Predictive Modeling of Hybrid Rocket Engine Hot-Fire Tests

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Abstract

Hot-fire testing is a critical step in the evaluation of the performance of hybrid rocket engines. However, this process is both expensive and time-consuming. In order to address these challenges, the utilisation of accurate physical models has the potential to enhance our understanding of engine behaviour and optimise testing procedures. This study presents the development of comprehensive physical models for key engine components, including the oxidiser tank, injector, and combustion chamber. A Non-Homogeneous Non-Equilibrium (NHNE) approach was employed to model oxidizer flow dynamics, while CoolProp was used to determine thermodynamic properties. Furthermore, the Chemical Equilibrium with Applications (CEA) code, developed by NASA, was utilised to derive theoretical estimates of impulse and combustion efficiency.
The accuracy of the proposed models was assessed by comparing the predictions against experimental data from the Invictus 1.0 hybrid rocket engine hot-fire test. The experimental results obtained from this investigation revealed a maximum chamber pressure of 26 bar and a maximum thrust of 2500 N. Furthermore, the specific impulse was found to stabilise at 200 seconds. Furthermore, the oxidizer-to-fuel ratio initially peaked at 12.4 before reaching a steady-state value. The model demonstrated an effective representation of the gradual depletion of oxidiser, thus demonstrating its capacity to replicate key combustion characteristics.
This modelling approach offers valuable insights that can reduce reliance on costly experimental testing by accurately predicting the performance of hybrid rocket engines. The simulation of oxidizer flow behaviour and combustion processes facilitates the refinement of engine designs and the optimisation of test conditions. This research contributes to the advancement of hybrid rocket technology by enabling more efficient, data-driven development cycles. Future work will focus on further improving model fidelity and integrating real-time predictive capabilities for enhanced test planning and performance optimisation.

Keywords: Hybrid Rocket Engines, Hot, Fire Testing, Physical Modeling, Oxidizer Flow Dynamics, Performance Optimization

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