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MULTI-OBJECTIVE DESIGN OPTIMIZATION OF FUEL INJECTION WITH FLEXIBLE GEOMETRY VIA SURROGATE-BASED EVOLUTIONARY ALGORITHMS USING HIGHLY PARALLEL GPU ARCHITECTURE

Abstract

Scramjet engines offer great potential for reusable, and economic systems for access-to-space. One of the critical challenges in scramjet design is maintaining adequate mixing and low total pressure loss for sustained operation. Parametric investigations were performed in preceding studies employing inclined porthole fuel injectors and various injector geometries (Ogawa et al. 2015,2016). However, all preceding studies on fuel injection have been conducted by assuming specific injector shapes such as circular, elliptic, rectangular, triangle and diamond (Tomioka et al. 2003,2012), but broader design exploration using a flexible injector geometry has never been conducted to date.

The present work aims to investigate optimal injector shapes using flexible geometric representation and injection conditions that maximize mixing efficiency and minimize total pressure loss. Multi-objective optimization (MDO) is performed to achieve these objectives at a design condition with crossflow Mach number 3 at the combustor entrance, corresponding to a flight Mach number of 10 at a constant dynamic pressure of approximately 50 kPa.

Fuel (hydrogen) is injected into the crossflow (air) in the combustor. A 4th-order Bezier curve represents the injector shape at a constant equivalence ratio with sonic injection. Four geometric parameters are employed as the decision variables, along with injection pressure and angle. Viscous, turbulent flowfields are simulated utilizing computational fluid dynamics (CFD) that solves the Reynolds averaged Navier-Stokes equations.

Using archive of CFD evaluations, surrogate models are built, employing multiple meta-models such as the response surface model, artificial neural network models including the radial basis function network, multilayer perceptron model, and Kriging model. The MDO study is conducted via the surrogate based evolutionary algorithm, where the decision variables are evolved in the population pool via genetic operations, including crossover and mutation over generations, while the objective and constraint function values are predicted by surrogate models calculated on a highly parallel architecture based on GPU (graphical processing unit).

Flowfields are scrutinized for optimum injector designs selected from the Pareto optimal front. Variance-based global sensitivity analysis is performed to identify influential design parameters on the performance. In so doing, insights are gained into the critical design factors and underlying flow physics for efficient and robust injector design for high-performance scramjet propulsion. This is the first optimization study that employs flexible fuel injector shapes using a GPU-based highly parallel architecture, which allows for thorough exploration in the design space, and will pave the way for novel, high-performance injector design configurations to enable efficient space transportation.