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ACTIVE FLOW CONTROL USING SYNTHETIC JETS

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INTRODUCTION

The synthetic jet is an effective flow control technique with many advantages. It has been applied in various fields, which have been reviewed by Glezer and Amitay [1], Zhang et al. [2] and Glezer [3]. Recently, the present authors and their co-workers have conducted a series of studies into the synthetic jet and its applications and found some new and interesting results. They will be introduced briefly here.

NOVEL SYNTHETIC JETS

In most studies, the standard-sinusoidal actuation function was used, such as Smith and Glezer [4] and Shuster and Smith [5]. Zhang and Wang [6] proposed a novel actuator signal, which was characterized by the variable ratio of the suction cycle (T_S) to the blowing cycle (T_B) in one period. The suction duty cycle factor was defined as $k = T_S/T_B$. The numerical results indicated that increasing k could generate a much stronger vortex pair with larger scale and higher convecting velocity (Figure 1). Shan and Wang [7] and Wang et al. [8] further experimentally confirmed that the novel actuation function could enhance the strength of the synthetic jet vortex ring and vortex pair, respectively. Thus, they can be used for efficient flow control [9].

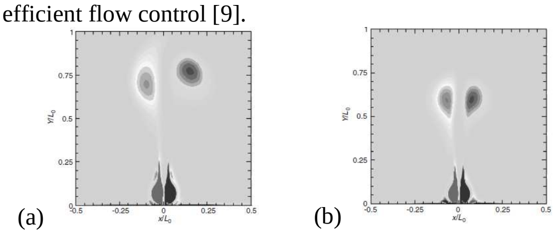


Figure 1: Synthetic jet vortex pair at k = 2 (a) and 1 (b) [6].

PLASMA SYNTHETIC JETS

The dielectric barrier discharge (DBD) plasma actuator is another active flow control technique that can induce a wall jet and a starting vortex [10-11]. Based on its basic characteristics, the plasma synthetic jet could be achieved. A plasma synthetic jet was composed of two DBD plasma actuators, which produced two wall jets moving oppositely. The wall jets encountered in the center of the plasma actuators and rolled up to form a jet normal to the wall [12]. Zhang et al. [13] indicated that increasing the actuation frequency, the streamwise distance of the adjacent vortex pairs decreased monotonically. Feng et al. [14] further found that the recirculation region downstream of a circular cylinder could be modified using the plasma synthetic jet.

CONTROL OF FLOW AROUND A CYLINDER

A series of studies have been conducted by the present authors to control the flow around a circular cylinder using the synthetic jet. When the synthetic jet was positioned at the front stagnation point [15-18], the virtual aeroshaping effect on the bluff body was found. Such effect could reduce the cylinder drag, while the wake pattern could also be changed (Figure 2a). When the synthetic jet was positioned at the rear stagnation point [19-22], the synthetic jet vortex pair interacted with the wake shear layers directly to dominate the wake evolution (Figure 2b). When the synthetic jets were issuing from both front and rear stagnation points [23], the control effect were influenced by both virtual aeroshaping and direct vortex-wake interaction effects.

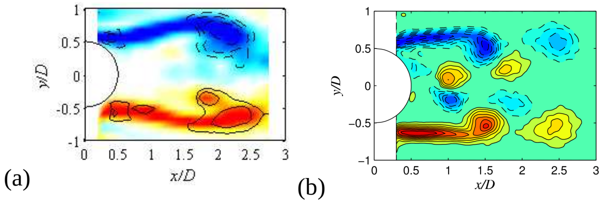
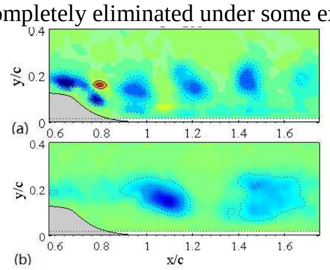


Figure 2: Symmetric vortex mode induced by synthetic jet position at the front (a) [17] and rear (b) [19] stagnation point.

CONTROL OF FLOW AROUND A BUMP

Wang et al. [24] experimentally investigated the control of flow over a two-dimensional bump by the synthetic jet positioned near the separation point at Re = 700 and 1120. As the synthetic jet vortex pair was convected downstream, the negative vortex with clockwise rotation drew the separated wake shear layer over the bump surface and then they syncretised together, forming the new shedding vortex periodically (Figure 3). Thus, the vortex lock-on phenomenon occurred. Besides, the flow separation was found to be completely eliminated under some excitation frequencies.



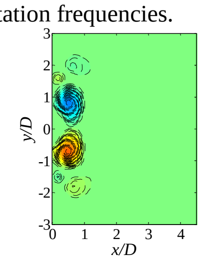


Figure 3: Vortex fomation over a bump with (a) and withou (b) control [24].

Figure 4: Formation of secondary vortex [28].

CONTROL OF FLOW AROUND AN AIRFOIL

Zhang et al. [25] used the synthetic jet to control the flow around an airfoil to simulate the circulation control by steady jet. It was indicated that the synthetic jet could effectively delay the separation point on the airfoil trailing edge and increase the circulation and lift of the airfoil by Coanda effect. The lift augmentation efficiency was also found to be higher than the steady jet circulation control.

CONTROL OF FLOW AROUND AN INLET DUCT

Synthetic jets were used by Chen and Wang [26] to control the flow inside an S-inlet duct. It was found that the actuators located at different spanwise positions could weaken the secondary flows by improving the flow separation to get energetic and uniform main flow. They suggested that actuation in the middle of duct before the onset of separation was an efficient way of flow control in the inlet duct.

SYNTHETIC JETS IMPINGING ON A WALL

The synthetic jet can be used as a cooling technique due to the strong entrainment capacity of the vortical structures by impinging on a fixed wall [27]. Xu et al. [28] indicated that as the primary vortex ring approaching the wall, the secondary vortex with its rotation direction opposite to the primary vortex was induced near the wall surface (Figure 4). Xu and Feng [29] pointed out that the secondary vortex could be observed only when the dimensionless orifice-to-wall distance was close to or less than the dimensionless stroke length.

CONCLUSIONS

We present the recent research process about the synthetic jet and its applications in our lab, including the novel synthetic jets with variable suction and blowing cycles, plasma synthetic jets, control of flow around a circular cylinder, a bump, an airfoil, an inlet duct and the impingement on a fixed wall.

ACKNOWLEDGMENTS

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