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PHYSICAL INSIGHTS INTO CAVITY FLOWFIELD IN SCRAMJET COMBUSTOR VIA DEEP LEARNING

Abstract

Supersonic combustion ramjet (scramjet) engines are a promising candidate for the propulsion of future space transportation systems due to its simple structure and high efficiency during hypersonic flight. Airbreathing engines remove the need for on-board oxidizers and aircraft-like operation, which are desirable characteristics for a fully reusable space transportation system. One of the key issues in the design of scramjets to date is the achievement of efficient fuel/air mixing. Successful combustion and thrust generation in a scramjet require rapid fuel/air mixing at the molecular level, however, the time available for mixing is extremely short, on the order of milliseconds. Thus, various mixing enhancement devices have been considered to improve mixing efficiency. Cavity-based flame holders are widely recognized for their ability to enhance fuel/air mixing and support the ignition zone by creating a recirculation region. Previous studies have considered various cavity configurations and have revealed that a trapezoidal cavity is one of the most effective shapes for preserving the ignition zone. Therefore, most studies of cavity-based scramjets have employed trapezoidal shapes, which are defined by straight lines. However, it requires further investigation to understand effective vortex structures to enhance fuel mixing and flame holding as well as the cavity shapes that can produce such vortices.

The present study is thus conducted to gain physical insights into the effects of vortex structures on fuel mixing and flame holding inside cavities of a scramjet combustor. To achieve this, multi-objective design optimization is performed to identify optimum vortex structures in terms of mixing performance. Global design exploration is enabled by employing a flexible geometric representation via Bézier curves. The optimality of the obtained vortex structures and the cavity design that produces ideal vortices are discussed based on sensitivity analysis. While such studies would require a large number of computational fluid dynamics (CFD) simulations hence substantial computational cost in conventional approaches, fast and cost-efficient flowfield prediction using deep-learning techniques is utilized in lieu of CFD in this paper. This allows for instantaneous inspection of flowfields and detailed and systematic investigation of flow structures. This feature is particularly effective for optimization studies, allowing for understanding the optimality behind high mixing performance and flame holding capability. This study not only identifies the optimal cavity shapes but also yields new insights into ideal vortex structures for optimum mixing enhancement and flame holding as well as the underlying physical mechanisms.