Combustion Chronicle Issue 1

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Introduction and Mission

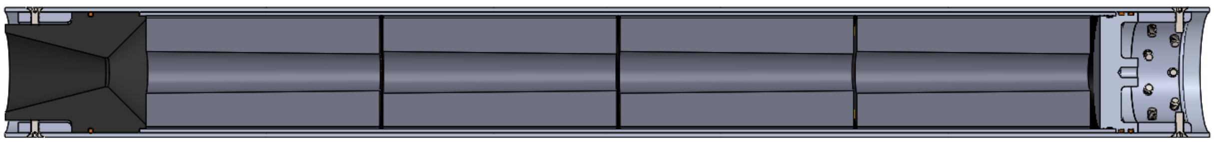
Welcome to the MIT Rocket Team and the solid propulsion subteam! The propulsion team is dedicated to researching, designing, and developing a student built solid rocket motor to support the team's entry into the Spaceport America Cup. For the 2018 Cup, the team will be competing in the "Unlimited" category, which does not assign teams an altitude target. In light of this, we have decided to fly to 80,000 feet, a bold goal that requires the best from every subteam and places a high demand on the propulsion system. In previous years, the propulsion team has designed a custom propellant formulation, mixed and tested small batches to characterize its performance, and fired motors containing up to 10,000 Ns of impulse ("M" class). This year, we will be building on the progress of last year to soar to new heights, building a "P" class motor burning 85 lbs of propellant, containing 70,000 Ns of impulse, and capable of delivering the vehicle to the target altitude.

This newsletter serves as a summary of the weekly progress made by the propulsion subteam; this first edition highlights work done over the summer.

98mm Case Redesign

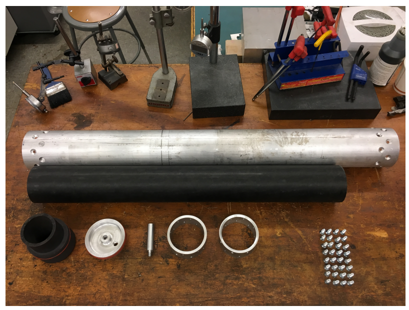
The 98mm motor case is being redesigned to accommodate this year's goals and budget. Last year's 98mm case featured closure retention by threaded rings, but it is being redesigned with radial bolt retention. Radial bolt retention is cheaper as manufacturing can be done completely in-house, and is scalable to larger diameter motors. In addition, testing radial bolted closures in a motor of familiar diameter provides us with a proof of concept of our design before tackling a 6" diameter motor.

The case was designed with an outer diameter of 4" and a wall thickness of 3/16", compatible with current hardware such as liners and nozzles. The bolt number and size for each end - 16 x 1/4-20 - was computed assuming a chamber pressure of 650 psi and a factor of safety (FoS) of 6 on bolt shear and 3 on case hole shear. Parts were acquired from Discount Steel and McMaster, and machining took place over the course of REX week with Kevin and Sam working in MITERS and Edgerton into absurd hours of the night. Shoutout to Maddie G. for helping machine the retention rings and to Amy for providing o-ring sizing tips.

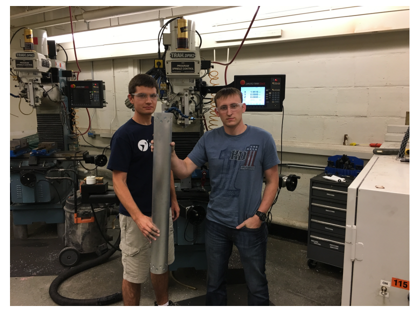


Cutaway CAD of the radial bolted motor case

Kevin countersinks the radial bolt pattern on the case exterior



Motor parts (without propellant) prior to assembly



Sam and Kevin with the completed case

Propellant Modifications

The current propellant formulation, dubbed Xaphan Blue, was developed a year ago by Zach, last year's propulsion lead, and Charlie. Xaphan Blue is being iterated to improve efficiency, cost, and decrease complexity by removing a chemical, Copper Oxychloride, that gives the exhaust a light blue color. While we will be sad to see the blue flame go, propellant performance is especially critical when designing large motors and will go a long way toward this years' project and projects in the future.

Sam and Claire conducted research using Rocket Propulsion Analysis (RPA) to obtain theoretical performance numbers for new propellant combinations. One of the more promising results was obtained by replacing the Copper Oxychloride with Ammonium Perchlorate, decreasing the amount of binder by several percent, and increasing the amount of plasticizer slightly. This allows us to achieve a higher solids loading while still working with a pourable propellant. This new formulation shows an increase in Isp by 7.6%, from 224 seconds to 241 seconds (theoretical Isp by weight at S.L.). Characterization will follow, although the best method to accomplish this has yet to be determined.

Thermodynamic properties | Performance | Altitude performance | Throttled performance

Theoretical (ideal) performance

Parameter	Sea level	Optimum expansion	Vacuum	Unit
Characteristic velocity		1382.86		m/s
Effective exhaust velocity	2198.43	2238.34	2397.98	m/s
Specific impulse (by mass)	2198.43	2238.34	2397.98	N·s/kg
Specific impulse (by weight)	224.18	228.25	244.53	s
Thrust coefficient	1.5898	1.6186	1.7341	

Theoretical performance of the Xpahan Blue propellant

Thermodynamic properties | Performance | Altitude performance | Throttled performance

Theoretical (ideal) performance

Parameter	Sea level	Optimum expansion	Vacuum	Unit
Characteristic velocity		1482.43		m/s
Effective exhaust velocity	2372.36	2417.00	2595.54	m/s
Specific impulse (by mass)	2372.36	2417.00	2595.54	N·s/kg
Specific impulse (by weight)	241.91	246.47	264.67	s
Thrust coefficient	1.6003	1.6304	1.7509	

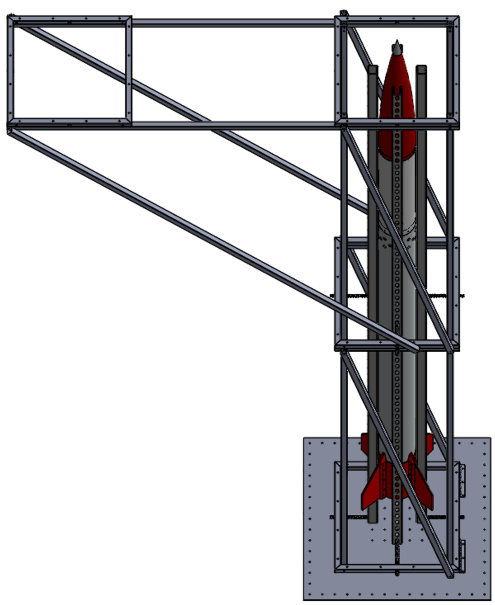
Theoretical performance of the new propellant

Test Stand, Launch Tower, and DAQ

A launch tower is under development that will support the vehicle during setup and launch, as well as double as a test stand for motor static fires. Luis designed the stand from steel tubing and unistrut, and it is intended to be as collapsible as possible, allowing for ease of transportation. The design was completed two weeks ago, and parts were ordered last week - they started coming in yesterday. The test stand is approximately 12 feet tall and is raised and lowered with an electric winch.

To collect quantitative information from our static fires, Andrew R. is designing a Data Acquisition Computer (DAQ) that accepts inputs from pressure transducers, load cells, and thermocouples to output and log data at 100Hz. A Teensy microcontroller is at the heart of the setup and communicates with a variety of amplifiers and regulators. The descope option is a commercial DATAQ system.

It came to our attention that using the forward closure as a load transfer point to the load cell may amplify chamber pressure oscillations. As such, a thrust takeup structure is being designed for the 6" motor that utilizes the case as the load transfer point and not the forward closure.



CAD model of the test stand supporting a concept of this year's vehicle

Powder coated stock for the test stand arrived in lab

Casting Equipment

Making the transition from motors with 12 pounds of propellant to ones with almost 90 requires a significant upscale of propellant production infrastructure. Special consideration has been given to the mixer and vacuum processing equipment. In mid August, a 30 qt mixer was found on the Rocketry Forum (TRF) for $200, a small fraction of the typical $2-3,000 cost on Ebay. The issue was that it was only available for pick-up in southern Virginia. Claire and Sam made the 13 hour drive both ways, fending off full-service gas station attendants and naval base guards to acquire the new mixer. It now stands proudly in lab next to the fasteners table. This will allow us to increase our batch size by a factor of 6 and drastically reduce the time required to mix the full scale flight motor.

An 18"x18" shake table was acquired (thanks Stata loading dock) that runs smoothly. It will be used to agitate the propellant while under vacuum to remove bubbles and decrease the number of voids in the cured propellant.

Loading and unloading the mixer proved quite challenging

The 30 qt mixer rests in lab after its 1,154 mi journey, next to the new shake table

Miscellaneous

The speaker in lab is now bluetooth, so you can change Fat Rat songs in the middle of a layup without being contrained by the cord. To connect to it, pair your device with "Nyrius Receiver".

Looking Ahead

- Hydrostatic testing of the new motor case will take place next week, as will work on the DAQ. The goal is to have the first static fire by next week Saturday (or as soon as Crow Island gets back to us).
- ITAR training needs to take place in order for mixing to occur.
- The 98mm test stand needs to be revived from its sad state after the last CATO.
- The modified propellant needs to be characterized. A plan for this needs to be develop and drafted.
- The new mixer needs to be refurbished and tested.