Harvard Rocket Propulsion Group

Expanding Harvard’s engineering footprint

Developing rocket engineers of the future

Table of Contents:

Overview

Propulsion

Phase 0

Phase 1

Phase 2

Rocketry

Administration

Appendix

Overview

Objectives and Timeline

Why A Rocket Propulsion Project?

Core Beneficiaries of HRPG:

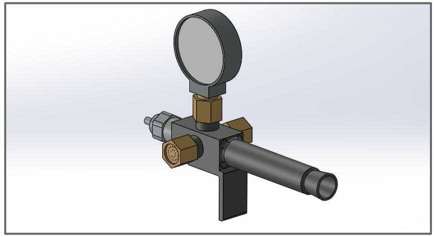
1. **Students** - Provide student engineers with industry-relevant, hands-on mechanical, electrical, aerospace, materials and systems engineering experience and training
2. **University -** Engineering programs across the country are defined not just by their competitive curriculums, but by the initiative and performance of their student engineering teams
3. **Industry** - Establish relationships with a network of accomplished engineering and technology alumni, peer universities, and corporate partners

Why Liquid Propulsion?

Benefits of Liquid Propulsion:

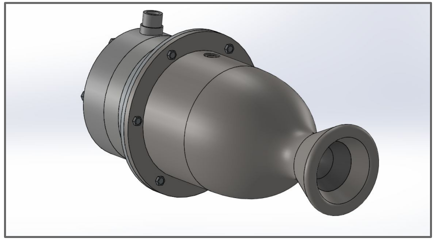
1. **Surmountable:** Liquid rocket engines are difficult, but possible. Dozens of university rocketry teams in the last 5 years have begun tackling this challenge demonstrating the commitment and excellence of their engineers
2. **Scalable:** This project scales steadily over time in both difficulty and risk, allowing students to develop competence in smaller components of the project building up to the main objectives
3. **Applicable:** Revolutions in propulsion technology are paving the way to the Moon and Mars. Lessons learned in Harvard's labs will prepare students to enter this cutting edge industry out of college

Project Outline



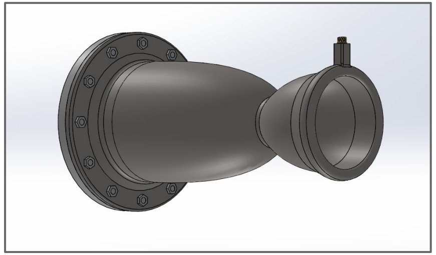
Phase 0 - Igniter

- Procedure development
- Pressure systems practice
- Test stand construction
- Safety evaluation



Phase 1 - Initial Engine

- Liquid bi-propellant experience
- Fuel injection experience
- Cold-flow tests
- Hot-fire tests



Phase 2 - Advanced Engine

- Regenerative cooling
- Advanced propellant injection
- Longer-duration hot-fires
- Higher-thrust tests

Technical Objectives and Methodology

Phase 0 Gas/Liquid Spark Igniter	Phase 1 Initial Engine	Phase 2 Advanced Engine
Thrust: 10-15 lbf	**Thrust:** 350-500 lbf	**Thrust:** 1000 lbf
Fuel: GOX/TBD	**Fuel:** TBD	**Fuel:** TBD
Cooling: N/A	**Cooling:** TBD	**Cooling:** Regen/Film
Injection: Like-Impinging	**Injection:** Pintle	**Injection:** TBD
Test Site: TBD	**Test Site:** TBD	**Test Site:** TBD

Phase 0 Timeline (2021-2022)

Summer 2021: Initial Research Phase

- Literature review
- Peer organization interviews
- Supplier/sponsor research

Fall 2021: Outline Phase

- Initial test stand design
- Initial spark igniter design
- Harvard support and funding

Fall-Spring 2022: Development Phase

- Team assembly and training
- Igniter + test stand design
- Part acquisition

May 2022: Testing Phase

- Spark igniter assembly
- Igniter hot fire
- Initial liquid engine development

Phase 1-2 Timeline (2022-2025)

Combustor Design

- Design iteration
- Test stand part acquisition
- Zucrow Outreach

Water Flow Test Stand

- V1 injector assembly
- Test stand assembly
- Water flow tests

Cryo Feed System

- Feed system design
- Part acquisition
- Initial assembly

Engine 1 Assembly

- Feed system assembly
- Combustor assembly
- Hot fire

Regen Chamber

- Design iteration
- Injector development
- Part acquisition

Propulsion

Liquid Engine Development

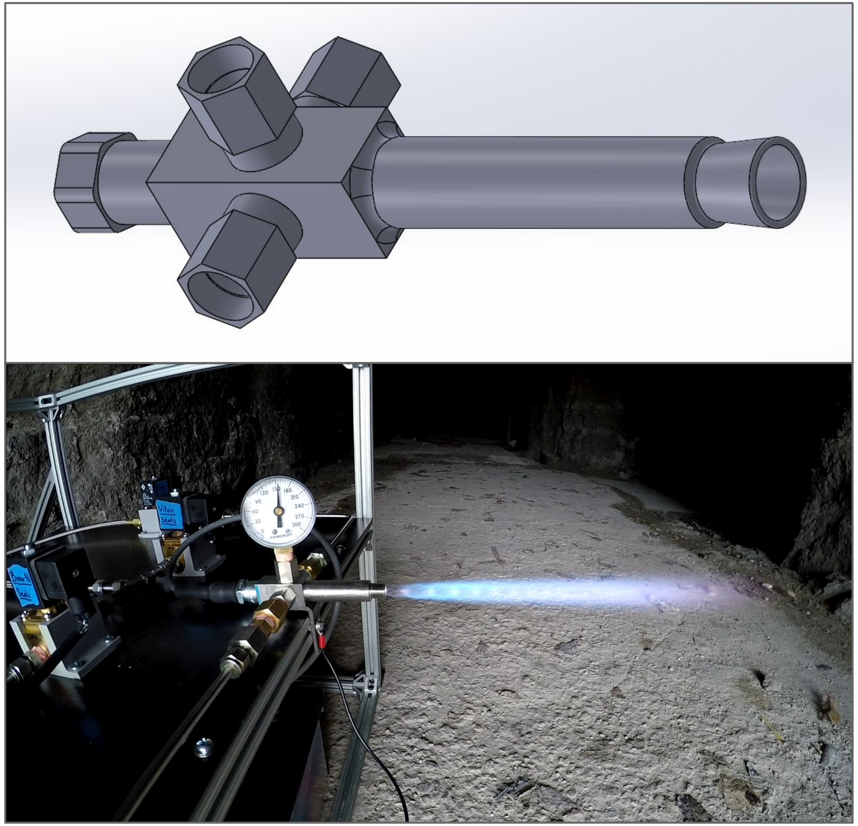
Phase 0: Initial Propulsion

Introduction to Rocket Engines

Igniter Design

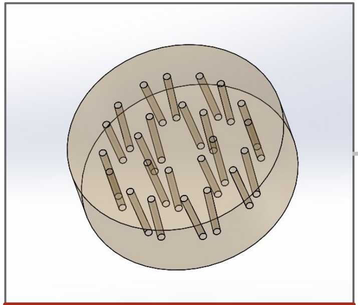
Considerations:
- Cost: <$1500 (Igniter + Stand)
- Fuel: Ethanol/Kerosene
- OX: GOX
- Thrust: 10-15 lbf

Goals:
- Develop a reusable spark igniter
- Atomize and mix liquid fuel
- Produce target thrust

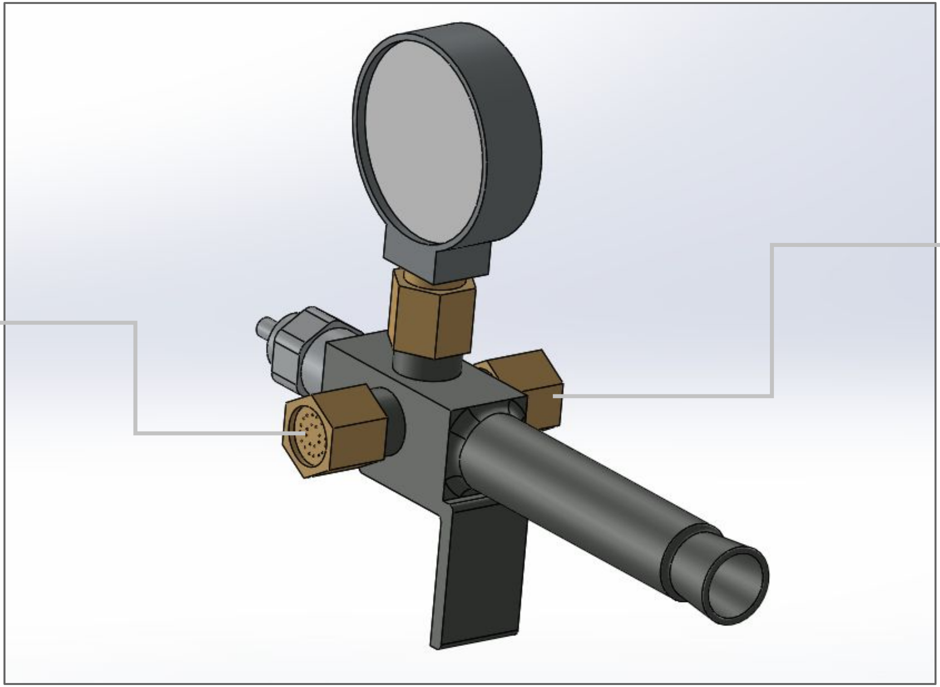


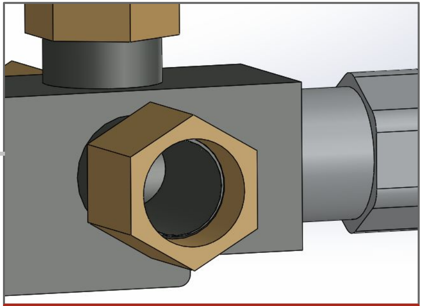
Missouri S&T Rocket Design Team Spark Torch Igniter

Thruster Layout – Gas/Liquid Injection



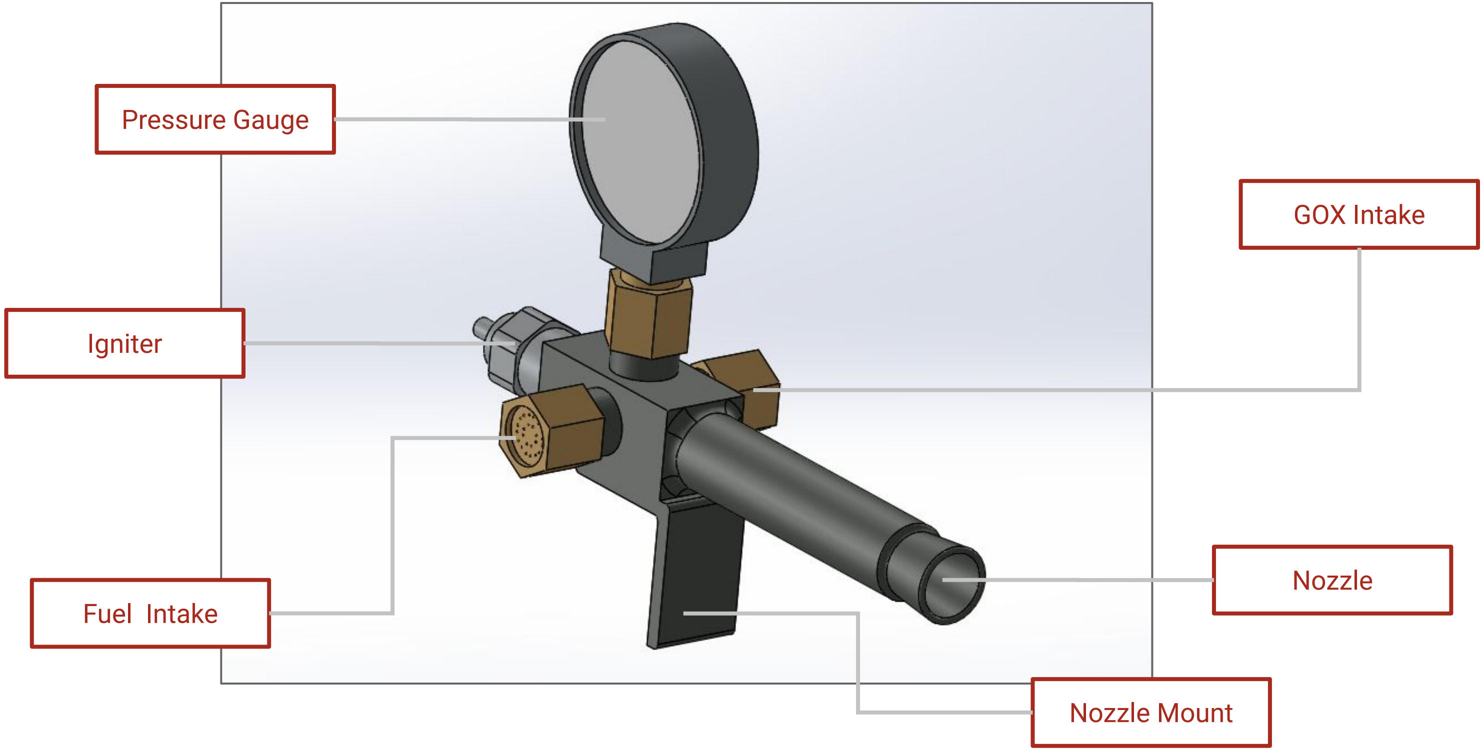
Like-Impinging Fuel Injector





Gaseous Oxidizer Intake

Thruster Layout



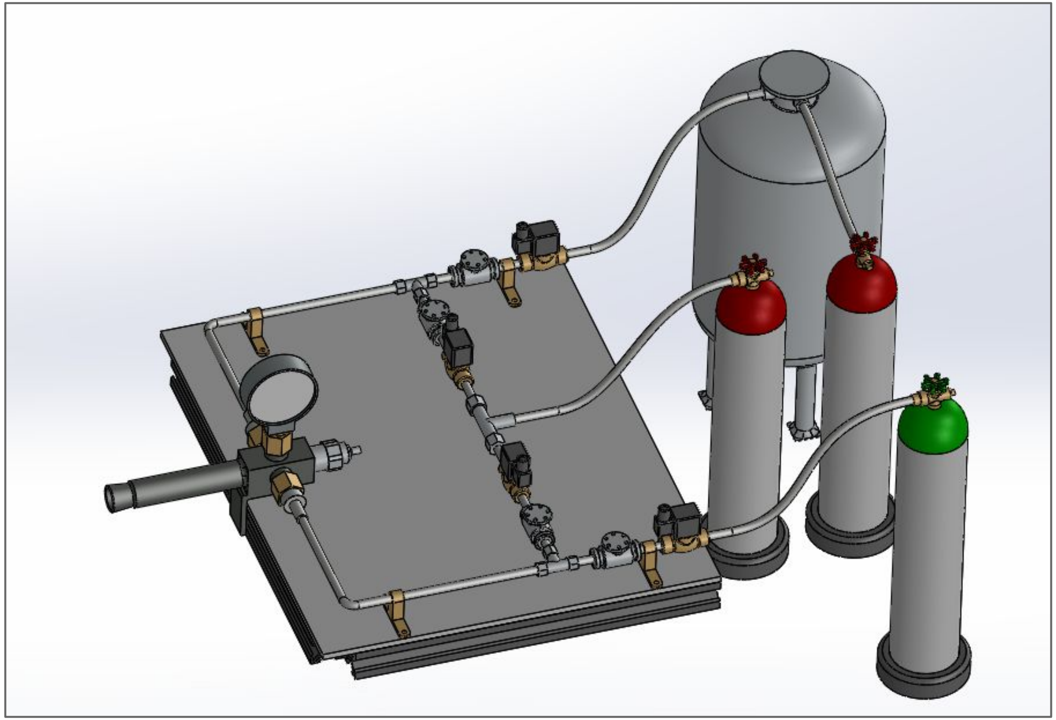
Feed Stand Design

Considerations:

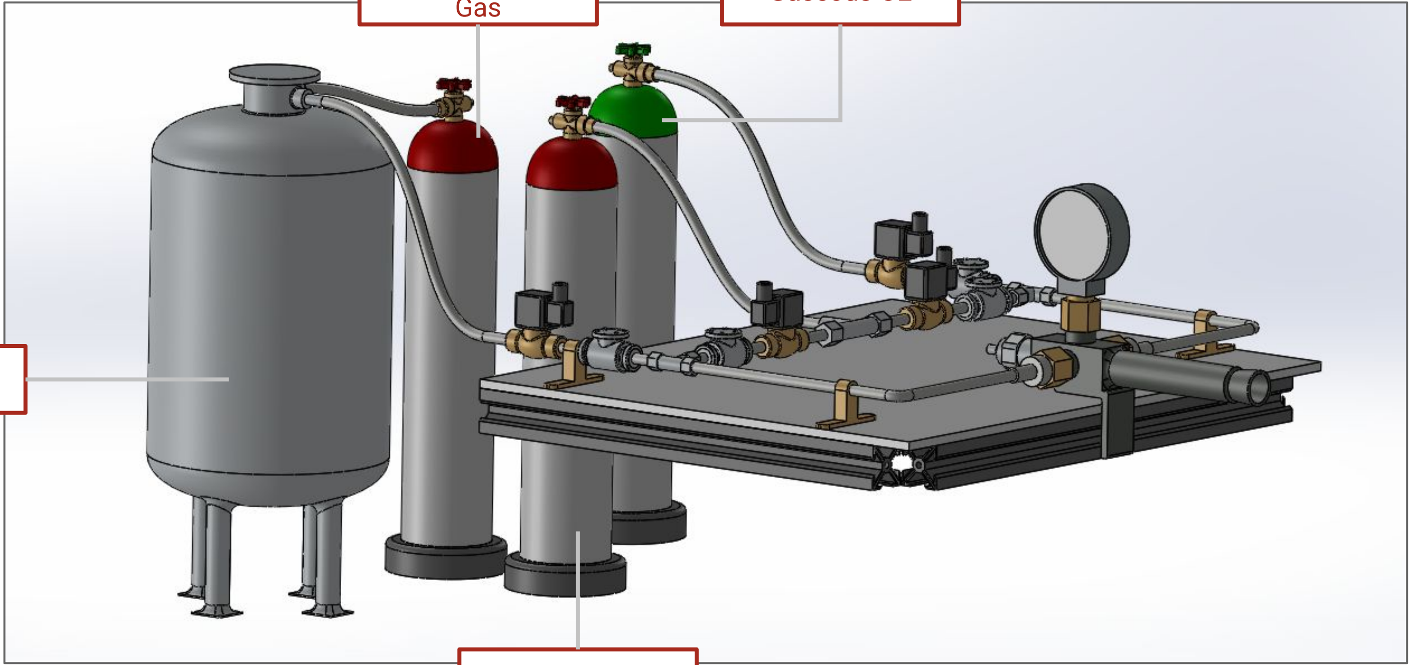
- Cost: <$1500 (Igniter + Stand)
- Fuel: Ethanol/Kerosene
- OX: GOX
- Thrust: 10-15 lbf

Goals:

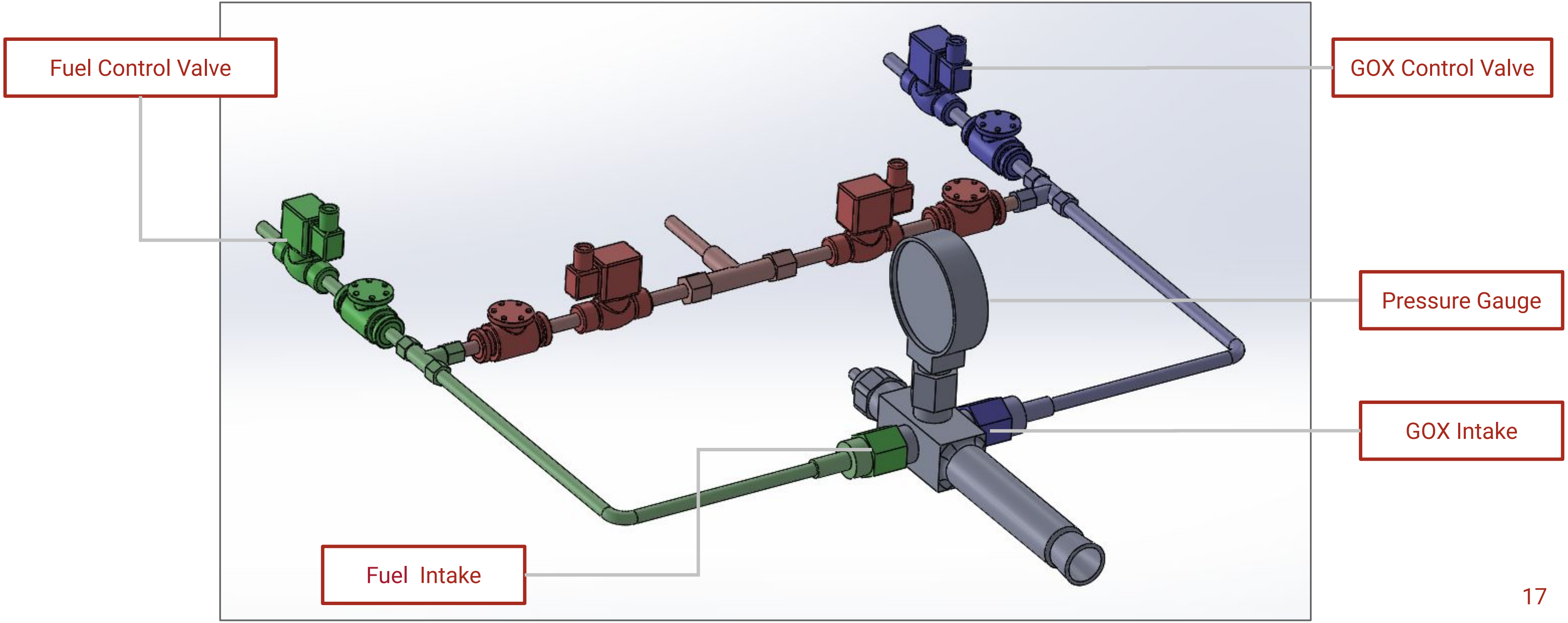
- Feed a gas/liquid fuel mixture
- Achieve target mass flow rate



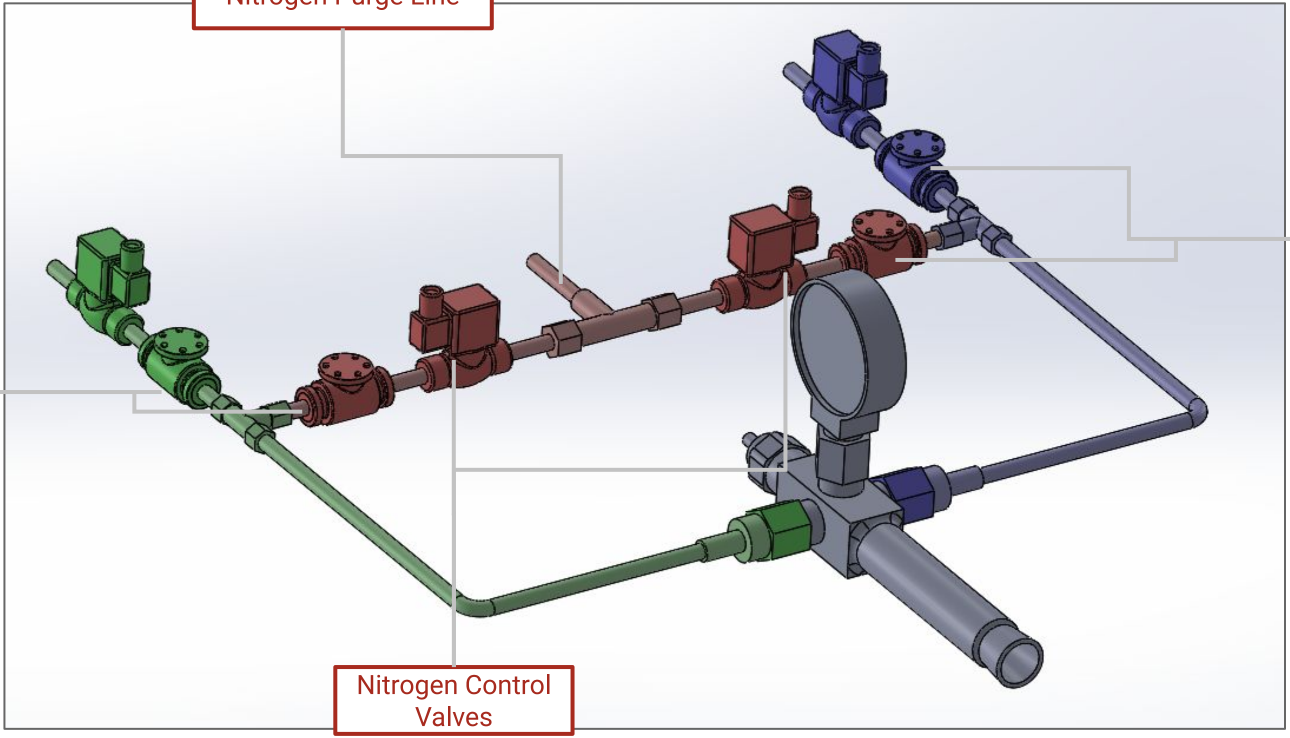
Feed Stand Layout – Gas/Liquid Fuel Mixture



Feed Stand Layout – Functionality



Feed Stand Layout – Safety



Phase 0: Big Questions

1. **Igniter or Low-Thrust Engine?**
    a. Consider mass flow rate
    b. Initial project scope, cost, and safety

Answer: Will go with an igniter for simpler scope and to ensure safety

2. **Phase 0: Gas/gas or gas/liquid igniter?**
    a. Definitely gaseous oxidizer
    b. Liquid would cost a little more (more parts, needs pressurant, etc)
        i. Slightly larger scope (injection matters more)
        ii. Better preparation for liquid bipropellant

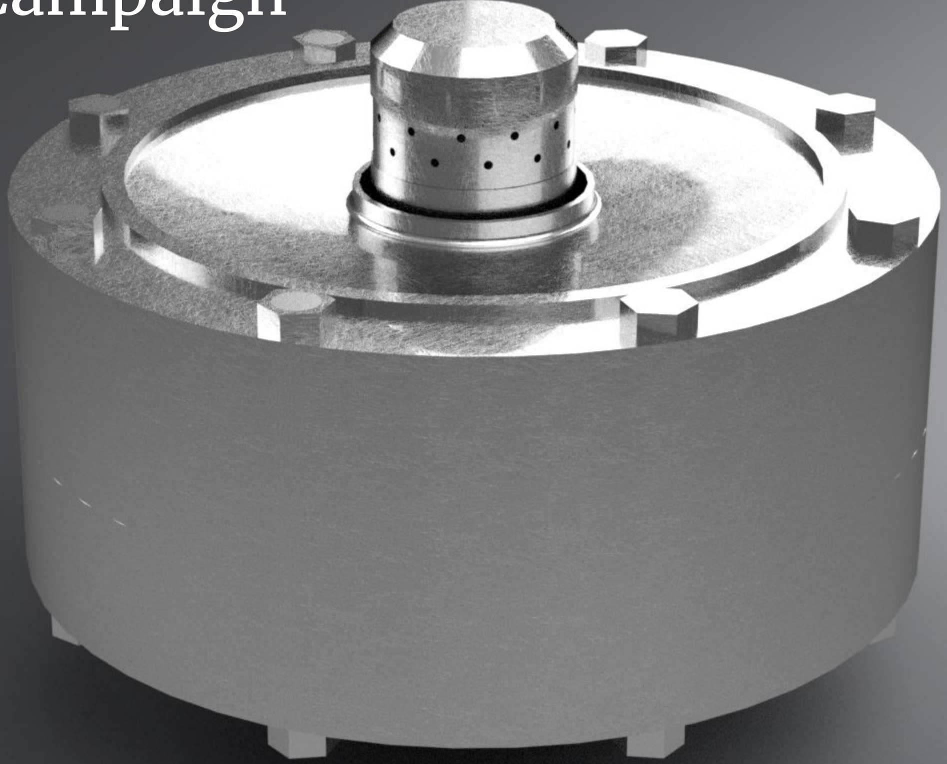
Answer: Will likely go with a gas/liquid mixture of GOX/Kerosene or GOX/Ethanol

Phase 1: Liquid Propulsion

Introduction to Liquid Propellant

Phase 1.1: Water Flow Test Stand

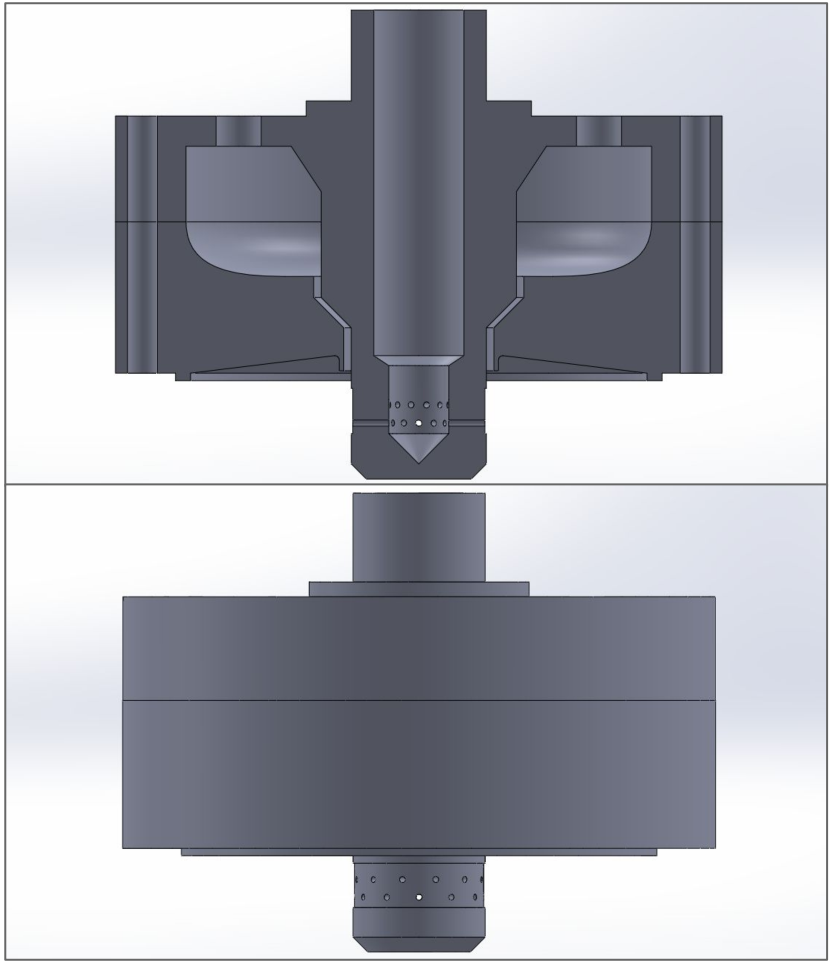
Injector Test Campaign



Pintle Injector

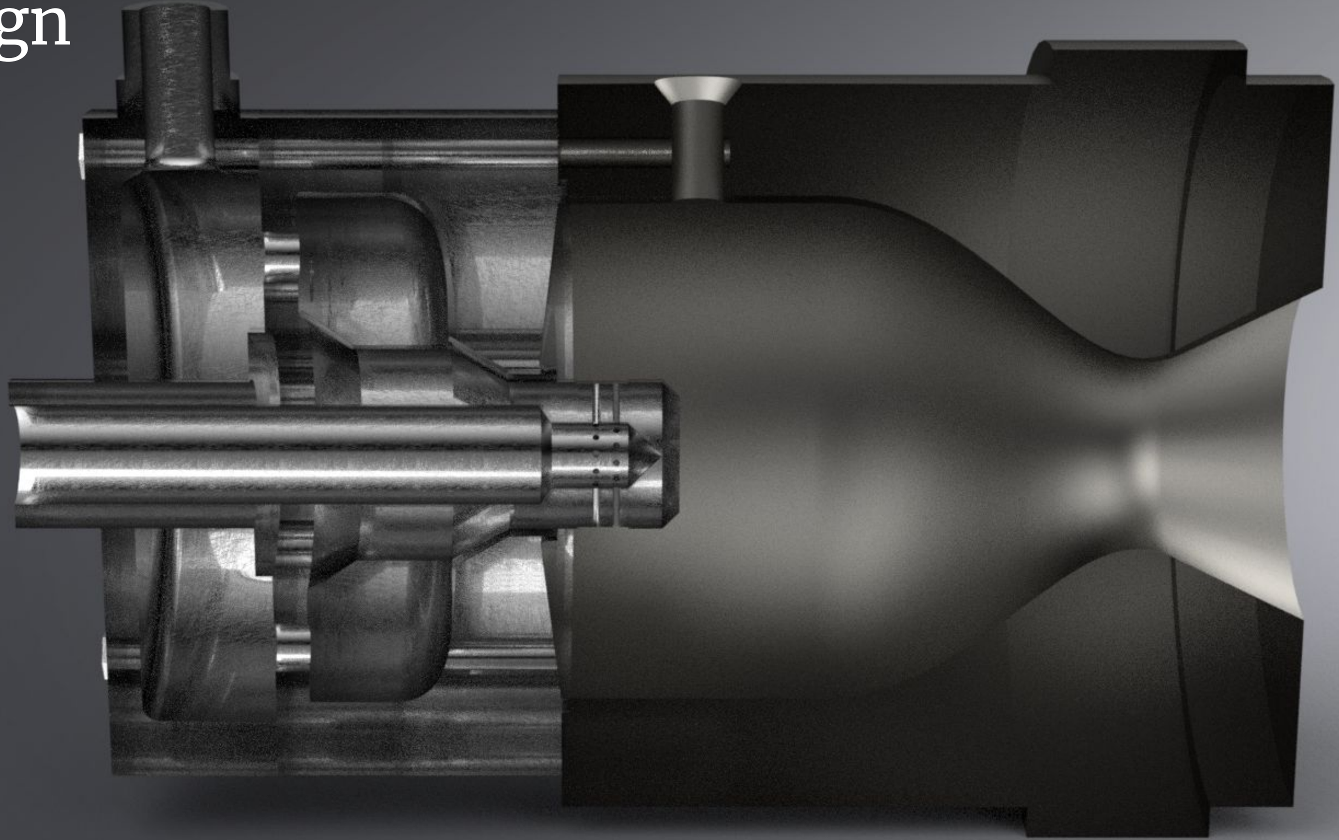
Considerations:
- Injection Type: Pintle
- Injector Material: TBD
- Mixture ratio
- Pressure losses

Goals:
- Ensure optimal fuel/ox mixture
- Reduce design complexity
- Minimize cost



Phase 1.2: Combustion Chamber

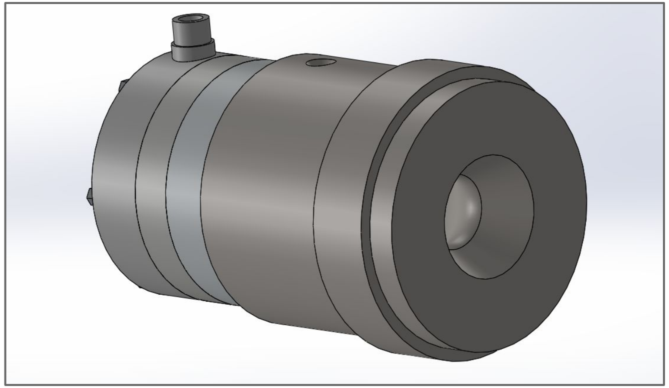
Initial Design



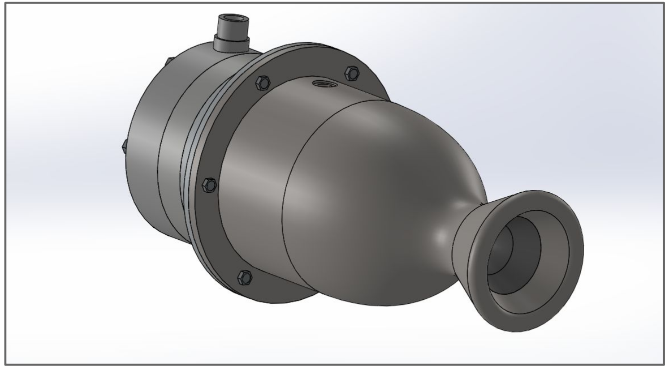
Combustor Design

Considerations:
- Cost: <$3000
- Fuel: Kerosene/Ethanol
- Oxidizer: LOX/GOX/N_2O
- Thrust: 350-500

Goals:
Develop a low thrust, pressure-fed, liquid bi-propellant rocket combustion chamber.

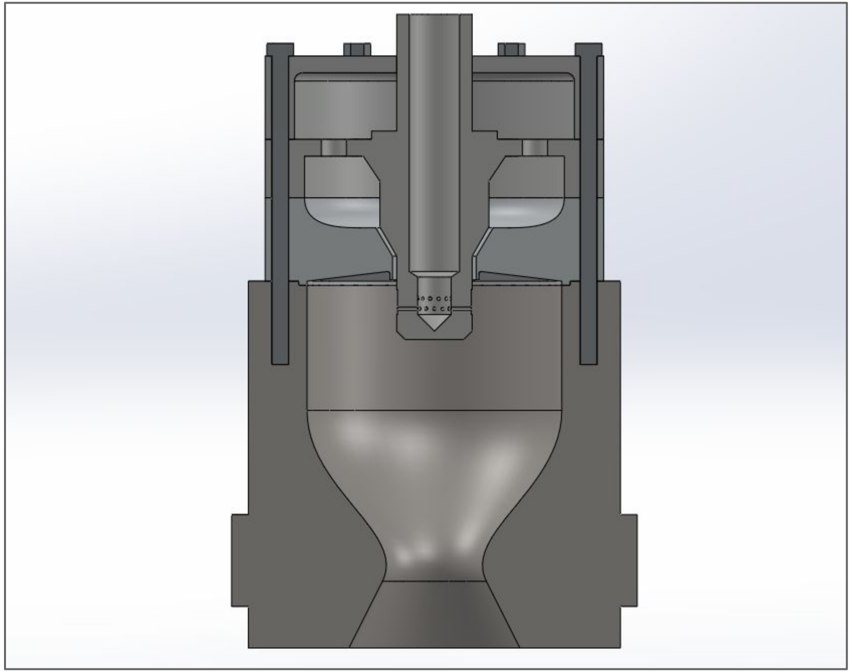


Heat Sink Variant

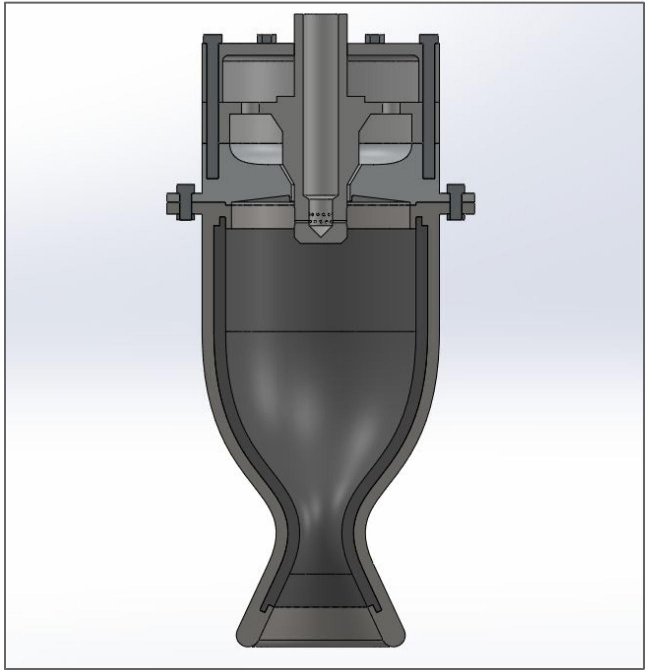


Ablative Variant

Engine 1 Variants: Heat Sink vs Ablative



Heat Sink Variant



Ablative Variant

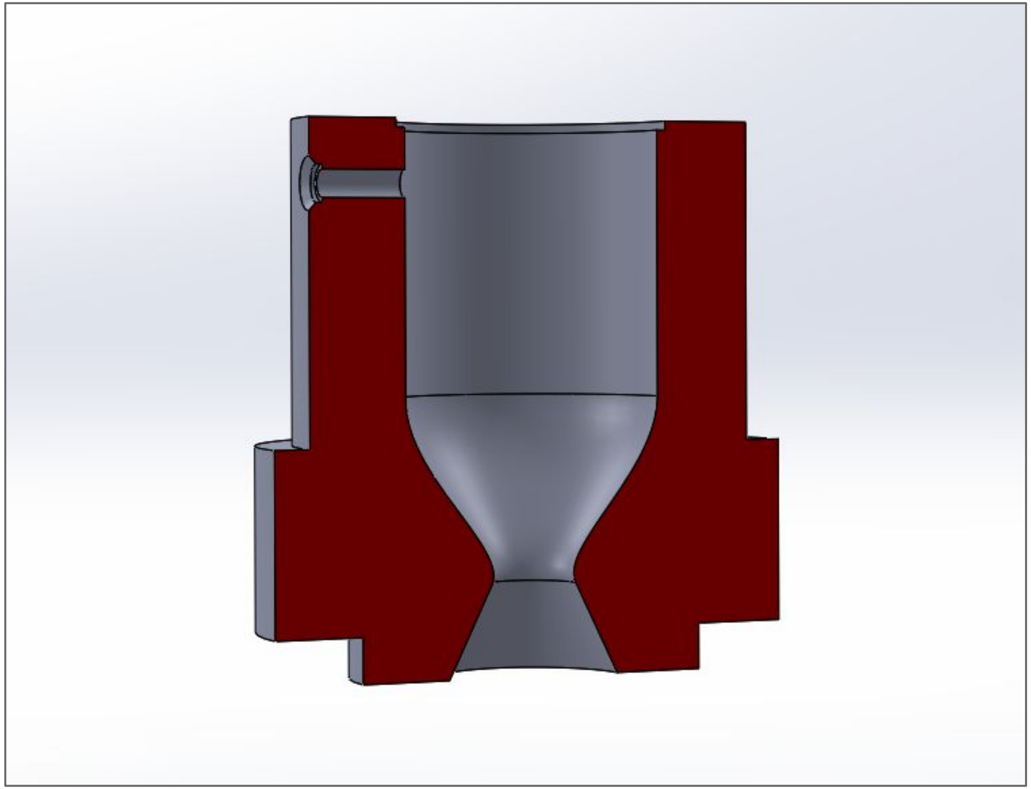
Heat Sink Cooling

Considerations:

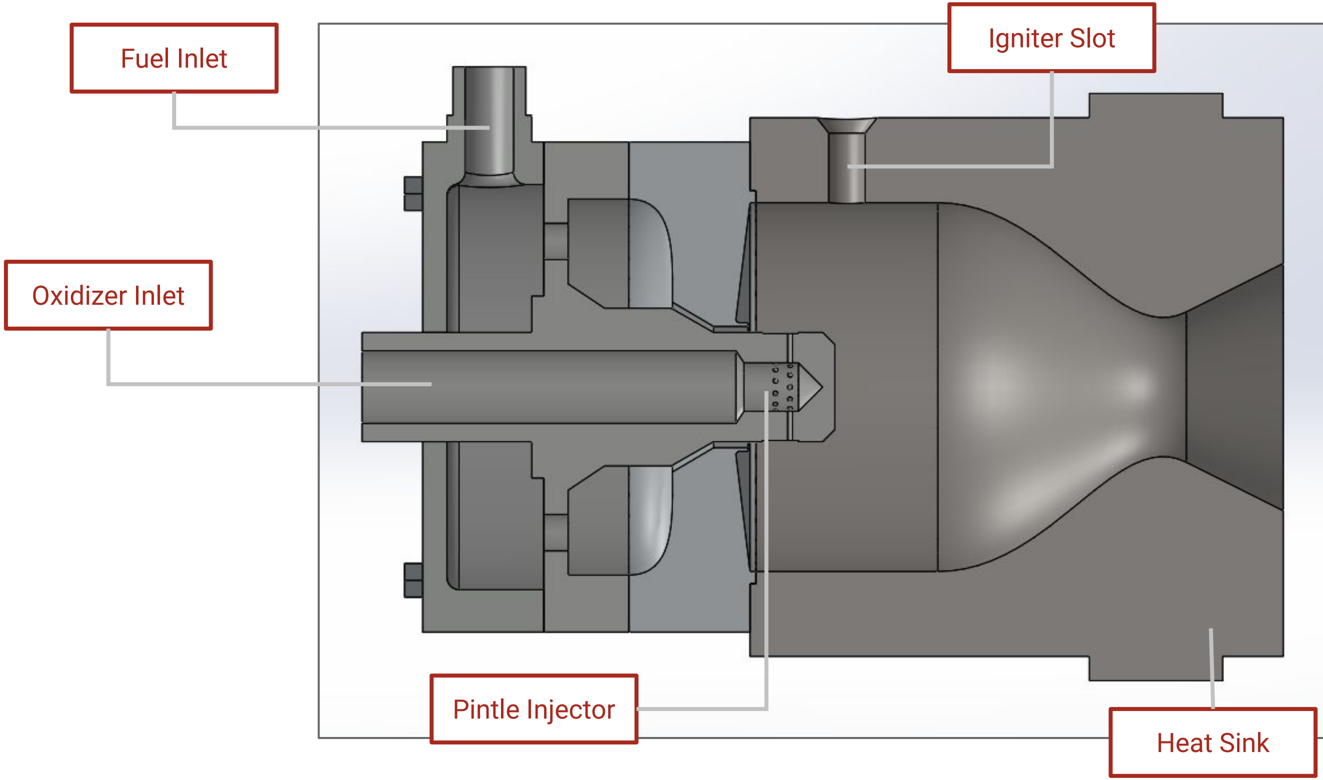
- Material: Stainless Steel/Copper
- Chamber Geometry
- Chamber Wall Thickness

Goals:

Prevent structural damage to combustion chamber components and allow for multiple short-duration hot fires.



Engine Layout



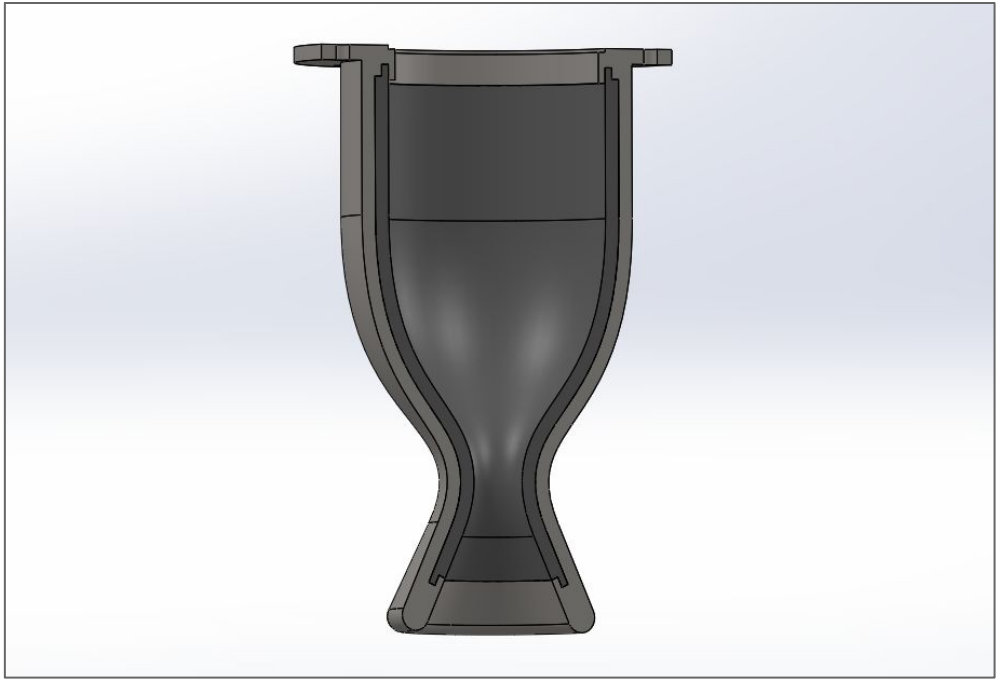
Ablative Cooling

Considerations:

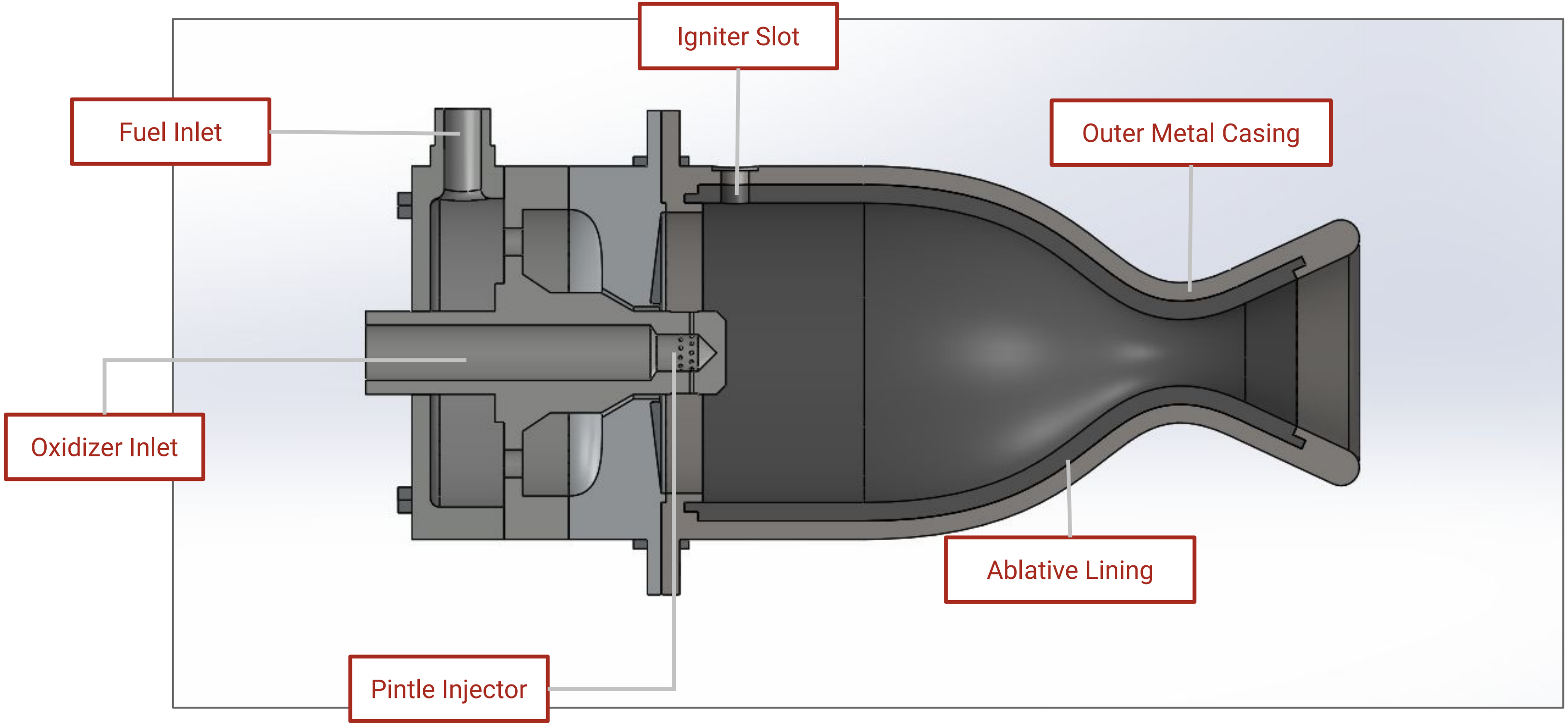
- Material: Phenolic Resin (CE or LE grade resin)/Graphite
- Design: Metal casing + resin liner

Goals:

Safely ablate heated material preventing structural damage and enabling longer-duration hot fires.

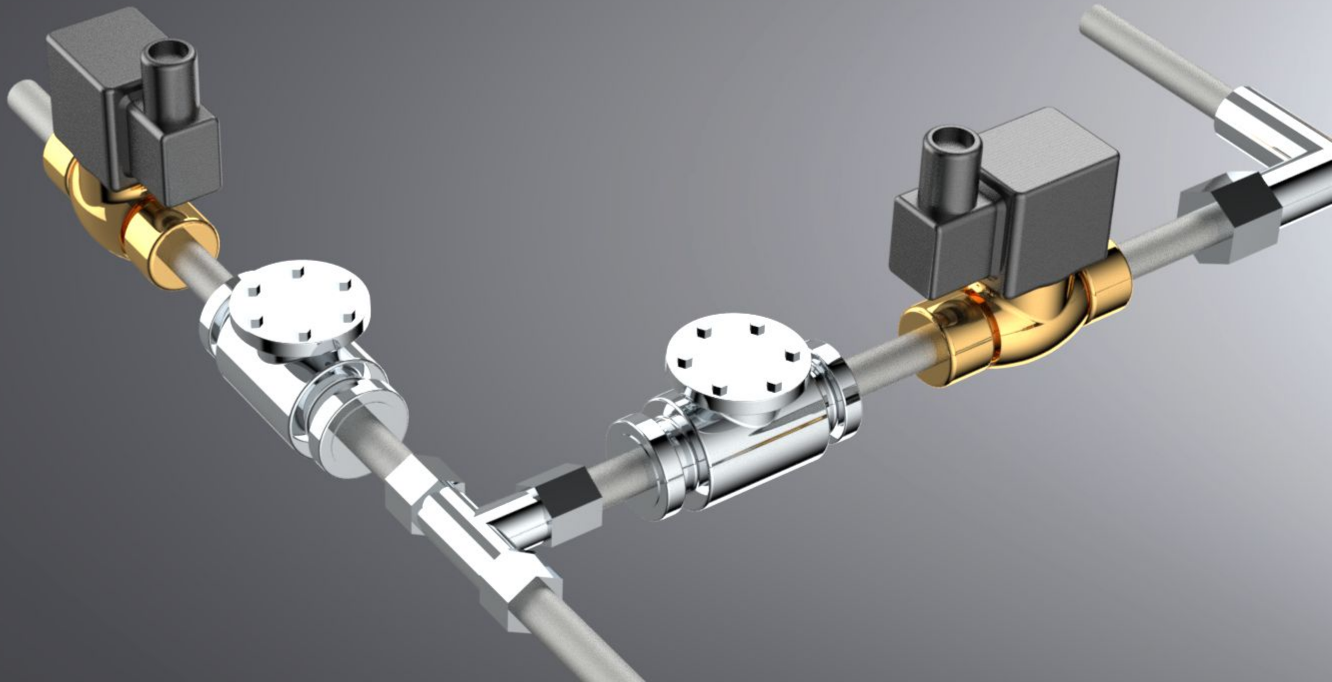


Engine Layout



Phase 1.3: Advanced Feed Stand

Liquid/Liquid Feed System



Feed Stand Design

Considerations:

- Cost: <$3000
- Fuel: Kerosene/Ethanol
- Oxidizer: LOX/N_2O
- Cryogenic rating?
- Thrust: 350-1000 lbf

Goals:

Develop a feed system rated for chosen fuel/oxidizer mixture and mass flow rates for target engine thrust.

MASA's Cryogenic Feed Stand at the University of Michigan

Phase 1: Big Questions

1. **Heat sink or ablative cooling?**
   a. Heat sink is simpler
   b. Heat sink limits hot fire burn time
   c. Ablative allows for longer burn time
2. **LOX, GOX or Nitrous?**
   a. LOX may be less volatile
   b. LOX must be stored at cryogenic temperatures and requires costly cryo-rated parts
3. **Alcohol (isopropanol or ethanol) vs kerosene:**
   a. Alcohol avoids coking
   b. Alcohol can be diluted with water (increasing safety at cost of performance)
   c. Kerosene can provide beneficial soot deposits in combustor but adds a variable
   d. Slightly better performance from kerosene

Phase 2: Advanced Propulsion

Advanced Cooling and Injection

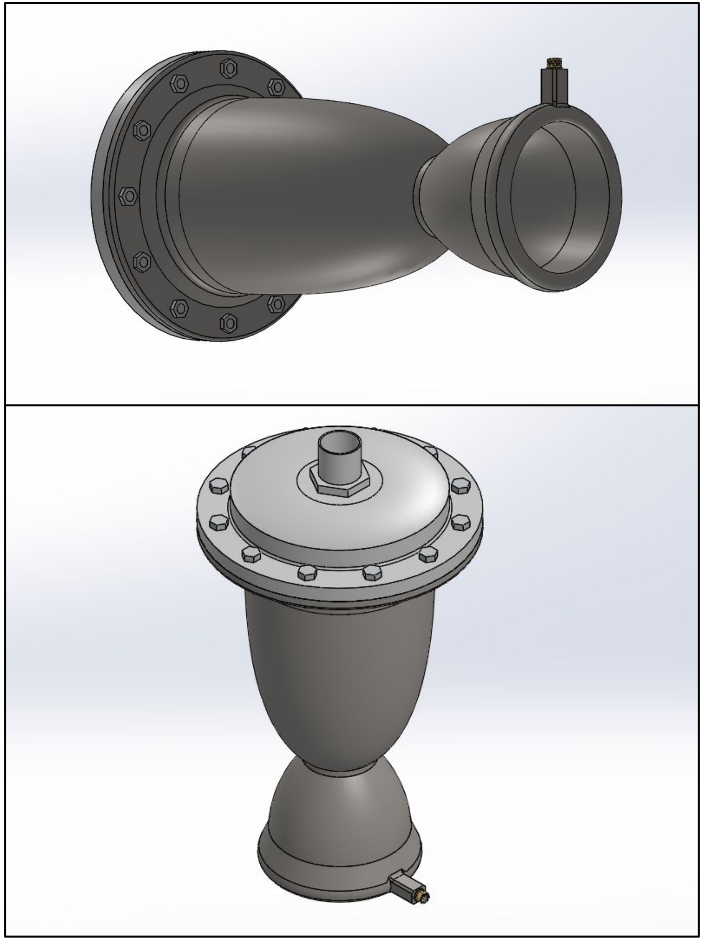
Engine Design

Considerations:

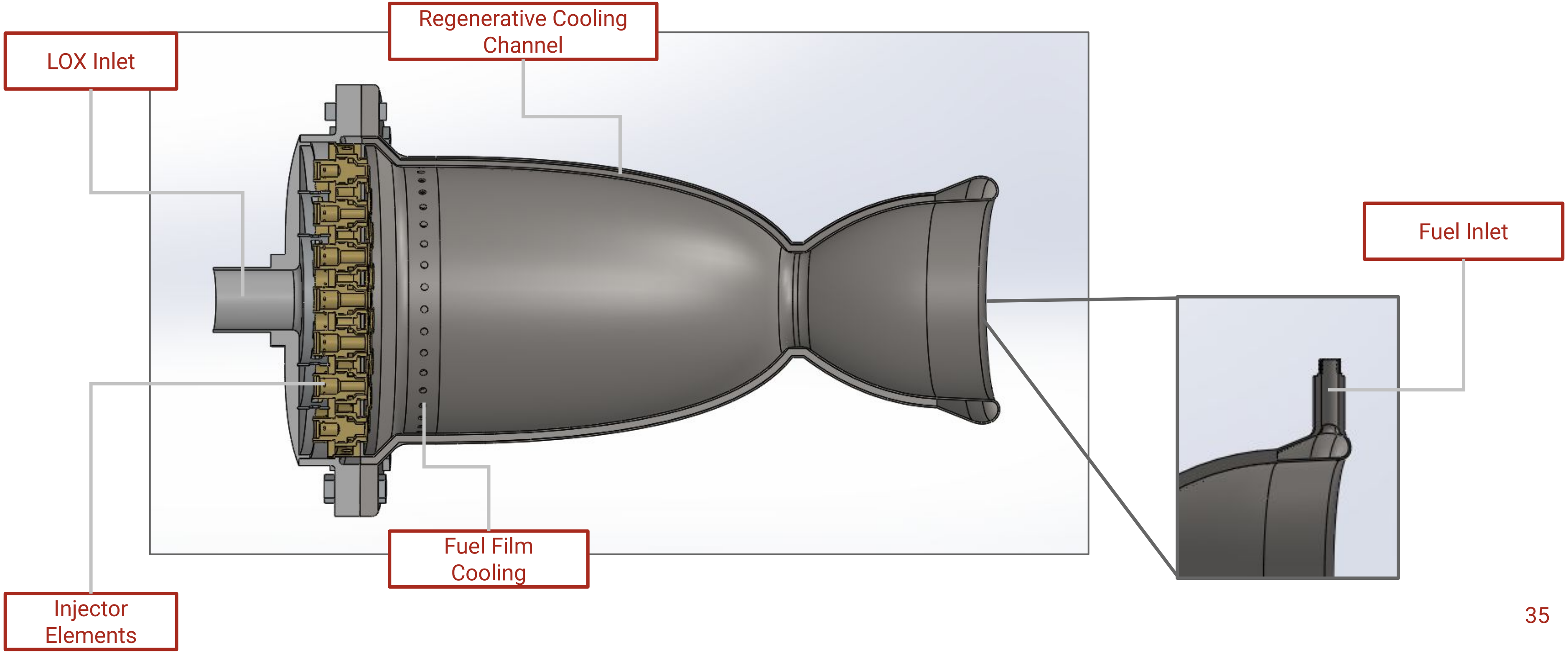
- Cost: <$10,000
- Fuel: LCH_4/Kerosene/Ethanol
- Oxidizer: LOX/N_2O
- Thrust: 1000+ lbf

Goals:

Develop a 1000+ lbf pressure-fed, liquid bi-propellant rocket engine.



Engine Layout



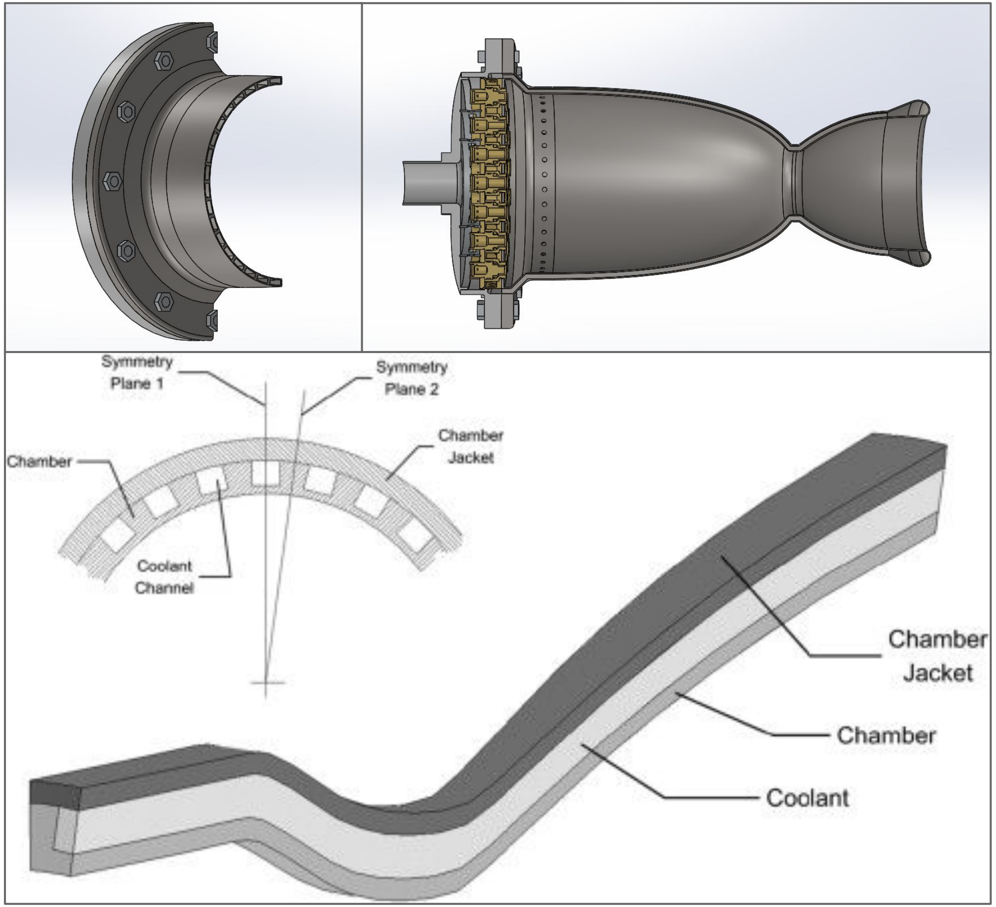
Regenerative Cooling

Considerations:

- Coolant Choice
- Channel Geometry
- Channel Count
- Chamber Wall Thickness
- Chamber Coolant-Film Lining

Goals:

Prevent structural damage to combustion chamber components and allow for reuse.



Numerical Analysis of Regenerative Cooling in Liquid Propellant Rocket Engines
https://doi.org/10.1016/j.ast.2011.11.006

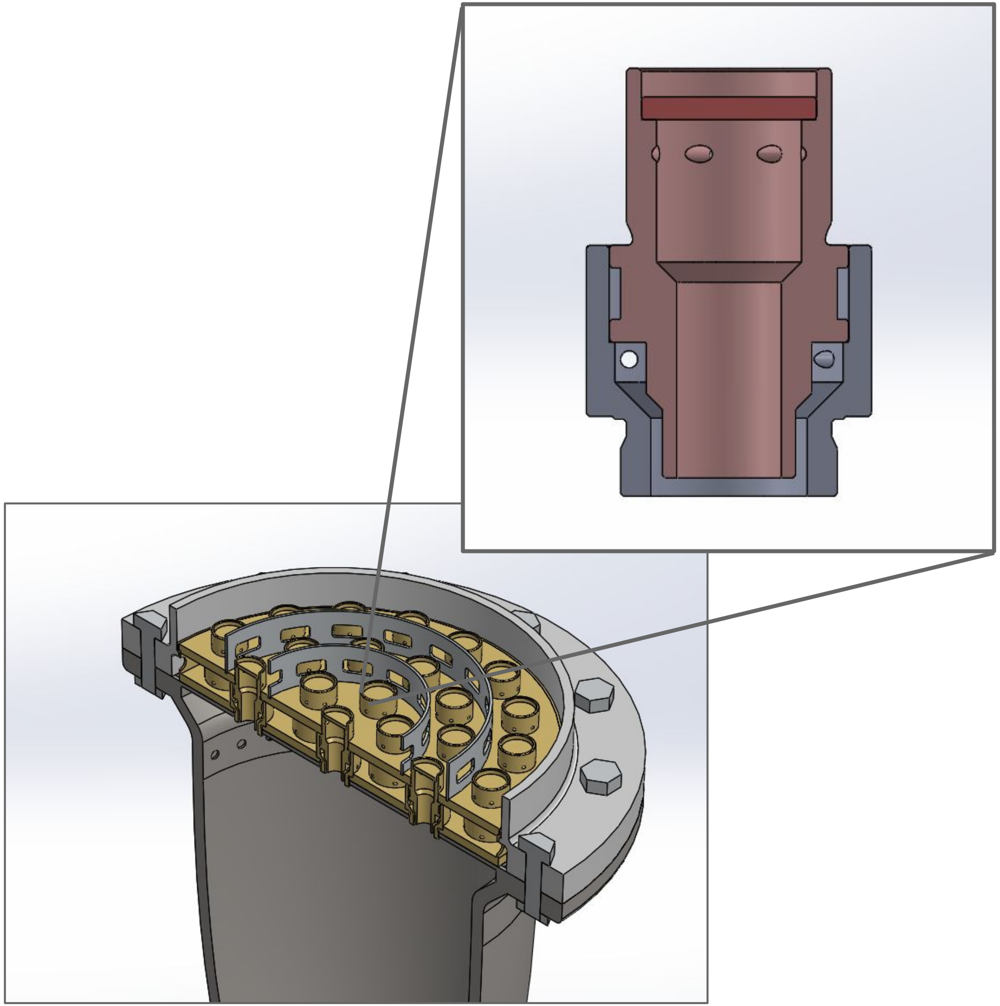
Injectors

Considerations:

- Injection Type: Coaxial Swirler
- Element Count
- Assembly: Machined/Additive

Goals:

Ensure optimal fuel/oxidizer mixture.



Phase 2: Big Questions

1. **Pintle or coaxial swirl injection?**
   a. Coaxial swirlers more difficult to model mathematically
   b. Coaxial swirlers are simple to manufacture (individual elements)
   c. Pintle also relatively simple to manufacture
2. **Fuel: LCH_4, kerosene, alcohol?**
   a. Kerosene has a coking issue that significantly hampers regen cooling
   b. LCH_4 can be hard to acquire
   c. Ethanol can be diluted for safety at cost of performance
   d. Likely depends on Engine 1 choice
3. **Oxidizer: Nitrous, LOX?**
   a. Depends on Engine 1 choice

Rocketry

Launch Vehicle Development

Competition Objectives

Considerations:

- Competition Guidelines
- Submission Paper
- Altitude Category: 10/30k ft

Goals:

Submit, fly, and recover a liquid bipropellant rocket as a part of the **Spaceport America Cup** in 2025.

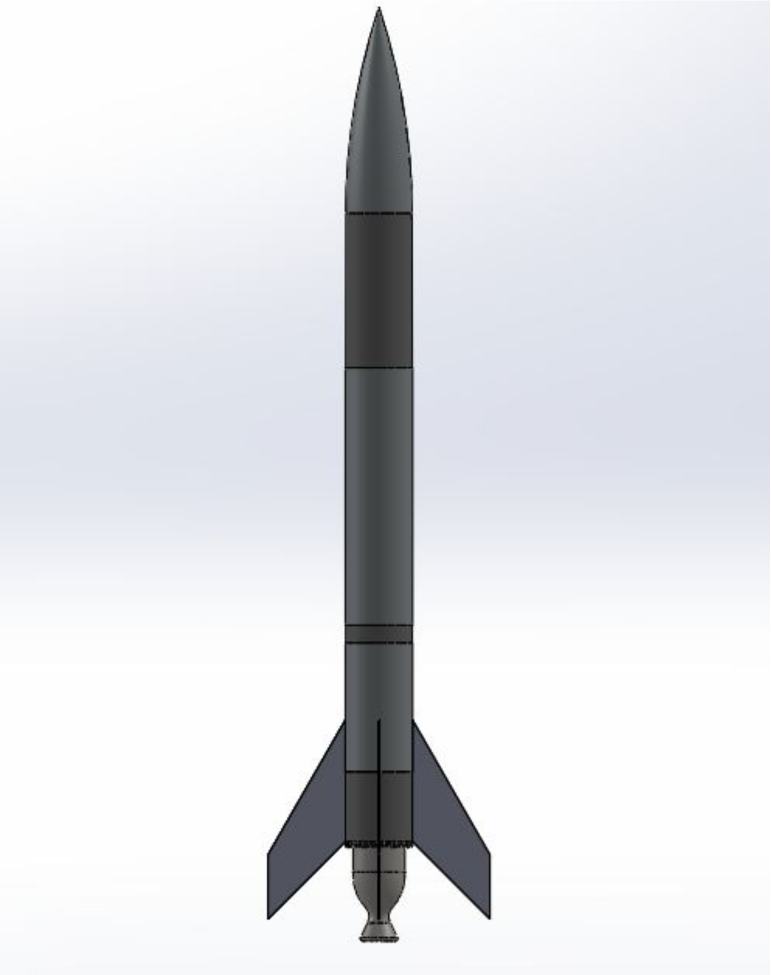
Rocket Design

Considerations:

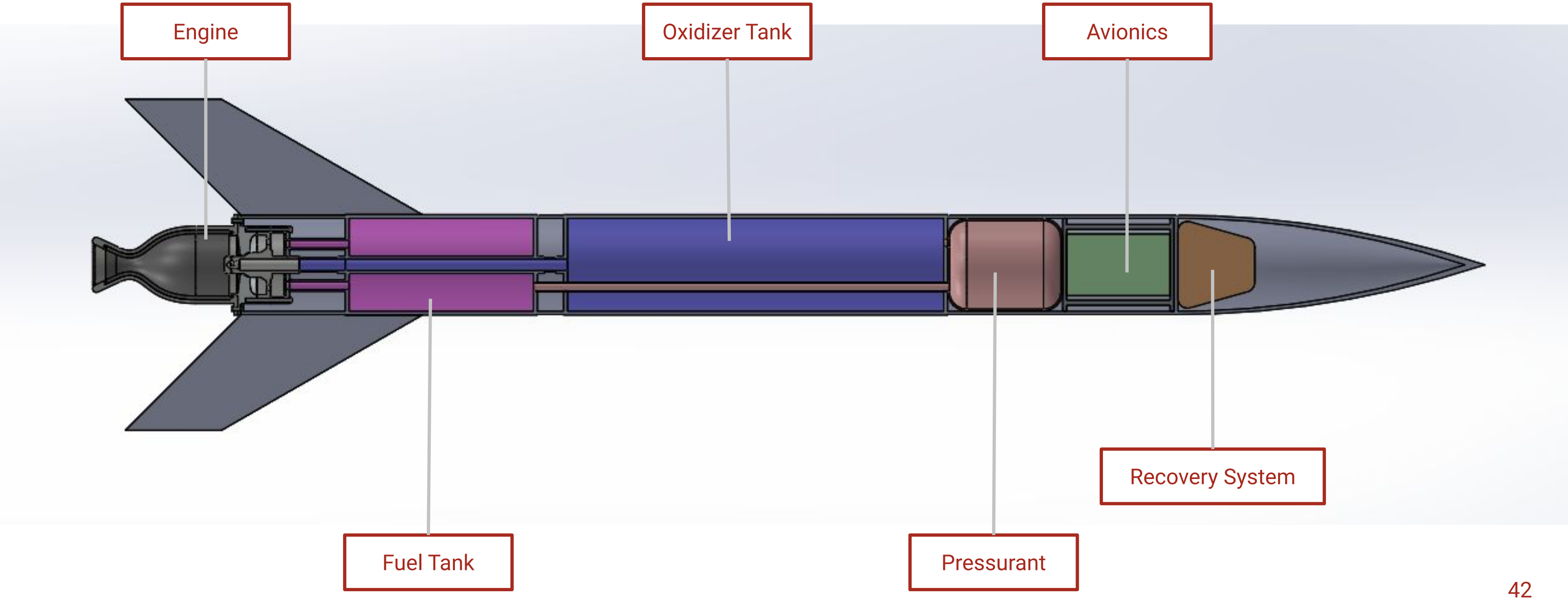
- Cost
- Target Altitude
- Engine Performance
- Guidance, Navigation, and Control
- Recovery

Goals:

Test a flight-configuration liquid bipropellant rocket engine while reaching a target altitude.



Rocket Layout



Rocketry: Big Questions

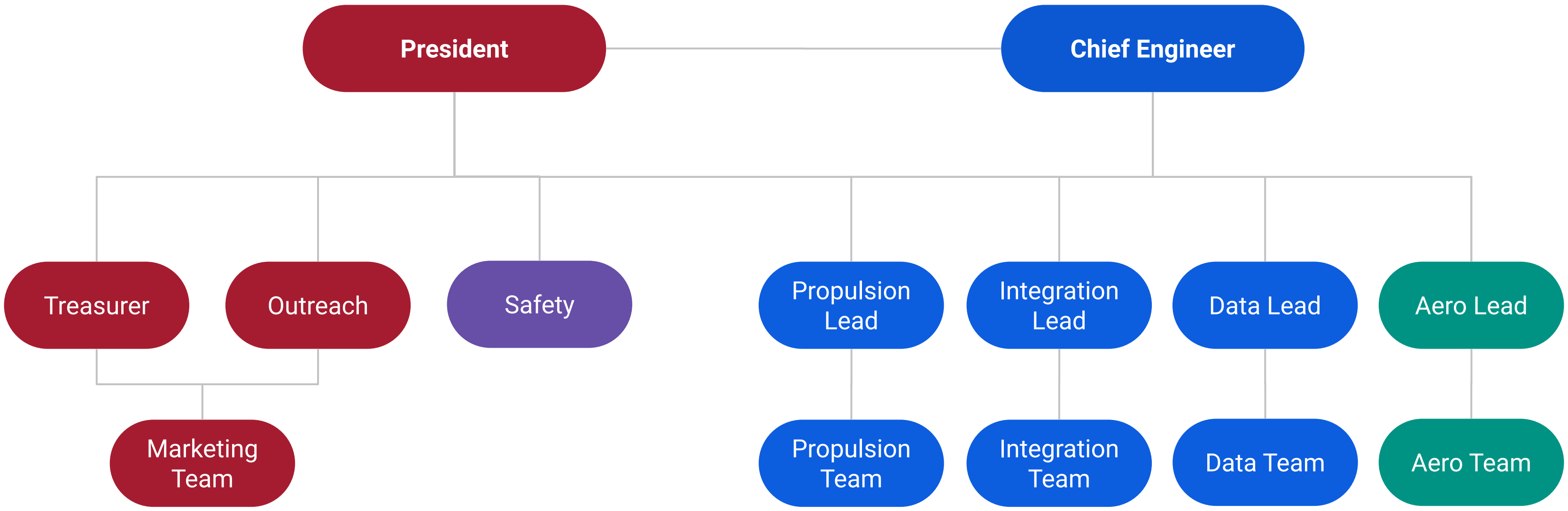
1. **Rocketry in general or just propulsion?**
    a. Rocket engine in flight config or no?
    b. Team stretched too thin with rocketry?
    c. Enough inspiration/recruiting with just propulsion?

Answer: Rocketry as the long term goal when a flight-config liquid engine has been built

2. **Attitude Adjustment?**
    a. Reaction wheels?
    b. Engine gimbal? (Probably not)
    c. Nothing? (Fins?)
3. **Data Collection?**
    a. Data important in hot fire vs flight?
        i. Changing engine performance at different atmospheric pressures
    b. Altitude, thrust, chamber pressure, burn time…?

Administration and Logistics

Organization Chart



Leadership Board Responsibilities

1. **President**
   - Project management and oversight
   - Administration interfacing

2. **Chief Engineer**
   - Engineering oversight
   - Knowledge transfer and training

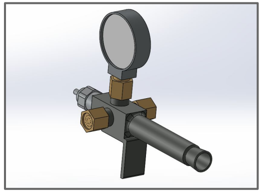
3. **Treasurer**
   - Sponsorship outreach
   - Funding and budget management

4. **Secretary and Outreach Officer**
   - Website and social media management
   - Recruiting and diversity oversight

5. **Environment and Safety Officer**
   - Legal and regulatory compliance
   - Student safety and training

Sub-Teams

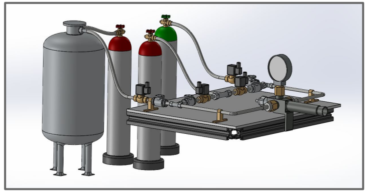
Propulsion



Responsibilities

- Combustor geometry
- Cooling
- Mixture ignition

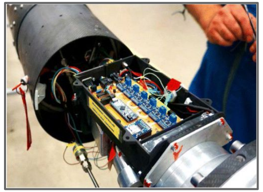
Integration



Responsibilities

- Test stand
- Fuel feed
- Liquid fuel injection

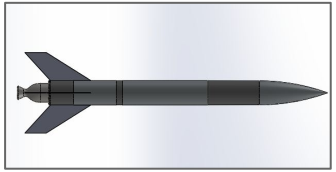
Data and Control



Responsibilities

- Valve actuation
- Sensor operation
- Data modeling

Aerodynamics



Responsibilities

- Fuselage design
- Control surfaces
- Parachute and vehicle recovery

Contacts

K17

	Name	Role	Organization	Contact(s)	Website	Contacted?	Response?	Meeting Date:	Last Follow Up:	Notes
2	-------------------------	Primary Contact	MIT Rocket Team	rt-exec@mit.edu	https://rocketry.mit.edu/	Yes	Yes			
3	Zander Hodge	Liquid Prop Lead	MIT Rocket Team	ahodge@mit.edu	https://rocketry.mit.edu/	Yes	Yes	June 13	June 13	
4	Josh Elmer	President (Outgoing)	Rocket Propulsion Laboratory (UCSD)	jelmer@ucsd.edu	https://rocketproplab.org/	Yes	Yes	June 8	July 13	
5	David Pope	President (Incoming)	Rocket Propulsion Laboratory (UCSD)	dpope@ucsd.edu	https://rocketproplab.org/	Yes	Yes	June 8	July 13	
6	Reilly Jensen	Chief Engineer	Rocket Propulsion Laboratory (UCSD)	rdjensen@ucsd.edu	https://rocketproplab.org/	Yes	Yes	June 8	July 13	
7	Joshua Hedgpeth	Engineer	Rocket Propulsion Laboratory (UCSD)	jhedgpet@ucsd.edu	https://rocketproplab.org/	Yes	Yes			
8	Kyle Perlin	Chief Engineer	Rocket Propulsion Laboratory (UCSD)	kperlin@ucsd.edu	https://rocketproplab.org/	Yes	No			
9	Elysse Lescarbeau	Project Lead (Outgoing)	BU Rocket Propulsion Group	elescarb@bu.edu	http://burpg.org/	Yes	No			
10	Joshua Bender	Mechanical Engineer	BU Rocket Propulsion Group	benderj@bu.edu	http://burpg.org/	Yes	Yes			
11	Casey Goodwin	Secretary	BU Rocket Propulsion Group	cwin@bu.edu	http://burpg.org/	Yes	Yes	July 3	July 3	
12	John Sullivan	Director	BU Rocket Propulsion Group	jwsulliv@bu.edu	http://burpg.org/	Yes	Yes	July 3	July 3	Stay in touch regarding test locations. May be able to use their test stand?
13	-------------------------	Primary Contact	BU Rocket Propulsion Group	burpg@bu.edu	http://burpg.org/	Yes	Yes			
14	Theo Rulko	President	MASA (U Michigan)	trulko@umich.edu SLACK	https://masa.engin.umich.edu/	Yes	Yes	July 20	July 20	Contact them about ITAR clearance
15	Nathaniel Craig Camp	Prop Lead (Current)	MASA (U Michigan)	natecamp@umich.edu	https://masa.engin.umich.edu/	Yes	Yes	July 20	July 20	
16	Jack Taliercio	Chief Engineer	MASA (U Michigan)	jtalier@umich.edu	https://masa.engin.umich.edu/	Yes	No			
17	Josh Miller	Propulsion Lead	MASA (U Michigan)	joshmi@umich.edu	https://masa.engin.umich.edu/	Yes	No			
18	Kara Vanderwest	Production Lead	MASA (U Michigan)	kvwest@umich.edu	https://masa.engin.umich.edu/	Yes	No			
19	Cameron Crandall	Structures Lead	MASA (U Michigan)	ccrand@umich.edu	https://masa.engin.umich.edu/	Yes	No			
20	Minori Higashiyama	Safety Officer	MASA (U Michigan)	minorih@umich.edu	https://masa.engin.umich.edu/	Yes	No			
21	Eric Williamson	President	Purdue Space Program	will1904@purdue.edu	https://purdueseds.space/	No	No			
22	Nathan Gurgens	Vice President	Purdue Space Program	ngurgens@purdue.edu	https://purdueseds.space/	Yes	No			
23	Andrew Darmody	Treasurer	Purdue Space Program	adarmody@purdue.edu	https://purdueseds.space/	Yes	No			
24	Ayush Srivastava	Secretary	Purdue Space Program	srivas92@purdue.edu	https://purdueseds.space/	Yes	Yes			
25	Kush Patel	Technical Director	Purdue Space Program	pate1037@purdue.edu (765) 967-0349	https://purdueseds.space/	Yes	Yes			
26	Stefan Lazaroae	Outreach Chair	Purdue Space Program	slazaroa@purdue.edu	https://purdueseds.space/	Yes	No			
27	Chris Nilsen	Associate Prop Engineer	Purdue Space Program	cnilsen@purdue.edu	https://purdueseds.space/	Yes	Yes	June 21	June 21	Very helpful, shoot him questions and stay in contact. WORKS AT ZUCROW
28	Brynne Hunt	Liquids Project Manager	Purdue Space Program	hunt132@purdue.edu	https://purdueseds.space/	Yes	No			
29	Jonah Fouts	Propulsion Engineer	Purdue Space Program	LINKEDIN	https://purdueseds.space/	Yes	Yes	June 21	June 21	
30	Matt Ryan	President	RIT Launch Initiative	mxr9154@rit.edu	http://launch.rit.edu/	Yes	No			
31	Jim Heaney	Director of Operations	RIT Launch Initiative	jxh6319@rit.edu	http://launch.rit.edu/	Yes	No			
32	Gillian Doolittle	Treasurer	RIT Launch Initiative	gld2262@rit.edu	http://launch.rit.edu/	Yes	No			
33	Aubrey Figoras	Director of Outreach	RIT Launch Initiative	amf2630@rit.edu	http://launch.rit.edu/	Yes	No			
34	Derek Basta	Propulsion Co-Lead	RIT Launch Initiative	djb7784@rit.edu	http://launch.rit.edu/	Yes	No			
35	Justin Silva	Propulsion Co-Lead	RIT Launch Initiative	[illegible]	http://launch.rit.edu/	Yes	No			

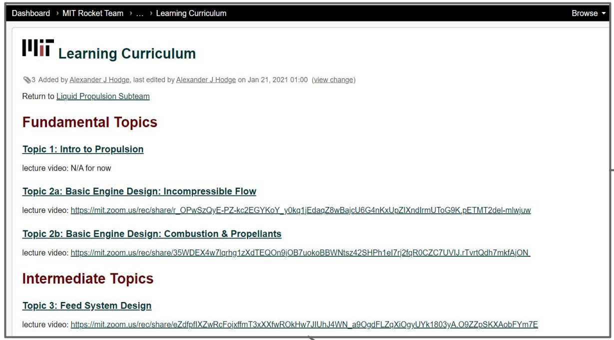
University Rocket Teams | Harvard Faculty | Companies/Organizations | Harvard Alumni

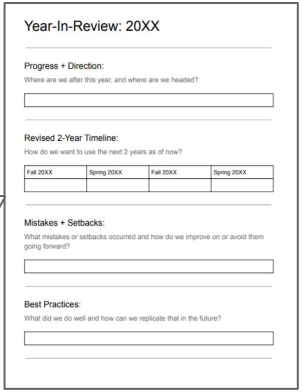
Knowledge Documentation

Year-In-Reviews:
A yearly summary of the project, it's accomplishments, goals, and questions, providing a narrative summary of the project across multiple years.

Project Wiki:
One-stop-shop repository of knowledge for onboarding and continued reference.

Team Website:
Digestible overview of the project and membership for members, sponsors, and the general public.





Knowledge Share: A Sample Year

August	September	Fall	Year-Round	May
Pre-Year Planning	**Year-Start Project Review**	**Incoming Engineer Lab Training**	**Document Updates**	**Year-End Review**
A team lead meeting establishing the roadmap, schedule, and goals for the upcoming year.	The initial full-team meeting following recruitment which will organize the team for that year's objectives.	Untrained engineers will receive the relevant training and certification to make use of the SEC's amenities.	The project wiki and website are updated throughout the year based on project milestones and new knowledge.	A final team meeting summarizing the year and completing the Year-In-Review document.

Funding, Sponsors, and Suppliers

Funding:

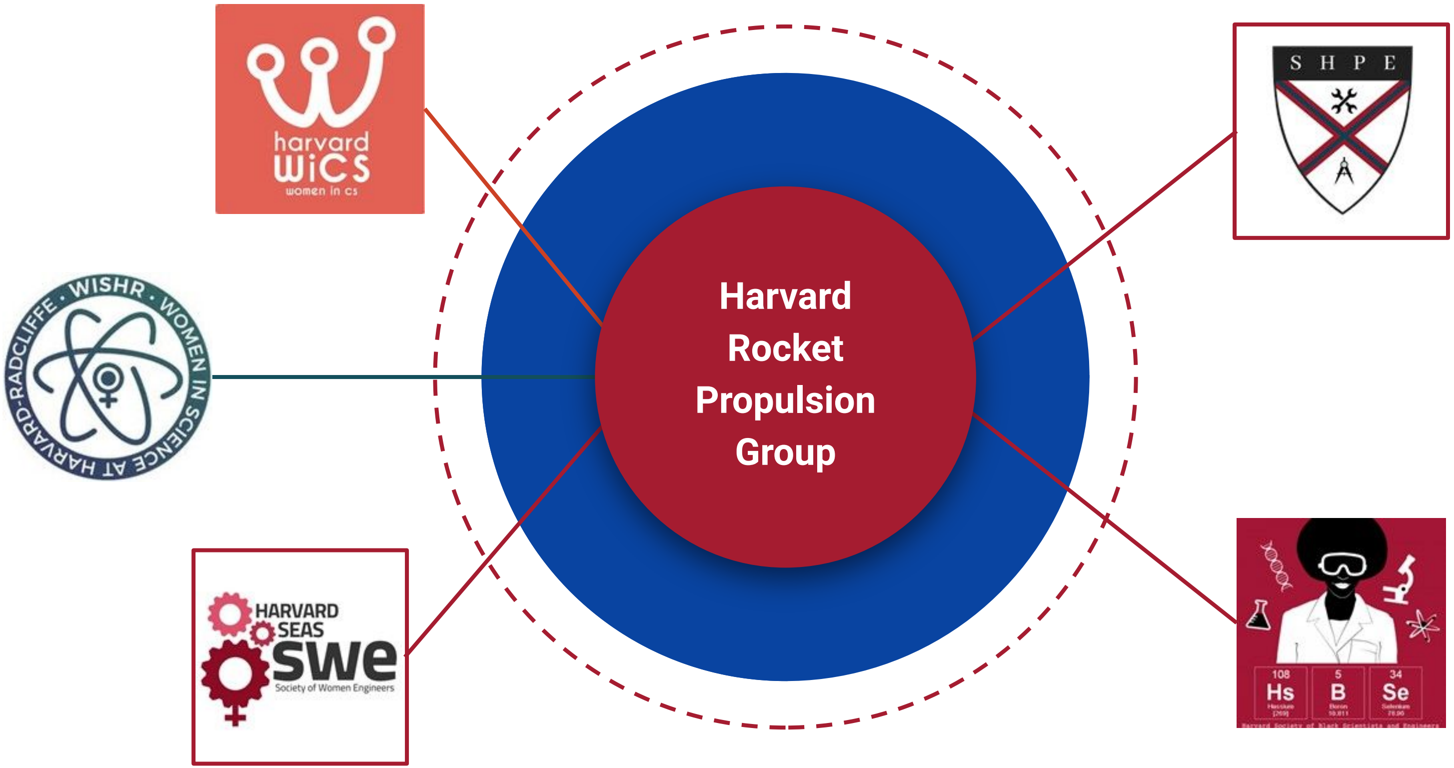
1. Nectar
2. UC Funding
3. Harvard Office of Sustainability

Potential Sponsors/Suppliers:

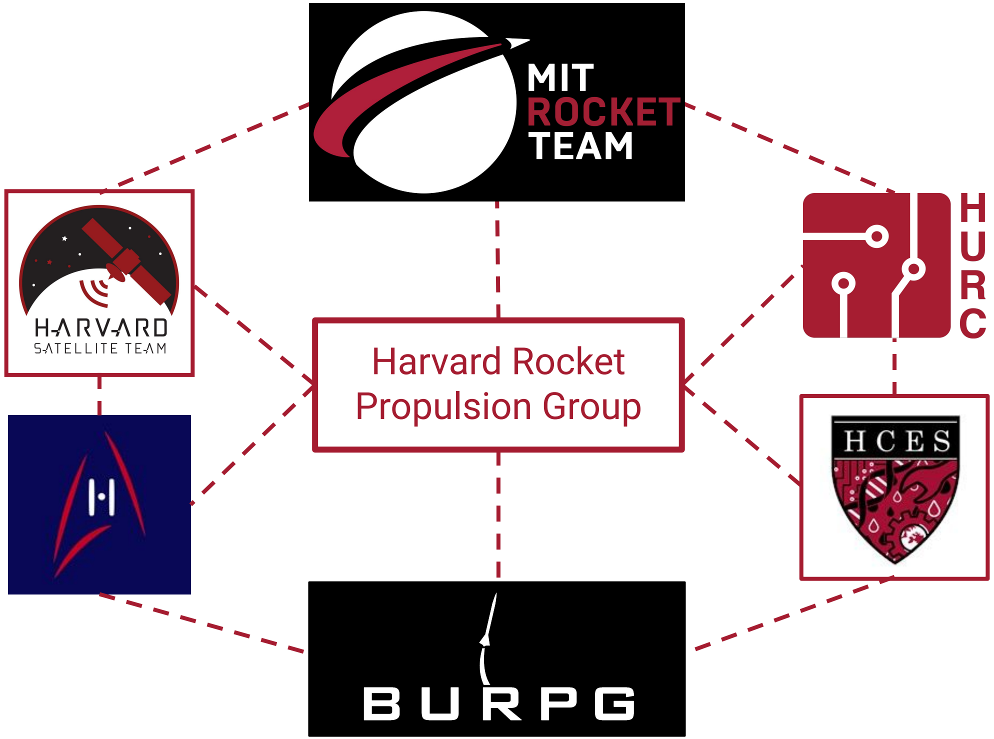
1. McMaster-Carr
2. Swagelok
3. Triton Space Technology
4. General Dynamics
5. BMP Machining Solutions
6. Graphitestore.com

Diversity and Outreach

Representation and Outreach



Boston Partnerships and Outreach



Joining the Collegiate Rocket Propulsion Community

Missouri S&T Rocket Design Team

MIT ROCKET TEAM

L P L

Half Cat ROCKETRY

AUBURN UNIVERSITY NASA *SL AEROSPACE PROJECT NOVA

YJSP

RPL ROCKET PROPULSION LABORATORY

PSP

PARSEC

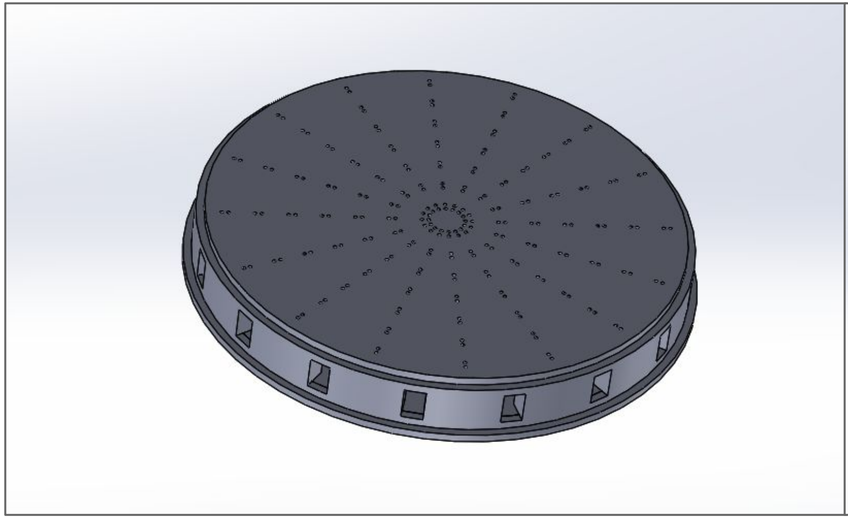
NASA

BURPG

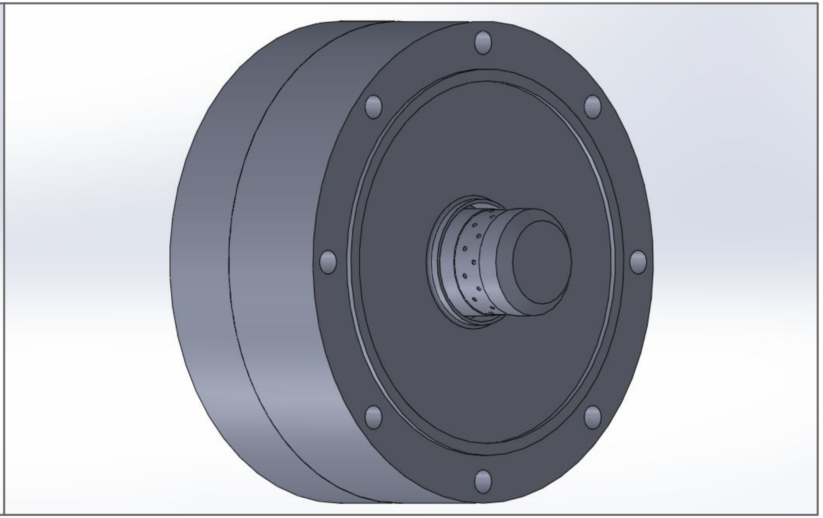
GEORGIA TECH RAMBLIN' ROCKET CLUB

Appendix

Injection: Impinging Jet vs Pintle



Unlike Impinging Jet Injector



Pintle Injector

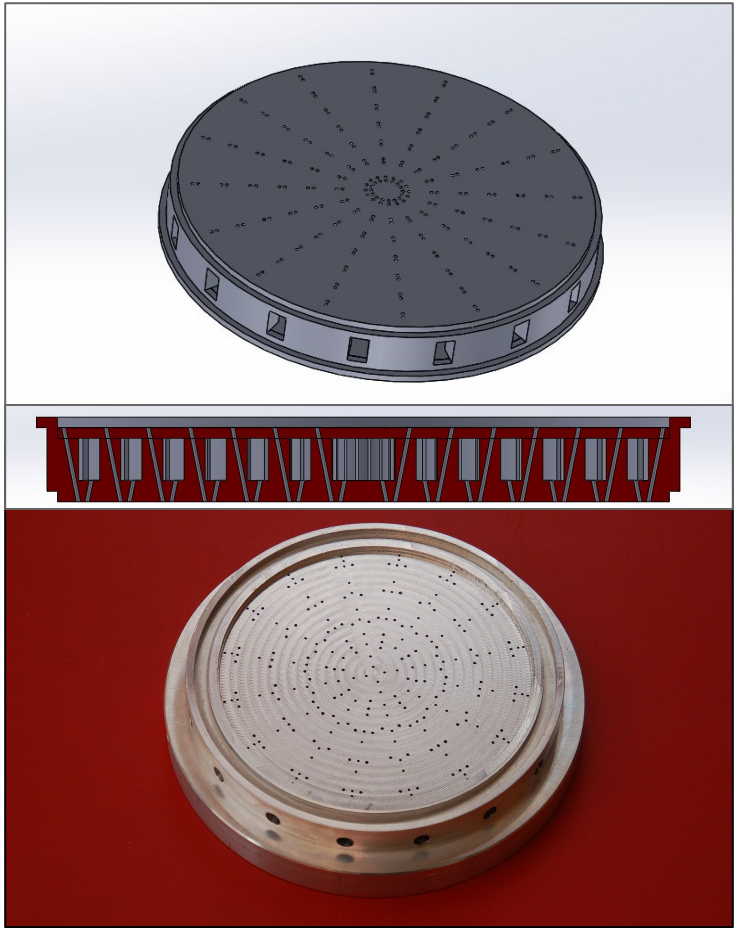
Injector Plate

Considerations:

- Injection Type: Unlike Impingement
- Injector Material: Brass
- Assembly: Machined/Additive
- Injection type: Unlike Impingement

Goals:

Ensure optimal fuel/oxidizer mixture while reducing manufacturing complexity.



Copenhagen Suborbitals: BPM-5 Injector Plate

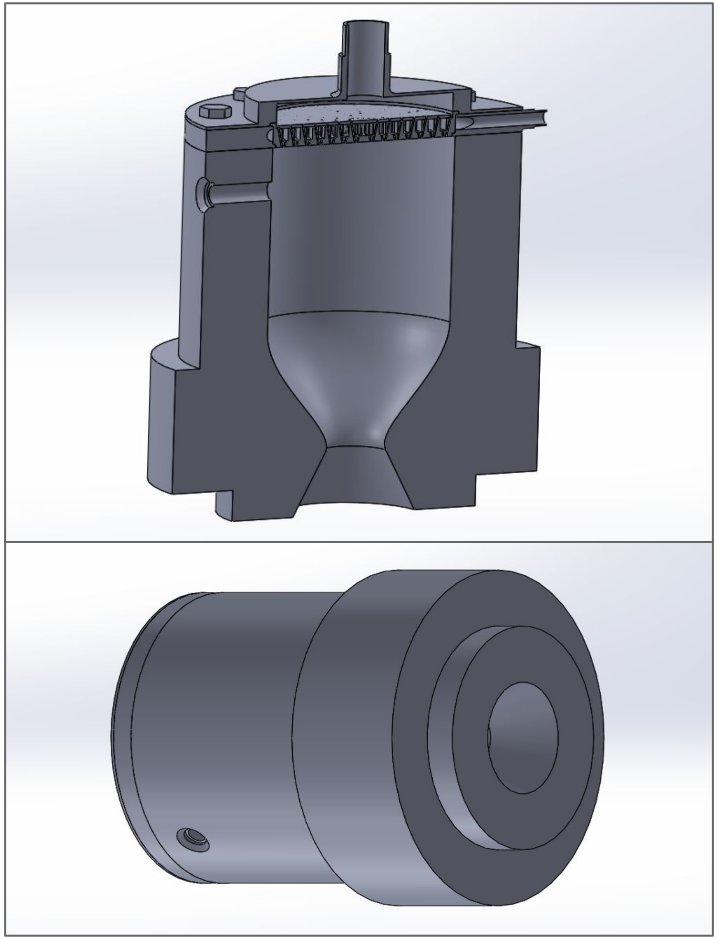
Combustion Chamber Design

Considerations:

- Combustion Chamber Material
- Chamber Geometry
- Fuel: LCH_4/Isopropyl Alc/Ethanol
- Oxidizer: LOX/N_2O
- Ignition: Augmented Spark
- Assembly: Machined/Additive

Goals:

Develop a ~1000 lbf pressure-fed, liquid bi-propellant rocket combustion chamber.



Engine Layout