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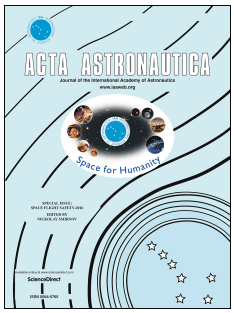

High-frequency counter-flow plasma synthetic jet actuator and its application in suppression of supersonic flow separation

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High-frequency counter-flow plasma synthetic jet actuator and its application in suppression of supersonic flow separation

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Abstract

We come up with a control strategy for suppression of supersonic flow separation based on high-frequency Counter-flow Plasma Synthetic Jet Actuator (CPSJA). The main purpose of this investigation is to verify if its control authority can be enhanced by the jet/shock interaction. We use a blunt nose to generate a bow shock, a step on a flat plate to introduce a massive separation in a Mach 2 wind tunnel, and the CPSJA to generate Plasma Synthetic Jet (PSJ). In this study, pulsed capacitive discharge is provided for an array of CPSJAs, which makes the actuation (discharge) frequency f_1 = 1kHz, f_2 = 2kHz and f_3 = 3kHz. We use the high-speed schlieren imaging and fast response pressure transducers as well as a numerical simulation to investigate the quiescent PSJ properties, the interaction between the jet and bow shock, and its disturbance effect on the downstream separated region. The schlieren images show that PSJ is characterized by a succession of vortex rings; the jet strength weakens with the increase of frequency. A 4.5mN jet thrust is found for all the frequencies. The simulation results show that jet/shock interaction produces vorticity in the vortex ring of the jet, enhancing turbulent mixing in PSJ so that a great deal of momentum is produced into the flow. We found the downstream flow is significantly disturbed by the enhanced actuation. Actuation with frequency of f_2, f_3 which is close to the natural frequency f_n of the separation bubble suppresses the separation with the upstream laminar boundary layer being periodically attenuated, which has a better control effect than f_1. The control effect is sensitive to the position where PSJ interacts with the shear layer, but the amount of energy deposited in one pulse is not crucial in a separation reduction in the experiment.

Key words: shock wave; boundary layer; plasma synthetic jet; flow separation; flow control

1. Introduction

In terms of flow manipulation, plasma-based flow control devices attract popular attention intensively due to its flexibility and reliability[1]. Dielectric Barrier Discharge(DBD) actuator has been widely investigated and optimized for aerodynamic control, which has shown its superiority in low speed flows[2-4]. However, an efficient control effect for high-speed flows using such actuator has scarcely been reported because of its extremely low energy deposition. Therefore, it is imperative that a new-style actuator that has high actuation intensity has been developed for manipulation of high-speed flows.

Shock Wave/Boundary Layer Interaction(SWBLI) is a common phenomenon in high-speed flows which results in considerable vicious drag and even an expansive boundary layer separation[5]. This particular form of separation has an adverse impact on high-speed vehicle performance, such as unstart in the scramjet inlet[6]. Primarily motivated by applications of active flow control strategies in aerodynamics to alleviate the negative aspects, the energy deposition techniques have been widely investigated such as arc plasma, laser, microwave. etc[7-9]. Russell. et al[10] has provided an overview of these Joule heating based techniques for high speed flows.

According to diverse control targets applied in high-speed flows including boundary layers, shock waves and