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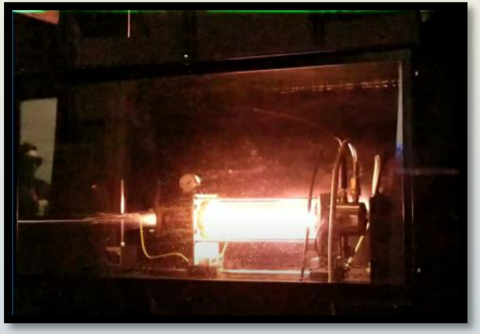
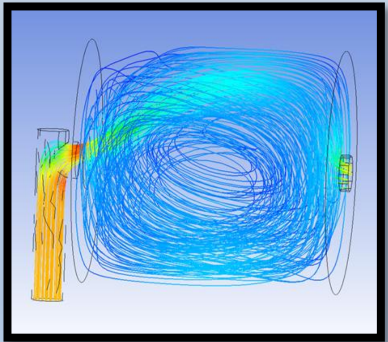


Acrylic Hybrid Rocket Propulsion: NDSU Design Project



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and

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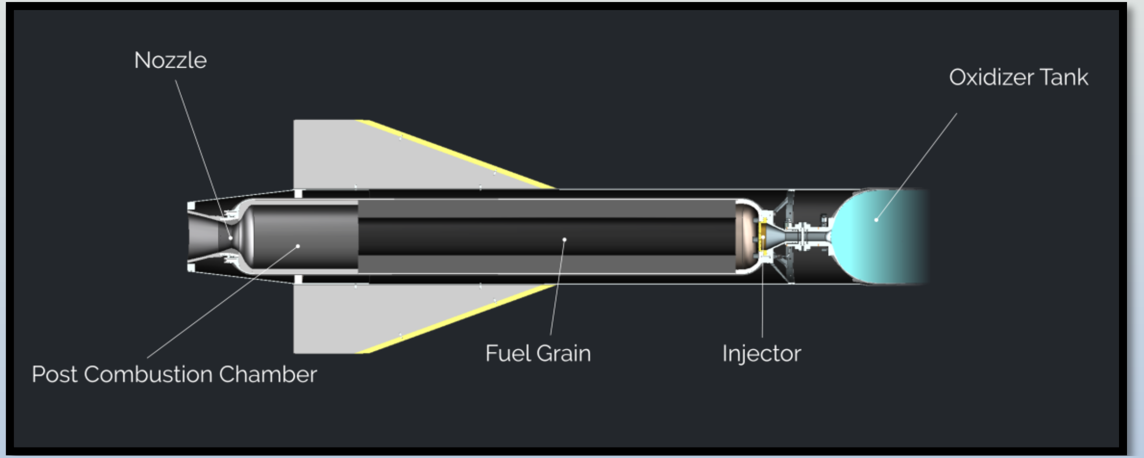
Introduction: Background and Motivation

Interplanetary travel is of great interest and finding new and innovative ways to achieve this is of great importance.

Hybrid fuel rockets are a sought-after method to achieve due to cheap operation and simple manufacturing.



Goal: Design and Characterize a PMMA/GOx based hybrid rocket propulsion system. We want to investigate the combustion behavior, fuel regression and propulsion of the engine design.

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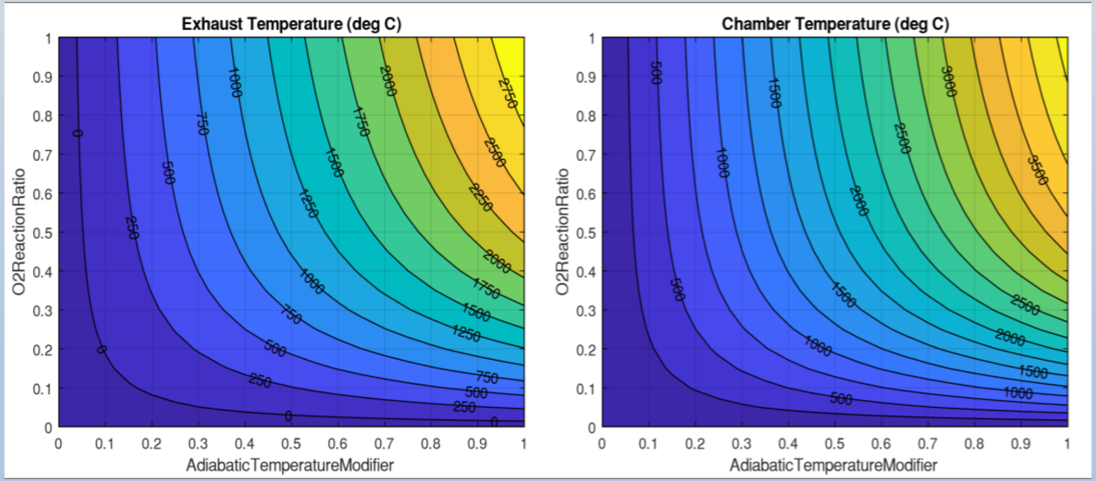
Propulsion system design

The combustion of PMMA (Acrylic) can be shown as the following reaction.

$$aC_5H_8O_2 + bO_2 \rightarrow n_{CO_2}CO_2 + n_{H_2O}H_2O + n_{O_2}O_2$$

JPL PMMA hybrid rocket data was used to estimate this parameter used in design.



$$(O/F)_{mol} = \frac{b}{a}$$

With the O2 reaction ratio, we can estimate our Exhaust and Chamber temperature using an adiabatic temperature modifier.

$$AdiabaticTempModifier = \frac{T_0 - T_\infty}{T_{Adi} - T_\infty}$$

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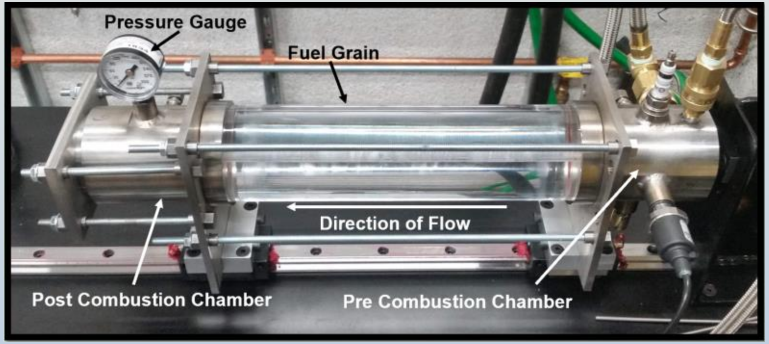
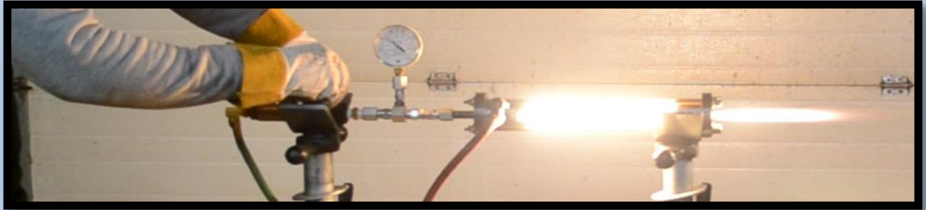
Rocket Engine Design

Rocket consisted of a combustion chamber, where a reaction of oxygen and the solid fuel source occurred. Downstream was Mach 2 nozzle to direct the flow and generate thrust.



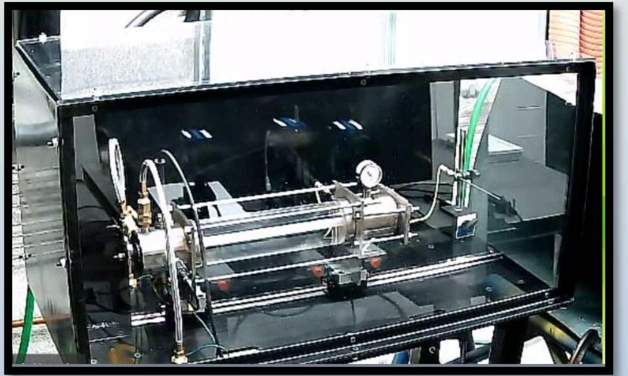
Initially propane would start the reaction and would be slowly turned off as the acrylic core began combustion. Afterwards, the oxygen was adjusted to the desired flow rate for the reaction.

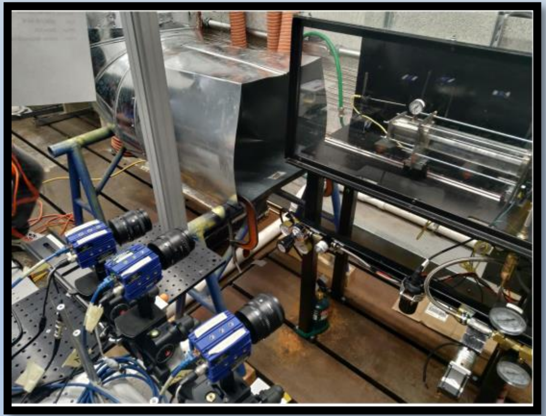


Before the final design was constructed, a prototype was constructed to demonstrate validity of the initial design.

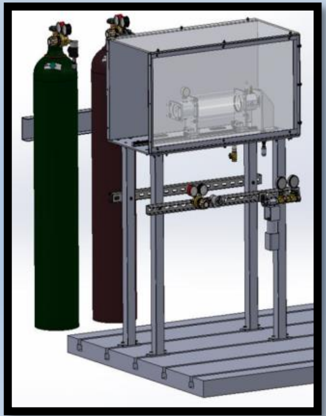
Measurements and Laboratory Testing

A test stand was developed to house the control equipment and rocket, while ensuring safety during the test duration. Final design could take temperature, force, pressure measurements while controlling fuel ratios.



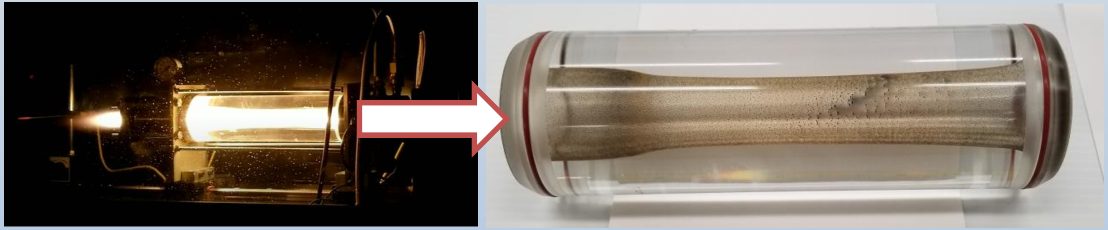


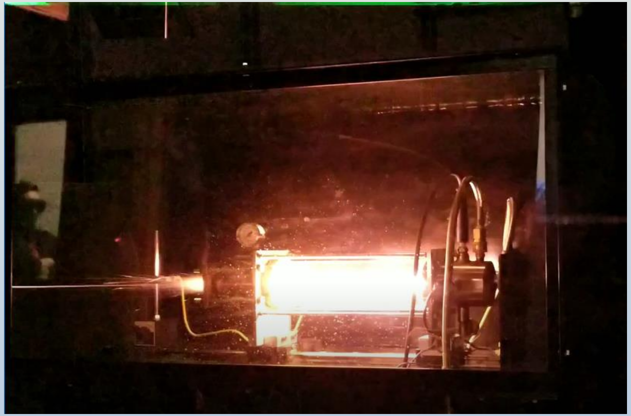
Imaging was also conducted to observe the exhaust and combustion chamber during test runs of the rocket.

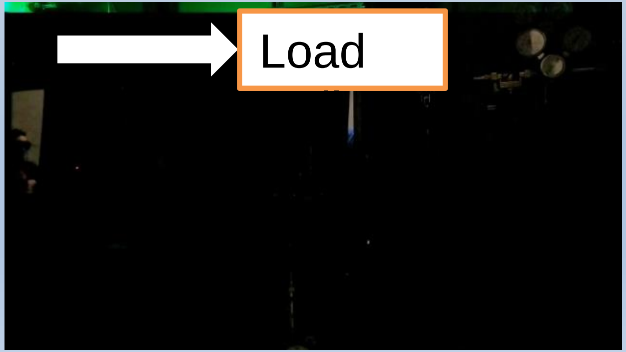


Initial Results

Exhaust cone shape appeared during experimental runs of the designed rocket. Thrust was observed as you see the rocket move to contact the load cell.







Void entrainment was observed by the acrylic fuel grain, and more importantly the fuel core survived the test showing success of the design.

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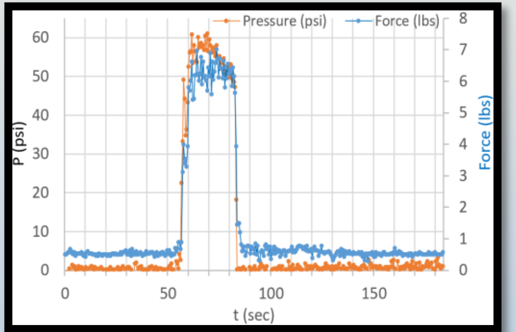
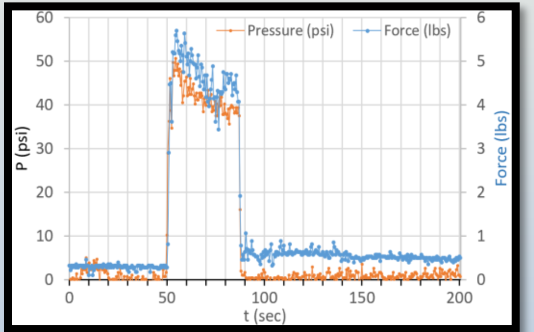
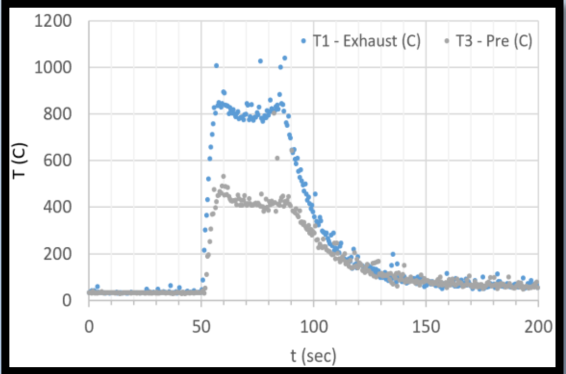
Measured Test Data







2 test runs were completed, and the temperature, pressure and force measurements were taken. The testing conditions are now more well known, and more tests are being setup to investigate differences between theoretical and experimental results.

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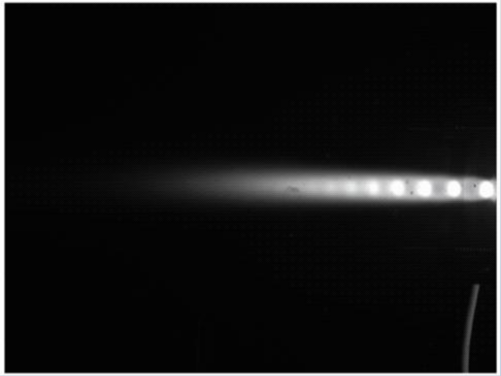
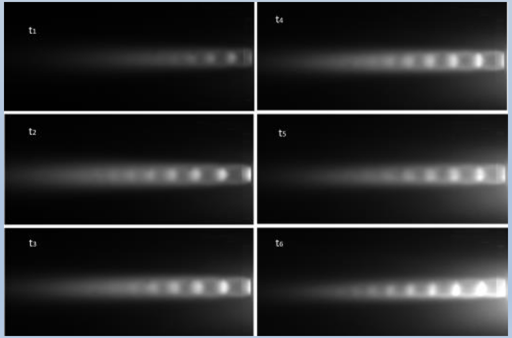
Exhaust Imaging

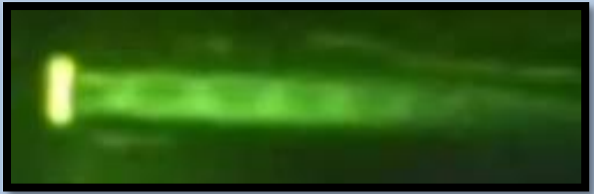




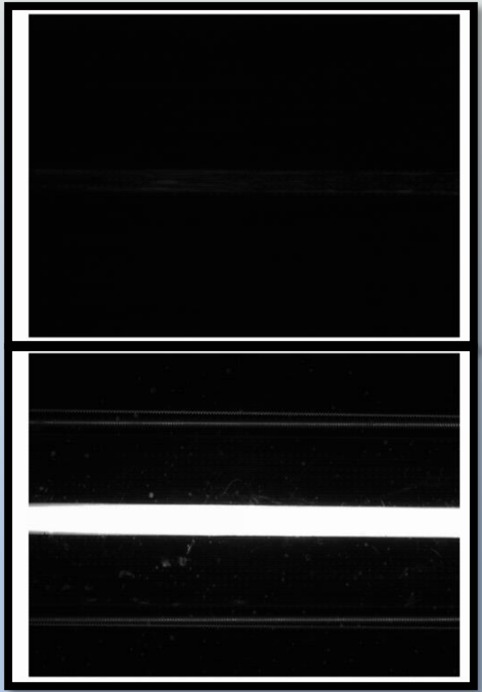
Prototype images were able to be collected using a Shade-10 and Shade-5 filter.

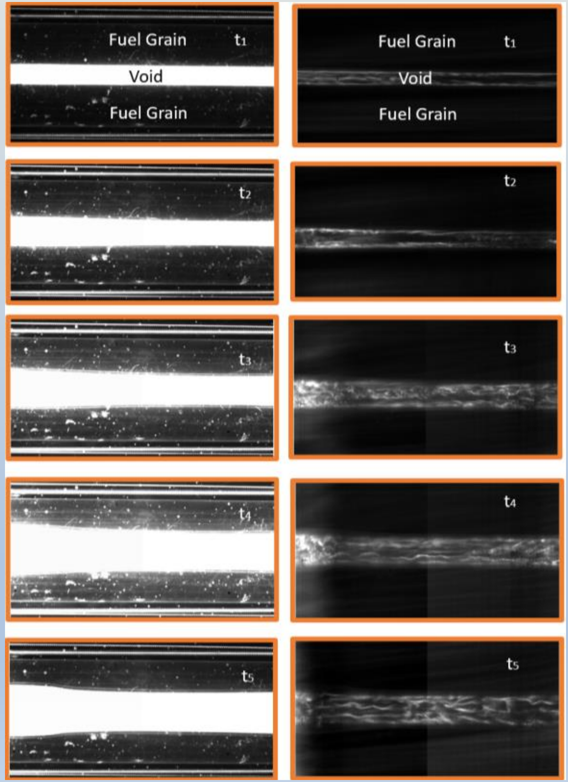
Camera filtering was required to acquire images, which resulted in the use of a 532nm camera filter. This allowed excess wavelength of light to be filtered and clear imaging to happen.

As a result, a clear diamond pattern occurs of the intersecting shockwaves in the exhaust of the nozzle.



Combustion Chamber Imaging





Imaging of the combustion chamber was completed requiring low exposure rates to record. Degradation of the fuel core was seen over the duration of the test runs. By the end of the test a clear void was obtained.

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Conclusions

The rocket was successfully designed and characterized using imaging methods, along with more traditional temperature, force and pressure readings during the tests. We believe with these results, reduced operation and manufacturing costs in hybrid engines can be achieved.

Currently we are working on conducting PIV imaging of the engine moving forward, to better understand its flow behavior.

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Acknowledgments

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Colton Mosser is acknowledged for starting the first designs of the RPDT at NDSU in Fall 2017

If you would like to learn more:

Yurek, J., Arstein, D., Lillis, G., Dixon, P., Miller, H., Leuders, G., Omerza, E., Ullah, A. H., Fabijanic, C., Refling, W., Estevadeordal, J., "Design and Characterization of Optically Clear PMMA/GOx Hybrid Rocket Propulsion System", ***AIAA Scitech 2021 Forum*****, Jan. 2021.**

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