Modification of the Flow Structure over a Highly Swept Delta-Wing Using Dielectric Barrier Discharge Actuators

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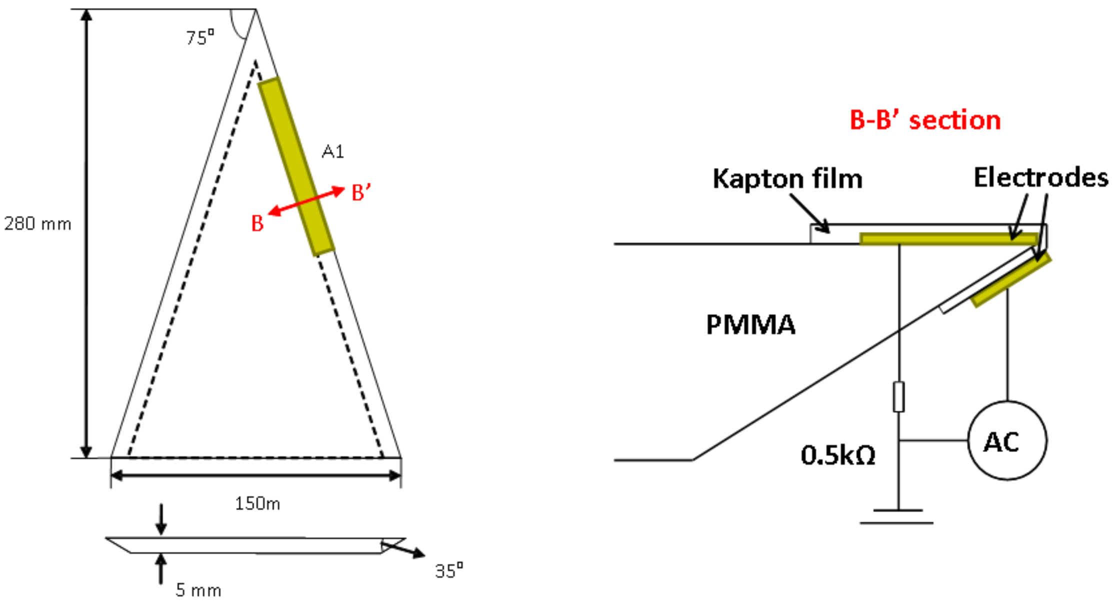
This work describes the use of leading-edge dielectric barrier discharge (DBD) plasma actuators for flow control over a 75–deg swept delta wing. The effects of the DBD actuators on the flow structure and aerodynamics of this highly swept delta wing at different angles of attack and chord Reynolds numbers are investigated.

Figure 1 shows the schematic of the delta-wing model and the plasma actuator configuration with a single DBD actuator (indicated by A1) along the wing leading edge, in this work. The model is constructed from 5–mm–thick acrylic plate with a 280–mm chord, a 75–deg swept angle, and a sharp leading edge beveled at 35 degree. The plasma actuator consists of two 0.025–mm–thick (0.001 in.) and 100–mm–long copper electrodes, with no overlap or recess between. The encapsulated and exposed electrodes, with widths of 10 and 5 mm, respectively, are separated by 10 layers of 0.025–mm–thick (0.001 in.) Kapton film and are mounted on opposite surface of the wing (Fig. 1b). This arrangement produced a plasma–induced jet inboard from the leading edge. The electrodes The Kapton film provides good electrical properties, which has a dielectric constant of 3.3 and a breakdown voltage of approximately 7 kV per 10^{-3}–in. In all of the plasma control experiments presented here, the actuators are operated in a steady manner. The ac carrier frequency and voltage supplied to the electrodes are 20 kHz and 14.5 kV_{p-p}, respectively.

A series of experiments are performed in two facilities at National Cheng Kung University, Taiwan, beginning with flow visualization in a water tunnel that documented the vortex breakdown features of flow over the wing at different angles of attack. Following this, smoke-wire flow visualization and lift measurements are conducted in a wind tunnel to investigate the effects of the leading-edge DBD actuators on the flow structure and aerodynamics of the delta wing model. The range of the angle of attack varies from 0 to 50 degrees in two degree increments. The wind tunnel experiments are conducted at three chord Reynolds numbers of 7.5×10^4, 1.0×10^5 and 1.25×10^5.

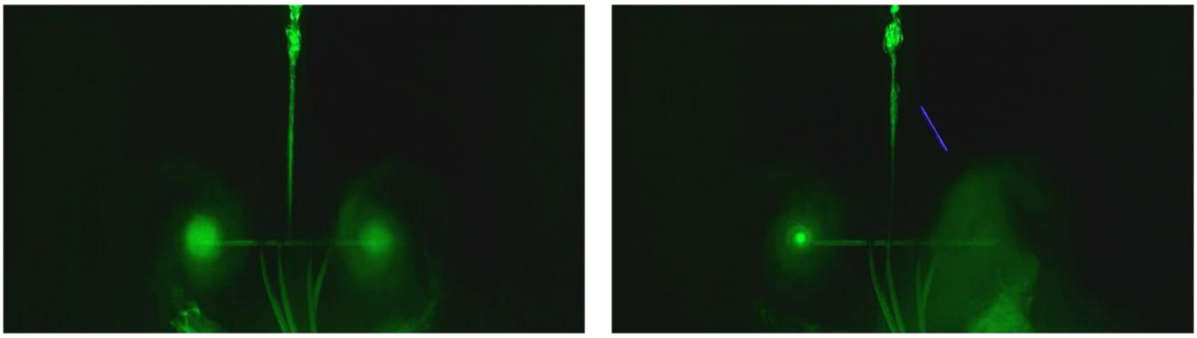
Figure 2 shows typical smoke wire visualization photos of the delta wing model with the actuator A1 on/off at $\alpha = 20^o$, $x/c = 1.4$ and $Re_c = 7.5 \times 10^4$ for comparison. The blue uniform plasma is clearly seen in Fig. 2b. As seen, the two leading edge vortices stay intact and symmetrical under this flow condition with the actuator A1 off. This flow structure is consistent with the dye visualization result in the water tunnel. The functioning of A1 plasma actuator surprisingly causes the breakdown of the leading edge vortex on the actuator side, while makes the leading edge vortex on the opposite side of the actuator more intact. This concentrated leading edge vortex is believed to be responsible for lift enhancement. The destroying of the leading edge vortex symmetry also has an important implication of roll control. More smoke wire visualization photos for other cases with different actuators on and at different angles of attack will be presented in the paper. A clip of movie will also be presented with actuators on and off to demonstrate the evolution of the vortex structures. The correlation between the flow structure and lift enhancement will be discussed in detail in the final paper. Overall, the actuators show the largest increases in the lift and roll moment coefficients at Reynolds number $Re_c = 7.5 \times 10^4$ and high angles of attack near stall.

Keywords: Dielectric Barrier Discharge (DBD) Plasma Actuator, Flow Control, Highly Swept Delta Wing.



(a) (b)

Fig.1 Schematic of the delta wing model showing: (a) the dimensions and the plasma actuator configuration with multiple DBD actuators and (b) the layout of the DBD plasma actuator at the wing leading edge



(a) (b)

Fig. 2. Smoke wire visualization of the flow over the delta wing model with A1 actuator (A) off and (B) on, at $\alpha = 20^o$, $x/c = 1.4$ and $Re_c = 7.5 \times 10^4$. The blue uniform plasma is clearly seen in (B).