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Microgravity Experiments from Sub-Orbital to Orbital Platforms (3)

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CENTRIFUGAL CASTING OF WAX-BASED FUEL GRAINS IN MICROGRAVITY: PRELIMINARY RESULTS FROM A SUB-ORBITAL LAUNCH

Abstract

The Space Enabled Research Group at MIT has a long-running research program investigating the use of waxes as solid fuel grains in hybrid propulsion systems to provide deorbit/maneuvering capabilities for small satellites. Wax-based fuels have potential benefits of being low-cost, non-toxic, and can be sustainably sourced through natural beeswax. Wax-based fuels are typically not used in space due to their brittleness and tendency to crack during launch, leading to risks of combustion instability. These risks can be averted by re-casting the fuel grain in space. Our research is focused on the technical logistics of manufacturing fuel grains in space through a process of centrifugal casting, wherein a tube containing paraffin wax is heated to melt the wax, and then cooled while rotating at a constant RPM to produce an annular-shaped solid fuel grain with a hollow centre through which liquid oxidizer can be injected for combustion. The primary goals of the project are to demonstrate that wax-based fuel grains can be effectively manufactured in microgravity, and at much lower RPM rates than are required on Earth.

To test these goals, the Space Enabled group developed a series of experiments consisting of wax-filled tubes with heating elements and motors, and thermocouples and cameras to monitor the behaviour of the contained wax during rotation. Variations of these experiments have been operated in three different gravity environments: 1) Ground-based laboratory at 1g; 2) Reduced-gravity parabolic flights at lunar (0.166g), martian (0.376g), and microgravity; and 3) Sub-orbital flight at microgravity.

Previous works by the authors have presented findings from ground-based experiments, reduced-gravity parabolic flights operated by the Zero Gravity Corporation in May 2021, and numerical thermal and fluid dynamics simulations. This paper presents preliminary results obtained during a sub-orbital flight aboard

the Blue Origin New Shepard rocket in December 2023. This flight contained two tubes of wax: one heated, and one unheated tube containing wax that is liquid at room temperature. During the 3-minute microgravity phase, both tubes were rotated in short increments at discrete rotation rates between 300 and 700 RPM, separated by short periods of rest. Analysis of videos demonstrate positive results of annulus formation during all RPM cases in the unheated tube. These results agree with those observed during parabolic flights, while ground-based tests show no annulus formation at rates lower than 1000 RPM. These initial results support the feasibility and benefits of the in-space manufacturing of wax-based fuel grains.