Critical Design Review:
Hybrid Experimental Engine-1 (HX-1)

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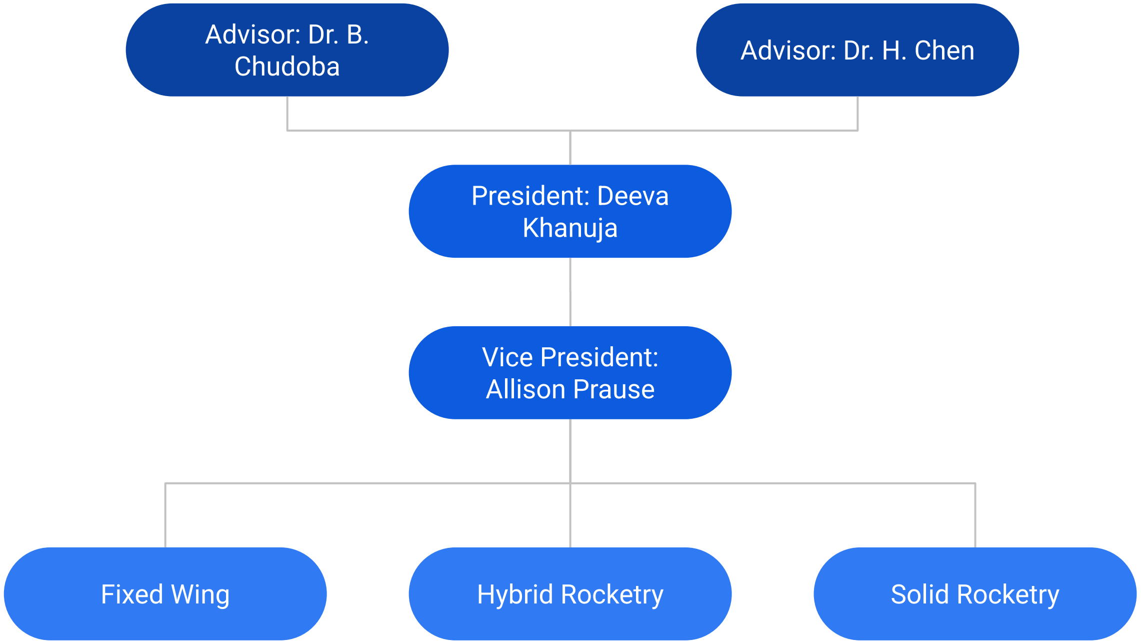
AeroMavs Organizational Structure



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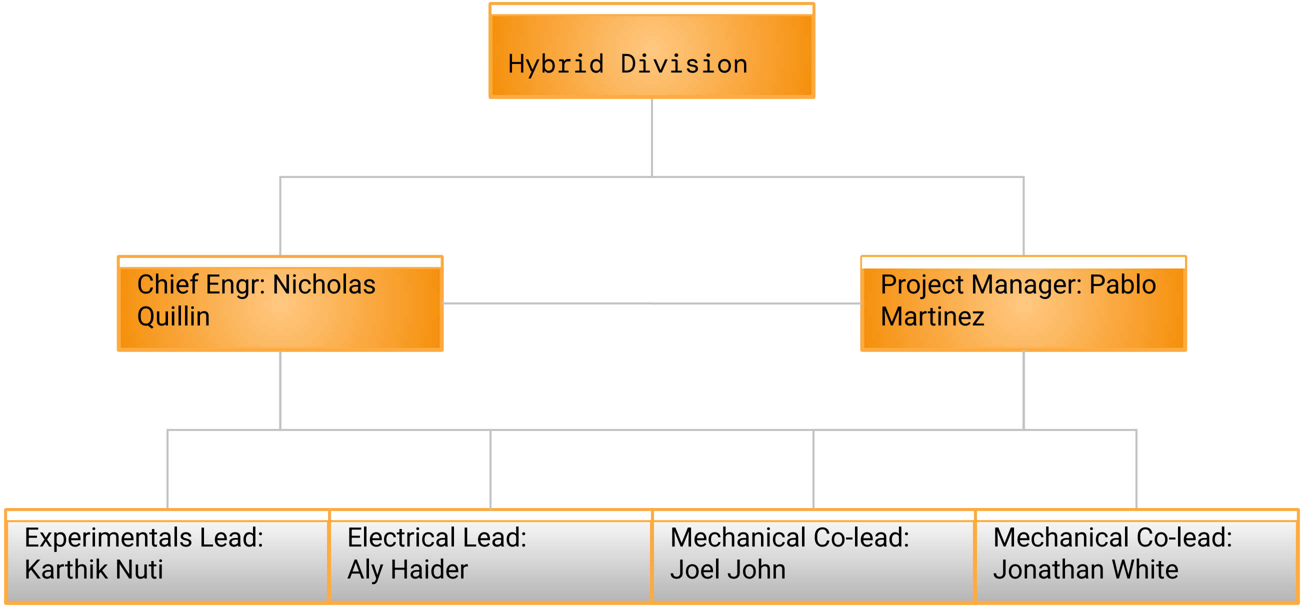
Hybrid Division Structure



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HYBRID TEAM INVOLVED

Advisors

Dr. Bernd Chudoba
ADVISOR

Dr. Hongru Chen
ADVISOR

Email: Chudoba@uta.edu

Email: Hongru.chen@uta.edu

Leadership Involved

Deeva Khanuja
President

Allison Prause
Vice President

Nicholas Quillin
Hybrid Rocketry Chief Engineer

Pablo Martinez
Hybrid Rocketry Project Manager

Leads

Karthik Nuti
Experimentals

Aly Haider
Electrical

Joel John
Mechanical

Jonathan White
Mechanical

Email: aeromavs@gmail.com

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Mission Overview

11.25	12.25	1.26	2.26	3.26	4.26	5.26

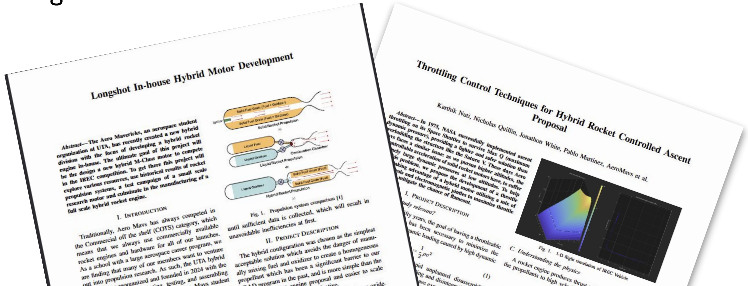
HX-1 → HX-2 → HX-3 → PROJECT LONG SHOT → Upcoming Missions

Demonstrator
- Build Experience and protocol
- Collect preliminary performance data

Technology Testbed
- 3D reinforced propellants
- Throttling

High Fidelity Engine Modelling

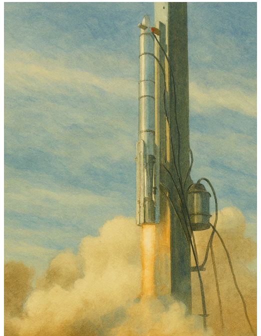
Test a M-Class Motor



Longshot In-house Hybrid Motor Development

Throttling Control Techniques for Hybrid Rocket Controlled Ascent Proposal

Karthik Nuti, Nicholas Quillin, Jonathon White, Pablo Martinez, AeroMavs et al.



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Project Overview: HX-1

- Objectives:
  - Gain regression data.
  - Confirm theories of characteristics.
  - Achieve multi test capability.
- Output:
  - Functional test hardware.
  - Data to improve upon for HX-2.
- Future:
  - HX-2 second iteration of the experimental hybrid.

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PROJECT OVERVIEW: HX-1
By: Nicholas Quillin, Pablo Martinez

Mission Requirements:
- Prove the feasibility of HX-1
- Iterative design that can be scaled for HX-2

Objectives:
- Do multiple short test burns
- Gain regression data
- Analyze and validate initial estimates

Output:
- Determine parameter deviations
- Identify improved parameter fidelity for HX-2

Literature Review:

- [1] "Mojave Sphinx," *Half Cat Rocketry* Available: https://www.halfcatrocketry.com/mojave-sphinx.
- [2] Ogata, K., *Modern Control Engineering*, Prentice Hall, 2022.
- [3] Nise, N. S., *Control Systems Engineering*, Hoboken, NJ: Wiley, 2015.
- [4] Newlands, R. M., *Science and design of the Hybrid Rocket Engine*, Lulu, 2017.
- [5] Humble, R. W., Henry, G. N., and Larson, W. J., *Space Propulsion Analysis and design*, New York: McGraw-Hill, 2007.
- [6] Sutton, G. P., and Biblarz, O., *Rocket Propulsion Elements, Ninth Edition*, John Wiley & Sons (US), 2017.

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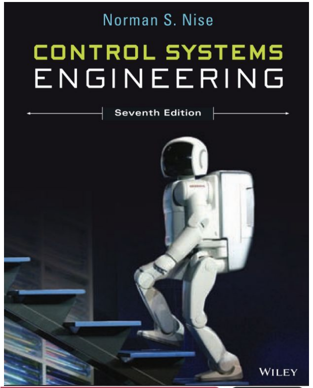
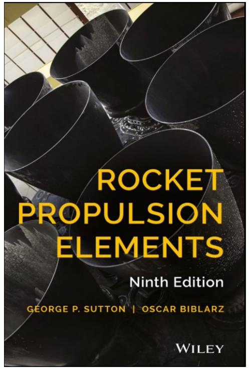
Specified Literature



Control Systems engineering

- Control systems: planning pintle injector variance

Nise, N. S., *Control Systems Engineering*, Hoboken, NJ: Wiley, 2015.



Rocket Propulsion Elements (9th edition)

- Defined the fundamentals for rocket propulsion including nozzle theory, propellant analysis, and flight performance

Helped us define parameters and understand the necessary equations for the motor.

Sutton, G. P., and Biblarz, O., *Rocket Propulsion Elements, Ninth Edition*, John Wiley & Sons (US), 2017.

Mojave Sphinx HCR 5100

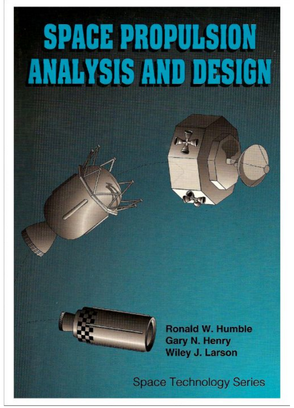
- Successfully flown low budget bipropellant liquid rocket design

Helped us source parts at affordable prices and precedent for cost cutting measures

The design of the servo-actuated ball valve

Practical safety and testing

“Mojave Sphinx,” *Half Cat Rocketry* Available: https://www.halfcatrocketry.com/mojave-sphinx.



Space Propulsion Analysis and Design

- Chapter 7 talks about hybrid rocket propulsions.

Helped us define basic parameters of said hybrid engine. Provided basic information about internal ballistics utilizing regression rates, modelling, and burning rate equations.

Humble, R. W., Henry, G. N., and Larson, W. J., *Space Propulsion Analysis and design*, New York: McGraw-Hill, 2007.

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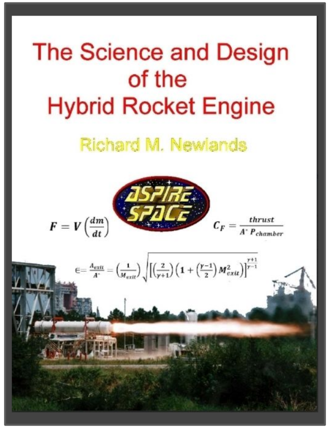
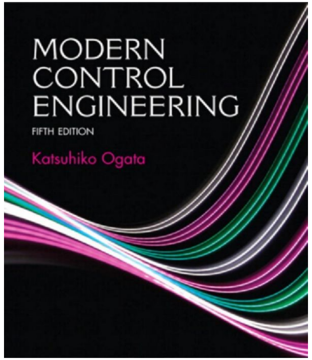
Specified Literature



Science and Design of HRE

- Provides insight into the basics of rocketry.
- Explains how to design and build a functional hybrid engine.
- Also explains which set of propellants are suggested to use in these systems (ie. using N2O).

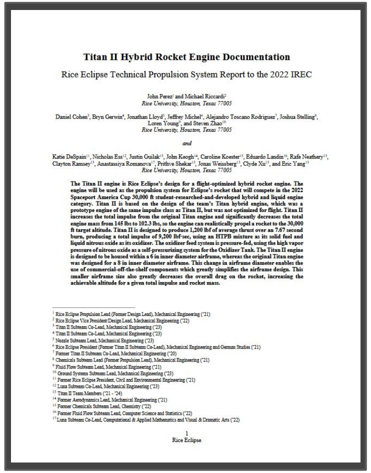
Newlands, R. M., *Science and design of the Hybrid Rocket Engine*, Lulu, 2017.



Modern Control Engineering (5th Edition)

- Helped define and design the basics of the electrical systems for control surfaces. Also helped establish solutions for electrical designs for the entire engine.

Ogata, K., *Modern Control Engineering*, Prentice Hall, 2022.



Titan II Hybrid Rocket Engine Documentation

Rice Eclipse Technical Propulsion System Report to the 2022 IREC

John Perez[1] and Michael Riccardi[2]
Rice University, Houston, Texas 77005

Daniel Cohen[3], Bryn Gerwin[4], Jonathan Lloyd[5], Jeffrey Michel[6], Alejandro Toscano Rodriguez[7], Joshua Stelling[8], Loren Young[9], and Steven Zhao[10]
Rice University, Houston, Texas 77005

and

Katie DeSpain[11], Nicholas Ess[12], Justin Guilak[13], John Keogh[14], Caroline Koester[15], Eduardo Landin[16], Rafe Neathery[13], Clayton Ramsey[13], Anastassiya Romanova[17], Prithve Shekar[13], Jonas Weissberg[13], Clyde Xu[13], and Eric Yang[13]
Rice University, Houston, Texas 77005

The Titan II engine is Rice Eclipse's design for a flight-optimized hybrid rocket engine. The engine will be used as the propulsion system for Eclipse's rocket that will compete in the 2022 Spaceport America Cup 30,000 ft student-researched-and-developed hybrid and liquid engine category. Titan II is based on the design of the team's Titan hybrid engine, which was a prototype engine of the same impulse class as Titan II, but was not optimized for flight. Titan II increases the total impulse from the original Titan engine and significantly decreases the total engine mass from 145 lbs to 102.3 lbs, so the engine can realistically propel a rocket to the 30,000 ft target altitude. Titan II is designed to produce 1,200 lbf of average thrust over an 7.67 second burn, producing a total impulse of 9,200 lbf·sec, using an HTPB mixture as its solid fuel and liquid nitrous oxide as its oxidizer. The oxidizer feed system is pressure-fed, using the high vapor pressure of nitrous oxide as a self-pressurizing system for the Oxidizer Tank. The Titan II engine is designed to be housed within a 6 in inner diameter airframe, whereas the original Titan engine was designed for a 8 in inner diameter airframe. This change in airframe diameter enables the use of commercial-off-the-shelf components which greatly simplifies the airframe design. This smaller airframe size also greatly decreases the overall drag on the rocket, increasing the achievable altitude for a given total impulse and rocket mass.

[1] Rice Eclipse Propulsion Lead (Former Design Lead), Mechanical Engineering ('21)
[2] Rice Eclipse Vice President/Design Lead, Mechanical Engineering ('22)
[3] Titan II Subteam Co-Lead, Mechanical Engineering ('23)
[4] Titan II Subteam Co-Lead, Mechanical Engineering ('23)
[5] Nozzle Subteam Lead, Mechanical Engineering ('23)
[6] Rice Eclipse President (Former Titan II Subteam Co-Lead), Mechanical Engineering and German Studies ('21)
[7] Former Titan II Subteam Co-Lead, Mechanical Engineering ('20)
[8] Chemicals Subteam Lead (Former Propulsion Lead), Mechanical Engineering ('21)
[9] Fluid Flow Subteam Lead, Mechanical Engineering ('21)
[10] Ground Systems Subteam Lead, Mechanical Engineering ('23)
[11] Former Rice Eclipse President, Civil and Environmental Engineering ('21)
[12] Luna Subteam Co-Lead, Mechanical Engineering ('23)
[13] Titan II Team Members ('21 - '24)
[14] Former Aerodynamics Lead, Mechanical Engineering ('21)
[15] Former Chemicals Subteam Lead, Chemistry ('22)
[16] Former Fluid Flow Subteam Lead, Computer Science and Statistics ('22)
[17] Luna Subteam Co-Lead, Computational & Applied Mathematics and Visual & Dramatic Arts ('22)

1
Rice Eclipse

Titan 2 Hybrid Rocket Engine Documentation

- Successfully flown hybrid engines
- Helped us source parts at affordable prices and precedent for cost cutting measures
- The design of the servo-actuated ball valve
- Practical safety and testing

"Titan Hybrid Engines," *Rice Eclipse* Available: https://eclipse.rice.edu/titan-hybrid-engines.

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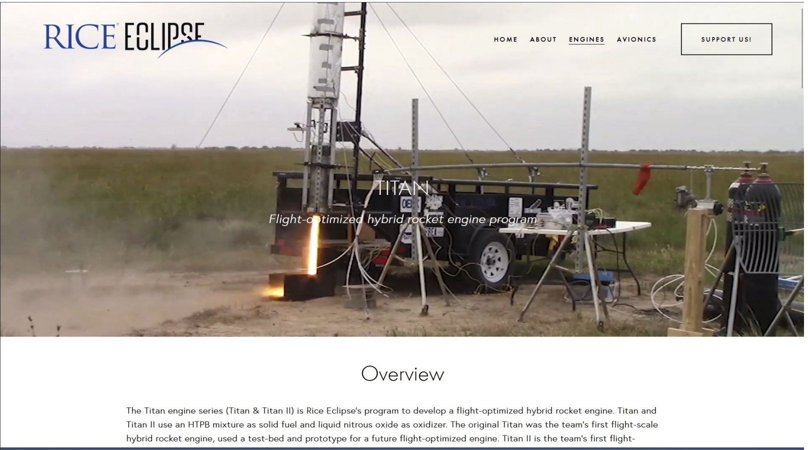
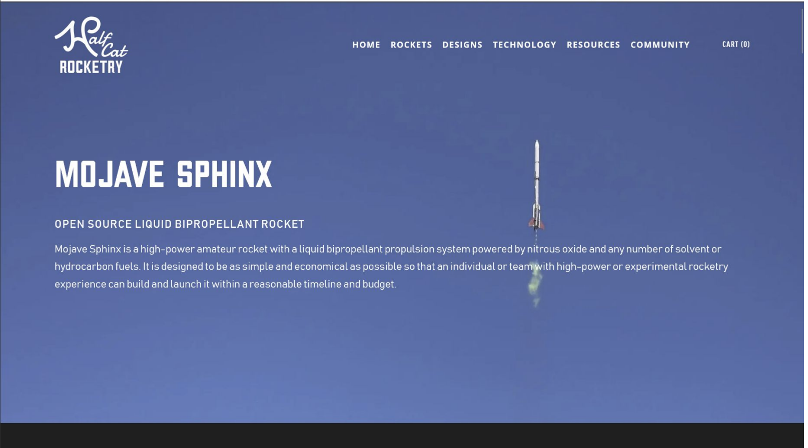
Organizations Consulted





Rice Eclipse: Titan 2
We looked to Rice eclipse for inspiration on designing and testing hybrid engines especially considering their success with Titan 2. They also had a standard for safety, SOP, N2O, Phenolic liner, Test stand
Website:https://eclipse.rice.edu/titan-hybrid-engines

Half-Cat: Mojave Sphinx
We looked to Half-cat to inspiration on the utilization of N2O as an oxidizer and the design specifications to move the fluid. We also looked to their combustion chamber for reference.
Website:https://www.halfcatrocketry.com/mojave-sphinx

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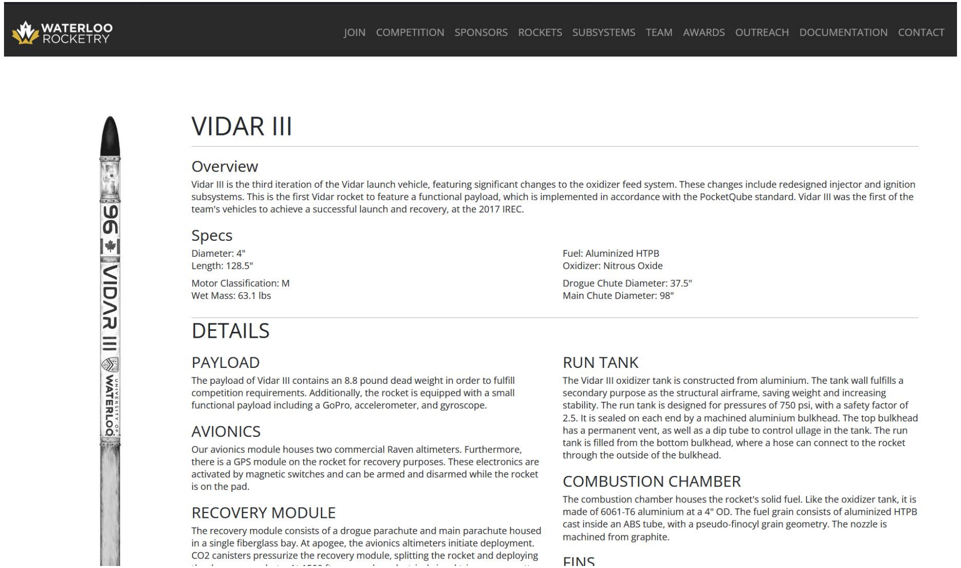
Organizations Consulted



University of Waterloo: Vidar III
We looked to Waterloo Rocketry for inspiration on designing and testing hybrid engines especially considering their success with Vidar III 2017 IREC Rocket: we got ideas on safety, SOPs, and using nitrous oxide.

Website:https://www.waterloorocketry.com/rockets/vidar3

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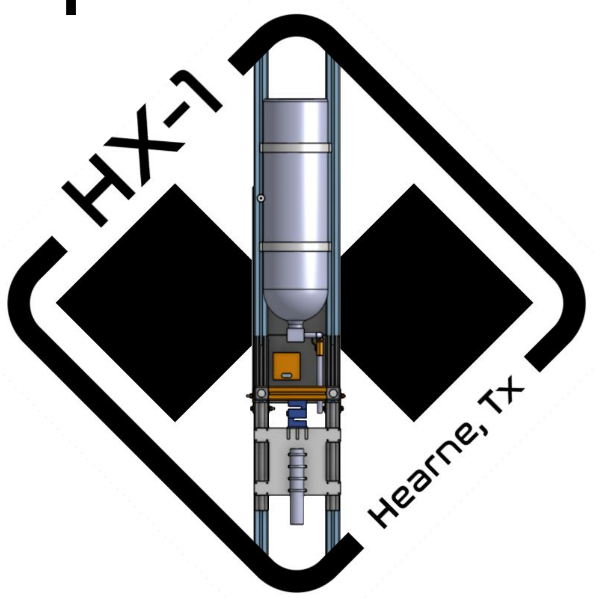
Next Speaker: Ms. Aero Mavs

TIMELINE: HX-1

Current Speaker: Mr. Aero Mavs
Next Speaker: Ms. Aero Mavs

Summary -

Design Requirements



Design Requirements help organize and direct the project.

These design requirements inform every aspect of design and will be referenced throughout.

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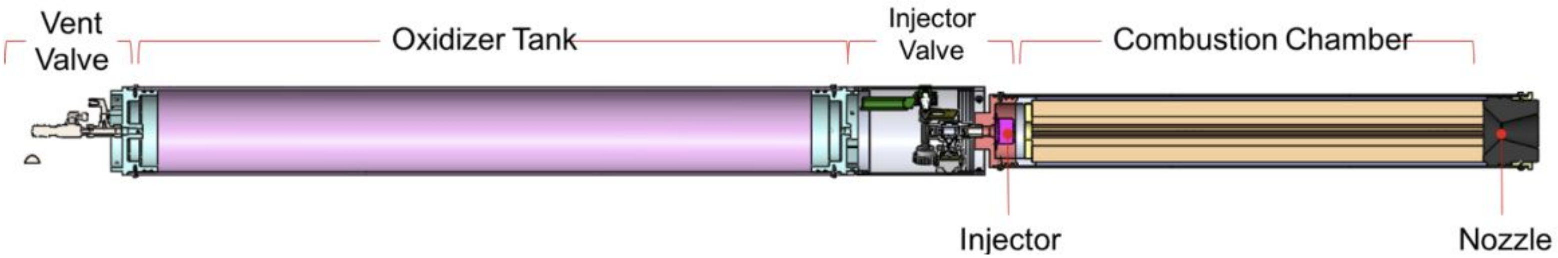
Inspiration on Engine Design



Our hybrid rocket engine has received some inspiration from Waterloo Rocketry Vidar III in terms of nitrous utilization and general designs of hybrid engines.

Waterloo Rocketry: Hybrid rocket engine IDEAs Design Analysis Competition 2018

Waterloo Rocketry, 2018
N. Christopher, S. Dalgliesh, N. Wong

Wong, N., Dalgliesh, S., Christopher, N., Lambert, S., and Hickey, J.-P., "Hybrid Rocket Engine IDEAs Design Analysis Competition 2018," *Waterloo IDEAs Design Analysis Competition 2018*. Available at: https://uwaterloo.ca/engineering-ideas-clinic/sites/default/files/uploads/documents/hybrid_rocket_engine_-_design_analysis_competition_presentation_1.pdf

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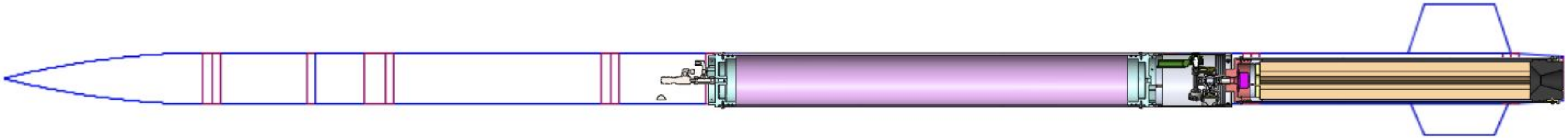
Inspiration on Rocket Design



Once the engine has been finalized, the engine would be applied to a rocket - for now called Longshot - for an IREC competition. The diagram above is representative of how HX-1 would be applied to a competition rocket.

Waterloo Rocketry: Hybrid rocket engine IDEAs Design Analysis Competition 2018

Waterloo Rocketry, 2018
N. Christopher, S. Dalgliesh, N. Wong

Wong, N., Dalgliesh, S., Christopher, N., Lambert, S., and Hickey, J.-P., "Hybrid Rocket Engine IDEAs Design Analysis Competition 2018," *Waterloo IDEAs Design Analysis Competition 2018*. Available at: https://uwaterloo.ca/engineering-ideas-clinic/sites/default/files/uploads/documents/hybrid_rocket_engine_-_design_analysis_competition_presentation_1.pdf

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Next Speaker: Ms. Aero Mavs

1.1 Combustion chamber

1.1 The engine shall provide data can be used to scale the design

1.1a The engine's thrust shall be measured

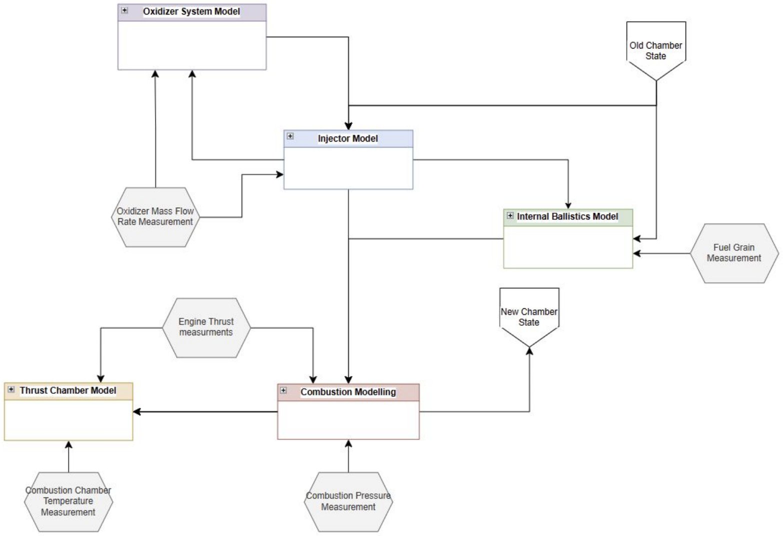
1.1b The engines pressure shall be measured

1.1c The oxidizer mass flow rate shall be measured

1.1d The fuel grain burn shall be measured

1.1e The engine temperature should be measured

These measurements will help us tune our in-house model that will used in subsequent hybrid designs



Model made on DrawIO
Made by: Nicholas Quillin
Date: 10/18/25

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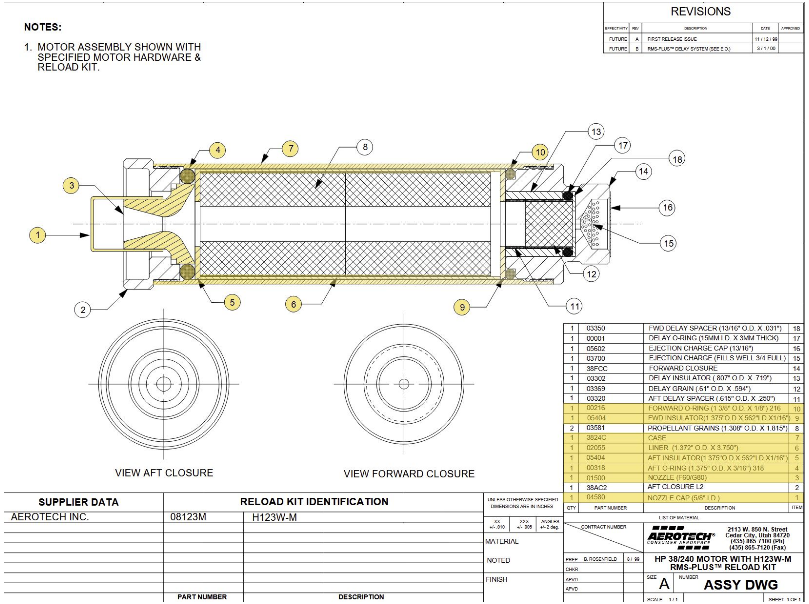
1.2 Combustion chamber

1.2 Motor should use COTS hardware wherever possible



Intended to reduce cost many of these parts are well designed, tested, and more affordable to buy.

A list of intended manufacturers are: Mcmaster carr

Many different manufacturers of COTS equipment exists

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1.3 Combustion chamber

1.3 The engine shall have at least 2 inhibitions

Based on common industry practice

Table 13.1. Clarification on Valid and Independent Inhibits.

A key consideration in providing inhibits in an ordnance circuit is that they be both valid and independent. Valid means the inhibits reside in the direct current path for firing the EED, not in the control circuit used to change the status of an inhibit. For example, if your two-inhibit compliance approach is to close two control circuit relays to close a single firing line relay, you are not compliant because you do not have two valid inhibits. In other words, the single firing line relay is the only inhibit. Independent means a singular action to remove a singular inhibit. You can have two inhibits; for example, two open relays in a firing line. However, if a single command removes both inhibits, (for example, closes both relays), then the inhibits are not independent. In other words, you do not have two independent inhibits. A concept that is often overlooked is that inhibits are not independent if a single failure can negate both inhibits.

* From sscman91-710v3

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1.4 Combustion chamber

1.4 The engine shall not exceed 2000 Ns of total impulse

Safe Distance Table

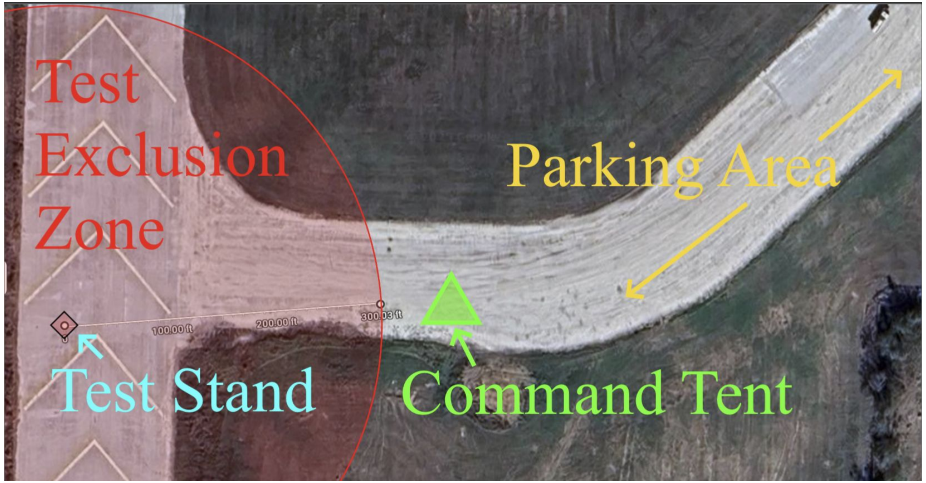
Motor Designation	Total Installed Impulse Newton-seconds		Single Motor feet	Single Motor meters	Complex feet	Complex meters
A-G	0.01	160	50	15	50	15
A-G Class 1 HP*	0.01	160	100	30	200	60
H-J	160.01	1,280	100	30	200	60
K	1,280.01	2,560	200	60	300	90
L	2,560.01	5,120	300	90	500	150
M	5,120.01	10,240	500	150	1,000	300
N	10,240.01	20,480	1,000	300	1,500	460
O	20,480.01	40,960	1,500	460	2,000	610
P-T	40,960.01	889,600	2,000	610	2,500	760

*Class 1 High Power are motors which fall into the Class 1 impulse range, but are regulated as High Power motors because they have greater than 80 Newtons average thrust, contain metal particles to make them sparkies, or contain more than 125 grams of propellant.

* From TRA Unified Safety Code

This requirement ensures that testing operations need not disturb regular launch operations on launch days.

Credit: Google maps



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1.5 Combustion chamber

1.5 The engine shall conform to all of the Tripoli Rocketry Association Unified Safety Code (TRA) and National Fire Prevention Association 1125 (NFPA 1125) code.

Cite:

[1]"Tripoli Rocketry Association Safety Code ," *unified safety code - Tripoli Rocketry Association* Available: https://www.tripoli.org/safetycode.
[2]"Code for the manufacture of model rocket and high power rocket motors," National Fire Prevention Association Available at: http://ftp.demec.ufpr.br/foguete/bibliografia/NFPA1125.pdf

Outline some of the major implications.

On most overlap TRA is typically more stringent and thus takes priority

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Next Speaker: Ms. Aero Mavs

1.6 Combustion Chamber

1.6 The Oxidizer Mass Flux shall never exceed 600 kg/m^2.

Cite:

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Next Speaker: Ms. Aero Mavs

2.1 Ground System Equipment

2.1 The test stand shall be safely returned to a safe state if power is cut.

This is standard procedure and required by IREC Design Test and Evaluation guide Section 5.

“International Rocket Engineering Competition Design, Test, & Evaluation guide,“ IREC, 2025 Available at: https://www.soundingrocket.org/uploads/9/0/6/4/9064598/2025-irec_dteg_v1.1.6_02-14-25.pdf

5.7.4 Hybrid or liquid teams shall provide launch control systems that ensure their rocket is properly made safe, *i.e.*, not armed.

5.7.4.1 A software-based control system that automatically cycles through an “arm function” and an “ignition function” shall include a manual interrupt capability between the “arm” and “ignition” functions.

5.7.4.2 Additional requirements for team-provided launch control systems are defined in Section 11.3 of this document.

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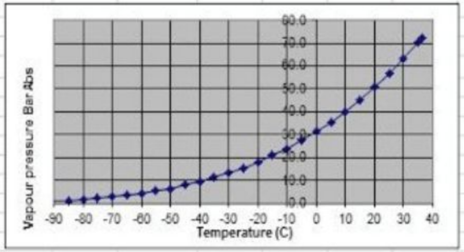
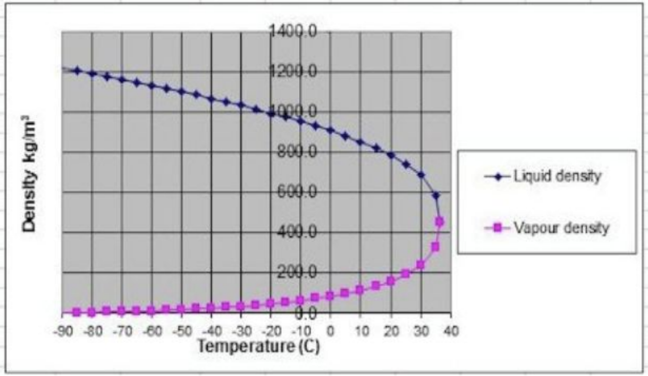
2.2 Ground System Equipment

2.2 All Nitrous systems operating downstream of main bottle valve are expected to operate at 15C or less.

Temperature (degC)	liquid density ρ (kg/m³)	vapour density ρ (kg/m³)	vapour pressure Bar Abs
-90.82	1222.8	2.7	0.9
-85	1206.7	3.8	1.2
-80	1192.7	4.9	1.6
-75	1178.3	6.3	2.1
-70	1163.7	7.9	2.7
-65	1148.8	9.9	3.5
-60	1133.6	12.2	4.3
-55	1118.0	14.9	5.3
-50	1102.0	18.0	6.5
-45	1085.6	21.6	7.9
-40	1068.8	25.6	9.4
-35	1051.4	30.3	11.2
-30	1033.4	35.6	13.2
-25	1014.8	41.6	15.5
-20	995.4	48.4	18.0
-15	975.2	56.2	20.8
-10	953.9	65.0	24.0
-5	931.4	75.0	27.4
0	907.4	86.7	31.3
5	881.6	100.2	35.5
10	853.5	116.1	40.1
15	822.2	135.4	45.1
20	786.6	159.4	50.6
25	743.9	191.1	56.6
30	688.0	237.3	63.1
35	589.4	330.5	70.3
36.42	452.0	452.0	72.5





Under saturated conditions, Nitrous properties scale with temperature

These properties are used to autogenously pressurize the system

Nitrous must be kept below this temperature in order to not exceed design requirements

Nitrous Properties from The Science and design of the Hybrid Rocket Engine, actual design uses tabulated properties from coolprop

Newlands, R. M., *Science and design of the Hybrid Rocket Engine*, Lulu, 2017.

2.3 Ground System Equipment

2.3 All pressurized systems must be designed with a minimum FOS of 2 and tested to 1.5 times the Maximum expected operating pressure (MEOP). 2.3a All parts including the combustion chamber MEOP is to be considered at Maximum expected operating temperature (MEOT)

For commercial rockets the FOS typically ranges from 1.2-1.5. For experimental rockets FOS 2 is standard and recommended by Richard Nakka, Newlands, and ESRA

Hydrostatic testing requirements outlined by ESRA from IREC Design Test and Evaluation guide Section 6.17.6.

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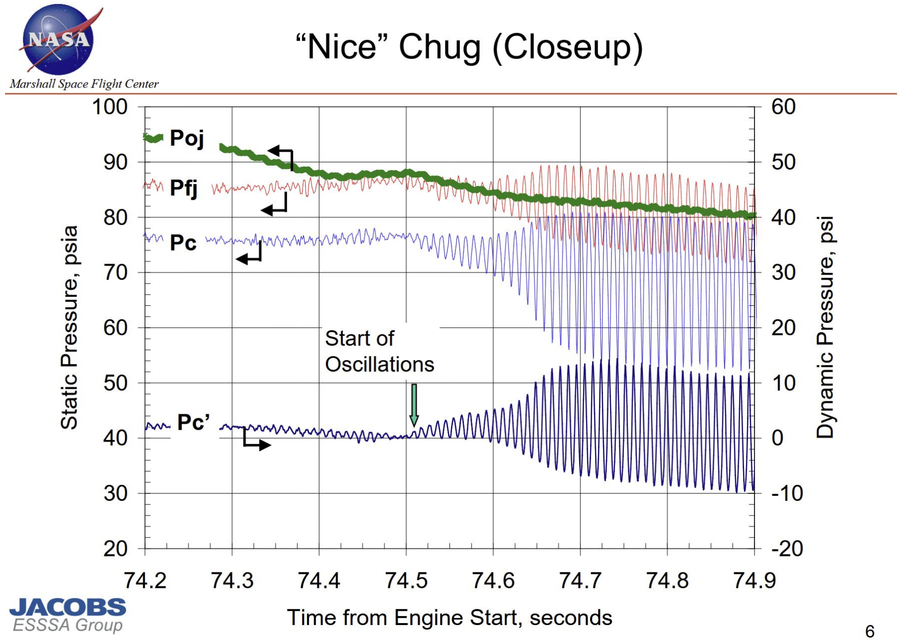
2.4 Ground System Equipment

2.4 The steady state pressure drop across the injector shall always exceed 20% of tank pressure



This is intended to harden the system against combustion instability, particularly chug instability.

A safe target recommended in The Science and Design of the Hybrid Rocket Engine by Richard Newlands

Figure is somewhat exaggerated but comes from NTRS 20170008957

[1]"Chug and Buzz.... the neglected and disrespected combustion instabilities - NASA technical reports server (NTRS)," *NASA* Available: https://ntrs.nasa.gov/citations/20170008957.

[2] "*Science and design of the Hybrid Rocket Engine*,"Newlands, R. M. 2017.

2.5 Ground System Equipment

2.4 The test stand shall always be grounded

This requirement is to avoid accidental sparking resulting in Nitrous oxide decomposition.

Scaled Composites Cold-flow failure caused by Nitrous oxide decomposition

Picture credit:

3.1 Manufacturing

Machining will be done primarily through UTA machine shop.

Only metal parts should be machined.

This requirement is in order to avoid the safety implications of machining and manufacturing phenolic, graphite, and other materials.

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3.2 Manufacturing

3.2 The oxidizer system shall be cleaned of all combustible matter

This is required to avoid the spontaneous combustion in an oxygenated environment

Testing Summary

Parts Received -

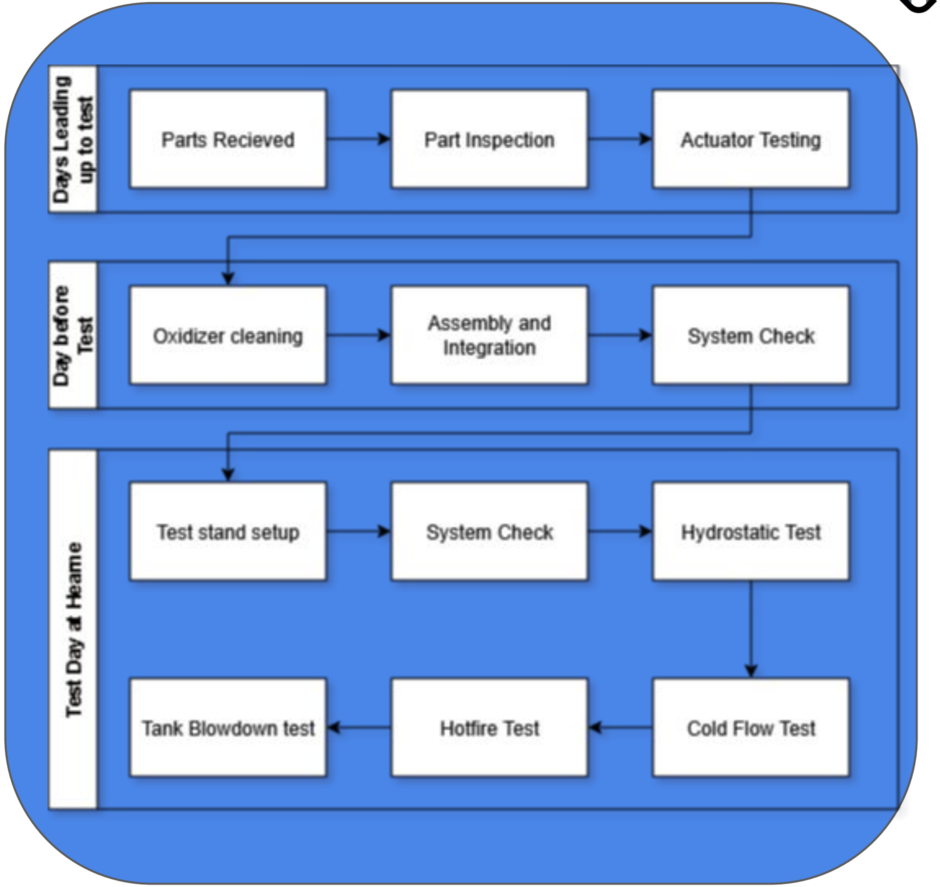


Diagram made by: Nicholas Quillin
Date:
Software:
Sources:

Current Speaker: Mr. Aero Mavs
Next Speaker: Ms. Aero Mavs

Budget

Total Budget: **$1543.19**

HX-1 Projected Expenditures: $794.33

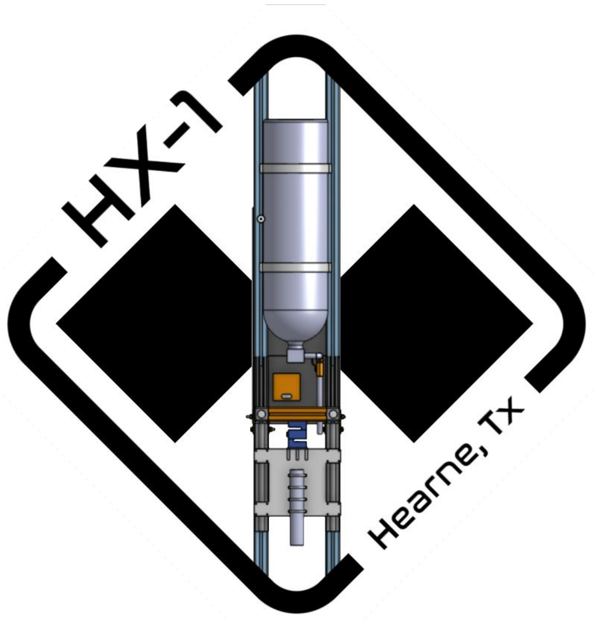
- Majority of Test Stand components are sourced from the lab

Budget: HX-1	
Nitrous Oxide Equipment	$41.40
Thrust Chamber	$16.51
Nitrogen Purge System	$263.40
Test Stand	$42.03
Electronic Components	$321.24
Hydrostatic Test	$70.98
Cleaning Equipment	$24.68

Current Speaker: Mr. Aero Mavs
Next Speaker: Ms. Aero Mavs

Summary -

HX Simulation Models



The purpose of HX-1 as well as all the subsequent systems in the HX series is to collect data for an in-house design tool which will pave the way for future designs

This section goes over this product piece of SOFTWARE that will be produced using HX Data

HX Model is incomplete without test data, so the design of HX-1 makes heavy use of external resources and data to get an approximate

Simulation Model Architecture

HX-1 is composed of various simulations, primarily written in the MATLAB/Simulink/Simscape environment.

While the model uses both empirical and theoretical relations to model the system.

This section will predominantly go over some of the models used as well as their limitations and state of development

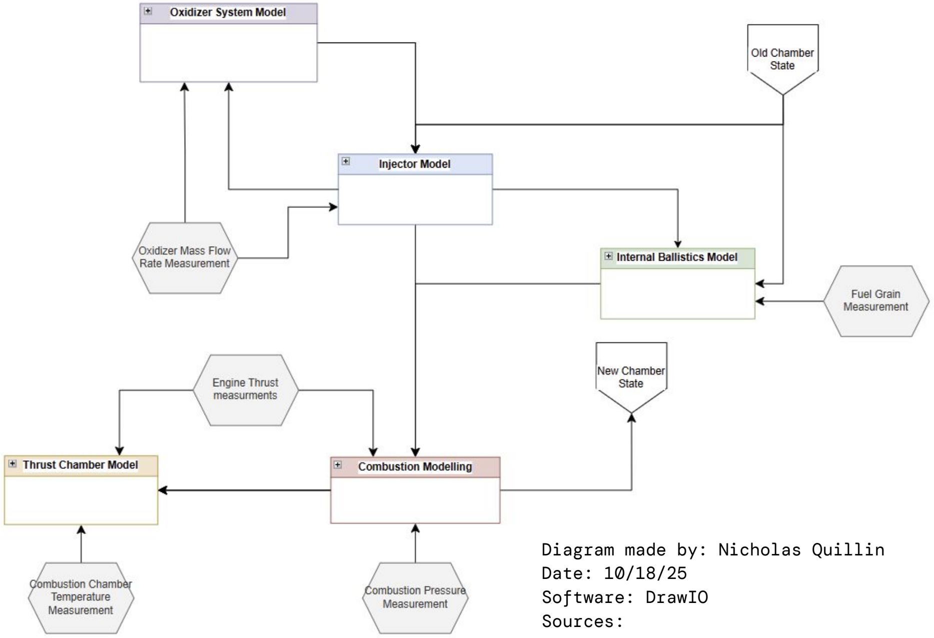


Diagram made by: Nicholas Quillin
Date: 10/18/25
Software: DrawIO
Sources:

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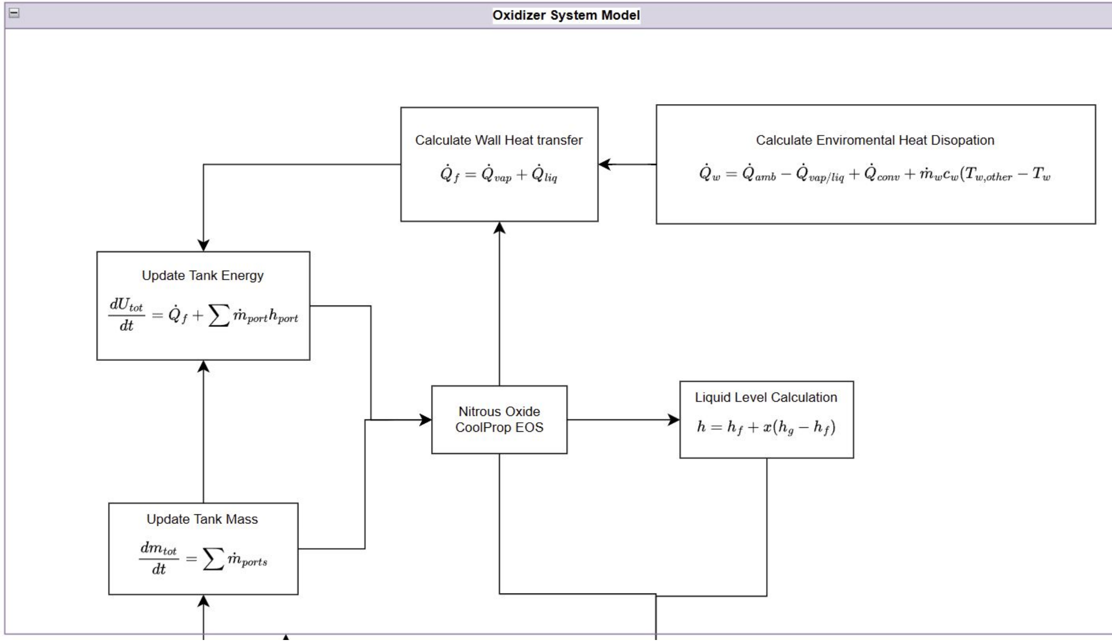
Tank Simulation diagram (Matlab/Simulink)

Currently assumes

Check Documentation for usage

Thermochemical Data from Precompiled LUT in CoolProp

Secondary simscape model



Equilibrium tank simulation based on on this research

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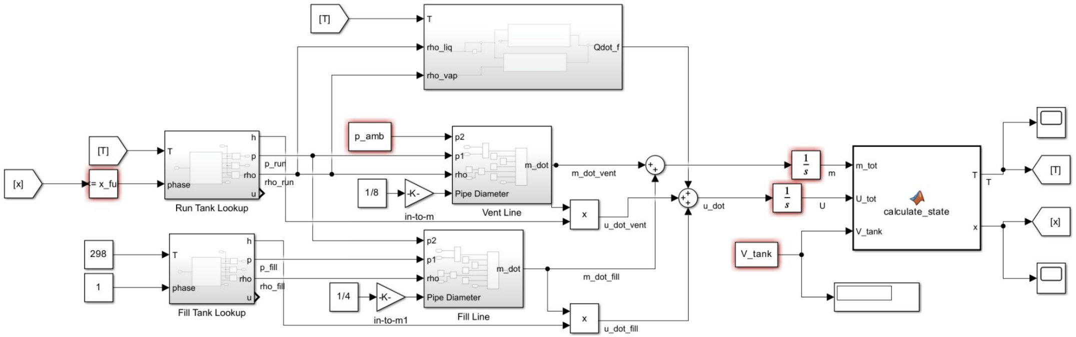
Tank Simulation (Matlab/Simulink)

2 models in use

1. written in simulink model shown below, this one is more versatile and will be expanded upon later to take in account dynamic-non equilibrium behavior.
2. Written in simscape, mainly used for validation at the moment but will be combined with the first at some point using custom simscape components



Current implementation in simscape
By: Nicholas Quillin
Date:

Current Speaker: Mr. Aero Mavs
Next Speaker: Ms. Aero Mavs

Flow simulation and calculation

The main constriction in

The Model utilizes the following equation:

The Model assumes the following:

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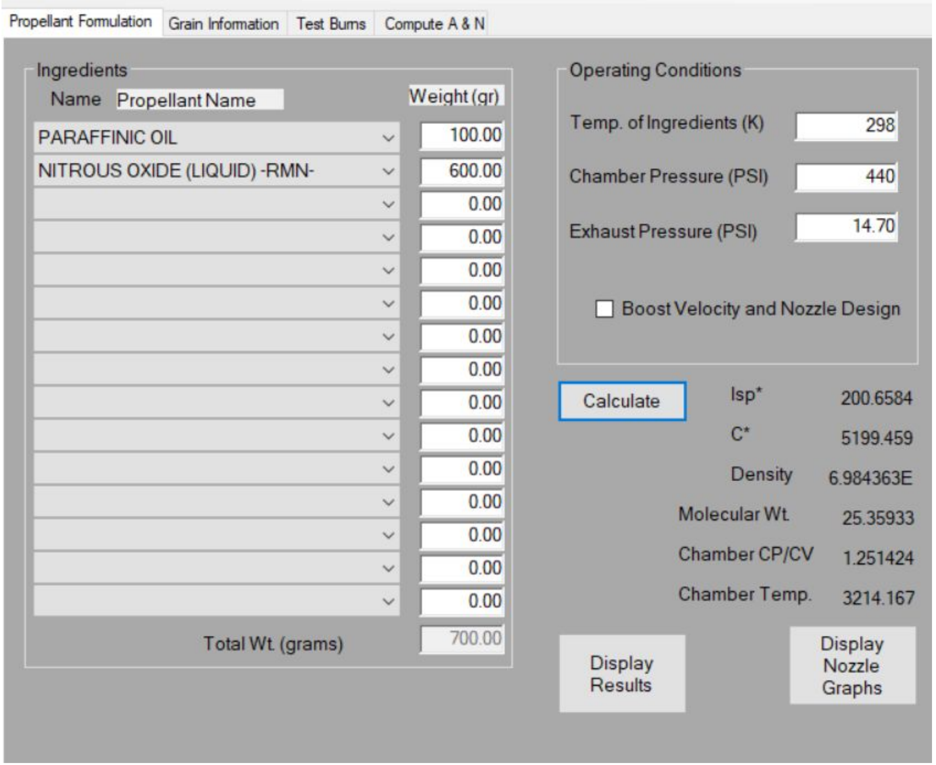
Next Speaker: Ms. Aero Mavs

Chemical Equilibrium

ProPEP

NASA CEA

Determine the heat generated for any system



Model is made through Simscape 2025A
By: Pablo Martinez
Date:

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Next Speaker: Ms. Aero Mavs

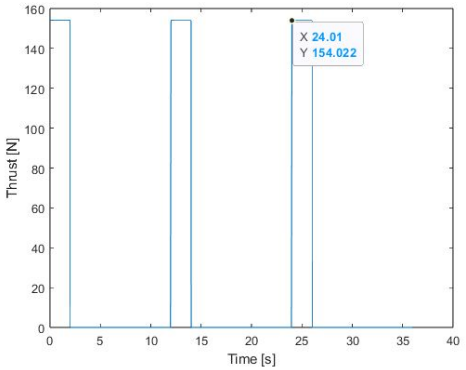
Sources

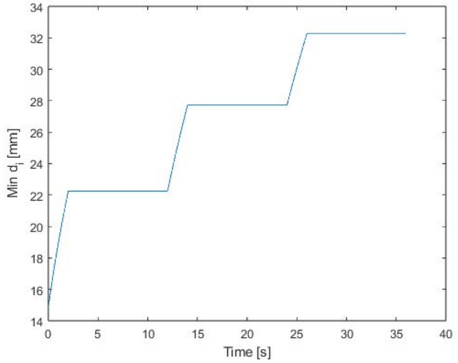
Internal Ballistics

Internal ballistics is the study of how propellant burns and behaves inside the combustion chamber. Thus the effect is how that internal behavior sets chamber pressure, mass flow, and ultimately thrust.

The initial simulation models are homogenous types - it is a simplified theoretical model and assumes that all gasses in the chamber are perfectly mixed. It will be able to model dynamic burning.

The matlab provided graphs provided are too idealistic; however, they provide a clear insight on the pulsing hot-fire test. The top graph focuses on the the thrust produced from the pulse.





Model made through Matlab 2024B
By: Karthik Nuti
Date:

Current Speaker: Mr. Aero Mavs
Next Speaker: Ms. Aero Mavs

Internal Ballistics

Internal Ballistics Code Analysis
By: Karthik Nuti
Date: 10.19.25

Code Requirements:
- Provide a rudimentary analysis on the combustion of fuel grain

Inputs/Parameters:
- Total Impulse: It = 1000. [Ns]
- Specific Impulse: Is = 200.0 [s]
- Gravitational acceleration at Hearne: g = 9.820 m/s^2
- Oxidizer-to-Fuel Ratio: O/F = 6.000
- Fuel density: ρ = 870.0 [kg/m³]
- Regression coefficient: a = 0.1146
- Regression exponent: n = 0.5036
- Oxidizer mass flux: G = 128.0 [kg/m²·s]
- Fuel grain length: L = 0.1199 [m]
- Outer diameter (design): D = 0.03332 [m]
- cstar=1500;
- Nozzle throat area=7.126e-5 [m^2]
- Gas-side h during burn = 8000.
- Gas temp during burn (CEA) =2800.;
- N2 cooling (depends on purge flow)=300.0 [W/m^2-K]
- Purge gas N2 temperature = 300.0 [K]
- Paraffin wax cp=2200. [J/kg-k]
- Delta (effective heated layer) = 7.500e-4 [m]
- Tsurf=300.0*ones(N,1);
- Burn_dt (burn phase timestep) = 0.0050 [s]
- Purge_dt (purge timestep) = 0.0500 [s]
- Burn_time (duration per pulse) =2.000 [s]
- Purge_time (purge duration per gap) = 10.00 [s]
- Pulses (number of pulses) = 3.000
- relax (under-relaxation factor) =0.6000

Initialize Parameters

Burn Phase (2 second pulse):
- Iterate for burn time (ensuring burn time is within 2 seconds).
  - Within this loop

Geometry Update:

Purge Phase:
- Utilizing the purge flow in

Plot data against time:
- Plot 1: Thrust vs Time
- Port Diameter vs Time

Output:
- Thrust vs Time
- Port Diameter vs Time

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Next Speaker: Ms. Aero Mavs

Thrust simulation (simscape)

Simulink Model

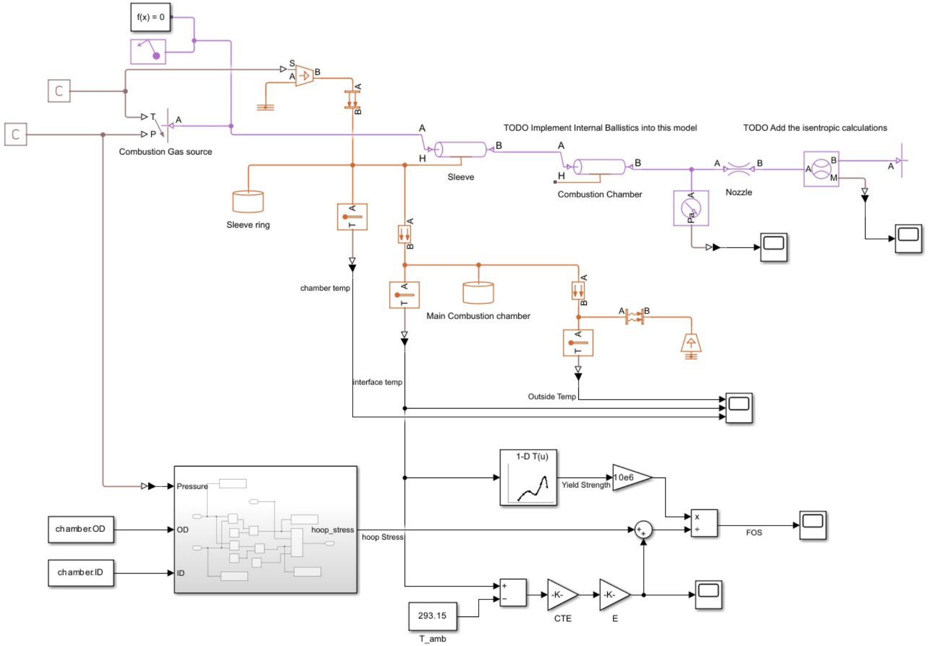
- Heating of pipe
- Stress and strain of combustion chamber.

Manual Calculations

- Injector
- Nozzle Flow

CFD simulations

- Axisymmetric Flow simulation



Model is made through Simscape 2025A
By: Nicholas Quillin
Date:

Current Speaker: Mr. Aero Mavs
Next Speaker: Ms. Aero Mavs

Data Analysis

- Extracting data on **regression rate, O/F ratio, Thrust curve, and Chamber pressure & blowdown profile**
- Organization of data within a burn log in a database
  - Test ID, grain geometry, tank fill, ignition method, run time, etc.
  - Pre/post tank mass (oxidizer used)
  - Pre/post grain mass or port measurements
  - Pressure trace file, thrust data
- Version Control of Raw versus Processed Data
  - DAQ vs analysis sheet
- Process each data set
- Fit models
  - Fit the regression data to the empirical law
  - Extract coefficients a,n with regression (curve fitting)
  - Compare experimental impulse and thrust to prediction from this CDR review
- Compare & Conclude
  - Validation: Does measured thrust/impulse align with CDR estimates? Within what percent error?
  - Sensitivity: Which parameter caused the biggest deviation?
  - Next step: Identification of what HX-2 should testwith better fidelity
- Graphs

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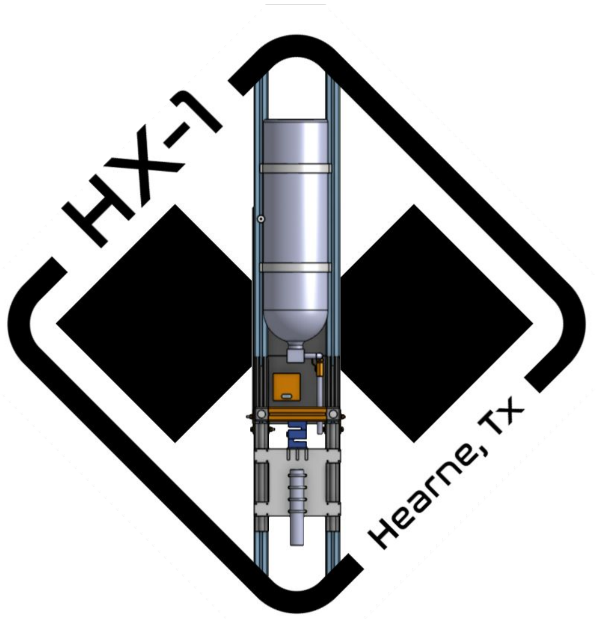
Next Speaker: Ms. Aero Mavs

Summary -

Thrust Chamber



The thrust chamber encompasses the design of the generation, containment, and expulsion of propulsive gasses.

Current Speaker: Mr. Aero Mavs
Next Speaker: Ms. Aero Mavs

Design Procedure

1. [Design Parameters](#) (Preliminary design Decisions)
2. Simulate the burn (Done with [internal ballistics model](#))
3. Size the Individual Components

Step	Action	Comments
1.) Summarize require-ments	Summarize	• Performance requirements • Envelope constraints • Mass requirements • Thrust history • The "ilities"
2.) Make preliminary design decisions **Section 7.4**	Choose propellants	• Evaluate thermochemistry (c, c_f, I_{sp}) • Choose design O/F and allowable O/F range • Environmental requirements • Performance requirements
	Determine pressure levels for the engine and feed system	• Pump or pressure feed system • Combustion-chamber pressure & nozzle expansion • Injector pressure drop • Profile of feed-system pressure • Dynamic pressure • Tank pressure • Pressurant system
	Determine require-ments for the initial propellant flow	• Estimate initial specific impulse • Determine required flow rates based on required thrust level
	Size system	• Choose the inert mass fraction • Use the ideal rocket equation • Estimate fuel and oxidizer masses • Estimate inert mass
	Configure combustion ports	• Choose number of ports • Port cross section, length, and web thickness
3.) Estimate performance **Section 7.5**	Simulate the burn	• Estimate operating parameters • Predict the grain and nozzle configuration over the burn duration
4.) Size and configure components **Section 7.6**	Nozzle	• Characteristic velocity sizes the throat (Eq. 3.133) • Expansion ratio sizes the exit • Required efficiency determines length • See Secs. 5.4.1 and 6.3.7
	Combustion chamber	• Include fore and aft sections with grain length • Perform hoop-stress analysis • Include an injector mass • See Sec. 6.3.3
	Oxidizer tank	• Use hoop-stress or structural mass-factor approach • See Sec. 5.4.4
	Pressurant system	• See Sec. 5.4.5
	Support structure and ancillary parts	• 10% of mass • See Sec. 5.4.7
5.) Iterate as required		• Iteration can occur from any point to any other point in the process • Iteration ends when an adequate design emerges

* Design Procedure from Hybrid Rocket Propulsion Systems Chapter written by Ronald Humble

Fuel Selection

Specific Impulse: Measure of the efficiency of the propellant, data is average from Newlands. All shown propellants are similar to performance

Oxidizer to fuel ratio by wt: Larger values mean larger relative oxidizer tank weight resulting in enhanced rocket stability. data is average from Newlands, CEA, and various IREC reports,

Ease of Manufacture: Classified by process and considers the relevant safety hazards associated. Subjective Index based on past experience.

Affordability: Cost of the propellant. Compounded via amazon and RCS.

Other unlisted factors that was considered: regression rate, Transportability, Sensitivity.

Other unlisted propellants that was considered: PMMA(Acrylic), PETG, LDPE, PLA

Fuel	Specific Impulse	Oxidizer to fuel Ratio	Ease of Manufacture	Affordability
HTPB	236	5.5	Medium Chemical Casting	Average $15/kg
ABS	232	5.7	Trivial 3d Printing	Expensive ~$30/kg
Paraffin Wax	244	6.0	Easy Thermal Casting	Cheap ~$8/kg
HDPE	235	6.2	High Machining Required	Average ~$15/kg

Design Parameters

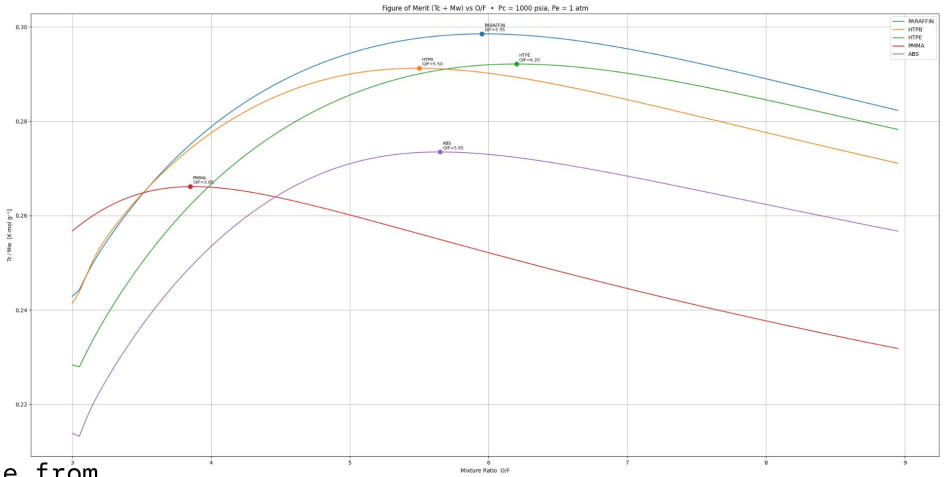
Target Pressure - 440 PSI
- Result of requirements 2.2 and 2.4, see pressure budget

o/f ratio = 6

Preliminary calculations showed that with these constraint 38mm, and 54mm motors where possible.

54mm(2.13") was eliminated due to the thin fuel grain (<5mm (0.2") thick) => design is to be compatible with 38mm (1.5") hardware

Fuel was chosen to be paraffin wax due to its combination of energy density, high o/f ratio, affordability



Oxidizer to fuel estimate from IREC 2027 Rocket sizing tool using Rocket CEA
By: Nicholas Quillin

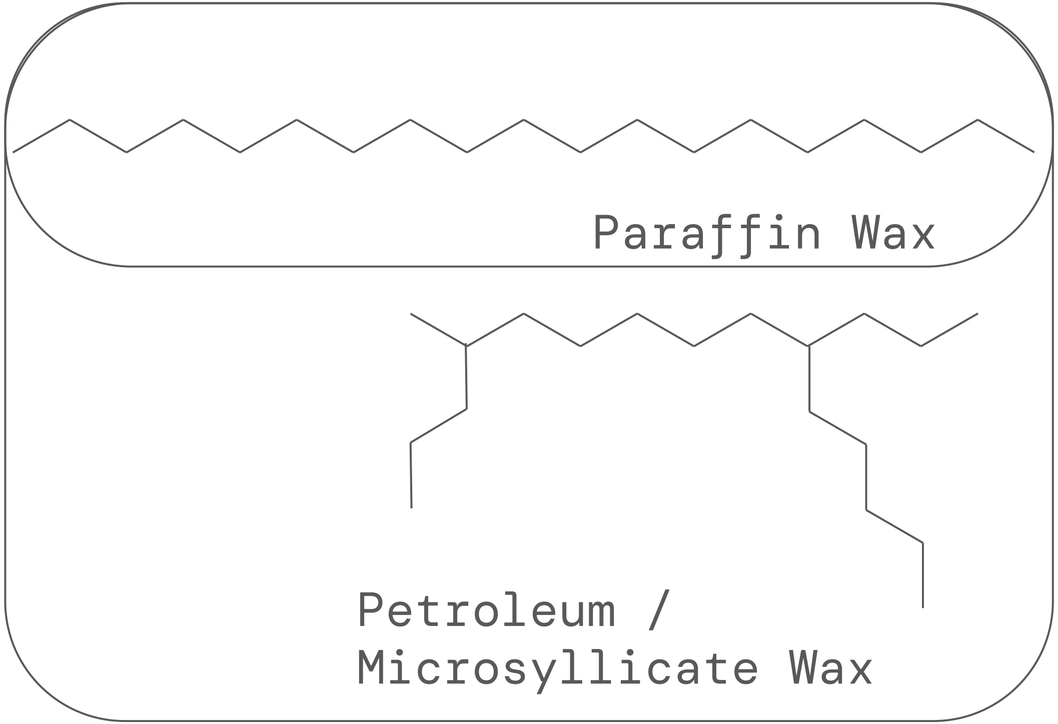
Current Speaker: Mr. Aero Mavs
Next Speaker: Ms. Aero Mavs

Paraffin Wax

Paraffin wax is a byproduct of the oil refining process and is composed of long alkanes between 20-40 carbons in length.

Paraffin is often confused with Microcrystalline wax which is better known as petroleum wax which combines the long alkanes of paraffin with branched-chain, and cyclic hydrocarbons.

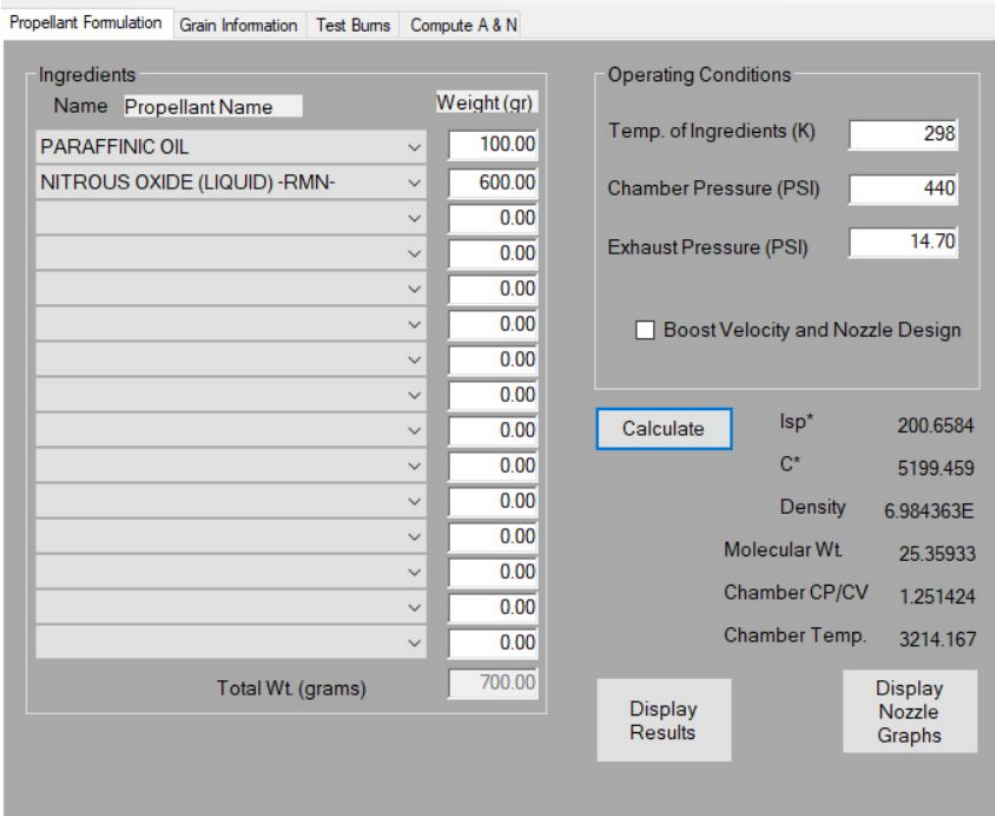
The longer length of paraffin results in reduced viscosity of propellant.



ProPEP analysis

Preliminary low fidelity model to calibrate main model against.

Paraffinic oil suggests that this is actually Microcrystalline wax.



guiPEP
By: Pablo Martinez
Date: 9.23.2025

CEA analysis

Chamber temperature is lower than PeP, these conservative values are used for thrust calculations while PEP results are used for heat flux

Since this model takes in account shifting chemical equilibrium, these values are used for the respective performance of the nozzles over PeP

THEORETICAL ROCKET PERFORMANCE ASSUMING EQUILIBRIUM

COMPOSITION DURING EXPANSION FROM INFINITE AREA COMBUSTOR

Pin = 440.0 PSIA
CASE = _______________

	REACTANT	WT FRACTION (SEE NOTE)	ENERGY KJ/KG-MOL	TEMP K
FUEL	paraffin	1.0000000	-1860600.000	298.150
OXIDANT	N2O	1.0000000	0.000	0.000

O/F= 6.00000 %FUEL= 14.285714 R,EQ.RATIO= 1.523088 PHI,EQ.RATIO= 1.523088

	CHAMBER	THROAT	EXIT
Pinf/P	1.0000	1.8014	29.930
P, BAR	30.337	16.841	1.0136
T, K	2505.44	2234.24	1255.71
RHO, KG/CU M	3.7567 0	2.3402 0	2.5069-1
H, KJ/KG	-265.33	-714.38	-2254.61
U, KJ/KG	-1072.87	-1434.01	-2658.94
G, KJ/KG	-24274.6	-22124.7	-14287.8
S, KJ/(KG)(K)	9.5828	9.5828	9.5828
M, (1/n)	25.796	25.814	25.822
MW, MOL WT	25.796	25.814	25.822
(dLV/dLP)t	-1.00052	-1.00016	-1.00000
(dLV/dLT)p	1.0124	1.0041	1.0000
Cp, KJ/(KG)(K)	1.7124	1.6328	1.5498
GAMMAs	1.2383	1.2480	1.2623
SON VEL,M/SEC	1000.0	947.7	714.4
MACH NUMBER	0.000	1.000	2.792

PERFORMANCE PARAMETERS

Ae/At	1.0000	4.4353
CSTAR, M/SEC	1367.9	1367.9
CF	0.6928	1.4582
Ivac, M/SEC	1707.0	2197.3
Isp, M/SEC	947.7	1994.6

MASS FRACTIONS

*CO	0.21154	0.20752	0.16968
*CO2	0.12577	0.13209	0.19155
*H	0.00005	0.00002	0.00000
*H2	0.00530	0.00559	0.00832
H2O	0.11127	0.10911	0.08489
*NO	0.00012	0.00002	0.00000
*N2	0.54550	0.54554	0.54555
*OH	0.00043	0.00010	0.00000
*O2	0.00001	0.00000	0.00000

* THERMODYNAMIC PROPERTIES FITTED TO 20000.K

Manual CEA predicts higher ideal O/F ratio then either Sutton or RocketCEA python wrapper. Still trying to figure out why this is the case

This translates to approx 203s of specific impulse, significantly lower than many reference material on this subject. It might be due to the composition of paraffin defined by the software

Exhaust properties cross referenced with performance properties using excel

NASA CEA
By: Nicholas Quillin
Date: 10.25.2025

Current Speaker: Mr. Aero Mavs
Next Speaker: Ms. Aero Mavs

Sizing

Grain sizing results:

Total Impulse = 1000 Ns

Average Force = 153 N

Maximum Oxidizer Mass Flux = 384 kg/m^2

Oxidizer Mass flow = 66.9 g/s

Grain Length= 11.99cm

Grain outer diameter = 33.32mm

Grain inside Diameter= 14.87 mm

Injector Sizing

2 holes,

Cut from ½” National pipe thread plug

Constraints:

The engine shall not exceed 2000 Ns of total impulse

The Combustion chamber should be primarily produced from COTS hardware with minimum machining

Oxidizer Mass flux shall not exceed 600kg/m^2

Regression rate coefficients based on data collected by
Lee, T.-S., and Tsai, H.-L., “(PDF) fuel regression rate in a paraffin-HTPB nitrous oxide hybrid rocket,” Research Gate Available: https://www.researchgate.net/publication/268343388_Fuel_Regression_Rate_in_a_Paraffin-HTPB_Nitrous_Oxide_Hybrid_Rocket.

Current Speaker: Mr. Aero Mavs
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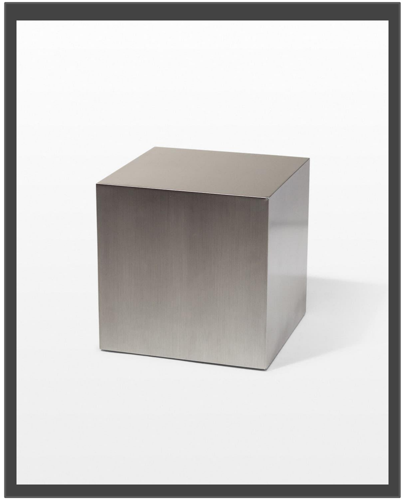
Material

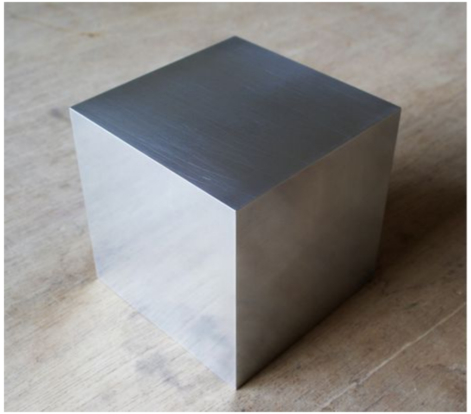
6061 Aluminum for combustion chamber assemble

Pipe fittings are stainless steel

316 Steel - Eliminated because it violates the unified tripoli safety code



“TB057 16" stainless steel cube prop rental,” *ACME Brooklyn* Available: https://www.acmebrooklyn.com/prop/tb057-small-stainless-steel-cube/.



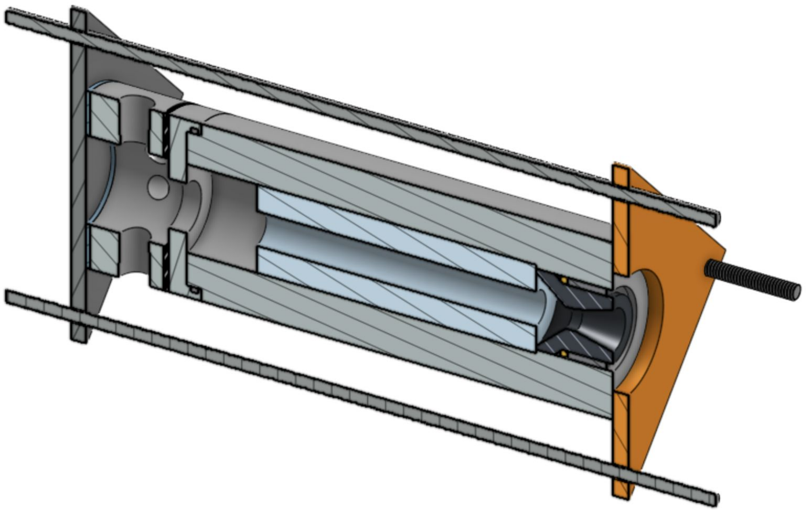
FastenersWEB, “Aluminum cube 6061 T6 suppliers, manufacturers, exporters from India - FastenersWEB,” *fastenersweb.com* Available: https://www.fastenersweb.com/proddetail/68007/aluminum-cube-6061-t6.

Chamber Assembly

Chamber is fabricated from a 3 in diameter 6061 aluminum tube. It is radiatively cooled. The radiatively cooled chamber configuration was chosen for its simplicity, and low cost capability.

3" was chosen as the smallest size which would allow the engine to run cool even with a failure to shut off the engine.

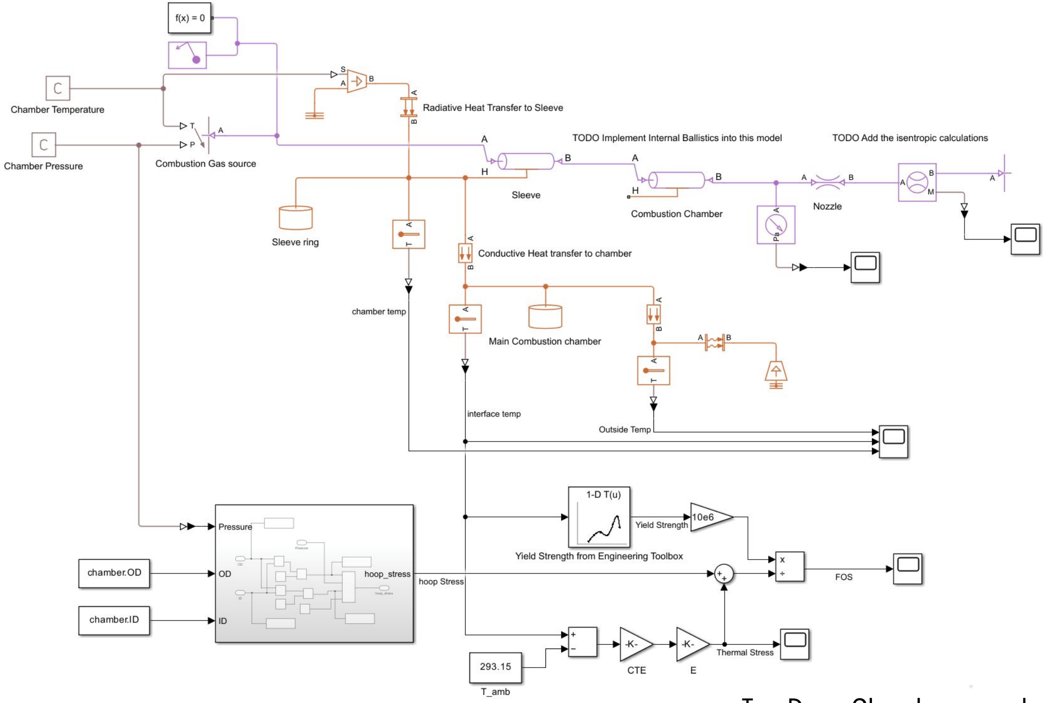
The Combustion chamber utilizes as many COTS components as possible to supplement the machined parts for cost reduction purposes.



Model is made through Onshape
By: Jonathan White
Date: 10.17.2025

Current Speaker: Mr. Aero Mavs
Next Speaker: Ms. Aero Mavs

Chamber Stresses



In-Dev Chamber model in simulink
By: Nicholas Quillin
Date: 10.16.2025

To ensure that the chamber would not fail, chamber stresses where calculated using 2 approaches

- Worst case heating (assumptions adiabatic heating) calculated in MATALB using ODE45.
- In-Dev chamber model assuming equilibrium with atmosphere that will be improved using data collected.

Models where very similar with about 35C final temp difference.

Equations used

- Thick-Wall Hoop stress formula.
- Convection/Conduction formula from thermal mech.
- Boltzmann Radiation formula
- Stress from solid mech.
- Thermal Strain from solid mech.

Thermal Protection System

Model assumes heat from the combustion gasses primarily travels through convection and radiation which is based on pretty much all available literature.

A simple metal sleeve (in red) slows down the heating experienced by the rocket engine chamber (in blue).

Maximum chamber temperature is under 140 C making it compliant with TRA and NFPA.

The chamber can absorb the heat from a full 6s burn in the case oxidizer system fails open.

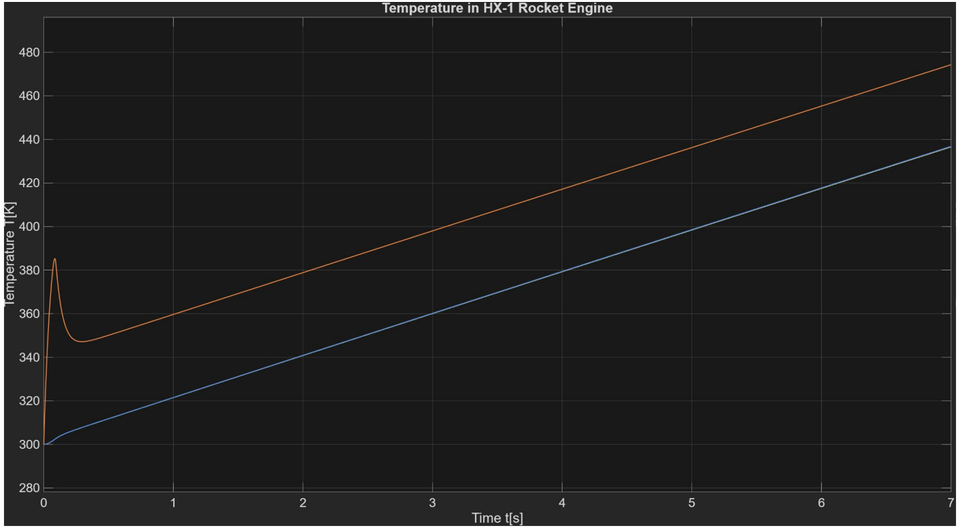


Diagram made by: Nicholas Quillin
Date:
Software:
Sources:

Current Speaker: Mr. Aero Mavs
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Chamber Stress

The chamber stress combines mechanical and thermal stresses and considers thermal weakening

The Stress of the system is far lower than the intended FOS.

Minimum FOS is over 10

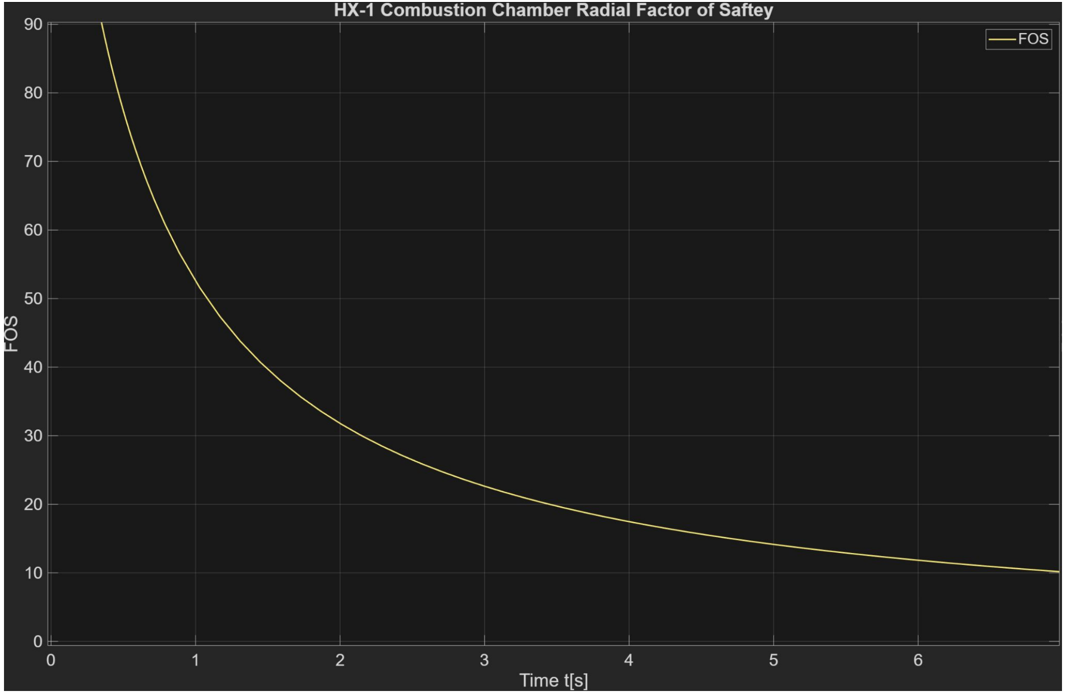
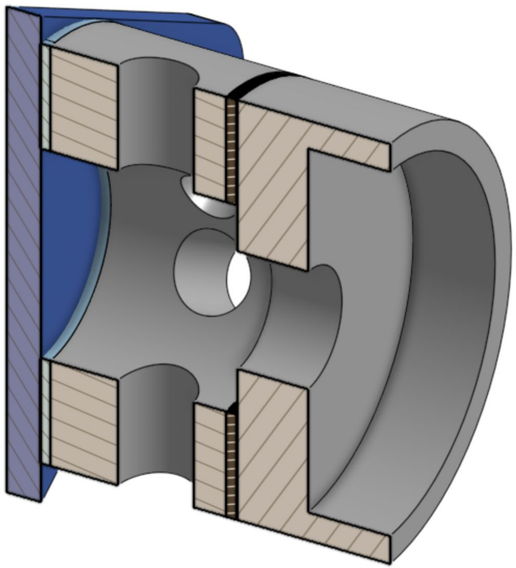


Diagram made by: Nicholas Quillin
Date:
Software:
Sources:

Current Speaker: Mr. Aero Mavs
Next Speaker: Ms. Aero Mavs

Forward Closure Subassembly

- The forward closure is designed to be modular and readily upgradable.
- The injector is mounted to the injector plate that is mounted between the NOX manifold and chamber.
- In the future we plan on using this to test a pintle injector design.



Model is made through Onshape
By: Jonathan White
Date: 10.17.2025

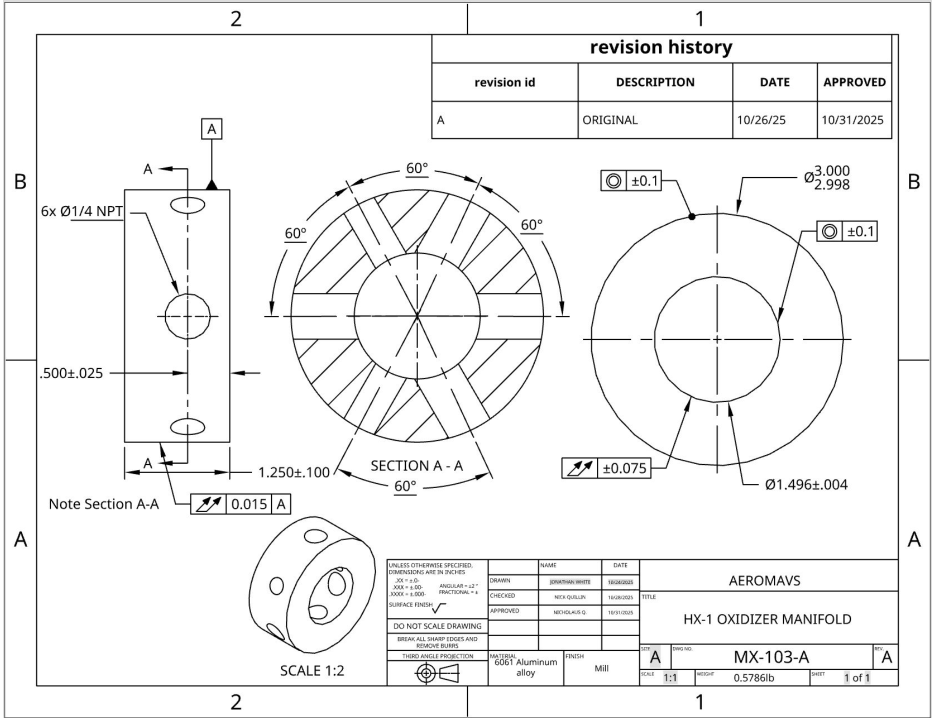
Current Speaker: Mr. Aero Mavs
Next Speaker: Ms. Aero Mavs

Intake Manifold

Intake manifold has six ¼NPT ports for various uses.

- 1x Pressure Ports
- 1x Temperature Ports
- 2x Nitrogen Extinguishing Line
- 2x Nitrous Feed Line

The use of 2 gas injection ports adds a level of redundancy if one gets blocked.



Injector Sizing

Due to the limitations of modelling we are not exactly sure how the flow will behave through inlets.

- Single Phase Incompressible (SPI): Traditional model used as first order approximate. Does not consider phase changes. Over estimates flow.
- Homogeneous Equilibrium Model (HEM) : Models the flow through the conservation of flow work. Assumes that the gas is always in equilibrium with external flow. Under estimates flow.
- Dyer Combined Model : Empirical combination of HEM and SPI that requires data.

Before conducting engine test, the flow rate will have to be determined and the closest match to the desired flow rate must be found through experimentation.

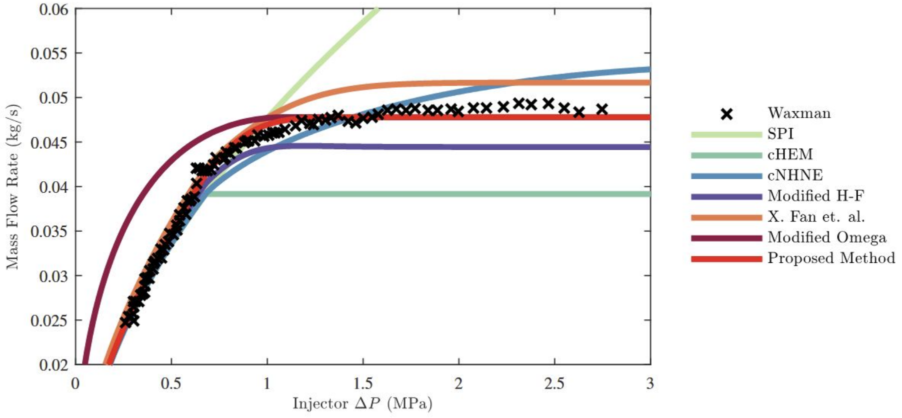


Fig. 2 Pressure drop and corresponding mass flow rate predictions of the models for a 1.5 mm, N_2O injector. Experimental data from identical Waxman [1] test case is also shown.

*From Design of Two-Phase Injectors Using Analytical and Numerical Methods with Application to Hybrid Rockets by Nino and Razavi

Injector Orifice Sizing

Using the Non-Homogeneous Non-Equilibrium (NHNE) Model (Niño and Razavi, 2019), the mass flux (G) and non-equilibrium parameter (K) were modeled using Matlab code & CoolProp thermodynamic properties of Nitrous.

- Inlet & outlet pressures were calculated from earlier ProPEP & thrust chamber simulations in Pascals.
- Assumed afternoon temperature for Hearne, Texas, in Kelvin.
- Inlet enthalpy calculated using inlet pressure and mixture quality of 0 (flow initially assumed to be only liquid).
- Outlet enthalpy calculated by assuming constant entropy from isentropic expansion of liquid Nitrous & outlet pressure.
- Inlet & outlet densities calculated using respective pressures and quality of 0, with outlet density representing Nitrous state just before flash boiling.
- Liquid discharge coefficient of 0.63 was used, as it is typically utilized for the NHNE model (Niño and Razavi, 2019).
- Program utilized inputs to calculate G_SPI & G_HEM, then used fsolve using the residuals of the NHNE flux & Non-Equilibrium Parameter equations (2 equations & 2 unknowns) to find G and K.
- Injector mass flow rate assumed to be 68 g/s from thrust chamber simulation.
- All units in the program inputs and outputs were converted to SI units, with the exception of A and D such that comparisons to imperial drill bit sizes could be made.
- <u>Results</u>:
    - K = 0.703
    - G = 3.07e+04 kg/(m^2 s)
    - A = 0.0034 in^2
    - D = 0.0467 in
    - 2 orifices of individual diameters 0.0467 in necessary to facilitate MFR.

```
function K = injectorParameters(x)
T = 20.6+273.15; % Hearne Temperature
P_i = (602+577)*6894.75729/2; % Average Injector Pressure (Slide 71 CDR)
P_o = 440*6894.75729; % Combustion Chamber Pressure (From Chamber Simulation)
h_i = py.CoolProp.CoolProp.PropsSI('H','P',P_i, 'Q',0, 'NitrousOxide'); % Injector Specific Enthalpy
s = py.CoolProp.CoolProp.PropsSI('S','P', P_i, 'Q', 0, 'NitrousOxide'); % Specific Entropy (Constant in Isentropic Expansion)
h_o = py.CoolProp.CoolProp.PropsSI('H','P', P_o, 'S', s, 'NitrousOxide'); % Chamber Specific Enthalpy
rho_i = py.CoolProp.CoolProp.PropsSI('D','P',P_i, 'Q',0, 'NitrousOxide'); % Nitrous Density @ Injector
rho_o = py.CoolProp.CoolProp.PropsSI('D','P', P_o, 'Q',0, 'NitrousOxide'); % Nitrous Density @ Chamber
P_sat = py.CoolProp.CoolProp.PropsSI('P','T', T, 'Q', 0, 'NitrousOxide'); % Saturation Pressure
C_d = 0.63; % Empirically Determined Discharge Coefficient from Design of 2-Phase Injectors

G_SPI = C_d*sqrt(2*rho_i*(P_i-P_o)); % Single-Phase Incompressible Mass Flux
G_HEM = C_d*rho_o*sqrt(2*(h_i-h_o)); % Homogeneous Equilibrium Model Mass Flux

K(1) = (1-1/(1+x(2)))*G_SPI+(1/(1+x(2)))*G_HEM-x(1);
K(2) = sqrt((P_i-P_o)/(P_sat-P_o))-x(2);
end
fun = @injectorParameters;
x0 = [0,0];
x = fsolve(fun,x0);
K = x(2);
G = x(1);
m_dot = 68/1000; % Injector Mass Flow Rate (kg/s)
A = m_dot/G*(100^2)/2.54^2; % Orifice Area (in^2)
n = 2; % # of orifices
D = 2*sqrt(A/(n*pi)); % Individual orifice diameter in inches
```

$$G = C_d\sqrt{2\rho_l(P_i - P_o)}$$

Single Phase Incompressible Model (SPI) Flux

$$G = C_d\rho_o\sqrt{2(h_i - h_o)}$$

Homogeneous Equilibrium Model (HEM) Flux

$$G = \left(1 - \frac{1}{1+\kappa}\right)G_{SPI} + \left(\frac{1}{1+\kappa}\right)G_{HEM}$$

NHNE Model (average of SPI & HEM) Flux

$$\kappa = \sqrt{\frac{P_i - P_o}{P_{sat} - P_o}}$$

Non-Equilibrium Parameter Equation

Niño, E. V., and Razavi, M. R., “Design of Two-Phase Injectors Using Analytical and Numerical Methods with Application to Hybrid Rockets,” AIAA Propulsion and Energy 2019 Forum, Indianapolis, IN, Aug. 2019. AIAA Paper 2019-4154. https://doi.org/10.2514/6.2019-4154

Injector Design

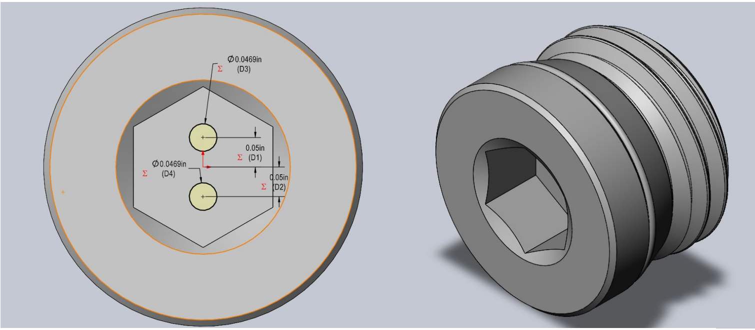
In order to facilitate the prototyping of various injectors, the injectors will be removable.

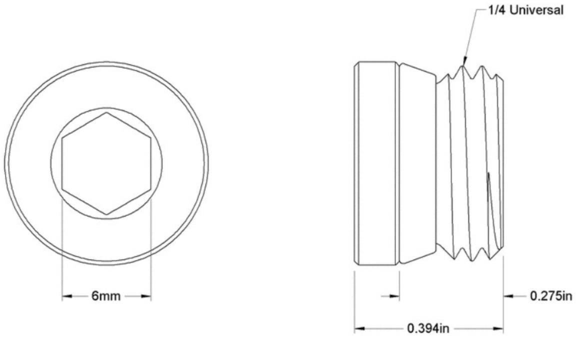
The first injector iteration will be machined out of a Nickel-Plated Brass Pipe Fitting Plug with Hex Drive, 1/4 Universal Male.This will simplify the machining process of the injector such that only the orifices will need to be drilled.

2 holes of drill bit size 3/64 in will be drilled into part for orifices.

- Drill bit size was chosen because 3/64 in diameter is equivalent to approximately Ø.0469 in, which serves as a close approximation to the previously calculated diameter of Ø.0467 in.
- Distance between orifices was set to be 0.1 in. This was chosen arbitrarily for the sake of geometrical simplicity.

For future research this part can be replaced with a pintle.

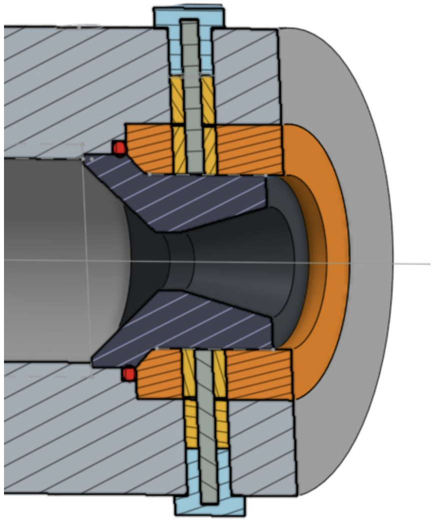




McMaster-Carr. "Nickel-Plated Brass Pipe Fitting, Plug with Hex Drive, 1/4 Universal Male." McMaster-Carr, n.d. https://www.mcmaster.com/4948N25/ (accessed Nov. 5, 2025).

Nozzle Subassembly

- A phenolic resin cast wide bore nozzle: 0.375”(9.525mm) throat diameter from RCS.
- The retaining system involves a Nylon 3D printed ring and shear pin that is designed to shear around 800 psi.
- To seal the nozzle we incorporate a high-temp O ring between the nozzle lip and the retaining ring to control the flow of gas exiting the nozzle.



Model is made through Onshape
By: Jonathan White
Date: 10.11.2025

Current Speaker: Mr. Aero Mavs
Next Speaker: Ms. Aero Mavs

Nozzle Failure System

Of the various systems considered the shear pin was chosen as the simplest and most practical method

	Cost	Analytical Complexity	Practical Considerations
Shear Pin	Medium	Low	Must be uniform Retention mechanism
Standoff	Medium	Medium Stress concentrator analysis	Machining Screw cannot strip before failure
Retaining Ring	Low	High FEA required	Groove may be worn down after repeated use

Retention Analysis

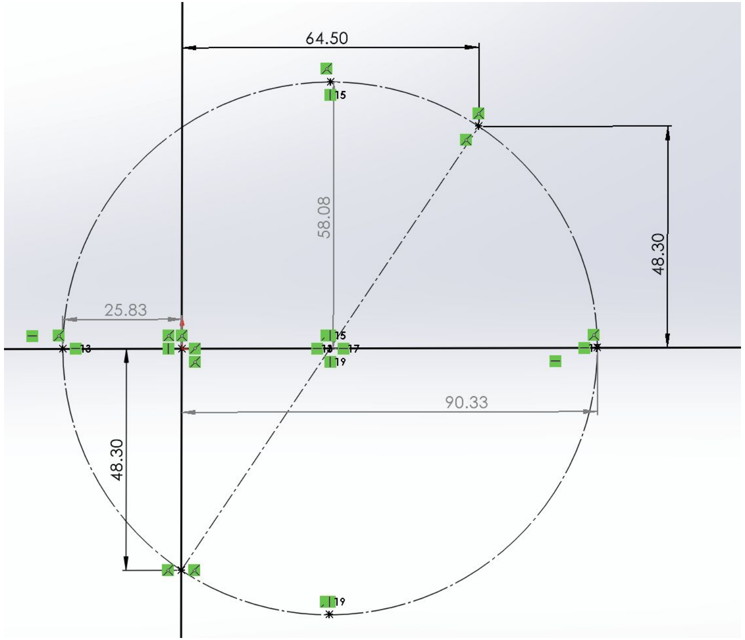
Due to the hardness and toughness of the pin, a drill bushing was added to distribute the force.

Simple analysis was done using solid mechanics textbook.

Assumptions

- The maximum bearing force the chamber would have to withstand was the maximum failure condition of 1300lb
- The Curved surface was approximated by a unwrapped plate with uniform rectangular cross sections
- The bushing is perfectly rigid, as the aluminum is much softer then the bushing
- The force is distributed along the surface based off of the normal angle => maximum stress was at the bottom most part of the hole.

FOS 3.06 was calculated for 6061 T6 Aluminum

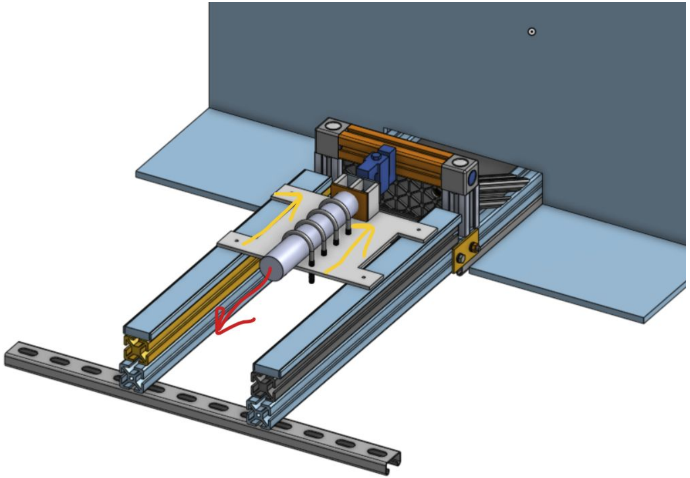


Highest Stress element mohr's circle
By: Nicholas Quillin
Date: 10.11.2025

Shear pin Mechanical Testing

In order to characterize the performance of the combustion chamber we are limiting the combustion chamber to have a max of 800 psi, and that results in an axial load of 5200N on the shear pins.

To test this we can place pressure on the combustion chamber and press it against the nozzle and shear pins and test at the limit it fractures.



Model is made through Onshape
By: Jonathan White
Date: 10.28.2025

Shear Mechanical Test Procedure:

1) Clear test stand.
2) Connect load cell normal to the engine (with nozzle and shear pins connected).
3) Zero the load cell, and begin the test by applying continuous increasing water pressure until the the shear pins fracture allowing the nozzle detach from the main combustion chamber.
4) Check the data and damage from the shear test.

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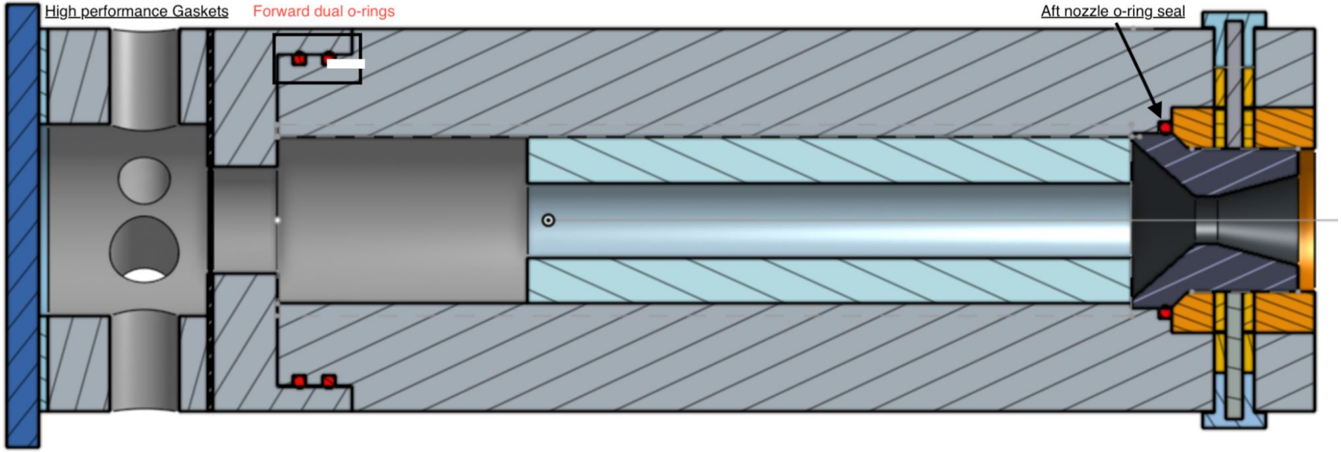
Next Speaker: Ms. Aero Mavs

Sealing and structure



"O-Ring Groove Design | Global O-Ring and seal," *Global O-rings and SEAL* Available at: https://www.globaloring.com/o-ring-groove-design/.
Engineering Drawing made on Onshape
By: Jonathan White
Date: 10.25.25

- The forward closure has 2 gaskets forward and aft consisting of gaskets rated for 2000 psi.
- The combustion chambers sealing mechanism is a dual radial seals.

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Next Speaker: Ms. Aero Mavs

Machining

Machine shop lab - Will machine our Combustion chamber casing.

Protospace Mfg - $1000 of credits Combustion chamber and forward closure.(3 day lead time)

Shear pins (open to discussion)

We will order all parts 2-3 weeks ahead of time

Nozzle Retaining ring

Oxidizer Manifold

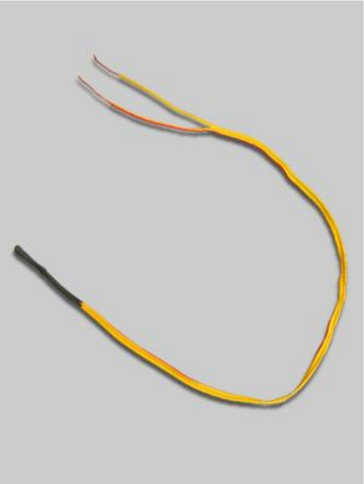
Current Speaker: Mr. Aero Mavs
Next Speaker: Ms. Aero Mavs

Ignition Subassembly

Ignition stub using nichrome wire - simplest as many licensing rocket use these and are within the standard of Tripoli.

Future plan for ignition subassembly:Referencing Benjamin Letourneau's (et.al.) research from the University of New Hampshire on a hybrid engine ignition subassembly.

Cite:Letourneau, B., Blampied, T., Johnson, M., and Pham, T., "Hybrid rocket engine ignition and control," *University of New Hampshire Scholars Repository* Available: https://scholars.unh.edu/honors/481/?utm_source=scholars.unh.edu%2Fhonors%2F481&utm_medium=PDF&utm_campaign=PDFCoverPages.

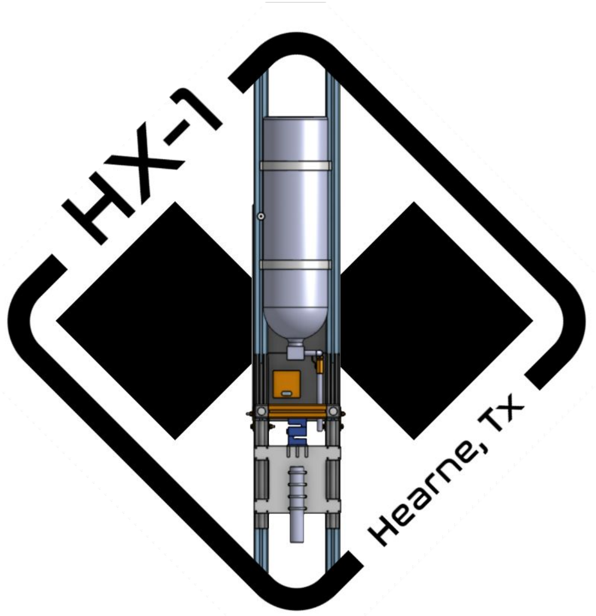


Apogee Components, I., "Apogee components - first fire starter for High Power Motors," *Model Rockets & How-To Rocketry Information* Available: https://www.apogeerockets.com/Rocket_Motors/AeroTech_Accessories/First_Fire_Starter?cPath=7_160&.

Current Speaker: Mr. Aero Mavs
Next Speaker: Ms. Aero Mavs

Summary -

Fluid System



The fluid system design encompasses the design of the oxidizer, filling, and any other pressurized fluids.

Current Speaker: Mr. Aero Mavs
Next Speaker: Ms. Aero Mavs

Nitrous oxide

Nitrous oxide was chosen because:

1. Only legal oxidizer for IREC
2. Has been demonstrated by other amateur groups (RICE and Half Cat)
3. Safety
4. Procurable

Safety cabinet in AeroMavs lab
Woolf Hall 113

Current Speaker: Mr. Aero Mavs
Next Speaker: Ms. Aero Mavs

Plumbing system

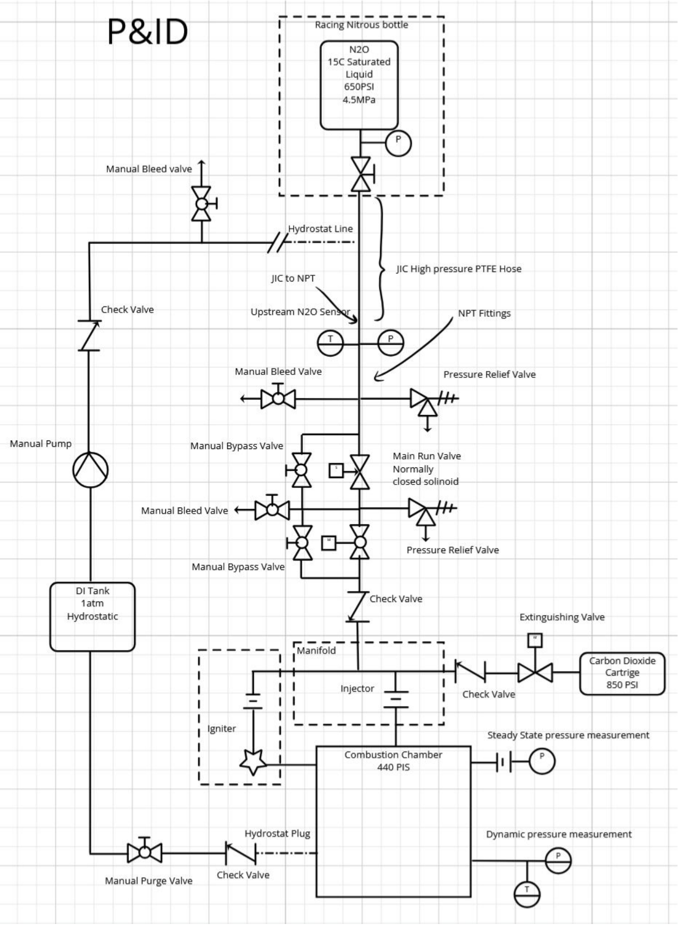
3 main assemblies, the main nitrous line, the secondary nitrogen gas extinguishing line, manual pump from DI water source.

Measuring the upstream /tank pressure with pressure transducer and tank pressure

Redundant valves allow to recover test from valve failures inspired by apollo lunar descent system

Diagram made by: Nicholas Quillin
Date:11.3.2025
Software:

Current Speaker: Mr. Aero Mavs
Next Speaker: Ms. Aero Mavs



Operation Loop

Igniter will be attached through secondary port in order to pr.

Cold flow test will be identical to hotfire except without the ignition charge. It will be used to characterize the blowdown of the Nitrous tank.

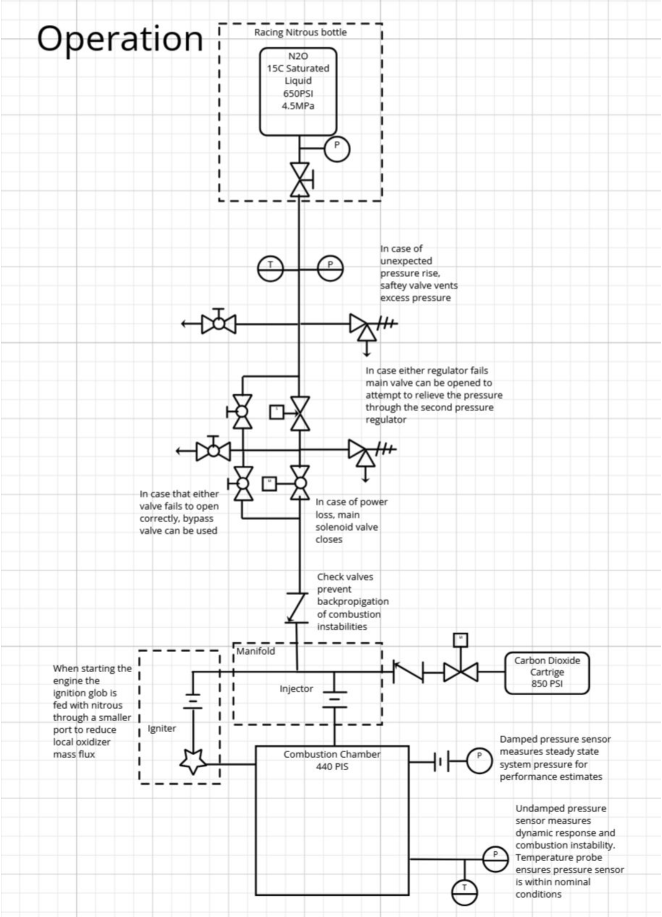


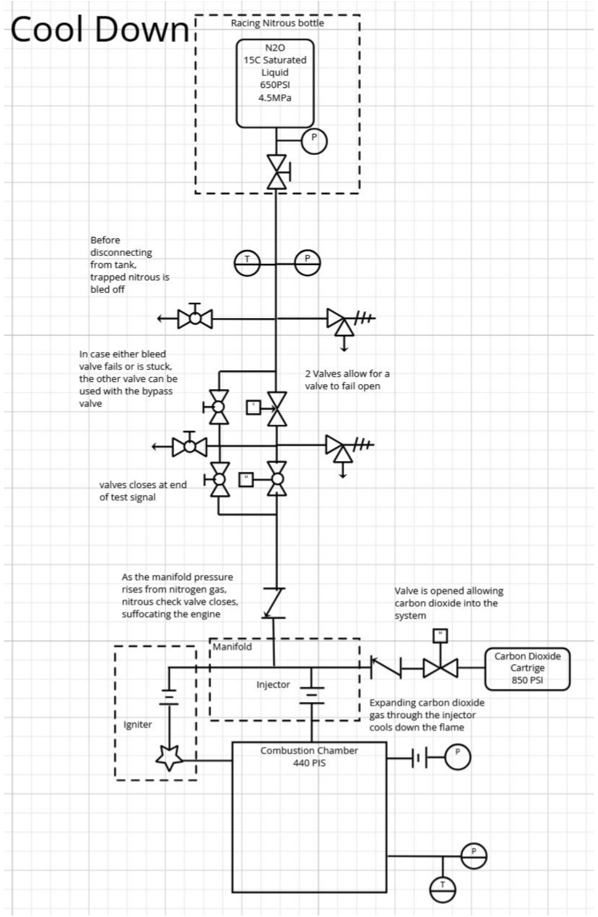
Diagram made by: Nicholas Quillin
Date:11.3.2025

Current Speaker: Mr. Aero Mavs
Next Speaker: Ms. Aero Mavs

Cool Down Loop

In order to take accurate measurements of fuel regression and prevent melting of the fuel grain, Nitrogen gas will be introduced into the chamber through the cooldown subsystem.

Diagram made by: Nicholas Quillin
Date:11.3.2025

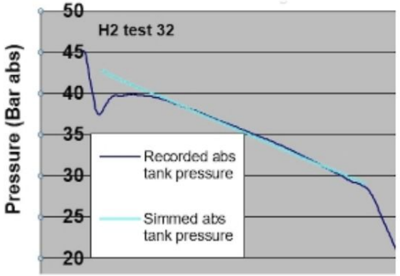


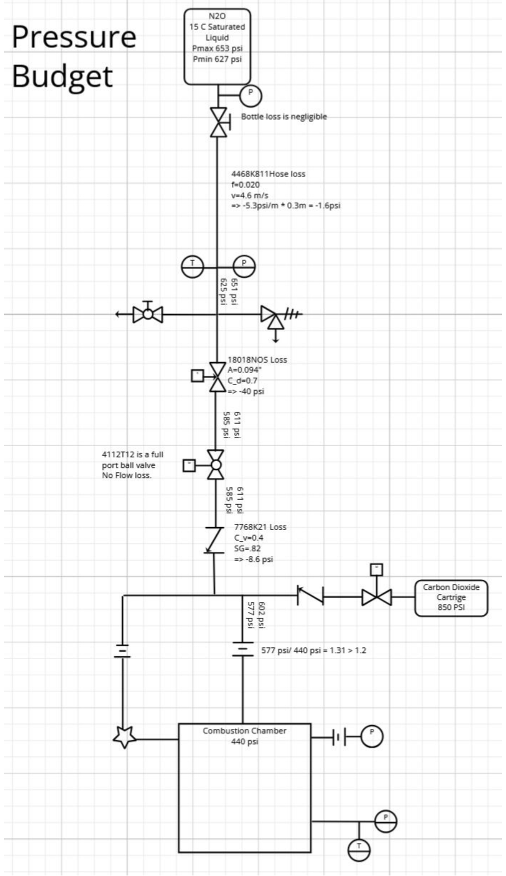
Current Speaker: Mr. Aero Mavs
Next Speaker: Ms. Aero Mavs

Pressure Profile

Pressure blowdown Calculated via conservative linear dP/dx = 0.7 from Humble textbook

- Similar hybrid engines have dP/dx of 0.75
- Nitrous express uses dP/dx = 0.8 on promotional material
- Adiabatic tank simulation predicts dP/dx = 0.72





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Next Speaker: Ms. Aero Mavs

Valves

Main valve 18018NOS Nitrous racing valve

- $114 much more affordable than industrial valves
- Tested for use with saturated Nitrous oxide
- Made to run off 12V DC car batteries, simplifying power train
- ¼"NPT to ⅛"NPT reduces number of fittings
- 3/32" orifice

Mcmaster carr High pressure ball valves

- Very affordable with high pressure rating
- Fluoroelastomer seals
- All Bleed valves
- Servo Actuated ball valves
- Proven in HCR 5100 System

Brass Body with Short Lever Handle

- Valve Type: Ball
- For Use With: Air, Argon, Helium, Krypton, Neon, Oil, Water, Xenon
- Seal Material: Fluoroelastomer Rubber

Pipe Size	Flow Coefficient (Cv)	Max. Pressure	Temperature Range, °F	Vacuum Rating, in. of Hg	Port Type	End-to-End Lg.		Each
NPT Female × NPT Female								
1/8 × 1/4	1.3	1000 psi @ 70° F	-15° to 300°	29	Full	2"	4112T811	$18.08
1/4 × 1/4	1.5	1000 psi @ 70° F	-15° to 300°	29	Full	1 15/16"	4112T22	17.26
NPT Female × NPT Male								
1/8 × 1/4	1.3	1000 psi @ 70° F	-15° to 300°	29	Full	1 15/16"	4112T812	24.95
1/4 × 1/4	1.5	1000 psi @ 70° F	-15° to 300°	29	Full	1 15/16"	4112T23	17.26
1/4 × 3/8	1.3	1000 psi @ 70° F	-15° to 300°	29	Full	2"	8393N102	25.18
NPT Male × NPT Male								
1/8 × 1/4	1.3	1000 psi @ 70° F	-15° to 300°	29	Full	2"	4112T814	25.69
1/4 × 1/4	1.5	1000 psi @ 70° F	-15° to 300°	29	Full	2 1/16"	4112T21	17.26

Current Speaker: Mr. Aero Mavs
Next Speaker: Ms. Aero Mavs

Actuator Testing Procedure

PPE Required

- Lab Coat
- Safety Glasses
- Gloves

Setup

- Ensure all PPE is on.
- One person will need to be observing the test, while another operates the testing hardware. All persons will need to be at least 30 feet away from the nozzle (in the case of testing at higher pressures) and behind the testing apparatus.
- The person conducting the test should ensure the system is properly assembled (pipe fitting SOP for reference) and that sensors are nominal. The load cells should read their predicted values, pressure transducers should read zero psig, and thermocouples should read ambient temperature.
- If any deviations are observed from anticipated measurements, the device should be recalibrated before beginning the test.
- All valves will initially be CLOSED before undergoing the test.
- At no point should the Maximum Expected Operating Pressure be exceeded.

Procedure

- Open the valves for the Nitrogen tank and set the regulator to 100 psig, filling the system with Nitrogen gas and allowing for purging.
- Actuate the oxidizer fill valve and then de-actuate it. The observer will communicate to the tester if the actuation was successful or not.
- Actuate the Run Tank venting valve and then de-actuate it. The observer will communicate to the hardware tester whether the actuation is successful or not.
- Actuate then de-actuate the Flow Control valve into the combustion chamber. The observer will communicate to the hardware tester whether the actuation is successful or not.
- Actuate then de-actuate the combustion chamber valve. The observer will communicate to the hardware tester whether the actuation is successful or not.

Current Speaker: Mr. Aero Mavs
Next Speaker: Ms. Aero Mavs

Actuator Testing Procedure

Unsuccessful actuation procedure

- If an actuation is unsuccessful at any point, the system dump valve will be opened, and the pressure source will be shut off. The valve will then need to be troubleshooted before restarting the test from the point of failure.
- Valve troubleshooting: After shutting off all pressure sources and draining the system, the valve will be remotely actuated again. If this does not work, a mechanical actuation must be attempted to inspect for any mechanical failures/freezing in the valve. If there is no mechanical failure or freezing, the person in charge of the hardware will approach the testing apparatus to ensure the component is receiving voltage from the valve controller.
- Restart the test after successful troubleshooting or disconnection from the system. If troubleshooting is unsuccessful, either the component or the controller will need to be replaced, depending on whether the failure source is the valve or the control system.
- After all components are verified to successfully actuate, drain the system, and shut off the pressure source, if no other testing is to be done. If undergoing other tests, keep the valves active for leak/hydrostatic testing.

Current Speaker: Mr. Aero Mavs
Next Speaker: Ms. Aero Mavs

Fittings and Connectors

Sourced from McMaster carr with various sizes

- Main feed line goes from ¼” to ⅛” at the inlet
- National Pipe Thread (NPT) attachments are semi-permanent
- Flared fittings used for parts that are frequently disconnected and and reconnected.
- Brass fittings are preferred because their NPT threads will not scratch steel threads allowing expensive components to be reused.

Current Speaker: Mr. Aero Mavs
Next Speaker: Ms. Aero Mavs

Electronic Sensors

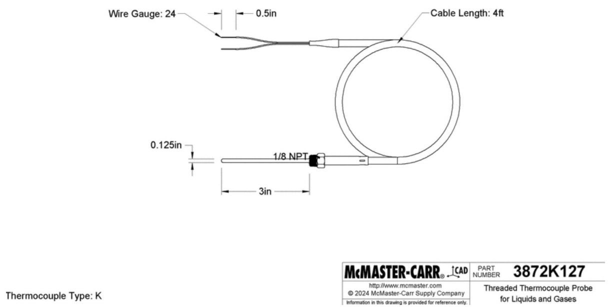
Used to measure real-time response

WIKA A-10 Pressure Transducer

- Already available stock
- Precalibrated and rated to 1000 psi
- 4-20 mA signal

K Type thermocouple

- Oxidizer temperature monitoring
- -6-20 mV signal



Current Speaker: Mr. Aero Mavs
Next Speaker: Ms. Aero Mavs

Physical Sensors

In addition to the analog sensors, analog sensors are used as a low cost alternative where precise, time sensitive data is not needed.

Analog pressure gages recorded via video capture on smartphones, and processed through vernier video analysis or python.

Current Speaker: Mr. Aero Mavs
Next Speaker: Ms. Aero Mavs

Pressure Safety System

The system only has one place where liquified gas can accumulate which is equipped with a safety pressure relief valve to prevent from system going critical

Used 1000 psi adjustable pressure relief valve from previous year REU project.

All trap points are also equipped with manual ball pressure relief valves.

Current Speaker: Mr. Aero Mavs
Next Speaker: Ms. Aero Mavs

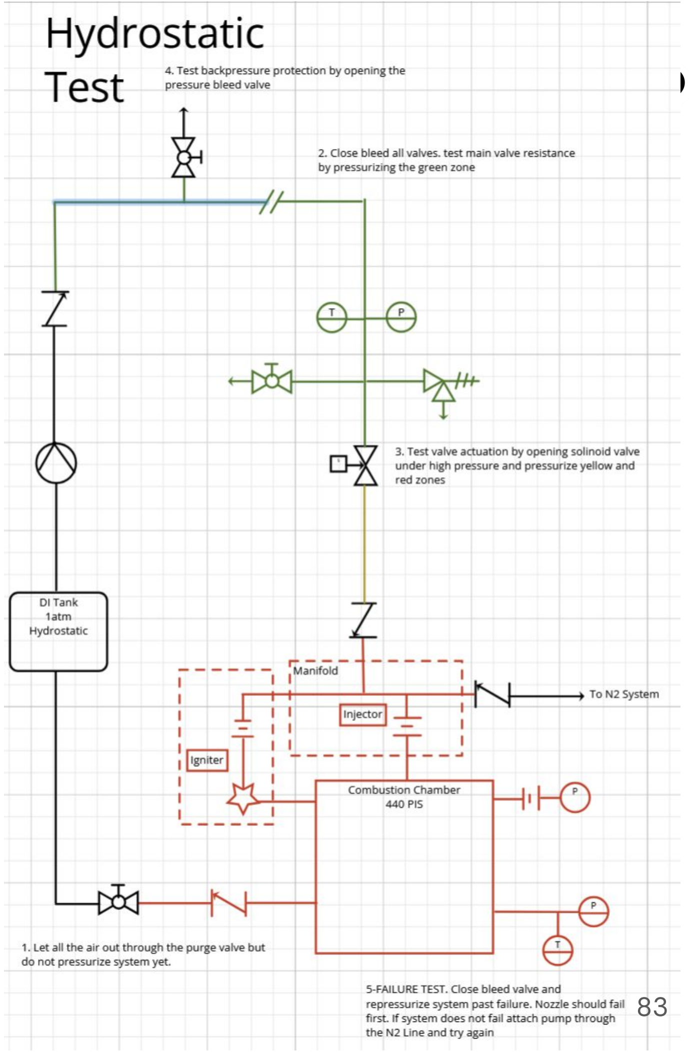
Hydrostatic Testing Loop

A hydrostatic test can be used to validate system can maintain pressure. First 4 test nondestructive, 5th test is destructive of the chamber.

Using a REX 6GDU5 hydrostatic pump to reduce variance from grainger.

Monitor pressure drops on transducers to ensure that the system has no leaks

50’ standoff distance



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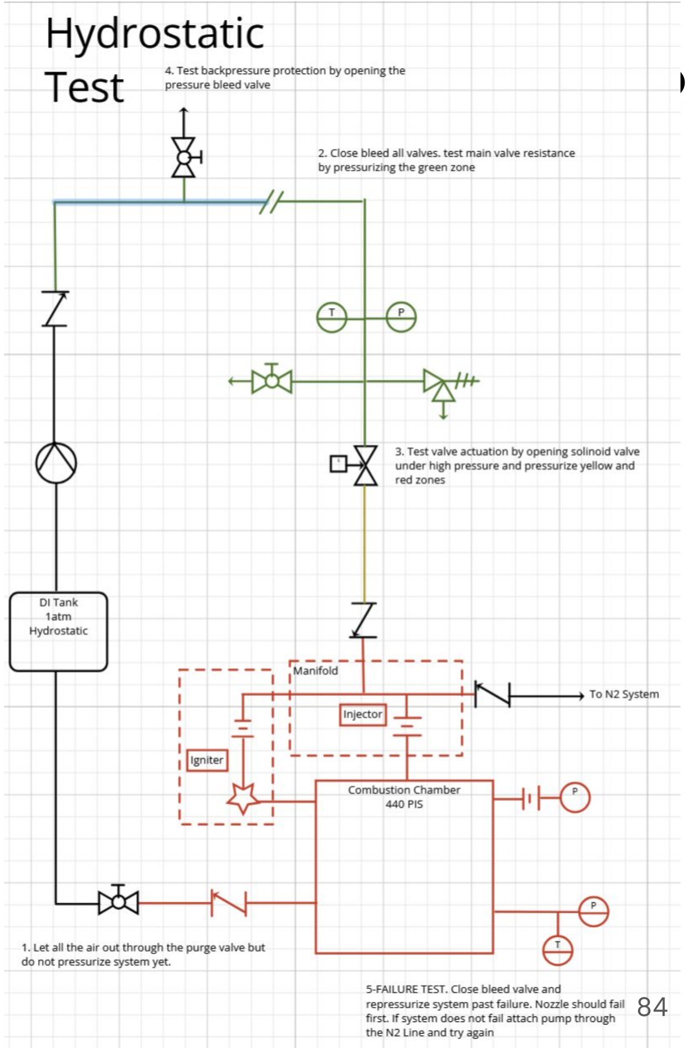
Hydrostatic Testing Loop



Current Speaker: Mr. Aero Mavs
Next Speaker: Ms. Aero Mavs

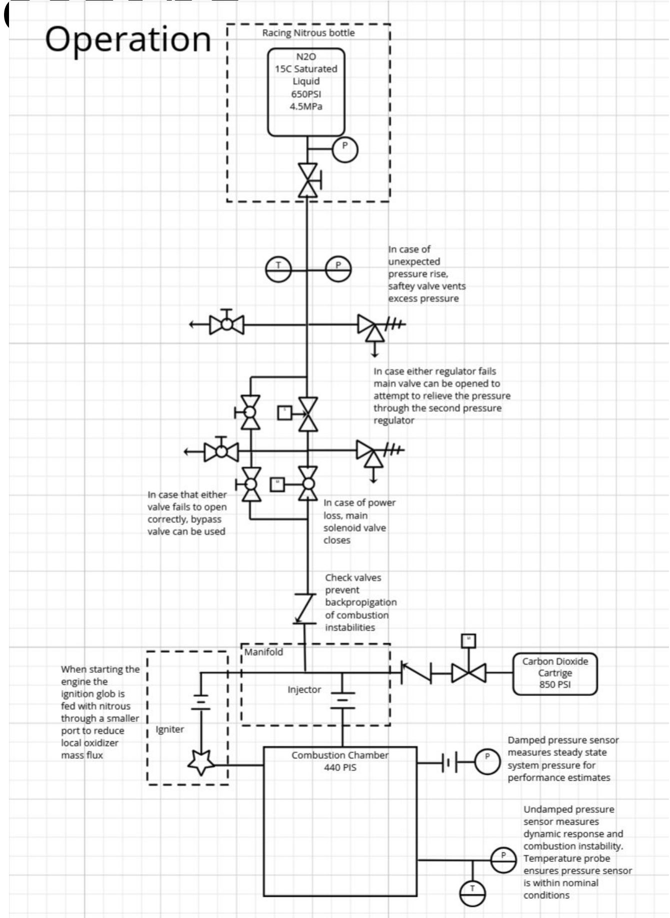
Cold Flow and Blowdown Testing

A Nitrous Cold flow test will be conducted to ensure system functions as intended & to observe the blowdown of the tank.

Pressure transducer on Nitrous fill line will be monitored to get pressure data over time.

Dump valve on fill line should be opened at any point to vent excess pressure.

50’ standoff distance



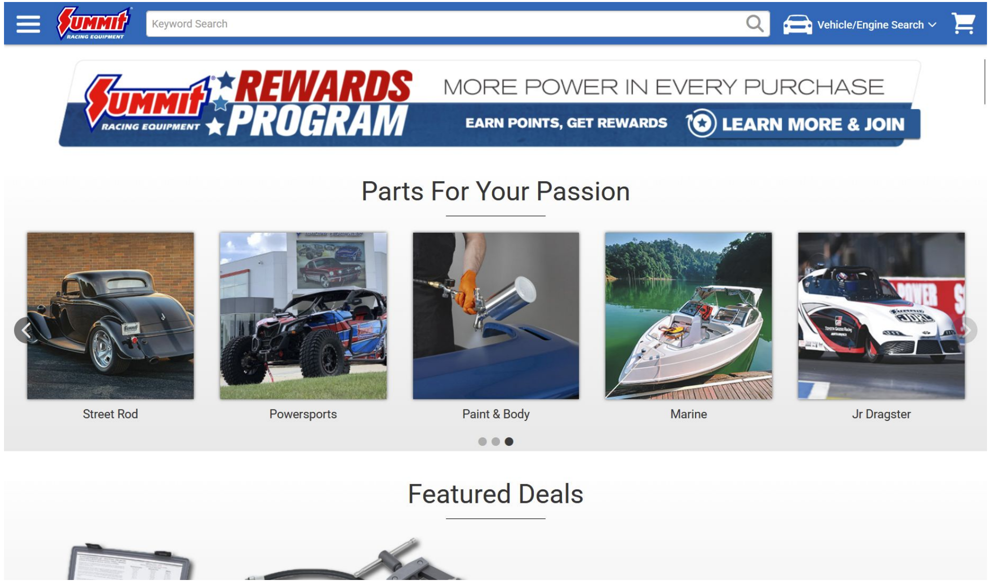
Current Speaker: Mr. Aero Mavs
Next Speaker: Ms. Aero Mavs

Compressed Gasses Sourcing

We can use disposable CO_2 cartridges for initial tests

Nitrous fill at start of day

- 10 lb Nitrous tank is large enough to be good for multiple tests. (Summit racing, Arlington Texas)



Cite: https://www.summitracing.com/

Current Speaker: Mr. Aero Mavs
Next Speaker: Ms. Aero Mavs

Nitrous Oxide Safety

Signal Word
DANGER

Hazards
May cause or intensify fire; oxidizer.
Contains gas under pressure; may explode if heated.
May cause drowsiness or dizziness.
May displace oxygen and cause rapid suffocation.

Precautionary Statements

Read label before use. Keep out of reach of children. If medical advice is needed, have product container or label at hand. Close valve after each use and when empty. Use equipment rated for cylinder pressure. Do not open valve until connected to equipment prepared for use. Use a back flow preventative device in the piping. Use only equipment of compatible materials of construction. Open valve slowly. Use only with equipment cleaned for Oxygen service. Always keep container in upright position.

* Nitrous SDS

Nitrous Bottle Storage

No Nitrous filled tank will be stored on campus.

Nitrous bottle fill before testing

Nitrous used in cold flow test

Nitrous used in hot fire

Nitrous blowdown and fully vented

Capped and sealed in closet empty.

WH113 is well ventilated with 8 ACH rating.

Current Speaker: Mr. Aero Mavs
Next Speaker: Ms. Aero Mavs

Oxygen Cleaning

1. Begin by cleaning as much as possible in a nonionic detergent bath
2. Ultrasonic clean with nonionic detergent
3. Triple rinse with DI water to dissolve surfactants
4. Ultrasonic clean with DI water in order to remove entrapped surfactants
5. Transfer to Isopropyl bath to dissolve water.
6. Place in toaster oven at 60 C

Where did we get this cleaning method?

Was it approved by EHS?

Current Speaker: Mr. Aero Mavs
Next Speaker: Ms. Aero Mavs

Cleaning Solvents

Crystal simple green

- Widely available and affordable
- Nonionic surfactants reduce the residue left behind
- 1-2% mixture
- Safe to handle
- Still leaves residue that must be removed

DI water

- Easily available at UTA labs
- Reduced residue
- Protects parts from airborne particles
- Wash away surfactants
- If not removed properly can cause icing conditions

ACS grade Isopropyl Alcohol

- Leaves practically no residue
- Highly volatile helping it easily be evacuated through bake

Current Speaker: Mr. Aero Mavs
Next Speaker: Ms. Aero Mavs

Ultrasonic Cleaner

Ultrasonic cleaner from Amazon

Allows for deep penetration for grease, oil, and leftover surfactants.

For use with detergent and DI water ONLY

- IPA fumes in the machine are dangerous and due to the heater element is a fire risk.

Image source:

IPA Safety

Signal Word
DANGER

Hazards
Highly flammable liquid and vapor Causes serious eye irritation May cause respiratory irritation May cause drowsiness or dizziness May cause damage to organs through prolonged or repeated exposure

Precautionary Statements Prevention
Wash face, hands and any exposed skin thoroughly after handling Do not breathe dust/fume/gas/mist/vapors/spray Use only outdoors or in a well-ventilated area Keep away from heat/sparks/open flames/hot surfaces. - No smoking Keep container tightly closed Ground/bond container and receiving equipment Use explosion-proof electrical/ventilating/lighting equipment Use only non-sparking tools Take precautionary measures against static discharge Wear protective gloves/protective clothing/eye protection/face protection Keep cool

* IPA SDS

IPA Safety Cont.

Response

IF INHALED: Remove person to fresh air and keep comfortable for breathing. Call a POISON CENTER or doctor if you feel unwell.
IF ON SKIN (or hair): Take off immediately all contaminated clothing. Rinse skin with water.
IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. If eye irritation persists: Get medical advice or attention.

Storage

Store locked up. Store in a well-ventilated place. Keep container tightly closed. Keep cool.

Disposal

Dispose of contents and container in accordance with all local, regional, national and international regulations.

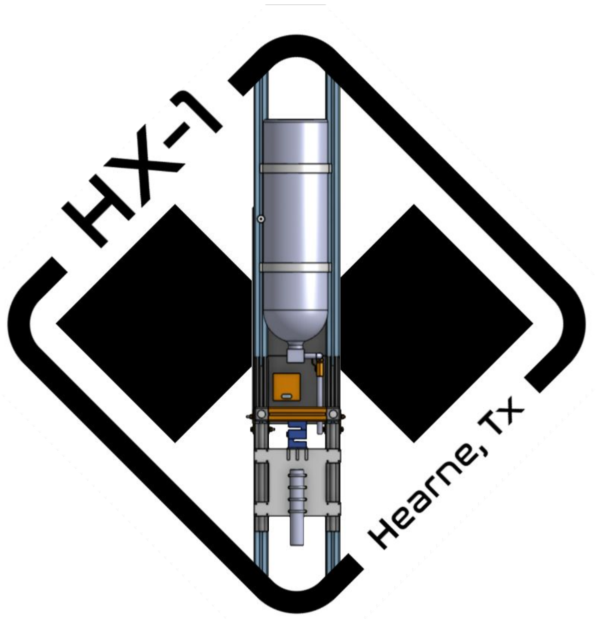
PPE

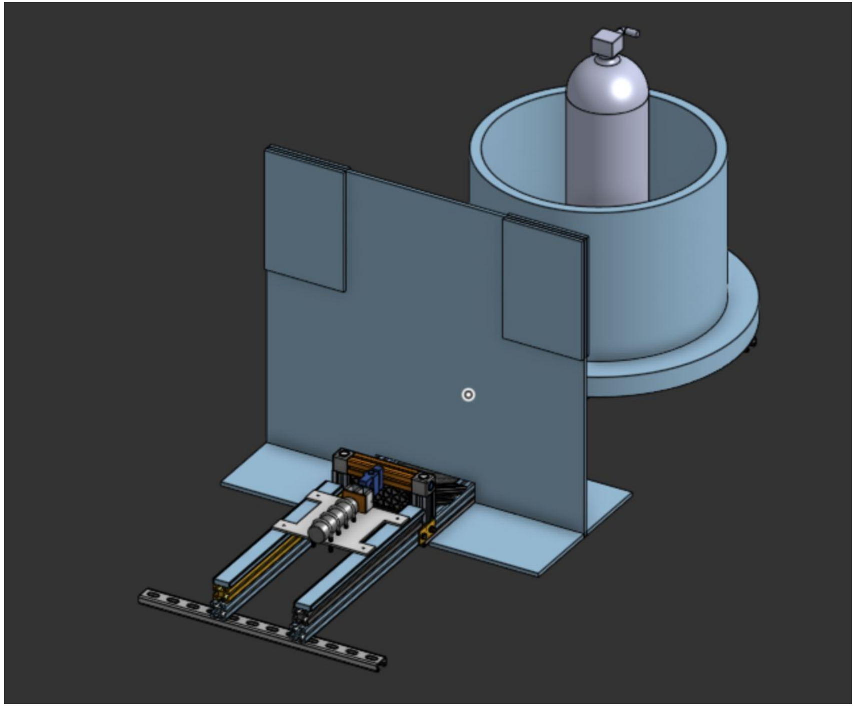
Avoid skin contact by wearing gloves. Wear a respirator equipped with a organic vapours (OV) filter.

Current Speaker: Mr. Aero Mavs   * IPA SDS
Next Speaker: Ms. Aero Mavs

Summary -

Test Stand





Model Made on Solidworks by AeroMavs Hybrid Division

Date:

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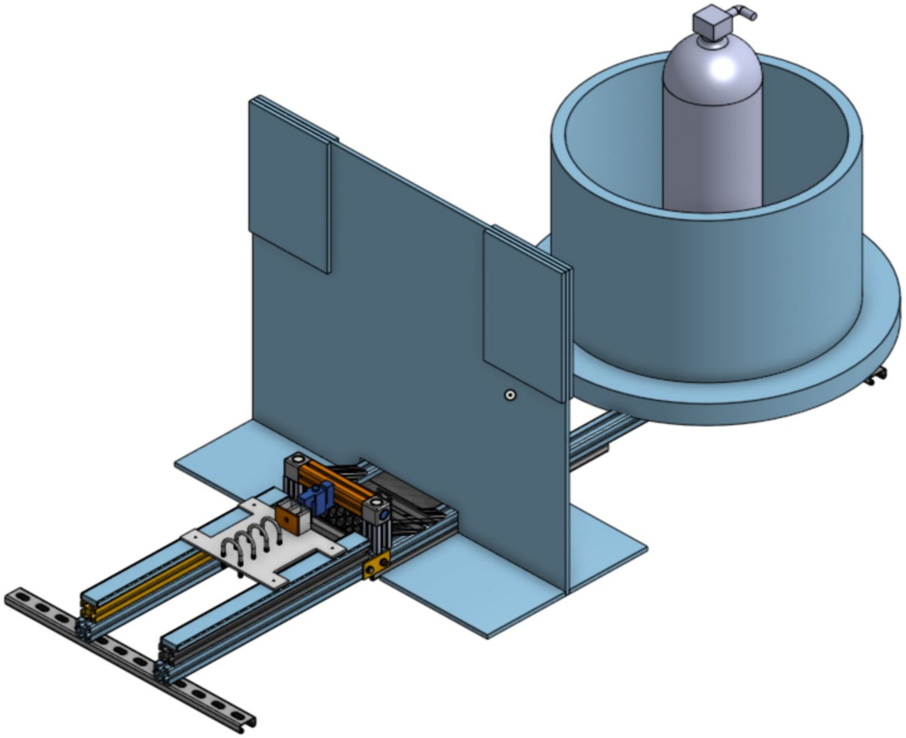
Test Stand

- Test stand rated for 1000 Ns of fo
- The dimensions are 66″x24″x6.5″.
- Instrumentation package
- The control hardware is aft of the vertical thrust beam.



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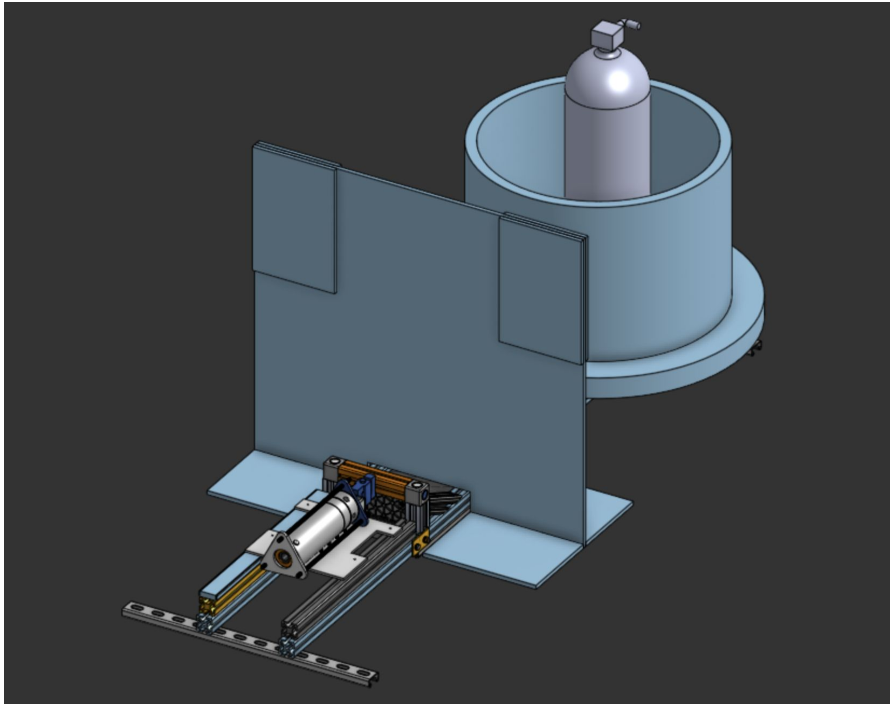
Configuration

The configuration was chosen because:

1. Test facility anchoring points were available from previous test fires by Rice University's Eclipse team
2. Cost factors: Majority of components were available in the AeroMavs stock.
3. Design safety factor (81.5).
4. Ease of fabrication and testing.



Model Made on Onshape by AeroMavs Hybrid Division

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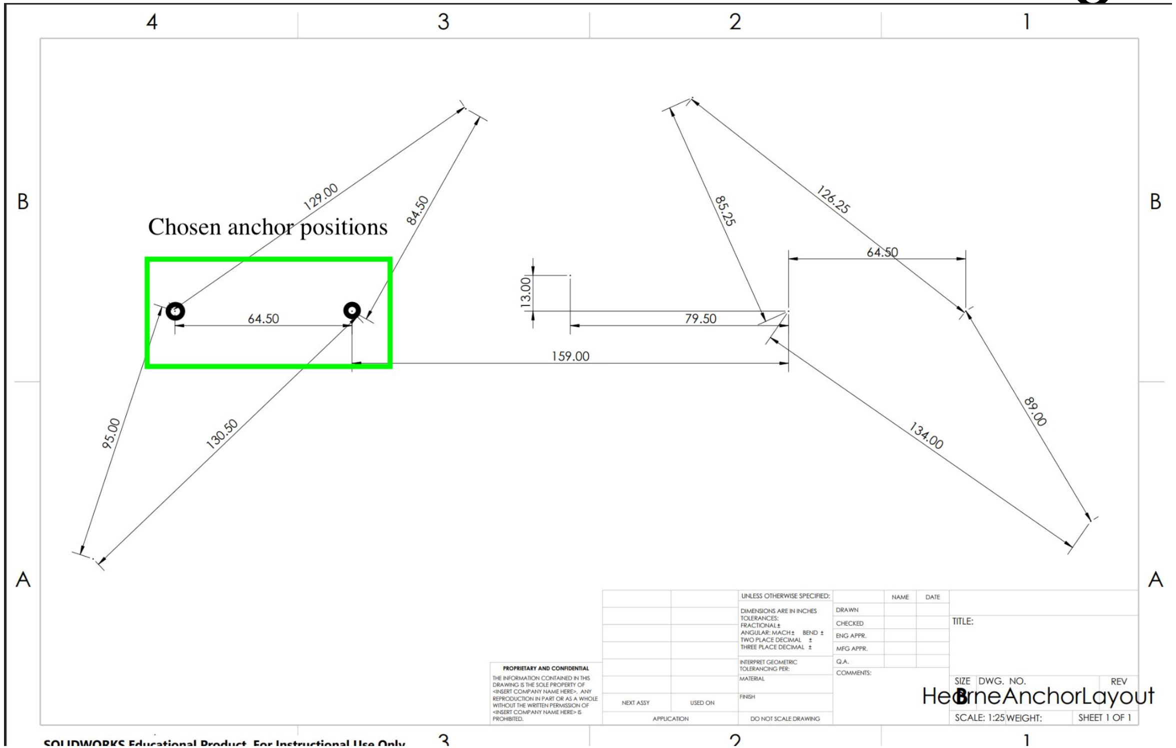
[4] Newlands, R. M., *Science and design of the Hybrid Rocket Engine*, Lulu, 2017.

Anchoring

Anchoring solution is 2 bolts with 64.5 inch spacing,at Hearne Tripoli launch facility.

- Anchor bolts are placed in concrete.



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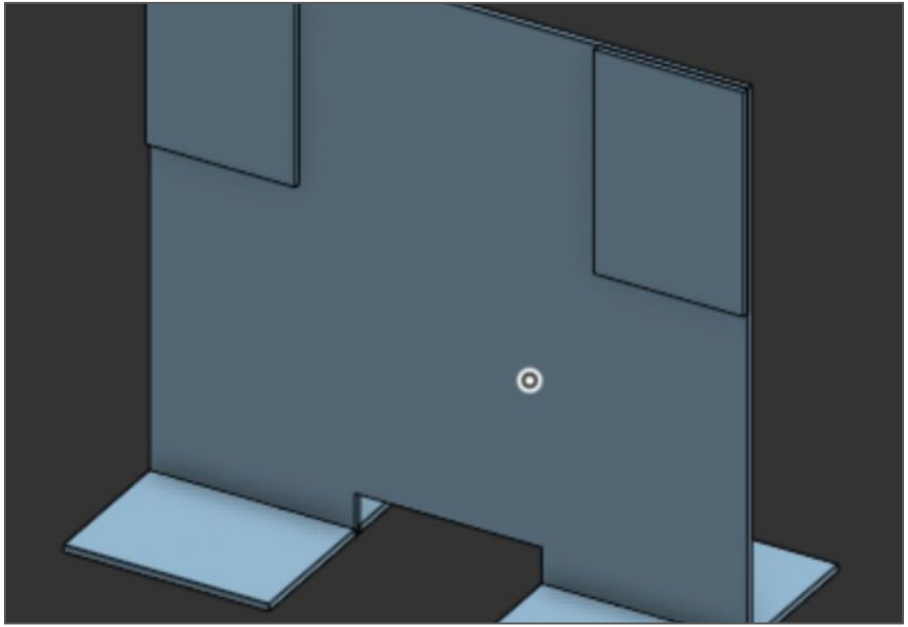
Thermal Shield

- Large wooden structure (0.375'' thick) to prevent any parts from impacting equipment placed behind the motor in case of structural failure.
- This shield is made from 2 2'x4' general purpose wooden panels.
- Weighed down by sandbags.
- Another option for shielding was a steel sheet.
  - Pros(Steel): Stronger
  - Cons(Steel): Expensive, difficult to machine and harder to fasten to the test stand.
- Suggested by Rice Eclipse



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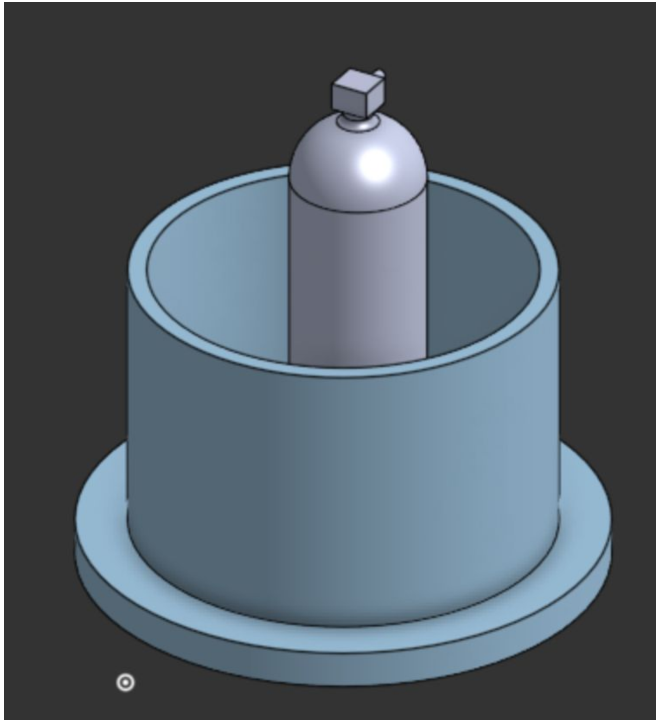
Nitrous Thermal Control

The nitrous tank will be thermally controlled by a water bath that contains a heater and cooling system.

Load cell measures weight of entire water bath + tank



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Chassis Assembly

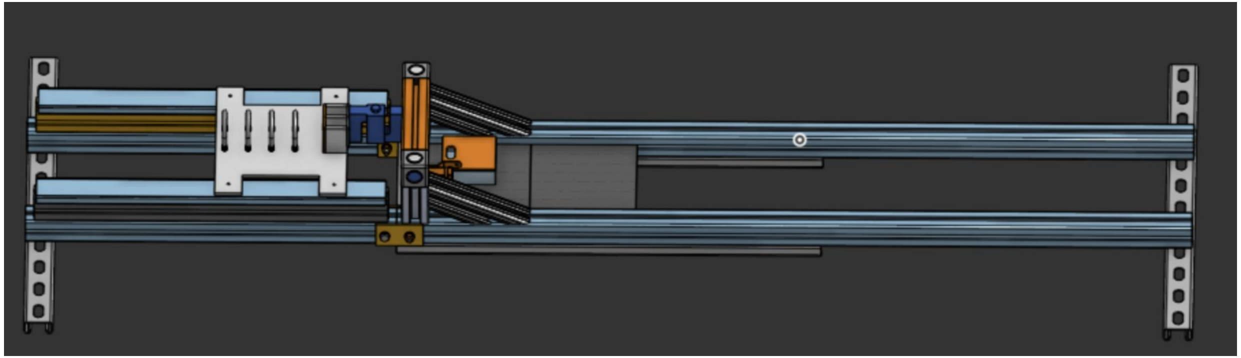
Frame construction:

Cots

- 12x Bolts
- 12x Nuts
- 1x All thread
- 16x washers

Surplus

- 4x Unistruts
- 10x T-slots
- 4x U bolts



Model Made on Solidworks by AeroMavs Hybrid Division

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Mounting

Ex-1 Mount

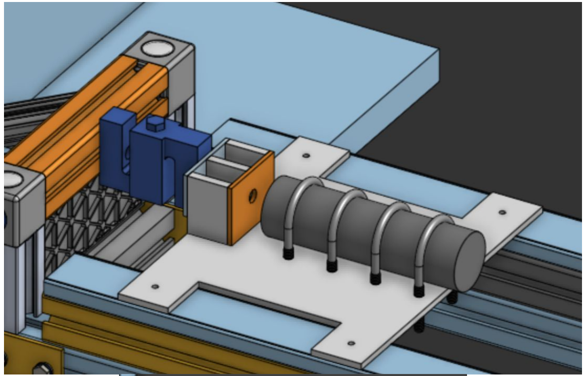
- Test bed combustion will be mounted to a plate using U bolts to secure it radially
- A vertical bracing to transfer axial motion into the load cell.
- The mounting plate will be on 2 linear telescoping rails.

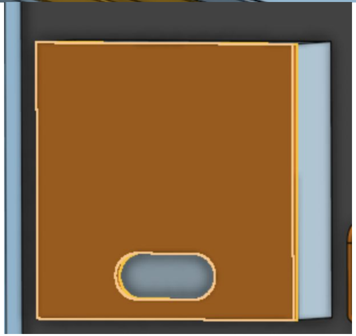
Electronics

- All electronics will be in waterproof closures protecting all components from the elements.

Oxidizer and nitrogen purge tank

- The nitrous tank will sit atop the test stand in a water bath. The nitrogen tank will be supported with a vertical beam.





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Transport and Assembly

- Built and assembled on campus.
- Transported to test site via car or pickup truck (will be confirmed closer to test day)

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Mechanical Analysis

- There are 4 contact points with the ground: forward/back anchor bolts, 2 unistrut beams
- The analysis conducted assumed the worst-case scenario with all of the thrust acting upon the forward bolt. The bolt was rated for 55 ksi in shear, which is far below the load applied to the stand by the motor.
- Motor acts low to ground for small reaction moment
- Minimum FOS = 81.5

Worst case scenario- is

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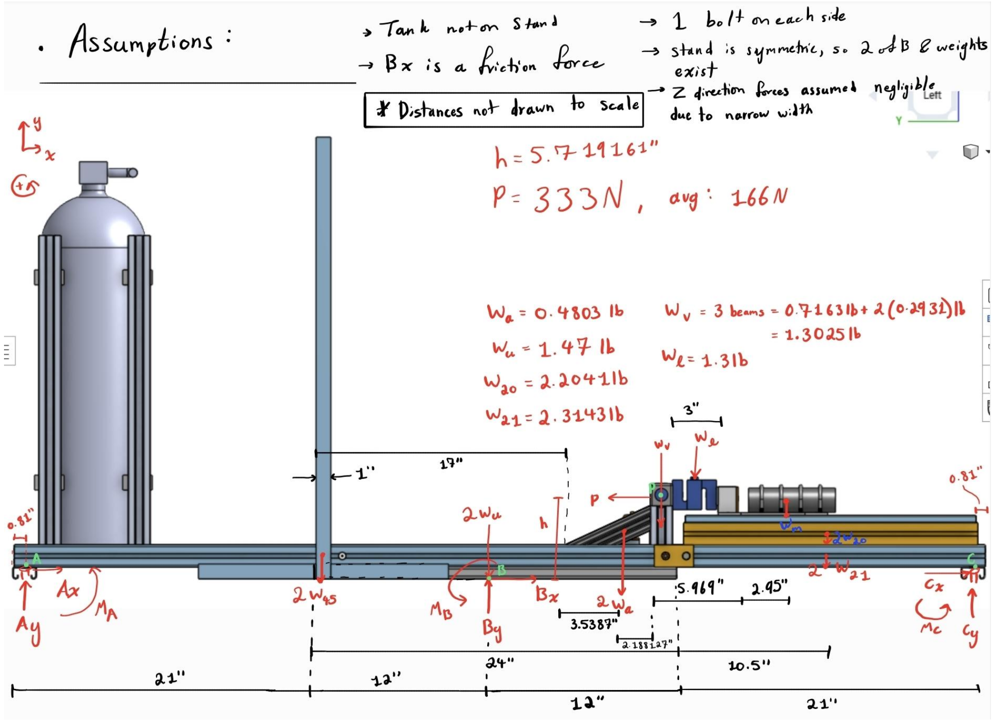
Anchor bolt data sheets

Mechanical Analysis

-



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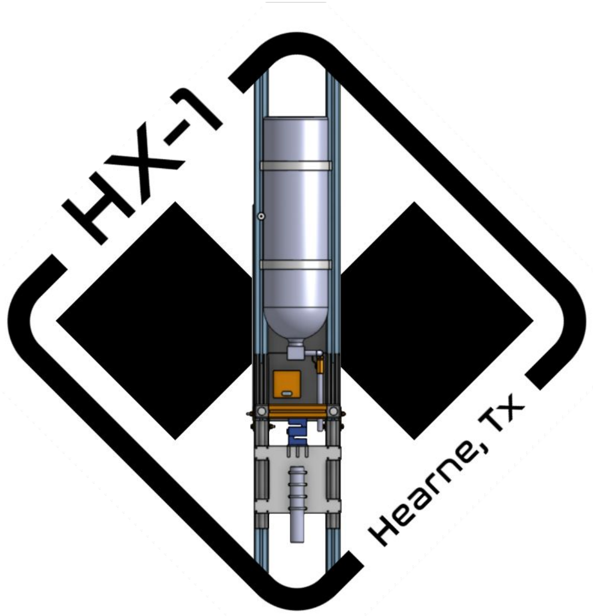
Anchor bolt data sheets

Summary -

Electronics



Electronics Tests and Sources

Communication between the Raspberry PI and host PC has been tested using dummy files.

The relay has been tested using a variable power supply in the campus electronics labs.

The solenoid will be tested using a battery with a high C or current output at 1 C. The relay will be used to turn it on and off.

PWM Module output has been be tested using an oscilloscope. It is as expected.

The motor will be tested using a the PWM module and a variable power supply in the electronics labs.

The thermocouple will be calibrated using a known temperature source

Testing will occur before exposure to pressurized gasses.

[8] Mariajose, P. F., *"Troubleshooting I2C Bus Protocol,"* Texas Instruments, Dallas, TX, Application Report SCAA106, Oct. 2009.

[9] Bishop, R. H., and ISA--The Instrumentation, Systems, and Automation Society, *The Mechatronics Handbook*, CRC Press, Boca Raton, FL, 2002.

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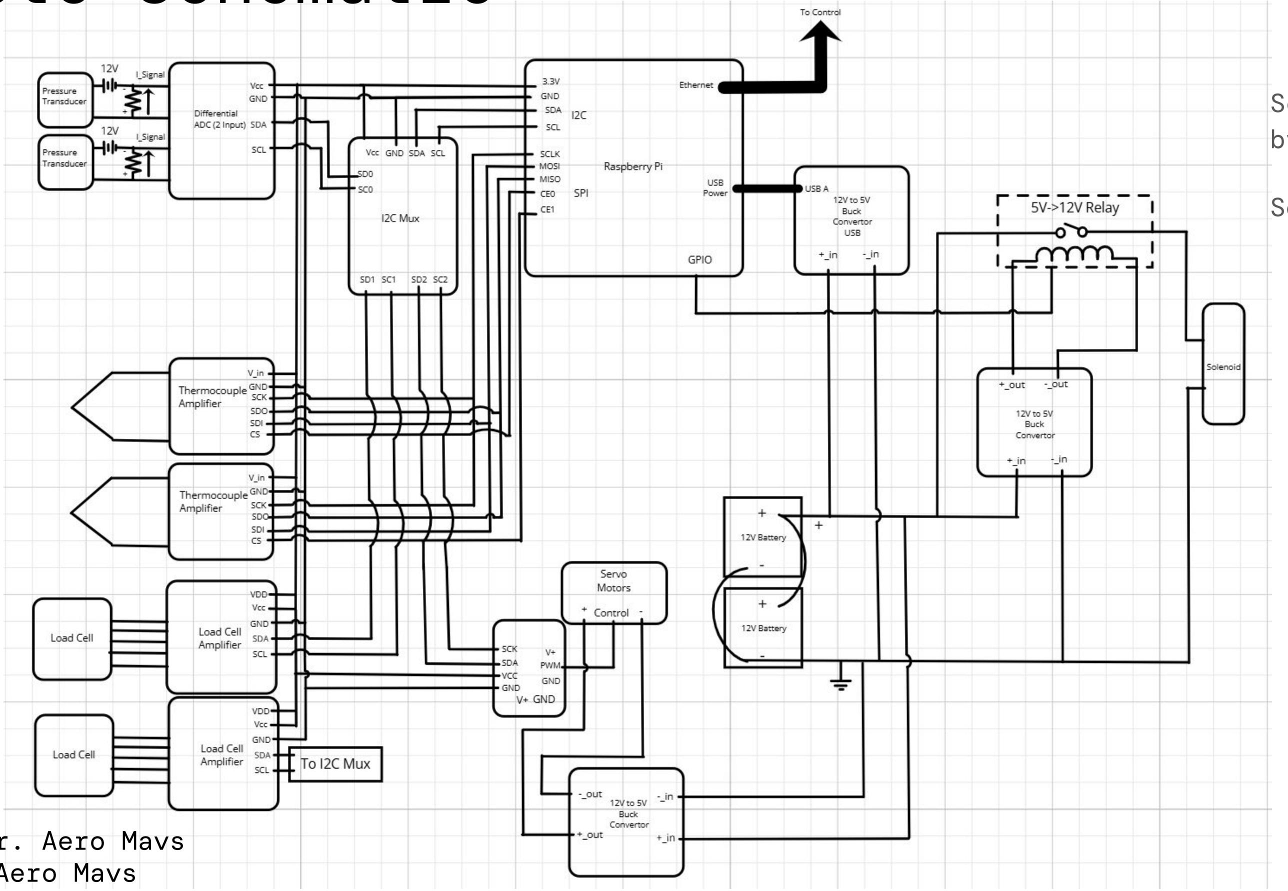
Complete Schematic



Schematic made by: Aly Haider

Software: IDroo

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Power

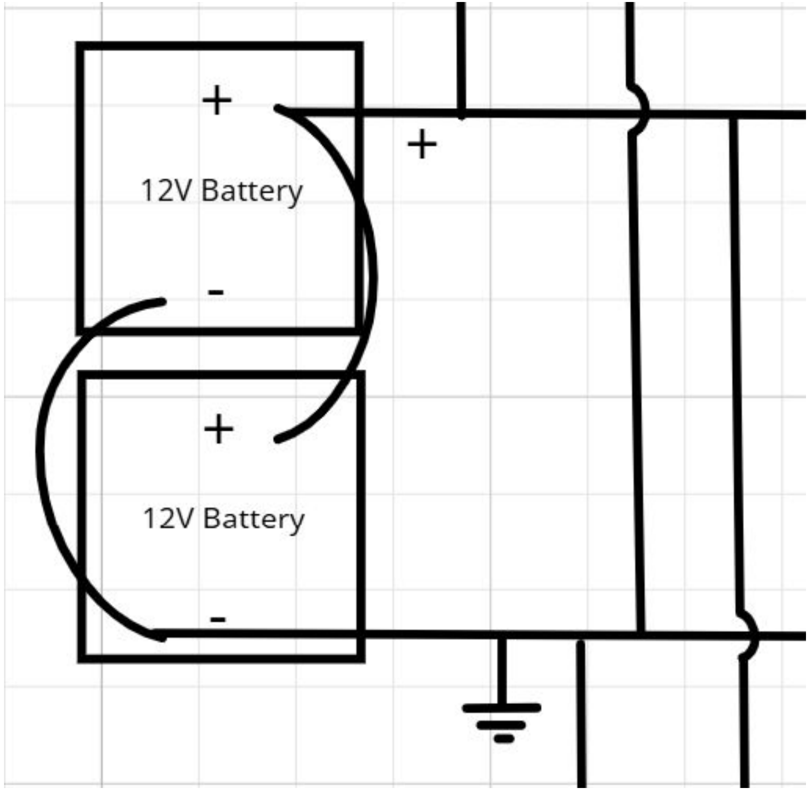
Consists of 2 ExpertPower EXP1270-2 12V 7Ah Sealed Lead Acid Batteries and 3 DIANN 12V to 5V Buck Convertor Modules for voltage regulation.

The buck convertors are shown with the part of the system they power.

The batteries provide primary power to the system. The batteries are wired in parallel to increase max current output. This is primarily to provide the current consumed by the solenoid and motors.

To power low(er) voltage components, buck converters are used to step down the 12V from the batteries to 5V. Each Buck convertor can also output 3A.

All components share a common ground. Some components like the solenoid and pressure transducers are wired to the battery without a buck convertor.



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Current Output

A total of 2 7Ah batteries were chosen due to the following estimated current requirements of the system.

The following maximum current draws are taken from specifications provided by the manufacturers:

- 700mA for the Raspberry PI 3b
- 10mA for the PCA9685 PWM motor controller
- 20 mA for the WIKA A10 pressure transducer
- .3mA for the ADS1115 ADC
- .035mA for the TCA9548A I2C multiplexor
- 2mA for the MAX31865 thermocouple amplifier
- 71.4mA for the JQC-3FF-S-Z relay
- 3A for each DS3225MG servo motor (9A total)
- 8A for the 18018NOS solenoid

The motors and solenoid are only expected to be on for 2-3 seconds, and not on at the same time. Therefore, the batteries are capable of providing the necessary power at 1C for standby use and 2C in brief bursts for active use, which should allow for an operation time of slightly less than 1 hour. Use of only 1 battery is possible, but 2 is better for redundancy and battery life.

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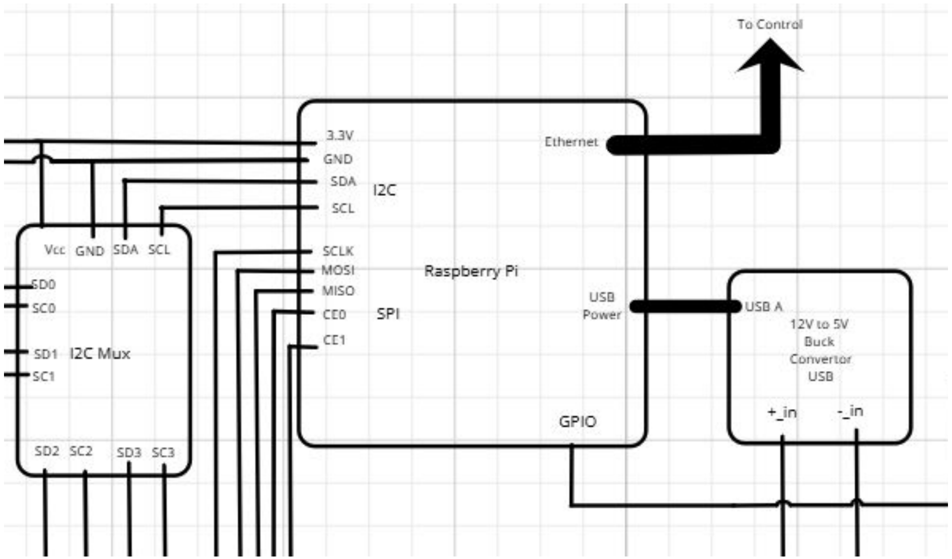
Data Processing/Communication

Consists of a Raspberry PI 3b, Acridine 12V to 5V Buck converter with USB-A output, USBA to Micro USB cable, 250 ft Ethernet cable, and a Adafruit TCA9548A I2C Multiplexer.

The PI takes in power exclusively using a micro usb cord. Therefore, a buck convertor with USB output and cable are needed to power it.

Components are wired to the PI using I2C and SPI. The I2C Multiplexer is used to address the potential for peripherals with the same address, which may cause issues if unaddressed [8].

The Ethernet cable is for transferring data to a host PC. We hope to transfer data in (almost) real time and also store it in the PI micro SD card



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Raspberry Pi Communication

To enable efficient data transfer, remote control, and testing, we established a secure SSH connection over Ethernet between a Raspberry Pi 3 and a host computer.

SSH (Secure Shell) was enabled on the Raspberry Pi to allow encrypted remote access and communication from the computer.

A direct Ethernet link was configured to create a private, wired network between both devices, ensuring reliable and low-latency communication.

Both the Raspberry Pi and the computer were assigned manual network settings to guarantee a stable, one-to-one connection.

Through SSH, the computer can send commands, transfer files, and monitor the Pi without using an external monitor or peripherals.

This setup allows for remote testing, software updates, and data acquisition in a controlled and secure environment.

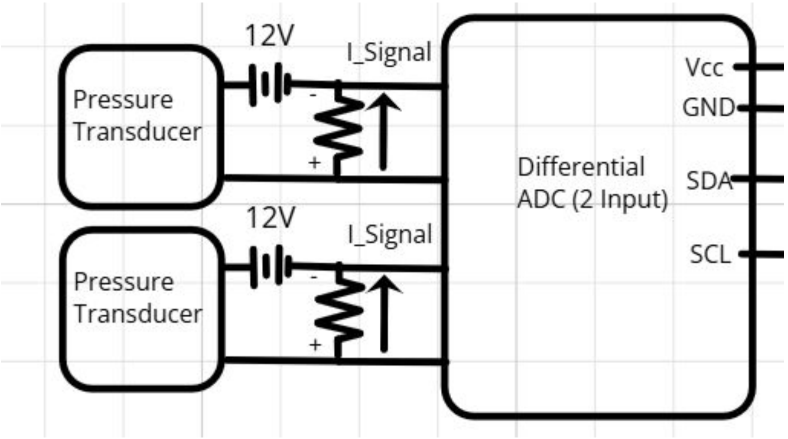
Pressure Sensor

Consists of 2 WIKA A10 Pressure transducers, and Adafruit ADS1115 ADC Breakout Board.

The 12V Voltage sources indicate a connection to the battery that was omitted for brevity.

Pressure transducer output is in the form of a current. This current is run through a sense resistor with a low resistance. The voltage difference across the resistor is then measured by the ADC.

The communication protocol between the ADC and Raspberry PI is I2C.



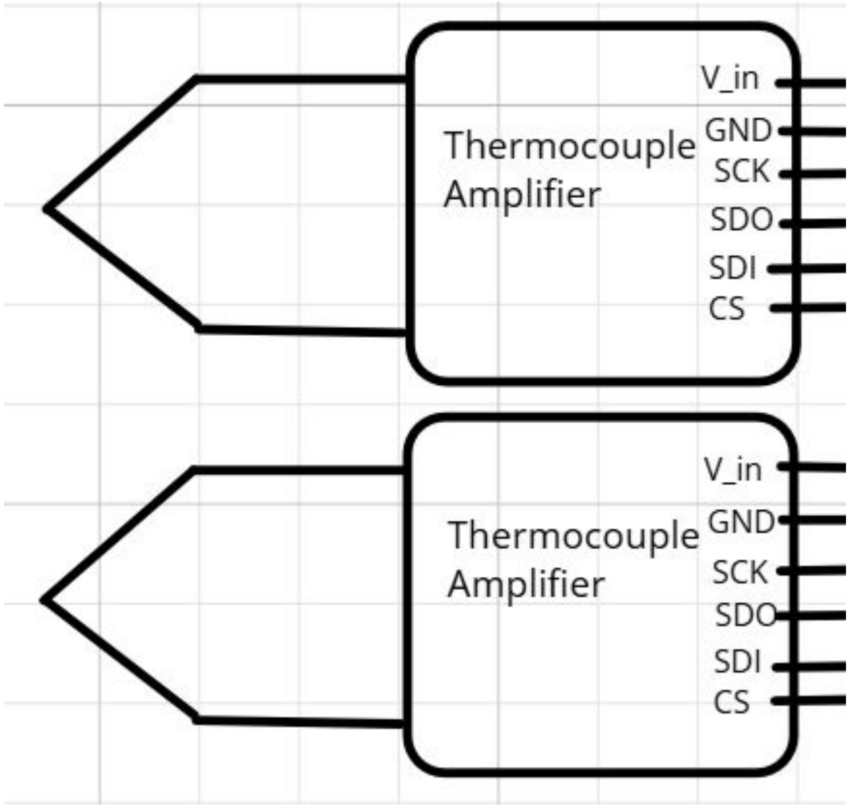
Thermal Sensor

Consists of Adafruit 3245 K type thermocouples and Adafruit MAX31865 thermocouple amplifier.

The thermocouple is type K and 39 inches long.

The breakout board has a 24 bit ADC and temperature sensor for cold junction compensation [9].

Data transferred to PI using SPI. The PI cannot handle more SPI inputs without a multiplexor. This may serve as a future design constraint.



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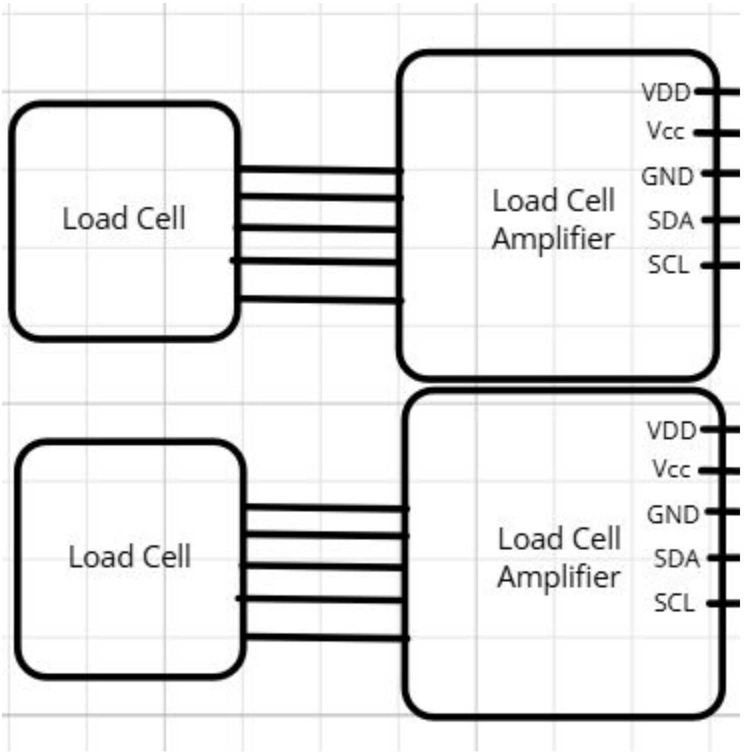
Thrust/Force Sensor

Consists of Load Cells, and Sparkfun HX711 Load Cell Amplifiers.

The load cell is piezoresistive and configured in a wheatstone bridge topology internally.

The amplifier excites the load cell and reads the voltage difference between the output points on the wheatstone bridge. It then feeds it into an internal ADC.

Data transferred to the PI using I2C.



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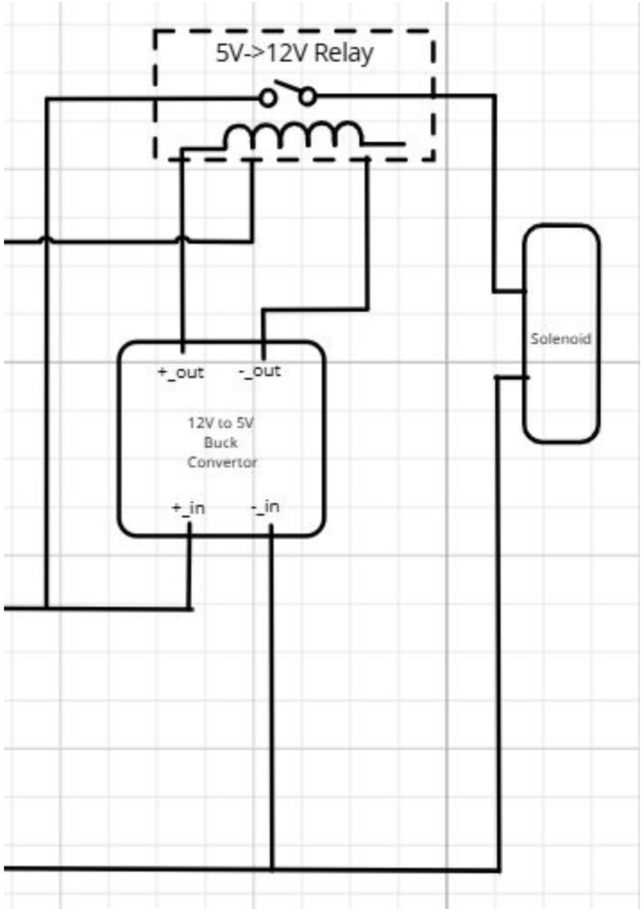
Solenoid Actuators

Consists of 18018NOS Nitrous Racing Valve and Tongling JQC-3FF-S-Z relay module.

The solenoid is powered by the 12V battery supply. This runs through the relay, which is used to control the solenoid.

The relay is normally open and operates at 5V. The relay is controlled using one of the PI's GPIO pins.

The relay's power is provided by a buck convertor. The solenoid is powered directly by the battery.



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Motor Actuators

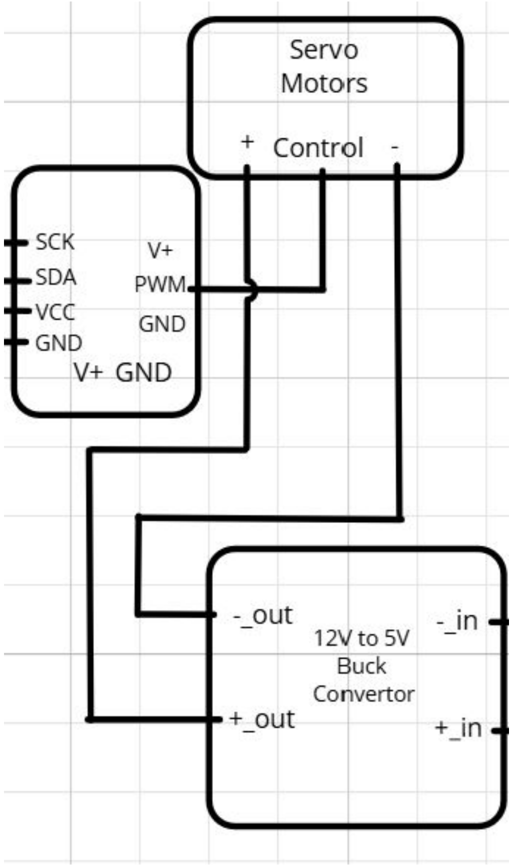
Consists of DSSERVO DS3225MG Servo Motors and Adafruit PCA9685 16 Channel PWM/Servo Driver.

The controller outputs PWM signals to the servos. The duty cycle of the PWM signal controls the degree of rotation of the servo motors. It should be noted that the servo motors are only capable of rotating between 0 and 180 degrees.

The buck convertor is used as a power source for the motors. The controller and convertor share a common ground.

Each additional motor consumes around 3A and requires an additional buck convertor.

Communication with the PI is conducted using I2C.



Current Speaker: Mr. Aero Mavs
Next Speaker: Ms. Aero Mavs

Summary -

References

[1] “Mojave Sphinx,” *Half Cat Rocketry* Available: https://www.halfcatrocketry.com/mojave-sphinx.

[2] Ogata, K., *Modern Control Engineering*, Prentice Hall, 2022.

[3] Nise, N. S., *Control Systems Engineering*, Hoboken, NJ: Wiley, 2015.

[4] Newlands, R. M., *Science and design of the Hybrid Rocket Engine*, Lulu, 2017.

[5] Humble, R. W., Henry, G. N., and Larson, W. J., *Space Propulsion Analysis and design*, New York: McGraw-Hill, 2007.

[6] Sutton, G. P., and Biblarz, O., *Rocket Propulsion Elements, Ninth Edition*, John Wiley & Sons (US), 2017.

[7] Apogee Components, I., “Apogee components - first fire starter for High Power Motors,” *Model Rockets & How-To Rocketry Information* Available: https://www.apogeerockets.com/Rocket_Motors/AeroTech_Accessories/First_Fire_Starter?cPath=7_160&.

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[9] Bishop, R. H., and ISA--The Instrumentation, Systems, and Automation Society, *The Mechatronics Handbook*, CRC Press, Boca Raton, FL, 2002.

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Thank You