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IMPINGING INJECTOR DESIGN FOR A PARAFFIN-NITROUS OXIDE HYBRID ROCKET ENGINE USED IN SOUNDING ROCKETS PART II: COLD-FLOW TESTING OF CANDIDATE DESIGNS

Abstract

This paper presents the candidate designs, cold-flow test results, and critical performance metrics used in the experimental validation and design selection for a hybrid rocket engine impinging injector plate. The University of Toronto Aerospace Team (UTAT) Rocketry Division's fourth-generation sounding rocket "Deliverance" is powered by a 4kN-thrust paraffin-nitrous oxide hybrid engine, with a target altitude of 25 000ft above ground level. Varying jet separation distances and hole diameters were compared for arrangements of impinging doublets. The key performance objectives of the injector were: (1) provide an average mass flow rate of 1.7kg/s at a steady-state pressure difference of 350psia; and (2) atomize the stored liquid oxidizer and promote mixing to support combustion. Furthermore, the injector had to meet a priori blow-out and quenching constraints.

A cold-flow test setup at the University of Toronto Institute for Aerospace Studies was used for experimental validation. The injector plate was mounted to the injector assembly, which was bolted to a horizontally oriented steel test stand flanked by a standard two first-surface mirror Schlieren system. This assembly was connected to the main flow system consisting of a Coriolis mass flow meter, a manual relief ball valve, and a 750psia tank of carbon dioxide. Carbon dioxide was chosen as a safer and similarly performing analogue for nitrous oxide, as proposed and tested by Zimmerman et al. A pressure transducer connected to the injector manifold provided pressure readings at the injector inlet. A total of six candidate injector designs were compared using this setup.

In general, the experimental results for mass flow rate fell within 10 percent error of the CFD simulations from Part I of this study, which are discussed in another paper. The Schlieren visualization and mass flow meter favour the design consisting of 7 pairs of 2mm-hole doublets, impinging at a 60-degree angle; this design provided the target mass flow rate, higher turbulence in support of mixing in the combustion chamber, and required a minimal axial distance (i.e. precombustor length) of 1.5" to become fully developed. Contrary to simulation, higher hole length-to-diameter ratios did not significantly increase the size of the dispersion cloud, and shorter jet separation distances did not significantly affect the dispersion cloud width. The maximum diameter of the dispersion cloud was typically attained 1-2 inches downstream the injector plate, as predicted.