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Hypersonic Air-breathing and Combined Cycle Propulsion, and Hypersonic Vehicle (7)

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INTEGRATED FLOWPATH MATCHING DESIGN FOR WIDE-ENVELOPE AIR-BREATHING LAUNCH VEHICLES WITH RBCC ENGINES

Abstract

Air-breathing launch vehicles equipped with Rocket-Based Combined Cycle (RBCC) engines demand precise matching of internal and external flowpaths to optimize performance across a broad range of altitudes and velocities. Achieving this requires meticulous design and optimization of flowpath components, a process traditionally reliant on costly experimental and numerical methods. This paper addresses the challenge by focusing on the integrated propulsive performance of wide-envelope air-breathing launch vehicles with RBCC engines and explores the technology behind matching design between various flowpath components using numerical methods and surrogate models.

1.Integrated Design of Forebody and Inlet: The research begins with the integrated design technology of the forebody and inlet within a wide range of altitude and velocity. Initial design of the wide-envelope inlet is established based on flight mission analysis. Numerical methods are then employed to analyze the impact of side plates and central struts in the inlet, along with studying the influence of total contraction ratio on inlet performance. Further enhancements to the wide-envelope performance of the inlet are investigated through multi-stage total contraction ratio adjustments.

2.Matching of Flowpath under Fixed Conditions: A surrogate model, constructed using the Kriging method, predicts the propulsive performance of isolator-combustor and nozzle components. This surrogate model facilitates rapid analysis of the entire flowpath performance, integrating numerical methods and surrogate model predictions. Utilizing this rapid analysis approach, optimal flowpath designs are developed at the inlet design point. The efficacy of these optimized configurations is confirmed through integrated numerical solutions.

3.Flowpath Matching within Wide Operating Envelope: Extending the research, surrogate models are employed to predict the propulsive performance of the entire flowpath in ramjet mode. Analysis of flowpath operation in ejector and scramjet modes is conducted, along with the development of corresponding flowpath matching methods. A comprehensive process for full flowpath matching design within a wide operating envelope, covering ejector, ramjet, and scramjet modes, is established. The proposed matching design scheme incorporates optimized flowpath configurations and multi-stage total contraction ratio adjustments. Numerical simulations validate the benefits of this approach, particularly evident in specific impulse improvements along the trajectory.

In conclusion, this paper presents a systematic approach to the integrated flowpath matching design for wide-envelope air-breathing launch vehicles equipped with RBCC engines. By leveraging numerical methods and surrogate models, the proposed methodology offers a cost-effective and efficient means to achieve optimal flowpath performance across diverse operating conditions, contributing to enhanced overall vehicle performance and mission success.