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Plasma Flow Control over Slender Delta Wing and Low Dorsal Fin Combination

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Abstract Experiments are performed on a 82.5° sweep flat-plate delta wing combined with a dorsal fin of height 0.6 of the wing semi-span at Reynolds number based on the wing root chord of 3.32×10^5, in which a pair of small and short dielectric barrier discharge plasma actuators are employed at the wing leading edge near the apex of the wing to effect flow control. Measured pressure distributions over the model are investigated. Lateral flow control is achieved at angle of attack of 30° by the plasma actuators. Flow induced by the leading-edge plasma actuator in still air is also studied. Ideals for further work are suggested.

Key words: delta wing, plasma actuator, single-dielectric barrier discharge(SDBD), active flow control, high angles of attack

INTRODUCTION

Cai, Liu, and Luo [1] developed a vortex stability theory for slender conical bodies and showed by their analytical methods that vortices over a flat-plate delta wing at zero sideslip are conical, symmetric, and stable for all angles of attack but adding a low dorsal fin to the wing would destabilize the vortices and therefore render the originally symmetric vortices asymmetric and/or non-conical. The flow would recover symmetry only when the fin height is increased to a critical level. Later, Cai et al. improved their stability predictions by considering the effects of vortex core. [2] In the mean time, models of strictly slender and conical flat-plate fins added to a sharp-edged flat-plate delta wing were made, and smoke-laser-sheet visualizations, [3] six-component internal strain-gage-balance measurements [4] and two-dimensional particle image velocimetry (PIV) [5] were performed to verify the theoretical results. [1,2]

In recent years, flow control with electromagnetic energy addition has received growing attention because of the advantages of not having mechanical parts while at the same time having broader frequency band-widths. One such development is the use of single dielectric barrier discharge (SDBD) plasma actuators. [6] The effect of the SDBD actuator is to impart momentum to the flow much like flow suction or blowing but without the mass injection. Recently, Liu et al. [7] reported wind-tunnel experiments that demonstrate nearly linear proportional control of lateral forces and moments over a slender conical forebody at high angles of attack by employing a novel design of a pair of single dielectric barrier discharge (SDBD) plasma actuators near the cone apex combined with a duty cycle technique.

In this work we employ a novel design and placement of a pair of SDBD plasma actuators near the wing apex. This work proves the feasibility of using low-power plasma actuators to not only avoid the unpredictable onset of asymmetric aerodynamic loads but also provide the highly needed lateral control of slender forebodies at high angles of attack.

EXPERIMENTAL SETUP

The wing of sweep angle 82.5° and root chord $c_0 = 990$ mm is made with a red pine plate of thickness 19.1 mm. The leading and trailing edges are beveled with a 20° angle from the windward side so that the leeward side of the wing is perfectly flat. The dorsal fin is made of red pine. The thickness is 3 mm in the tip portion $x = 0$-150 mm, and increased linearly to 9 mm at the trailing edge. The leading edge of the fin is sharpened symmetrically with a 45° angle from both sides. The fin height is 0.6 s. The dorsal fin is fixed vertically on the upper surface of the wing in its symmetry plane. The tip portion of the model from $x/c_0 = 0$ to $x/c_0 = 15.0\%$ is separately made of metal to maintain a sharp tip and high precision for a conical shape. The theoretical model for the conical wing and dorsal fin combination is shown in Figure 1.

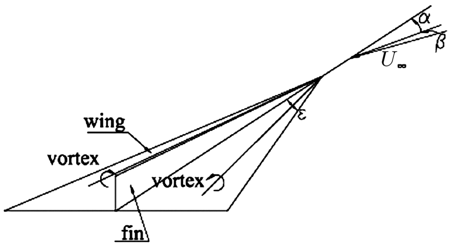
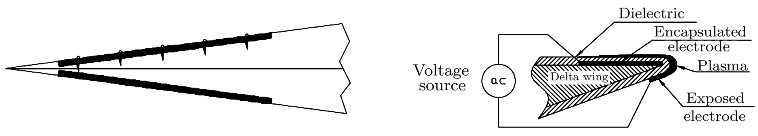


Figure 1: Theoretical model

A pair of the SDBD actuators are mounted on the wing leading edge symmetrically as shown in Figure 2. The cross-section shape of the actuator is similar to that used by Greenblatt et al. [8] Relatively small and short SDBD plasma actuators are made so that they can be placed as close to the cone apex as possible. The effect of the SDBD actuator is to impart momentum to the flow in the direction from the top exposed electrode around the wing leading edge toward the encapsulated electrode, [6] in a way similar to employing suction or blowing along the body surface but without the mass injection.Surface pressure measurements are instrumented at $x/c_0 = 0.3$, 0.5 and 0.7 on the wing.



(a) Arrangement (b) SDBD

Figure 2: Sketches of the plasma actuators

1. V. Plasma actuations Pressure measuements are conducted for port on and starboard on at a series of angle of attack same as for plasma off. The measured pressure distributions at $\alpha = 0° - 20°$ indicate no effect of port on and starboard on. It means that the symmetric and conical flow over the wing-fin body is stable under the disturbances of the plasma actuations.

Figures 3 compare the pressure distributions for port on and starboard on with those for plasma off at $\alpha = 30°$. Figure 3(a) shows that at $\alpha = 30°$ on the upper surface of the wing, for port on the port leading-edge pressure suction peak is raised, while the starboard leading-edge pressure suction peak is lowered. For starboard on the starboard leading-edge pressure suction peak is raised, while the port leading-edge pressure suction peak is lowered. The plasma actuation induces a momentum input in the direction of the local flow, which enhances the leading-edge separation vortex and thus raises the leading-edge suction peak on the same side of the wing. The port on and starboard on modes affect slightly the pressure distributions on the wing upper surface near the root chord and also on the fin surfaces as shown in Figure 3(b). No effects on the pressure distributions on the wing lower surface are observed as seen in Figure 3(a).

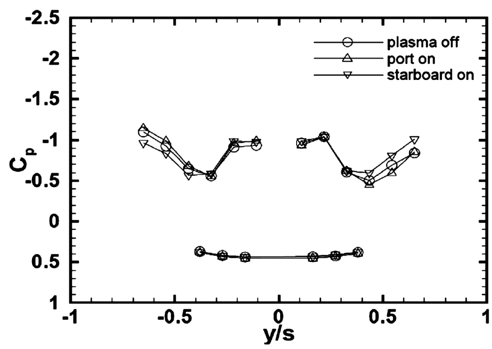


Figure 3: Pressure distributions over wing, $\alpha = 30°$, $\beta = 0°$

CONCLUSIONS

The pressure distributions over a 82.5° sweep delta wing combined with a dorsal fin of height 0.6 of the wing semi-span are measured at freestream velocity of 5 m/s, angles of attack upto 35°. The corresponding Reynolds number based on the wing root chord is 3.32×10^5. A pair of small and short plasma actuators are designed and placed symmetrically over the leading edge of the wing close to the wing apex.

At the angle of attack of 30°, the leading-edge plasma actuator induces a momentum input in the direction of the local flow which manipulates the relative strengths of the two leading-edge suction peaks from one of their bistable asymmetric modes to the other, and thus demonstrates the effectiveness of the plasma actuators in controlling bistable vortex flow patterns. Further investigations should be pursued to study the detailed flow mechanism, and refine and optimize the design of the actuators.

REFERENCES

1. Cai JS, Liu F, Luo SJ. Stability of symmetric vortices in two-dimensions and over three-dimensional slender conical bodies. *J. Fluid Mech.*, 2003; **480**(4): 65-94
2. Cai JS, Tsai HM, Luo SJ, et al. Vortex Core and Its Effects on the Stability of Vortex Flow over Slender Conical Bodies. *AIAA Paper* 2005-62, Jan. 2005
3. Meng XS, Qiao ZD, Gao C, et al. Visualization of vortex flow over delta wing with dorsal fin. *AIAA Paper* 2005-1058, Jan. 2005
4. Meng XS, Jia C, Qiao ZD, et al. Aerodynamic characteristics of slender delta wing with low dosal fin. *AIAA Paper* 2007-1272, Jan. 2007
5. Meng XS, Jia C, Qiao ZD, et al. Flow over Delta Wing with Low Dorsal Fin–PIV Study. *AIAA Paper* 2009-541, Jan. 2009
6. Corke TC, Post M. Overview of plasma flow control: concepts, optimization, and applications. *AIAA paper* 2005-563, Jan. 2005
7. Liu F, Luo SJ, Gao C, et al. Flow control over a conical forebody using duty-cycled plasma actuators. *AIAA Journal*, 2008; **46**(11): 2969-2973
8. Greenblatt D, Kastantin Y, Nayeri CN, et al. Delta-wing flow control using dielectric barrier discharge actuators. *AIAA Journal*, 2008; **46**(6): 1554–1560