor)

Electrical System (Shocks and Power)

Asphyxiants (Helium, Nitrogen)

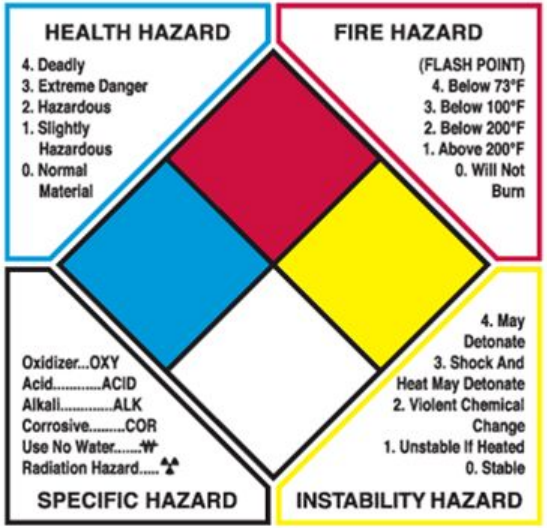
- Oxygen deprivation



Safety/Hazards

Personal Protective Equipment

- Safety Goggles
- Face Shield (Cryogenics)
- Leather/cryo-compatible boots
- Splashproof, cryo-rated lab coat
- Full length pants/long sleeve shirt
  - Non-flammable material
- Closed toed shoes
- Gloves (cryo-rated)
- Ear protection
- Common Sense



Tank Factors of Safety

- Equations: $\sigma_\theta = \frac{pr}{t}$ $K_I = \alpha\sigma\sqrt{\pi a}$

Liquid Oxygen (-183°C) 540 psi		
Failure Criterion	Room Temp	Cryogenic Temp
Yield	4.1	7.6
Tensile Failure	10.4	29.2
LBB	21.0	29.1

Liquid Methane (-162°C) 460 psi		
Failure Criterion	Room Temp	Cryogenic Temp
Yield	4.9	9.1
Tensile Failure	12.4	34.9
LBB	25.1	34.7

Feed System Components

- Include back up slide for each critical component
- Specs and stuff

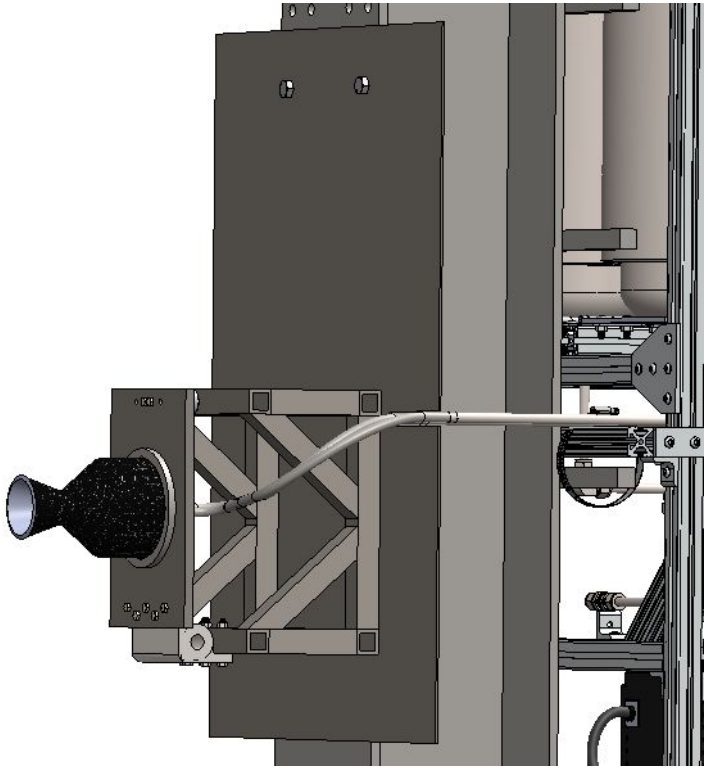
8020 Frame

ROCKET PROPULSION LABORATORY

- Fastened using 8020 brackets and 5/16 inch screws
- Separate plumbing components before and after the tanks
  - Top plumbing before tanks is at high pressure and ambient temperature
  - Bottom plumbing after tanks is at lower pressure and cryogenic temperature

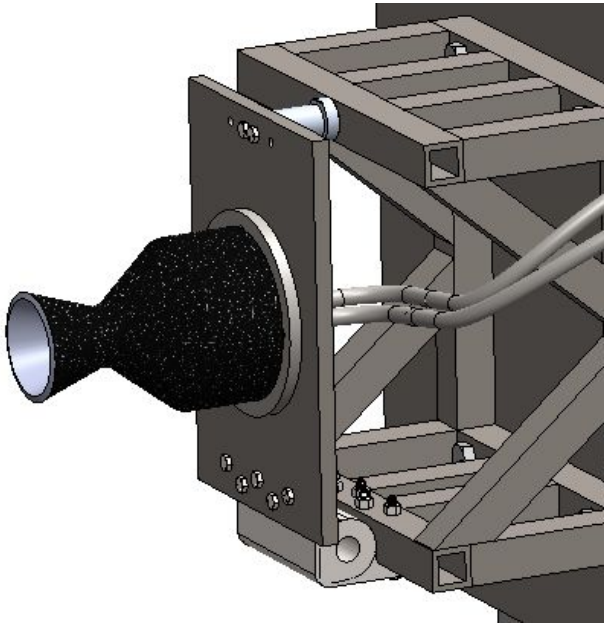
Welded Thrust Frame

- Will proof test the welded frame in Kirk Field's Mechanical Test Lab to 1000lbf
  - Confirm strength of welds and frame design
- 2ft by 3ft steel blast plate bolted between the weldment and I-beam to protect feed system from a potential explosion



Thrust Plate Extension

- ½ inch thick low-carbon steel
- Safety factor of 4.5 for local yield at the thrust plate mounting holes due to bending stress from engine's thrust
    - Safety factor of 5.6 for net section yield
- Tie top to welded frame using wires through the 2 holes on the top of the plate to prevent it from tilting before and after the fire

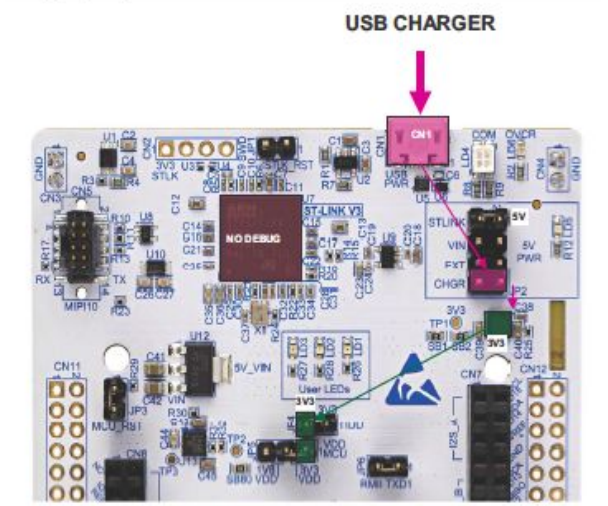


Hinge

- Restricts motion of engine so load cell can measure thrust
- Rated to 1,000 lb
  - SF = 2.9
- Place at bottom so can tilt engine downward during chill down to protect it from the cryogenic temperatures

Power Systems

- System will run on 120 V AC (power outlet)
  → 120V AC to 24V DC
  → 5V DC from STM
- External grounding rod
  - Prevent ESD buildup



Power supply input from ST-LINK USB connector with USB charger (5 V)

Electronics Housing

- Aluminum enclosure with:
  - PC fan
  - Heat sink
  - Thermaflect tape