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

Author: Mr. Chihiro Fujio
Kyushu University, Japan, fujio.chihiro.354@s.kyushu-u.ac.jp

Prof. Hideaki Ogawa
Kyushu University, Japan, hideaki.ogawa@aero.kyushu-u.ac.jp

MULTI-OBJECTIVE DESIGN OPTIMIZATION OF SHOCK-INDUCED MIXING ENHANCEMENT VIA EVOLUTIONARY ALGORITHMS ASSISTED BY DATA-DRIVEN APPROACHES

Abstract

Supersonic combustion ramjet (scramjet) engines are a promising propulsion technology for future access-to-space systems due to flexibility of operation, maneuverability of scramjet-powered vehicles, and reusability of the system. Since scramjets operate under hypersonic flight conditions, the processes to generate thrust comprising compression of inflow, fuel mixing, combustion, and expansion of the combusted gas, must be completed within an extremely short timeframe, and fuel injection and mixing have critical impact on the success or failure of supersonic combustion hence flight. Various methods have therefore been proposed for fuel injection and mixing. Shock-induced fuel/air mixing for transverse injection, in particular, draws attention due to high mixing efficiency and capabilities of ignition and flame holding. On the other hand, shock-induced mixing involves complex shock/jet-plume interactions, which result in a trade-off between mixing efficiency and total pressure recovery. Careful consideration is thus required for its design, but detailed design exploration is yet to be conducted due to large computational cost inherently required for evaluation of such flowfields.

The present study is undertaken to develop design strategies and physical insights into shock-induced mixing in a scramjet engine for access-to-space flights by means of multi-objective design optimization assisted by data-driven approaches to enable low-cost yet high-fidelity investigation. A state-of-art deep-learning technique is employed to predict the internal flowfields accurately at low computational cost, enabling efficient and high-fidelity design exploration by replacing numerical simulations. This allows for prompt execution of various optimization studies with different sets of objective and constraint functions, which dictate the characteristics of obtained solutions. Such flexibility is a desirable feature for the design exploration of scramjet fuel mixing because the selection of optimum injector designs highly depends on the requirements of the combustor downstream. Another notable advantage of using flowfield prediction is the flexibility of post-analysis, particularly data mining. Fast evaluation of flowfields facilitates comprehension of the relations among design, performance, and flowfields in a prompt manner. The optimality of the obtained solutions and its rationales are examined by applying sensitivity analysis techniques, which can identify key design factors of shock-induced mixing enhancement from the viewpoints of performance and flowfields. In so doing, the present study yields new insights into not only the design methodology using deep-learning prediction of flowfields but also design factors of shock-induced mixing for scramjet-powered access-to-space as well as underlying physical mechanism.