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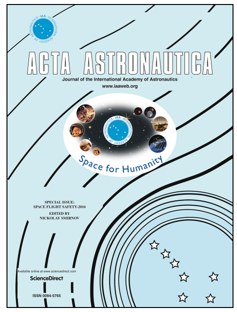

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Numerical analysis and design optimization of supersonic after-burning with strut fuel injectors for scramjet engines

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Abstract

Scramjets are a class of hypersonic airbreathing engine that offer promise for economical, reliable and high-speed access-to-space and atmospheric transport. The expanding flow in the scramjet nozzle comprises of unburned hydrogen. An after-burning scheme can be used to effectively utilize the remaining hydrogen by supplying additional oxygen into the nozzle, aiming to augment the thrust. This paper presents the results of a single-objective design optimization for a strut fuel injection scheme considering four design variables with the objective of maximizing thrust augmentation. Thrust is found to be augmented significantly owing to a combination of contributions from aerodynamic and combustion effects. Further understanding and physical insights have been gained by performing variance-based global sensitivity analysis, scrutinizing the nozzle flowfields, analyzing the distributions and contributions of the forces acting on the nozzle wall, and examining the combustion efficiency.

Keywords: after-burning, combustion, strut fuel injection, optimization, computational fluid dynamics, hypersonics scramjet engines, airbreathing propulsion

1. Introduction

The development of hypersonic airbreathing engines is of great interest in space transportation as they provide an economically sound, reusable and high-speed platform for the transport of both civilians and cargo from the Earth to the low Earth orbit. Scramjet (supersonic combustion ramjet) propulsion is a promising hypersonic airbreathing technology which eliminates the need to carry an oxidizer and offers higher specific impulse than conventional rocket engines. Significant progress has been made in the development of scramjet technology over the last decade, with projects including NASA's Hyper-X program [1] and the flight of the Boeing X-51A WaveRider in May 2010 [2]. A scramjet system shown schematically in Fig. 1 involves a process where hypersonic airflow captured by the inlet is compressed to high pressure and temperature, fuel is then injected and combusted supersonically in the combustion chamber, and the exhaust gas is expanded through the nozzle, resulting in net thrust.

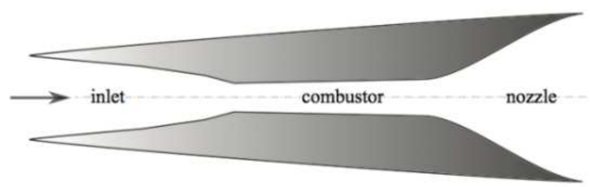

Fig. 1. Schematic of an axisymmetric scramjet with flow direction.

The expanding exhaust gas comprises of a significant proportion of unburned hydrogen, which, under ideal conditions, can be combusted via the injection of oxygen directly into the unburned hydrogen stream, *i.e.*, by introducing after-burning. This has the potential to significantly increase the thrust produced by the nozzle while also maintaining an ideal nozzle expansion ratio ($p_{\text{exit}} = p_{\text{atm}}$) by decreasing the injection pressure of oxygen as the

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