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CHARACTERISTICS OF FORE-BODY SEPARATE FLOW AT HIGH ANGLE OF ATTACK UNDER PLASMA CONTROL

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A pair of plasma actuators with horseshoe shape is proposed for dynamic manipulation of forebody aerodynamic load at high angles of attack. Preliminary wind tunnel pressure measurements show that asymmetric force over a conical forebody with semi-apex angle 10° can be manipulated by activating the plasma actuator mounted on one side of the cone tip. Further work is suggested.

Keywords: Single-dielectric barrier discharge (SDBD); plasma actuator; active flow control; high angles of attack; slender body.

1. Introduction

The most interesting phenomenon associated with high angle of attack aerodynamics is the sudden onset of vortex asymmetry on the forebody of an air vehicle in symmetric flight.[1] When vortex asymmetry occurs, the aerodynamic, stability, and control characteristics of the vehicle change dramatically. In the mean time, the conventional aerodynamic controls become ineffective due to the vortex wakes generated by the forebody. High-angle-of-attack flow control is most effective when applied at the region close with the point apex of the forebody. Excellent reviews on this activity can be found in the papers by Malcolm[2, 3] and Williams.[4]

Hanff, Lee and Kind[5] used the duty cycle modulation of the alternating blowing from two forward facing nozzles to control the mean lateral aerodynamic forces and moments over slender bodies. The method takes the advantage of the inherently bi-stable nature of the forebody vortices by deliberately switching them between their two stable states.

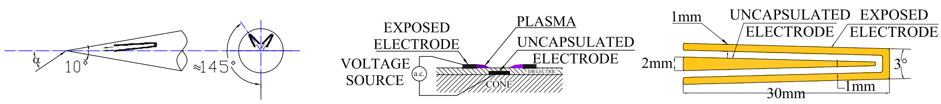
Flow control with electromagnetic energy addition receives significant attention, since it is fully electronic with no mechanical parts and has a broad frequency bandwidth so that it can have fast response for feedback control. It is highly desirable to replace the blowing nozzles in the method of Hanff *et al*.[5] with a pair of plasma actuators of single dielectric barrier discharge (SDBD).[6] The present paper is aimed at the study of a plasma flow control over a pointed slender forebody of revolution. Asymmetric vortices on slender body of revolution have been reported.[7] Hall[8] established an inherent relation between the vortex flow and the surface pressure distribution on a slender body by comparing oil flow visualization and surface pressure measurements in the literature. In the following sections, the experimental setup is described. The experimental results are then presented and discussed. Finally conclusions are drawn.

2. Experimental Setup

The tests are conducted in an open-circuit, low-speed wind tunnel at the Northwestern Polytechnical University. The test section has a 3.0 m × 1.6 m cross section. The experimental model is a circular cone of 10° semi-apex angle faired to a cylindrical afterbody. The length of the cone is 463.8 mm and the cone base diameter is 163.6 mm. The cone tip of length 150 mm is made of plastic for plasma-actuator accommodation and the rest of the model are made of metal.

The SDBD plasma actuators are designed small and compact so that they can be placed as close with the cone apex as possible and without mutual interference. Three different designs of the actuators and mounting schemes have been tested.[9,10] The one studied in this paper is shown in Fig.1. The SDBD actuator is to impart momentum to the flow like the forward facing nozzle used by Hanff *et al*.,[5] but without the mass injection. The gap between the electrodes for our particular actuators was optimized for maximum induced air flow based on experiments conducted in still air.

A pair of the SDBD actuators is mounted on the cone surface symmetrically. The central lines of the actuators are located at the meridian angle $\theta \approx \pm 145°$ shown in Fig.1, where θ is measured from the windward generator and the positive is clockwise when looking upstream. The leading edge of the actuator is located at 20 mm from the cone apex. The plasma blows upward and forward along the meridian of the cone tip. The plasma-actuator arrangement is intended to push the tip vortex on the same side of the cone away from the cone surface. In the present study, the plasma actuators are made by hands and then attached to the cone tip surface with glue.



(a) Arrangement (b) SDBD (c) Planform

Fig. 1. Sketches of the plasma actuators.

Two modes of operation are defined for the actuators. The plasma-off mode corresponds to the case when neither of the two actuators is activated. The port-on mode refers to the conditions when the port actuator is activated while the starboard actuator is kept off. Each of the two actuators on the cone model is separately driven by an a.c. voltage source. The waveform of the a.c. source is sine wave. The peak-to-peak voltage

V_{p-p} is 12 kV and frequency F = 8.9 kHz. The measured power consumption is approximately 15W. The maximum speed of the induced flow on the plane perpendicular to the cone axis at the apex, U_{max}, was measured with a hot-wire anemometer survey. Table1 shows the maximum speed, U_{max} vs. V_{p-p} at F ≈ 8.9 kHz. Surface pressure measurements are chosen for the test. The 252 pressure tapings are arranged in rings of 36, every 10° around the circumference of the cone, at 7 stations uniformly distributed from x/L = 0.340 to 0.813 on the cone forebody.[11]

Table 1. Induced effects of port plasma actuation in still air.

V_{p-p}/(KV)	9	10	11	12	14	15
U_{max}(m/s)	1.2	1.4	1.7	1.8	2.0	2.1

3. Experimental Results and Discussions

In a typical bi-stable mode, the asymmetry may be either towards the starboard side or the port side, affected by slight imperfections of the cone near the apex and also free-stream conditions.[7] By taking advantage of the sensitivity of the flow on the conditions near the apex of the cone, we can control the vortex configuration and thus the pressure distribution asymmetry by activating one of the installed plasma actuators. Experiments were performed for the plasma-off and port-on at α = 50° and U_∞ = 5 m/s. The Reynolds number based on the cone base diameter is 5×10^4 .

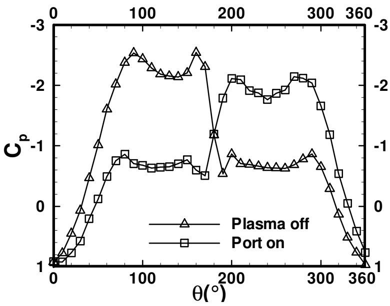


Fig. 2. Distribution for plasma off and port plasma on.

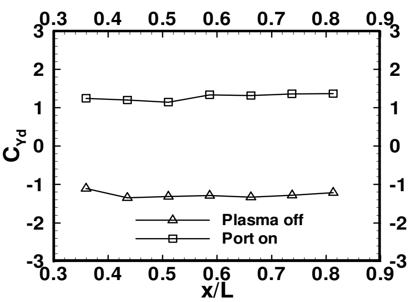


Fig. 3. Local side-force vs. x/L.

Figure 2 compares the pressure distribution for the plasma off and port on Stations 3. The plasma-off pressure distribution in Fig. 2 show a stronger suction on the port side than that on the starboard side of the cone, indicating that the port-side vortex is located closer to the cone than the starboard-side vortex.[8] The port-on pressure distribution shows stronger suction on the starboard side of the cone, indicating that the starboard-side vortex has moved close to the cone while the port-side vortex moved away from the cone. The port plasma actuator induces a momentum input in forward and upward directions, which presumably pushes the port-side vortex away from the cone surface, and brings the starboard vortex with its feeding shear-layer close by the cone. Similar effects were observed by Hanff *et al.*[5]

Figure 3 presents the local side-force along the cone axis. They are nearly constant for each mode, indicating the cross-flow pattern remains the same along the cone axis for each mode. The plasma-off local side forces are negative. The port-on local side forces switch to positive, confirming that the stronger suctions switch to the starboard side seen in Fig. 2.

4. Conclusion

Two horseshoe-shaped plasma actuators are symmetrically mounted on the leeward side of a conical forebody near the apex for dynamic manipulation of forebody lateral loads at high angles of attack. The plasma actuators are small and compact so that the two actuators can be placed extremely close to the forebody apex and without mutual interference. The plasma blows forward and upward over the leeward surface of the conical forebody toward the same-side tip vortex from behind and below to push it away from the body.

Acknowledgment

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