Experimental Hybrid Fuel Rocket Engine

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Abstract

The experimental hybrid fuel rocket engine project developed a high-performance, modular rocket engine from the ground up to increase the capabilities of the Yale Undergraduate Aerospace Association (YUAA) in the field of rocketry. This engine was fully student designed and constructed, and will serve as a foundation for YUAA rocketry development. In addition, a rocket motor static test apparatus was constructed, which will serve as a reusable testbed for future motor testing by YUAA.

Overview

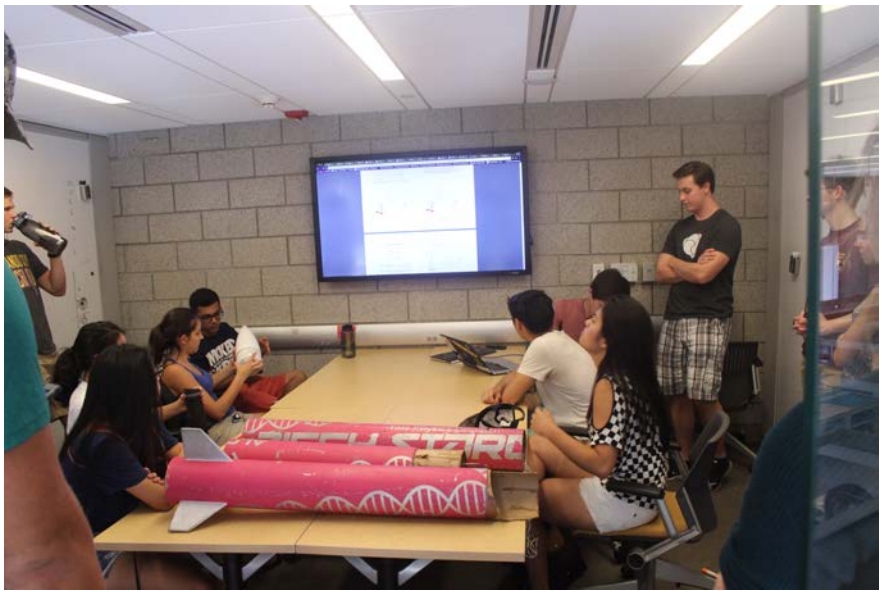
The year began with constructing a traditional solid-fuel rocket, which served as both a method of undergoing National Association of Rocketry certification, and also laying the groundwork for learning basic rocketry design and construction skills. This rocket was launched twice and the lessons learned from this, specifically about electronics bay design and recovery parachute deployment were used in designing the body for the hybrid fuel rocket itself. Following these two successful launches and recoveries of our preliminary rocket, we moved to designing the experimental hybrid motor.

Hybrid Fuel Rocket Engine

A traditional solid fuel rocket motor uses powderized fuel and oxidizer, which are mixed then compressed into a fuel grain. The advantage of this approach is its reliability; however, it does not permit us to accurately control flight characteristics such as burn time, thrust levels, or allow for cutoff and re-ignition. A hybrid fuel motor, by contrast, uses a liquid oxidizer pumped through a solid fuel grain, allowing for a large degree of thrust control by adjusting oxidizer flow.

Fully machined combustion chamber, preliminary valve assembly, and oxidizer tank alongside ground support equipment prototypes with nitrous fill tubing in the box above

We began by choosing rubber as our fuel grain and nitrous oxide as our liquid oxidizer. Rubber, specifically HTPB, is a common fuel used in hybrid rocket motors (currently used in the Bloodhound, the car designed to beat the land speed record), with its main advantages being safety and ability to mold it without the need for high temperatures by mixing HTPE resin and hardener. Nitrous oxide was the choice for an oxidizer due to its self-pressurization characteristics, which forgo the need for a complex oxidizer pump or positive-pressure injection system, simplifying the design and greatly increasing motor reliability.



Beginning of year preliminary design meeting

In the design of the actual motor body, we decided against the popular mono-tube design, consisting of a linearly stacked oxidizer tank, single injection port with plug, and combustion chamber all within the same capped tube. While simple and easy to construct, it has proved an unreliable design and perhaps more importantly does not allow for a tailoring of thrust characteristics, the goal of this project. Instead, we chose to have a separate oxidizer tank, injection and valve assembly, and combustion chamber. This provides for a mechanism to adjust oxidizer inflow with a variable-control valve, thus controlling the thrust of the rocket. We used high-pressure nitrous oxide injection valves from racing cars as the preliminary valve for this system, and will expand to a custom designed actuated ball valve which will give greater control over oxidizer flow.

On the business end of the rocket, graphite was chosen as a nozzle material due to its high thermal resistance, which results from its ablative nature when subjected to extreme temperature. It also is easier to machine than traditional high-temperature steel or phenolic nozzle materials. We are beginning with simple converging-diverging nozzle geometries, but plan to custom machine more diverse designs to explore how change nozzle characteristics affects flight. The oxidizer tank and combustion chamber themselves were constructed from 6061 aluminum, which provides a high strength-to-weight ratio and is predictable and easy to machine.

Static Test Stand

Test Stand Chassis and Load Cell Mounting System

In order to test and further refine our design on the ground, we constructed a test stand to take data during static firings of our rocket motor. This allows us not only to ensure the reliability of the rocket, but also to experiment with modifying components of the motor to see how they affect performance characteristics such as specific impulse and burn time. Constructed from 1/8 inch welded mild steel tubing into a cross-braced chassis, the load cell and safety bulkhead system seen above were custom designed for our motor with safety factors of a minimum of 3 for all components and welded by team members. The load cell was then calibrated using iron weights of known mass, which will give us reliable linearly dependent thrust readings during testing.

Team members performing medium-level stress testing of load cell mounting system

Results

The development of a complete rocket motor system and the majority of an advanced carbon-fiber composite rocket airframe were both successful. In addition, the team constructed a robust static test stand that withstood preliminary stress testing and calibration at expected thrust forces while producing reliable, repeatable, accurate results. Unfortunately, due to complications arising from Yale Environmental Health and Safety delays, we were not able to perform static testing of the motor this academic year. However, test procedures and pre-checks are complete and our design has been approved for testing, which will occur promptly upon returning to campus this upcoming fall.

Conclusions

This project will be the foundation for continued work this coming school year, which aims to optimize the motor itself as well as test stand integration and safe firing procedures. In addition, the team will continue to develop complimentary ground support equipment to ensure reliable engine preparation and ignition. In continuing to refine and test the design of this experimental motor, YUAA will increase the breadth of its knowledge in the area of engine design and move closer towards our goal of a fully liquid rocket engine by 2022.