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High Bandwidth Micro-Actuators for Active Flow Control

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Abstract

This paper describes an experimental study conducted at the Advanced Aero propulsion Lab (AAPL) for the design and development of actuator systems capable of producing high bandwidth, high momentum microjet arrays for active flow control applications. A systematic approach for designing micro-actuators with high unsteady and mean momentum efflux is followed. Beginning with a simple configuration, i.e., supersonic impinging microjets, we added more geometric complexity to the actuator design to finally arrive at an actuator configuration that provides the desired flow properties. Our first generation actuator design consists of a primary source jet, incident upon a cylindrical cavity. The lower surface of this cavity contains micronozzles through which the unsteady microjets (400µm) issue. Results clearly show that microjets produced by this actuator contain very high mean momentum (300-400 m/s) as well as a very significant unsteady component (70-100 m/s). Experiments were conducted over a large range of parameters, in terms of cavity length, source jet NPR and source jet impingement distance. The results unequivocally demonstrate the ability to vary the frequency as well as the amplitude of the mean and unsteady momentum of the microjets issuing from this actuator. By varying the dimensions of the actuator by only few hundred microns, we were able to tune the frequency of the unsteady component over intervals of 10-15 kHz. The ability to produce, unsteady flow with significant mean and unsteady components, where the dynamic range can be easily varied makes these actuators promising for a number of flow control applications.

I Introduction

Active Control of flows for a wide array of applications has seen a surge of activity in recent years due to the potentially substantial gains in performance offered by flow control schemes. For example, control or delay of flow separation over airfoils and lifting bodies can significantly extend the operating envelope of aircraft by improving their aerodynamic performance. The control of aeroacoustically induced flow oscillations in cavity flow is another area where various active (and passive) control methods are being explored[1]. Another ideal candidate for the use of flow control is the flowfield generated by supersonic impinging jets[2-4]. Such flows are ubiquitous in many applications, such as in STOVL aircraft during hover, and result in a highly unsteady flowfield with very high acoustic levels and dynamic pressure loads in the near-field. These examples demonstrate that flows where control can be applied are wide and varied with more applications are likely to appear as the technology matures.

Efficient control of flows requires the use of effective actuators, which can be adapted for specific applications. Among the most common actuators used are piezoelectric material based actuators, which can be fabricated in various shapes, such as flaps and wedges. Such actuators have been used for the control of cavity flows (Cattafesta et al.[5]) and shear flows (Wiltse & Glezer[6]). Actuators based on synthetic jets have also been used for separation control over airfoils and cylinders (Amitay et al.[7]). Although relatively successful at low speeds, most actuators are not very efficient when the primary flow velocities are high. This is primarily because the magnitude of the control input - be it tip deflection of the piezoelectric flap actuators or the momentum of the synthetic jet - becomes small relative to the inertia of the mean flow. The potential of Hartmann tube or modified Hartmann resonators for active flow control has also been explored by a few researchers[8-10] with limited success in part because their response is in a limited frequency range. Consequently, there is a need for actuators, which produce high-amplitude disturbances over a large frequency range that can be used for the control of high-speed flows.

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