Experimental Solid Fuel Propulsion System For A High-Powered Rocket

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Abstract

Rocket propulsion systems represent a complex interplay of chemistry, Newtonian physics, and other sciences fundamental in aerospace engineering. NAU has developed an incredible program where students delve into the field of rocketry through the NAU Rocket Club, allowing young engineers to develop critical skills for careers in aerospace. This capstone project is assigned the mission of developing tools and research for the future students of NAU Rocket Club to improve their understanding of rocketry. The tools developed through this capstone project include an adaptable rocket motor test stand to calculate thrust curves for the 38-75mm diameter motors and a pressure vessel designed to withstand up to 3000 psi. This allows for a quick iteration through propellant formulas by creating thrust curves from propellant strands. Additionally, the development of different sized rocket nozzles and the research of nozzle optimization will allow future students to understand nozzle design. Finally, the development of the motor casing, bulkheads and research associated in these designs will allow the future students to design their own, as well as utilize these components within their motors. The final display of the tools and research developed during this project will occur through the launch of a final 75mm motor rocket at a designated launch site, made from the team's optimized, unique ammonium perchlorate propellant formula. The rocket's peak elevation from this launch, desired to be above 15,000 feet, will determine the propellant formula efficiency in comparison to commonly used and tested formulas.

Requirements

- Design and develop a unique Ammonium-Perchlorate propellant formula for a high-power, level two rocket.
- Optimize the propellant formula to maximize the thrust output for the rocket.
- Design and build an adaptable rocket motor test stand with precise and accurate data collection instruments for testing motors of different diameters and heights.
- Prepare at least two rocket motors to be tested of sizes 38- and 54-mm and one of size 75 mm diameter before building a final 75 mm motor to launch at a designated launch site.

Propellant Formula

Requirements:
- A unique AP solid fuel formula
- Must be optimized with the intent of reaching the highest altitude

Methods:
- ProPep 3 was used to optimize the ratio of AP to AL
- Using this ratio eight different variants of the propellant formula were created using different amounts of binder, curative, and plasticizer
- Two of these formulas moved onto farther testing biased on the mixing and curing consistency

Results:
- The final formula was chosen based on 54 mm motor testing
- The final formula shown below was cast into a 75 mm motor of the final launch

Table 1. Final Formula

AP (Oxidizer) (50% 400 micron 50% 90 micron)	71.2%
R45 (Binder)	10.8%
MDI (Curative)	1.7%
Lamp Black	0.2%
DOA (Plasticizer)	5.4%
AL (Fuel)	10.7%

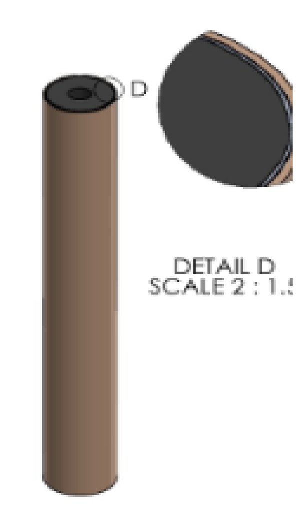

Figure 1. Propellant CAD


Figure 2. Propellant Grains

Test Stand

Requirements:
- Withstand a total impulse of 5120 Newton-Seconds (an average of ~250 lbf)
- Able to accept different size motors

Methods:
- Fully-Aluminum frame offers lightweight portability with adequate strength
- Height-adjustable gantry allowing for all different types of motors
- Steel base plate allows for extreme loading with negligible deformation

Results:
- Test stand was able to withstand the force from the motors without issue. Even the failed tests had no effect on the test stand's structural capacity
- Easy gantry height adjustment aided for quick height adjustment out while testing

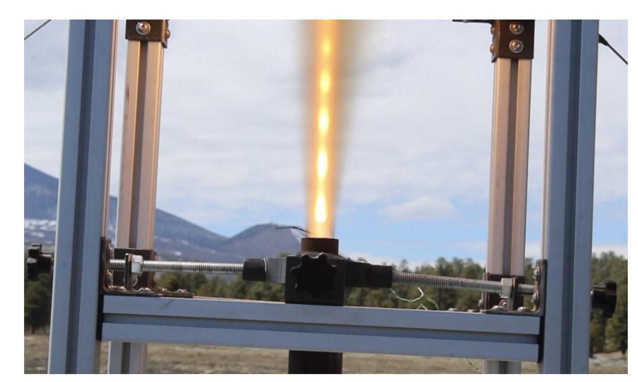
Figure 3. 54 mm Static Test


Figure 4. Test Stand

Pressure Vessel

Requirements:
- Must be able to withstand 1500 psi with a factor of safety of at least 2.
- Designed to take precise and accurate temperature and pressure data.
- Incorporates many safety precautions due to very high internal pressure during testing.

Methods:
- A high-pressure oxygen tank rated for 5000 psi with steel fittings rated for at least 5000 psi.
- A 2500 psi pressure transducer attached to the fittings as well as three K-type thermocouples for temperature readings incorporated.
- An emergency pressure release valve for 2000 psi

Results:
- Cold junction compensation was determined to be required to account for the cold temperatures outside for the thermocouples to function properly.
- Testing will need to be conducted again before results are determined

Nozzle

Requirements:
- Achieve a total impulse close to, but not exceeding 5120 Newton-Seconds
- Provide the rocket with a thrust-to-weight ratio of at least 5:1
- Withstand combustion temperatures with minimal erosion

Methods:
- Designed with ablative materials (graphite and phenolic resin) to remain strong under exhaust temperatures
- O-ring seal prevents the escape of hot gasses
- Graphite throat insert minimizes erosion at a critical location in the design

Results:
- Supersonic flow was achieved
- Thrust class of a level 2 motor was achieved
- Exit Mach 3.65


Figure 5. Strand Burner


Figure 6. Sample Strand


Figure 7. Nozzle Attached to Motor


Figure 8. Nozzle

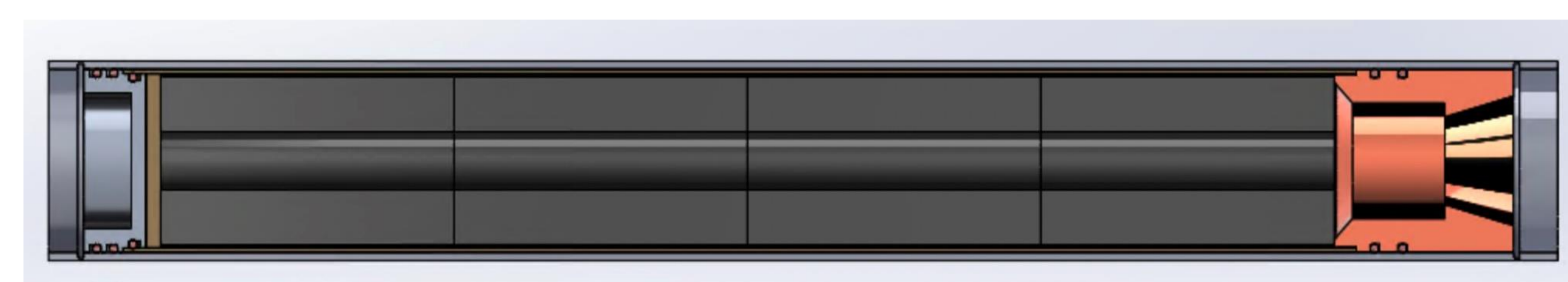
Figure 9. 75mm Casing Assembly Cross-Section

Conclusions

Solid rocketry remains a developing field that is getting better as experimental procedures proceed. The aim in this project was to attempt to develop NAU's own solid rocket propellant to give to the NAU Rocket Club for their future work. In this project, the team successfully completed the following:

- Manufactured a sturdy rocket test stand to help characterize different rocket formulations
- Developed and tested a unique solid rocket propellant.
- Used advanced CFD analysis and compressible flow models to develop an optimized nozzle for flight
- Designed and tested a unique 75mm rocket casing which may be used for future flights with the NAU Rocket Club

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