Formulation and Testing of Paraffin-Based Solid Fuels Containing Energetic Additives for Hybrid Rockets

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Many approaches have been considered in an effort to improve the regression rate of solid fuels for hybrid rocket applications. One promising method is to use a fuel with a fast burning rate such as paraffin wax; however, additional performance increases to the fuel regression rate are necessary to make the fuel a viable candidate to replace current launch propulsion systems. The addition of energetic and/or nano-sized particles is one way to increase mass-burning rates of the solid fuels and increase the overall performance of the hybrid rocket motor.[1,2]

Several paraffin-based fuel grains with various energetic additives (e.g., lithium aluminum hydride ($LiAlH_4$) have been cast in an attempt to improve regression rates. There are two major advantages to introducing $LiAlH_4$ additive into the solid fuel matrix: 1) the increased characteristic velocity, 2) decreased dependency of I_{sp} on oxidizer-to-fuel ratio. The testing and characterization of these solid-fuel grains have shown that continued work is necessary to eliminate unburned/unreacted fuel in downstream sections of the test apparatus.[3] Changes to the fuel matrix include higher melting point wax and smaller energetic additive particles. The reduction in particle size through various methods can result in more homogeneous grain structure. The higher melting point wax can serve to reduce the melt-layer thickness, allowing the $LiAlH_4$ particles to react closer to the burning surface, thus increasing the heat feedback rate and fuel regression rate. In addition to the formulation of $LiAlH_4$ and paraffin wax solid-fuel grains, liquid additives of triethylaluminum and diisobutylaluminum hydride will be included in this study.

Another promising fuel formulation consideration is to incorporate a small percentage of RDX as an additive to paraffin. A novel casting technique will be used by dissolving RDX in a solvent to crystallize the energetic additive. After dissolving the RDX in a solvent chosen for its compatibility with both paraffin and RDX, the mixture will be combined with the melted paraffin. With the melting point of the paraffin far below the decomposition temperature of the RDX, the solvent will be boiled off, leaving the crystallized RDX embedded in the paraffin. At low percentages of RDX additive and with crystallized RDX surrounded by paraffin, the fuel grains will remain inert, maintaining a key benefit of hybrids in the safety of the solid fuel.

Two hybrid rocket test motors located at the Pennsylvania State University's High Pressure Combustion Lab will be used to test the solid-fuel grains. The first motor, the Long-Grain Center-Perforated (LGCP) hybrid rocket motor, has been used for initial characterization of the solid-fuel grains. The LGCP, shown in Figure 1, uses a cartridge-loaded fuel grain, leading to fast turnaround times. The motor is capable of pressures up to 12 MPa (1,750 psig) and can accommodate fuel cartridges 38 mm in diameter with lengths up to 406 mm. Because of its small size, the LGCP requires minimum amounts of fuel to be cast for basic fuel regression rate characterization. The second motor, the X-ray Translucent Center-perforated (XTC) motor, uses a paper phenolic fuel cartridge that holds the fuel and acts as the pressure vessel. The heavy-walled phenolic cylinder is capable of operating pressures up to 4.2 MPa (600 psig). The XTC allows for instantaneous regression rate characterization via X-ray radiography. Both systems operate on a shared oxidizer feed system able to deliver oxygen mass flow rates up to 0.36 kg/s. Both the LGCP and XTC have been used for characterization of various hybrid rocket fuel formulations.[4,5]

It is anticipated that the solid-fuel grains developed in this study will demonstrate high regression rate behavior and favorable combustion characteristics. Detailed analyses and relationships will be offered in the full manuscript.

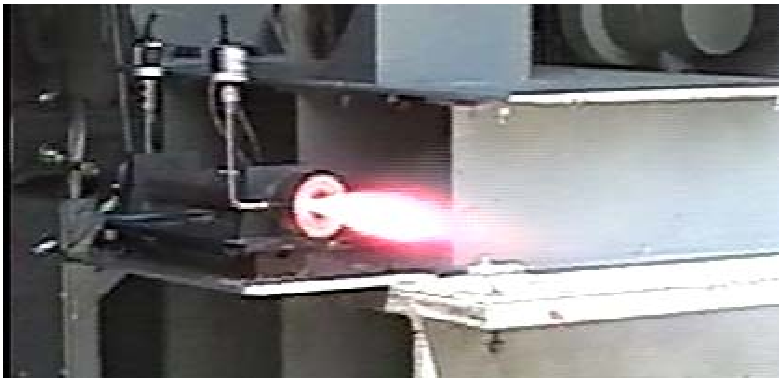

Figure 1. Photograph of LGCP hybrid rocket motor firing with paraffin-based solid-fuel grain containing 28% $LiAlH_4$ additive.

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