Design and Validation of Oregon State University's Propulsion System

Team 21 Project Technical Presentation to the 2018 Spaceport America Cup

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INTRODUCTION

The development and validation of this year's Oregon State University 30k team's propulsion system is a demonstration of the team's technical excellence. The product is a student researched and developed solid rocket propulsion system with notable aspects in propellant formulation and non-traditional motor diameter. These two challenges each resulted in catastrophic motor explosions.

Non-Standard Motor Diameter

The team selected a 5" internal diameter motor due to constraints from the rocket airframe diameter and length. A 6" motor would be too large to fit within the airframe. A 4" motor would need to be too long and cause erosivity. This meant the casting tubes and thermal liner would need to be from non-traditional and separate sources.

The thermal liner selected is a 5" outer diameter and 4.71" inner diameter vernatube exhaust tubing. It is made of corrosion-resistant E glass, and class 1 fire retardant epoxy vinyl ester thermoset at a 60% glass/resin ratio. The tubing is initially sold for boat exhaust, but is rated UL94V-0 for flame retardancy.

Another challenge was sourcing the casting tubes to pack propellant into. The casting tubes needed to be custom manufactured to match the thermal liner, and grain geometry. The initial set of casting tubes used caused the first catastrophic motor failure. The casting tubes had a thin spiral where edges of the paper met. During the full scale static fire, the flame was able to travel along this spiral, and casting tubes could not inhibit burning from the outer edge. Later tests with this casting tube demonstrate filling this spiral with wood filler sufficiently prevent burning along the outer edge, but new casting tubes were also ordered with more rigidity, thickness, and no spiral. For the final static test fire and subsequent test launches, the new commercial tubes were used.

Propellant Formulation

Over the course of the project, in conjunction with the high altitude team, the team tested several propellant formulations, and even created two new propellants. One aspect tested was unimodal versus bimodal ammonium perchlorate oxidizer. The bimodal refers to 200 and 90 micron particle sizes similar to fitting baseballs between basketballs. The bimodal slightly increased burn rate and ease of mixing. For the new propellants, compared to previous Oregon State propellant formulations, the two new formulations attempted higher solids loading at about 86%.[1] These mixes contained 6% Al fuel, and one with 0.2% red iron oxide catalyst. The higher solids loading allows for a more energetic burn at the expense of reducing the amount of binding agents. The red iron oxide even further increased the burn rate. In order to bind these higher solids loadings, the R45M resin was substituted for an NPE premix consisting of R45M HTPB resin, a phenolic antioxidant/ stabilizer, polyether bonding agent, and polyether cross linking agent.These propellants nicknamed Bare Bones and Beaver Buster respectively, proved to burn too fast and hot for the hardware. Therefore, the final propellant selected is a mix of various formulations, and similar formulations have proven successful for past OSU teams. The propellant takes advantage of a unimodal oxidizer with a mix of aluminum and zinc fuel, and a combination of burn inhibitors and catalysts. This provided the energetics required for the altitude while not as destructive on the flight hardware.[2]

For the last ingredient in each propellant, the curative is added to harden the mixture. Previous Oregon State teams use a set percentage of total propellant mass for the curative amount. This year's team uses an equation for a desired index ratio of isocyanate NCO compound to the hydroxyl OH compound.[3] This takes into account the isocyanate contribution from the curative as well as the hydroxyl compound from ingredients such as the castor oil and hydroxyl-terminated polybutadiene (HTPB). In order to gauge the influence of the curative to propellant performance, this year's team also introduced a Shore-A durometer. This allowed the team to experiment with curing durations, and the hardness required for optimal performance. The appropriate range for the propellant to be fired is high 80's to low 90's. If the propellant is too soft the fire could tear pieces off, while too hard and cracks could form during the fire. Each case increases burn area and chamber pressure.

Motor Testing and Performance

Starting March 3rd, the team transitioned from subscale tests to a full scale static test fire. This motor used the Bare Bones propellant. During this test the casting tubes failed to inhibit burning from the outer edge resulting in a catastrophic motor burst at 2250 psi. On March 23rd, another motor burst, this time due to an increased pressure from the Bare Bones with NPE premix resin, this time at 1900 psi.

Even though the desired and design failure mode is the nozzle ejecting out the aft end, inspired by professional design choices. The two motor bursts failed at the motor tube. Further tested was conducted by trying the fail the snap ring retaining the nozzle. Using the strength of the aluminum to fail the snap ring groove, the snap ring continued to hold past expected hydrostatic pressures. Testing and further research concluded that the snap ring failure is a combination of pressure chamber forces and thermal influences. Testing both factors was impossible in a safe and effective manner.

On April 15th, the team performed a full diameter, half length "midscale" motor to confirm motor hardware and propellant geometry, but this time with a team named, "Orange Koolaid" propellant variant. Finally, the team had a functional large motor at an N-class. On May 10th, another full scale static test was performed with the "Orange Koolaid" mix, resulting in a functional O-class motor. On May 13th, the team performed the first flight test of the fully integrated rocket. The rocket flew to 24,200 ft above ground level with a chuff of the rail. This chuff is believed to be from a lower hardness than previous fires. This was the first chuff of the year. Further work and testing is being conducted to reduce the risk of a chuff at the Spaceport America Cup competition.

RESULTS, CONCLUSIONS, AND FOLLOW-ON WORK

Over the course of this year, Oregon State University designed and validated a solid rocket motor for the Spaceport America Cup advanced category with an emphasis on a non-traditional motor diameter, propellant formulation, and several catastrophic motor bursts. With the successful static fire and several improvements to the overall flight rocket, the design and testing of the motor results in an expected altitude of just under 30,000 ft AGL at the Spaceport America Cup competition. The motor is significant to validate solid rockets at Oregon State University, and to demonstrate the ability to improve propellants and build odd sized motors. Moving forward, further study could be performed on larger motors or further tweaking of propellant formulation.

REFERENCES

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