Holloman Air Force Base High Speed Test Track Rocket Prototype

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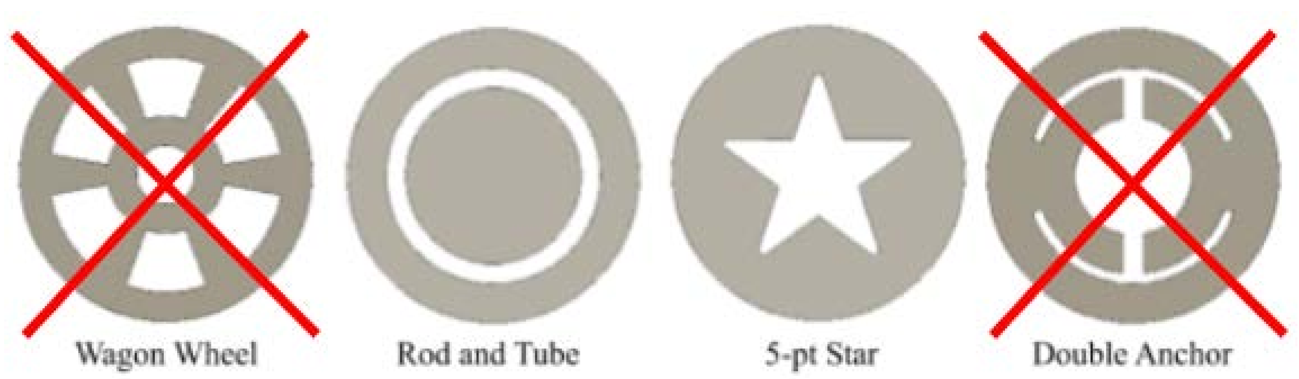
Background and Requirements

- 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:
    - Polymethylmethacrylate (PMMA), Acrylonitrile Butadiene Styrene (ABS), Hydroxyl-Terminated Polybutadiene (HTPB), and Paraffin Wax
    - Recycled crumb rubber was considered as an alternative to pure HTPB
  - Considered Fuel Grain Geometries:
    - Wagon Wheel, Rod & Tube, Star, and Double Anchor

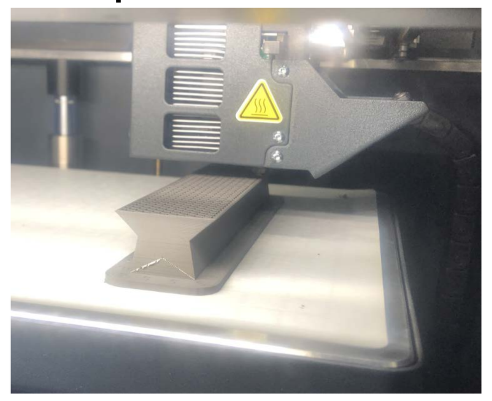


Selected fuel grain geometries

Small-Scale Prototype Manufacturing

- Additive manufacturing used to construct molds for Rod & Tube and 5-pt Star grains
  - 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


Rod & Tube mold


3D-printed metal star mandrel

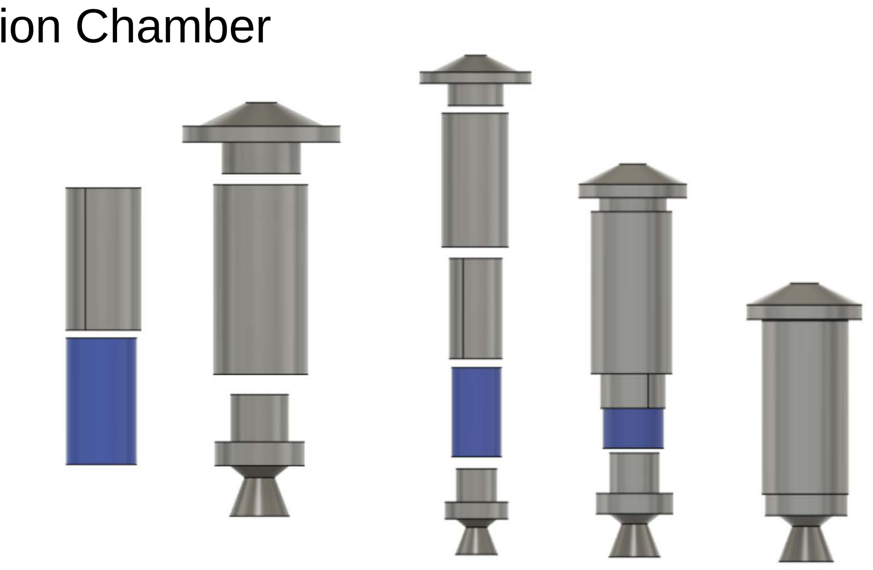

In-house Thrust Stand

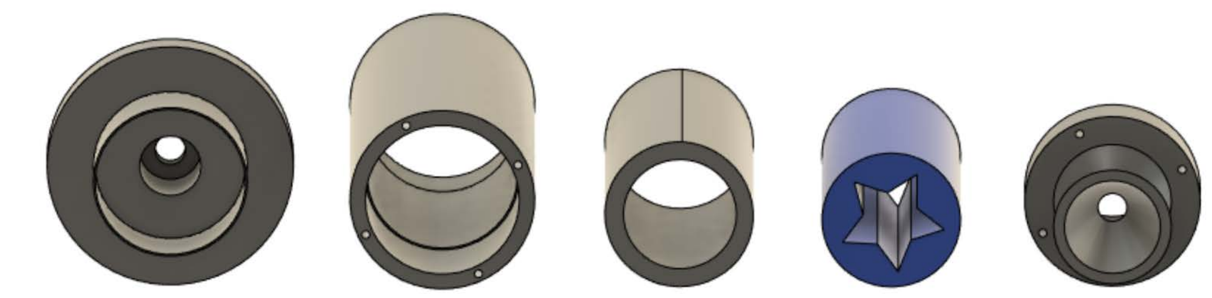
Design Sub-Systems


Machined ideal CON/DIV Nozzle insert (top view)


Machined ideal CON/DIV Nozzle insert (left, side view)

- Oxidizer Delivery Subsystem
  - Oxidizer Plumbing
  - Throttling
  - Injection ports
- Combustion Chamber Subsystem
  - Combustion Chamber
  - Nozzle
  - Grain
- Structure Subsystem
  - Rocket Body
  - Test Sled Interface
- Ignition Subsystem


Rocket Body Components (side view)
Far Left: Fuel Grain and Sabot
Second from Left: Main Body with Nozzle and Injector
Right Three: Fuel Grain, Sabot, Main Body, Nozzle, and Injector assembled


Rocket Body Components (perspective view)
Left to Right: Injector, Main Body, Fuel Sabot, Fuel Grain, Nozzle

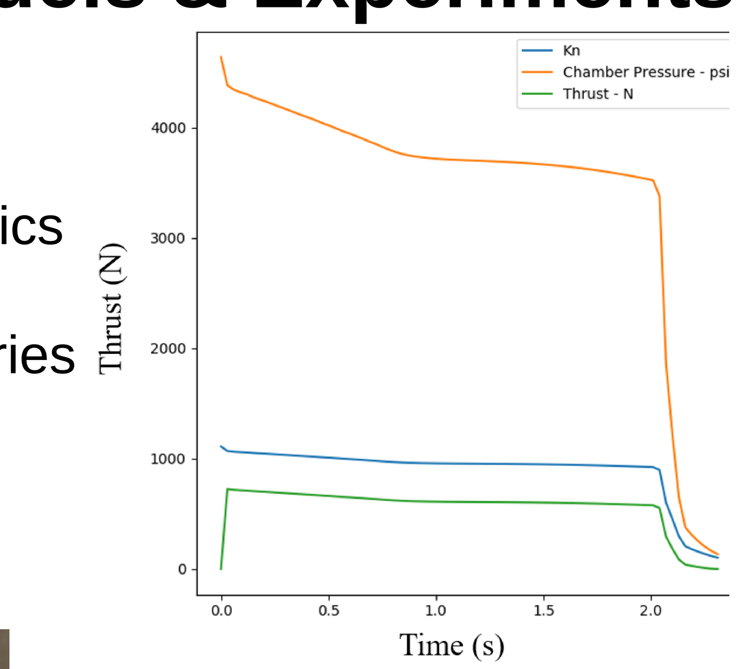
Prototype Rocket Design

- Rocket designed for reusability and simplicity
- Each component slides into another
  - Each seal is fitted with a rubber o-ring
- Bolts used in the injector and nozzle to secure entire rocket
- Rocket design allows for different grains to be used in Bates Motor fashion
- Fuel grains made using additive manufacturing, loaded into the sabot, then inserted into rocket body
- Rocket capable of rapid reload with a new sabot and grain
  - Also allows for disassembled deep cleaning

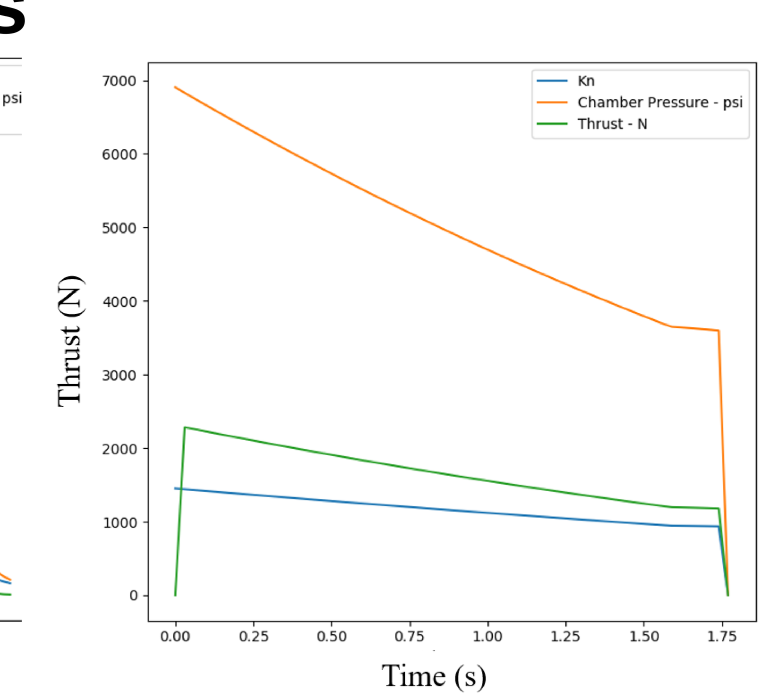
Models & Experiments

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

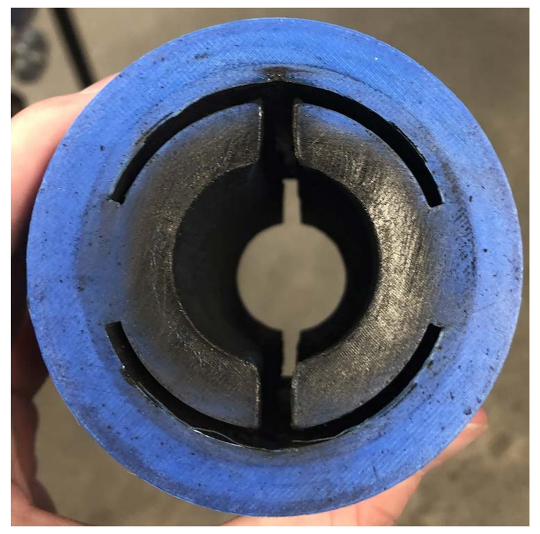


Rod & Tube Thrust Curve



5-pt Star Thrust Curve


ABS Firing


Double Anchor Grain Post Firing

ABS Firing

- Conducted to verify viability of ABS as a fuel
- Same rocket body as in PMMA O/F Ratio experiment but with additive manufactured Double Anchor grain
- Produced normal flame front
  - Byproducts: gummed residue, potent odor
- Unable to perform follow-on tests due to COVID-19

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
- Significantly higher or lower thrust from ABS is of interest
- Rod & Tube with ABS combo is the predicted best choice
  - Based on manufacturing difficulty level, simulated thrust curves, and cost
- Unable to complete due to COVID-19

Trial #	Geometry	Fuel
1	Rod & Tube	HTPB
2	Rod & Tube	ABS
3	5-pt Star	HTPB
4	5-pt Star	ABS

Trial Configurations

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.

USAFA-DF-2020-169