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ENHANCING BIPROPELLANT ATTITUDE CONTROL THRUSTER TESTING: A CONTROL THEORY APPROACH

Abstract

With the resurgence of interest in lunar landing missions propelled by NASA's Artemis program, the need for advanced uncrewed landers has become paramount. Attitude control thrusters play a crucial role in these missions, particularly during lunar descent and landing, where their operation differs significantly from that of orbiting spacecraft. A prevailing solution for attitude control utilizes pulse mode bipropellant thrusters for spacecraft attitude control and terrain avoidance maneuvers.

The unique demands of lunar descent pose challenges, necessitating a comprehensive understanding of thruster behavior across various operating conditions. Traditional testing methods face limitations due to the vast array of parameters involved, including oxidizer and fuel pressures, helium saturation conditions, propellant temperature, operating duty cycle, frequency, and operating duration.

To address these challenges and expedite testing while providing actionable insights for guidance, navigation, and control (GNC) engineers, a novel approach is proposed. This method involves characterizing pulse mode duty cycle and frequency using delta-sigma modulation of sine-sweep inputs to create digital command inputs. Unlike conventional digital command inputs, which oversimplify the thruster's analog nature, this approach captures the intricacies of its thermal response and performance curves.

By subjecting pulse mode thrusters to modulated analog inputs during testing, critical parameters such as thrust, specific impulse, and heat soakback can be accurately characterized, leading to enhanced models of thruster behavior. This approach leverages simulation and hot fire test data to generate amplitude and phase-lag responses, thereby facilitating the optimization of lunar landing attitude control thrusters.