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Space Structures I Design, Development and Verification (Launch Vehicles and Space Vehicles, including their Mechanical/Thermal/ Fluidic Systems) (1)

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DEVELOPMENT AND TESTING OF A THRUST VECTOR CONTROL SYSTEM FOR A HYBRID ROCKET ENGINE

Abstract

This research focuses on developing and testing a two-degrees-of-freedom thrust vector control (TVC) system tailored for a 1kN hybrid rocket engine. The study employs a comprehensive, multidisciplinary approach encompassing structural engineering and control systems. Exploration of various TVC methodologies compatible with hybrid rocket engines delves into Technology Readiness Level, structural materials, manufacturing technologies, and cost optimization considerations. Through a rigorous evaluation, chamber gimballing actioned by two linear actuators emerges as the most pragmatic TVC method, prompting substantial modifications to the conventional hybrid rocket engine design. To enhance overall performance, the authors provided studies on mass reduction of the engine through intricate thermal and structural analyses. These studies allowed the optimization of costs through standardization and simplified manufacturing processes. The engineering of flexible connections within the engine, including the oxidizer supply hose, gimbal connection, coupling adapters, and sensor cables, is meticulously carried out to meet stringent movement requirements. Validation of the proposed TVC system involves analytical and numerical studies, specifically focusing on structural and mechanical aspects. The authors developed a comprehensive analytical model of the chamber gimbal, establishing crucial relationships between the chamber gimbal angle, the displacement of actuators, and reaction forces experienced by the engine interface connections. This model was numerically solved and seamlessly integrated into the control software with simple approximations for real-time thrust vector control. Numerical simulations encompass a detailed analysis of system kinetics with a finite element approach, providing an enriched understanding of the TVC system's behavior during active engine control. The culmination of validated analytical and numerical models sets the stage for the fabrication and rigorous testing of the TVC system in a controlled laboratory environment. The vertical test stand assembled with the engine was used to find experimentally the relation between the chamber deflection angles and reaction forces. More than fifty experiments at different engine deflection angles were executed to find the relation between the main force vector actuators' reaction forces. Experimental research has also validated and quantified the system's safety margins. Future research plans extend into a comprehensive experimental campaign on the test bench, focusing on structural dynamics and mechanical aspects to corroborate findings and further support the numerical simulations.