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NOZZLE EROSION AVOIDANCE THROUGH REGENERATIVE COOLING SYSTEMS IN HYBRID ROCKET ENGINES: EXPERIMENTAL CAMPAIGN AND NUMERICAL MODELING

Abstract

Throat erosion, commonly present in uncooled nozzles, poses a significant challenge for both Solid Rocket Motors and Hybrid Rocket Engines, as changes to the nozzle throat area and expansion ratio can degrade rocket performance.

To address this issue, Hybrid Rocket Engines can incorporate a regenerative cooling system, leveraging the presence of cryogenic liquid propellant. The present study focuses on developing a predictive numerical model for such a system, considering the behaviour of the two-phase coolant in the cooling channels. This tool has the potential to assist in the preliminary design phase of the nozzle.

Empirical expressions crucial for the numerical model were established and validated through a static firing test campaign. Specifically, a regenerative cooling system was implemented for a 300 N thrust hybrid rocket engine at the Space System Laboratory of Hokkaido University in Japan, utilizing cryogenic liquid oxygen and high-density polyethylene. The cooling system, consisting of three helical channels within an aluminum cooling jacket, employed the oxidizer as a coolant before injection into the combustion chamber to mitigate erosion of the graphite nozzle throat.

The developed numerical model in Ansys-Fluent implements an iterative process, involving a 3D simulation of the cooling channels and a 2D simulation of the nozzle's wall. An empirical relation, derived from experimental data and physical observations, estimates the average number of bubbles formed in the channels. Investigations into dry-out phenomena led to important design insights.

The model demonstrated predictive capabilities, aligning nozzle temperatures and heat fluxes within an acceptable error range. Experimental results further confirmed the cooling system's effectiveness, identifying an optimal working condition, and notably, no nozzle erosion occurred during the firing tests.

Once validated, the numerical tool populated the experimental curves, detailing pressure and mass flow rate evolution, complementing experimental data and enhancing understanding of the channels' physical behaviour. This extends the application of the study beyond aiding in the preliminary design of the regenerative cooling system.