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MULTI-OBJECTIVE DESIGN OPTIMIZATION OF FUEL INJECTION USING FLEXIBLE GEOMETRY FOR SCRAMJET-POWERED ASCENT FLIGHT VIA SURROGATE-ASSISTED EVOLUTIONARY ALGORITHMS

Abstract

Scramjet engines, which are seen as one of the most promising key components of future access-to-space systems, have seen significant advancements in the past two decades. These developments include flight experiments conducted on the HyShot II in 2002, the X-43A flight programs in 2004, and the HIFiRE 7 in 2015. Despite these achievements, the challenge of maintaining adequate mixing while minimizing total pressure loss for sustained scramjet operation in the combustor remains a critical aspect of engine design. However, further examination of optimal design configurations in a broader design space is still necessary.

Although there have been some attempts to investigate, the understanding of how the injector shape affects fuel mixing and total pressure loss is still limited. Thus, this research investigates optimal injector shapes using a 4th-order Bezier curve representation with a constant fuel/air equivalence ratio with sonic injection. The goal is to enhance mixing efficiency while minimizing total pressure loss. To achieve these, a multi-objective optimization approach is applied.

At the entrance of the combustor, the air velocity slows down to Mach 3, which corresponds to the anticipated flight conditions during ascent at Mach 10, maintaining a constant dynamic pressure. Hydrogen fuel is injected into the crossflow of air where the injector's geometry is defined by four geometric parameters, which serve as decision variables. Additionally, injection pressure and angle contribute to a total of 8 decision variables. Although numerous computational fluid dynamics (CFD) analyses are conventionally required for such studies, due to high computational costs, a less demanding surrogate-based approach is used in this study. Latin Hypercube Sampling is employed to obtain sufficiently diverse decision variable sets for CFD analysis. The CFD simulations solve the Reynolds-averaged Navier-Stokes equations for steady, viscous, and turbulent flowfields. Based on the evaluation results, surrogate models are constructed using various meta-models, including the response surface model, and artificial neural networks, such as the radial basis function network, the multilayer perceptron model, and the Kriging model. Finally, surrogate-based multi-objective design optimization studies are conducted using a surrogate-assisted evolutionary algorithm, where injector designs evolve within a population pool through genetic operations like crossover and mutation across generations.

Flowfields are examined for optimum injector designs selected from the Pareto optimal front. A variance-based global sensitivity analysis is conducted to identify critical design parameters. Finally, insights are gained into essential design factors and the underlying flow physics, enabling efficient and robust injector design for high-performance scramjet propulsion.