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NUMERICAL AND EXPERIMENTAL DEMONSTRATION OF RESIDUAL THRUST PHENOMENON IN HYBRID ROCKET THRUSTERS UNDER VACUUM ENVIRONMENT

Abstract

This study aims to clarify the mechanism of residual thrust in hybrid thrusters through numerical simulations and experimental measurements. Residual thrust is defined as the unintended thrust generated after oxidizer cutoff due to the continued gasification of heated fuel. This phenomenon, especially prominent after long-duration firings, results in sustained high fuel surface temperatures, influenced by radiative heat transfer from surrounding components such as the nozzle and the injector. Although significantly lower than nominal thrust, residual thrust poses challenges for spacecraft attitude and orbit control, particularly for small satellites requiring precise thrust management. While recognized in solid rocket motors, residual thrust in hybrid thrusters has not been previously defined or quantified. Hybrid thrusters are widely considered for space propulsion system due to their ability to terminate thrust simply by ceasing oxidizer supply; however, the presence of residual thrust complicates this advantage and must be evaluated for effective and precise control of small satellite.

To estimate residual thrust, we developed a numerical model incorporating the rocket equation, unsteady heat conduction, solid fuel pyrolysis, and radiative heating. Applied to a single-port fuel configuration, the model analyzed surface temperature evolution and port-diameter expansion. Simulation results indicate that a residual thrust of more than 0.1 N is sustained for approximately 10 seconds at a fuel regression rate of 0.01 mm/s immediately after stopping firing. Furthermore, the analysis revealed that lower fuel regression rates lead to prolonged and more significant residual thrust, highlighting the importance of considering post-firing thermal effects in thruster design.

For further understanding of the residual thrust, direct measurement is necessary. Conventional load cells lack the sensitivity to detect such small thrust levels, necessitating an alternative approach. This study proposes using an inverted pendulum thrust stand, commonly employed in electric propulsion testing. A conceptual numerical model was developed to assess its feasibility. Simulations suggest the stand can achieve a resolution of approximately 10 mN, which is sufficient for detecting residual thrust at predicted levels. These findings support the suitability of the proposed design for characterizing residual thrust in hybrid thrusters. The thrust stand is currently being built, and the plan is to start actual residual thrust tests as soon as possible after March, so that the results can be reported. This research enhances the understanding of residual thrust behavior and lays the foundation for experimental studies to improve hybrid thruster performance in space applications.