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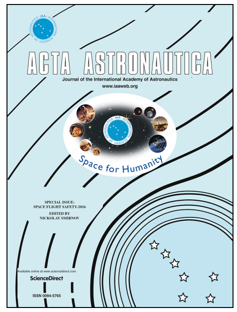

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Uncertainty and Sensitivity Analysis of flow parameters on aerodynamics of a hypersonic inlet

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Abstract

The performance of the inlet is crucial to the cruise flight of a hypersonic air-breathing propulsion vehicle. The objective of this work is to investigate the uncertainty and sensitivity of pressure field and the performance parameters for a hypersonic inlet due to the uncertainty of five flow parameters, including freestream Mach number, Reynolds number, angle of attack, temperature and wall temperature. The steady Reynolds Averaged Navier-Stokes equations are solved to predict the inlet start and unstart flows within the hysteresis loop. Then, a point-collocation non-intrusive polynomial chaos method (NIPC) is utilized to quantify the uncertainty and sensitivity in the output quantities of interest. The uncertainty analysis in pressure field shows that Mach number and angle of attack of freestream make dominant contributions to the total uncertainty, and the Mach number has remarkable impacts in the isolator. In the start flow, the angle of attack exerts its prominent influence in the post-shock regions, while Mach number mainly dominates these regions ahead of and around the shocks. The reason may be interpreted as the much greater pressure derivatives with respect to angle of attack in the post-shock regions. Significant discrepancies are presented for the unstart flow. The reflected shock waves in the unstart flow are less sensitive to the variations of flow parameters. The external flow field, separation bubble and reflected shocks are significantly affected by angle of attack. Besides, the uncertainties of the performance parameters in the start flow are about twice those in the unstart flow. The sensitivity analysis further reveals that Mach number is the major contributor to the total uncertainty of performance parameters. The correlation coefficients via linear regression method clearly illustrate the relationships between the five input parameters and the performance parameters.

***Keywords*:** hypersonic inlet; uncertainty quantification; sensitivity analysis; performance parameter; unstart

1. Introduction

For a hypersonic air-breathing propulsion system, the performance of the inlet is crucial to the cruise flight of a high-speed vehicle. In the flight envelope, the inlet is required to operate in a starting mode for safety and efficient operations [1]. The varied flight and combustion conditions, such as altitude, Mach number, angle of flight and heat release, may bring about adverse effects on the performance of the inlet, or even worse, causing the hypersonic inlet to unstart. During the inlet mode transition, the hysteresis phenomenon [2,3] can be found in the unstart and restarting process, challenging the control strategy for inlet operation. In previous flight tests, inlet unstart finally causes flight accidents, for instance, X-51A flight test in 2011 [4]. Due to its great complexity and significance, considerable researches have been devoted to this problem over the past decades. These theoretical, numerical and experimental studies focus on the inlet self-start limit [5,6], the mechanism underlying the flow choking phenomena [7,8],and the inlet unstart detection and control [9,10]. Comprehensive reviews can be referred to the literature [11-13].

A great number of studies have been conducted to investigate the key factors that determine the flow characteristics in hypersonic inlet flows. The underlying mechanism for effect of flow parameter on the aerodynamics was revealed and stimulated the flow-controlling strategy for unstarting phenomenon. Van Wie et al. [4] experimentally explored the unstart and restart characteristics of a 2-D supersonic inlet and analyzed the critical factors. They classified the unstart into two broad categories and mentioned that a significant uncertainty exists regarding the conditions under which an inlet will unstart or restart. Fischer and Olivier [14] investigated the influence of wall and total temperature at different Mach numbers on a shock train with experiments. In their wind-tunnel model, wall temperature deviations were less than 10% of the nominal value and an uncertainty of 7.1% for the pressure coefficient was caused by measurement error. Mayer et al. [15] simulated the axisymmetric unstart flow to investigate inlet sensitivity to freestream disturbances, involving freestream temperature, velocity and pressure. The authors pointed out that

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