Holloman Air Force Base High Speed Test Track Rocket Prototype
Cadets Nicholas Curtis, Matthew Olsen, Jackson Trent
United States Air Force Academy, Colorado

Background and Requirements
- Holloman High Speed Test Track (HHSTT) is in need of a rocket to replace currently aging fleet
- HHSTT Rocket Requirements:
  - Deliver 10,000-20,000 lbs thrust for 10 seconds
  - Take no more than 2 seconds to reach desired thrust
  - Contain materials safe for humans
  - Be highly storable with long life-expectancy
  - Be manufactured in-house
  - Be capable of scaling up or down
  - Reduce current cost of test track operations
- Prototype priorities: thrust curve, manufacturability, and cost
- Considered Fuels:
  - Polyethyleneoxide (PEO), which is a type of polymer derived from etherification of ethylene
  - Sodium hydroxide (NaOH), which is a highly corrosive alkali metal hydroxide
  - Nitric acid (HNO₃), which is a strong oxidizing acid
  - Hydroxyl-terminated polybutadiene (HTPB), which is a type of thermoplastic elastomer
- Recycled crumb rubber was considered as an alternative to pure HTPB
- Considered Fuel Grain Geometries:
  - Wagon Wheel, Rod & Tube, Star, and Double Anchor

Small-Scale Prototype Manufacturing
- Additive manufacturing used to construct molds for Rod & Tube and 5-pt Star grains
  - Rod & Tube mold
  - 5-pt Star mold
- Structure manufactured in-house
- Molds used to form fuels into solid grains
- Crumb rubber was pre-vulcanized and unable to be effectively molded
- ABS grains made using additive manufacturing were determined to be the most reliable and economical
- Grains printed: Double Anchor, 5-pt Star, and Rod & Tube
- Calculated and hand machined ideal CON/DIV nozzle
- In-house custom thrust stand manufactured
- Unable to complete due to COVID-19

Design Sub-Systems
- Oxidizer Delivery Subsystem
  - Oxygen Delivery  
  - Injection ports
- Structure Subsystem
  - Rocket Body  
  - Test Sled Interface
- Rocket Body Components
  - Left to Right: Injector, Main Body, Fuel Sabot, Fuel Grain, Nozzle

Thrust Curve Modelling
- The selected fuel grain geometries were modelled in an open source internal ballistics simulator called openMotor
- Indicated by the green trace, both geometries result in a fairly neutral thrust curve
- Provides analytical support for chosen geometries and meets requirements

Models & Experiments
- Thrust Curve:
  - Rod & Tube HTPB
  - Rod & Tube ABS
  - 5-pt Star HTPB
  - 5-pt Star ABS

Fuel Grain & Material Selection
- Experiment designed to determine best fuel material and geometry combination and validate predictions
- Four trials total utilizing the two selected fuels and grain geometries
- Experiment designed to determine best fuel material and geometry combination and validate predictions
- Four trials total utilizing the two selected fuels and grain geometries
- Commercially available fuels:
  - Hydroxyl-terminated polybutadiene (HTPB)
  - Acrylonitrile Butadiene Styrene (ABS)
  - Polymethylmethacrylate (PMMA)

Conclusions
- A reusable hybrid rocket utilizing additive manufacturing offers the best solution to fulfill the requirements as stated by the primary user, Holloman AFB. By using ABS and gaseous oxygen for the fuel and oxidizer, the rocket will serve as a cost-effective replacement for the aging fleet of rockets. The simplistic design allows for rapid disassembly and reuse for high-tempo sled operations. Together, the different design aspects provide a more versatile, safe, economical, and user-friendly product to the user.

Acknowledgements
We would like to thank Holloman AFB for allowing us the opportunity to conduct this research. We would also like to thank the USAFA Departments of Astronautical Engineering, Engineering Mechanics, Civil Engineering, Aeronautical Engineering, and Chemistry for use of facilities and collaboration with faculty.