75th International Astronautical Congress 2024

Paper ID: 86473
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IAF SPACE PROPULSION SYMPOSIUM (C4)
Hypersonic Air-breathing and Combined Cycle Propulsion, and Hypersonic Vehicle (7)

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MODEL-BASED KNOWLEDGE DISCOVERY ON DESIGN OF HYPERMIXER FUEL INJECTORS FOR SCRAMJET ENGINES VIA DEEP-LEARNING-BASED FLOWFIELD PREDICTION

Abstract

Scramjet engine is a promising candidate for propulsion of future access-to-space systems due to its high performance under hypersonic flight conditions. The air-breathing nature allows for the absence of oxidizer and airplane-like operation of scramjet-powered vehicles, which are favorable features in developing fully reusable space transportation systems. Among scramjet components, i.e., intake, injector, combustor, and nozzle, the fuel injector plays an important role in scramjet operation because it predominantly determines characteristics of supersonic combustion. While adequate fuel/air mixing is required for successful combustion and thrust generation, fuel/air mixing in supersonic flow undergoes compressibility effects, which strongly affects the growth of the shear layer hence mixing.

Using streamwise vortices was proposed for fuel mixing enhancement to address this difficulty. Various methods and devices have been examined to produce streamwise vortices while suppressing drag and total pressure loss. Alternating-wedge struts called Hypermixer injectors have been proposed to generate large-scale streamwise vortices and extensively investigated in both numerical and experimental approaches. Preceding studies investigated the fundamental physics of supersonic mixing and combustion due to Hypermixer injectors, with design exploration and sensitivity analysis conducted by means of surrogate modeling. While these studies revealed the flow physics related to mixing enhancement and a fundamental design strategy, further investigation is required to scrutinize the detailed interrelations among design, flow structures, and mixing performance.

The present study is undertaken to examine the effects of design parameters on flow structures and performance parameters via detailed sensitivity analysis, for which three approaches with different focuses are employed, i.e., Permutation Feature Importance and Partial Dependence Plot from global viewpoints and Individual Conditional Expectation from local viewpoints. Key flow structures that can enhance fuel mixing are identified, and the influence of each design parameter is then elucidated to allow for reproduction of favorable flow structures in future design. Multi-objective design optimization is also employed to provide favorable sets of design parameters for local sensitivity analysis. While such studies would conventionally require a substantial number of computational fluid dynamics (CFD) simulations hence formidable computational cost, CFD is replaced with data-driven deep-learning flowfield prediction. It can produce data that are equivalent to those from CFD at drastically reduced cost, helping with detailed and systematic investigation of flow structures. This study will provide not only detailed insights into the design of Hypermixer injectors for scramjet engines but also a new model-based methodology for knowledge discovery in fluid design.