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Selective Dielectric Barrier Discharge Actuation for Flow Control of Delta Wings

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Overview

This study investigated the efficiency of Dielectric Barrier Discharge (DBD) actuation on a delta wing leading edge vortex. A DBD actuator is an Active Flow Control (AFC) device comprised of two layers of copper tape, separated by layers of Kapton tape, which forms the dielectric layer, through which high voltage AC current is applied to produce a plasma discharge (Fig. 1). Symmetric and asymmetric leading edge (LE) DBD actuation was tested on a delta wing model of 60^{o} sweep angle in a subsonic recirculating wind tunnel (Figs. 2 & 3). The model's vortex flow field was investigated using Stereo (Fig. 4) and Mono Particle Image Velocimetry (PIV) obtaining vorticity magnitude contours to quantify the vortex structure.

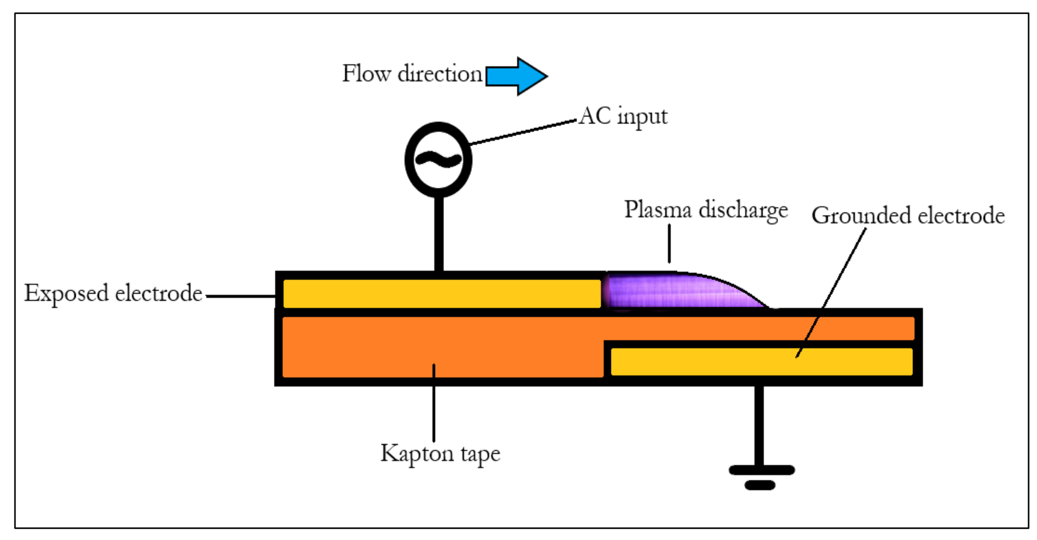

Fig. 1 – Schematic of a DBD actuator.

Fig. 2 – Model mounted in wind tunnel testing section.

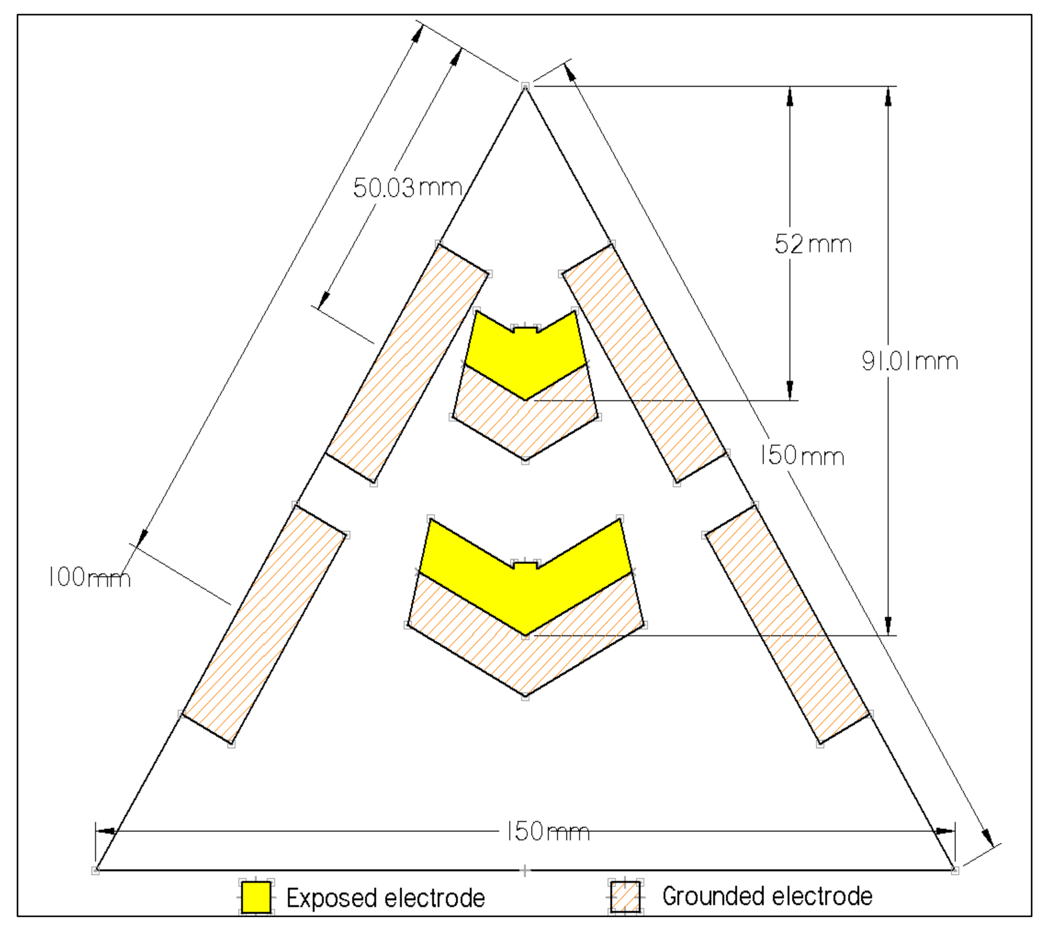

Fig. 3 – Actuator placement on delta wing model.

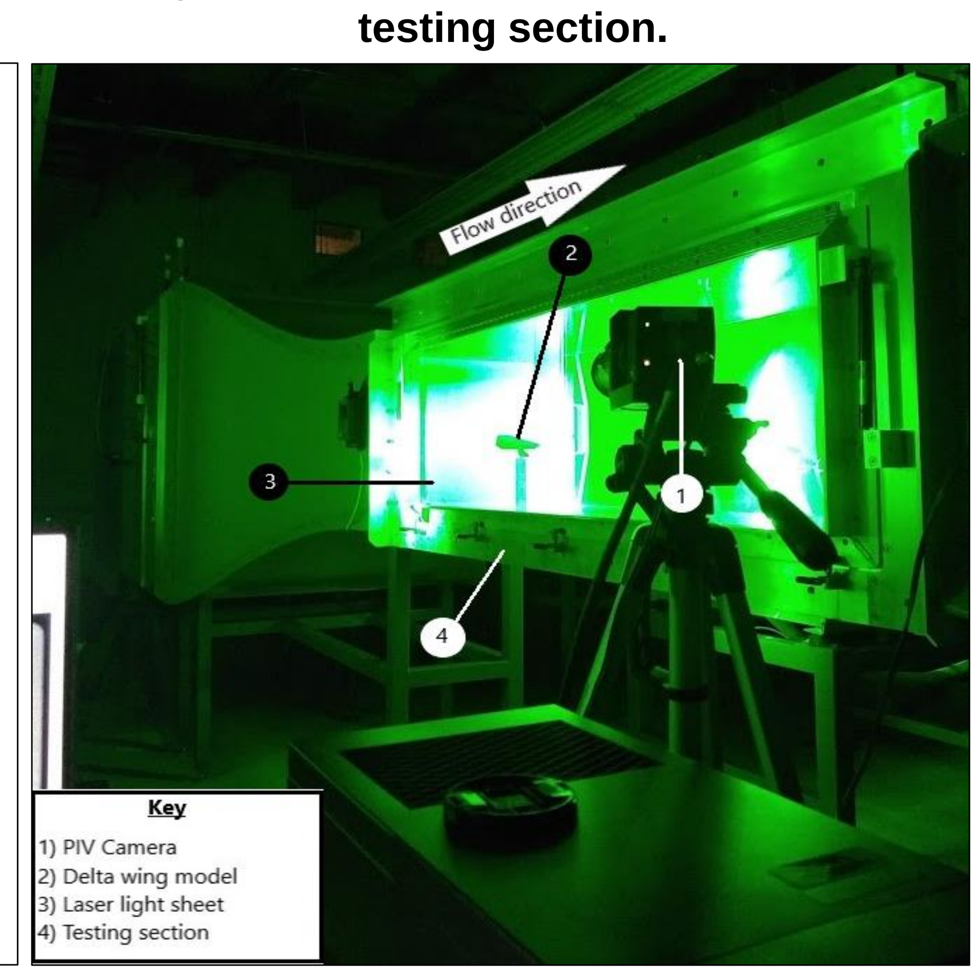

Fig. 4 – PIV test setup.

Conceptual Framework

Delta wing planforms, primarily efficient in high speed flight regimes, are dependent on their leading edge vortices (LEVs) for lift generation (Fig. 5) at low speeds (high angles of attack). LEVs are subject to breakdown due to a substantial lack of axial flow transport along the vortex core, thus affecting the wing's controllability. Leading edge DBD actuation has been shown to delay the vortex breakdown location through manipulation of the separated shear layer at the wing's leading edge [1, 2].

Future work would involve the investigation of the actuation effects of new *chevron* DBDs, designed and placed along the vortex reattachment angle in an effort to entrain high momentum axially attached flow to the leading edge vortices along their primary attachment lines.

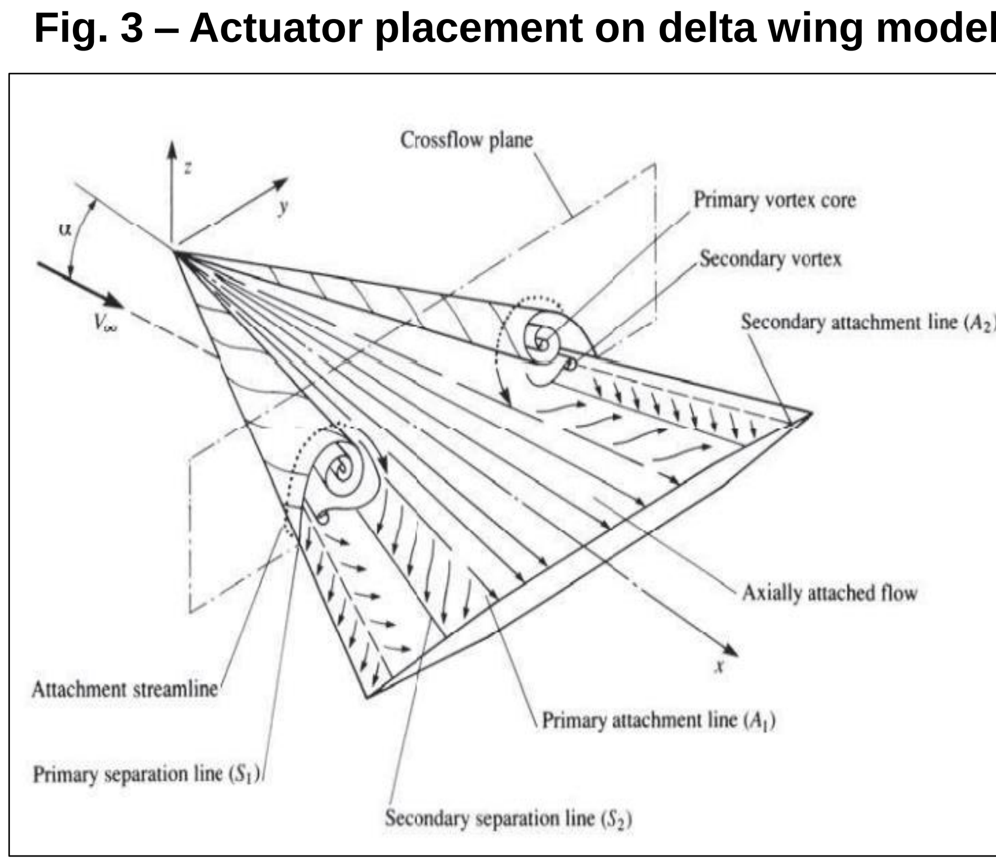

Fig. 5 – Subsonic flow field over a delta wing at an angle of attack [3].

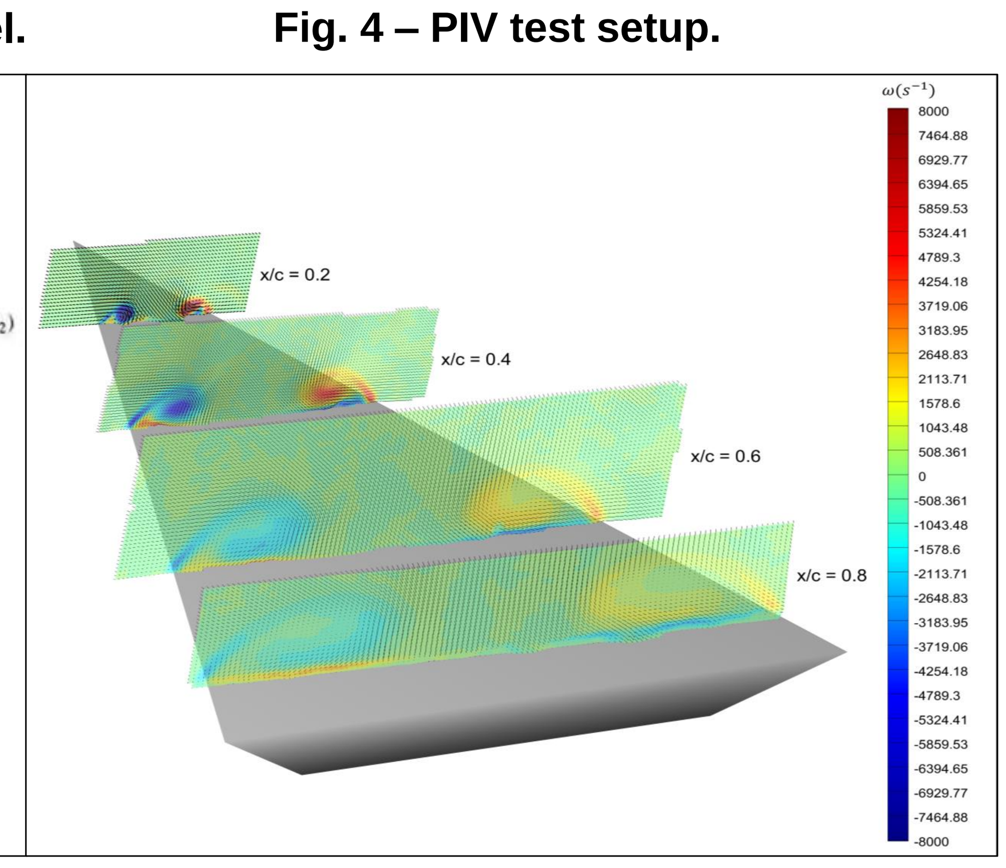

Fig. 6 – Baseline wing characterization through time-averaged SPIV vorticity contours

Key Findings

A baseline delta wing's vortex flow field was characterized at x/c=0.2 intervals to identify the vortex breakdown location at $\alpha = 20°$ (Fig. 6). Asymmetric actuation at x/c=0.4 (Fig. 7(a)) was shown to significantly strengthen the left vortex, leading to the formation of a well-defined core structure, along with observed increased vorticity on the right. Effects of symmetric leading-edge DBD actuation in a post breakdown phase at x/c=0.5 (Fig. 7(b)) shows a reduced region of increased peak vorticity for the right vortex along with the substantial strengthening of the left vortex which led to the reformation of the vortex core, consequently delaying vortex breakdown.

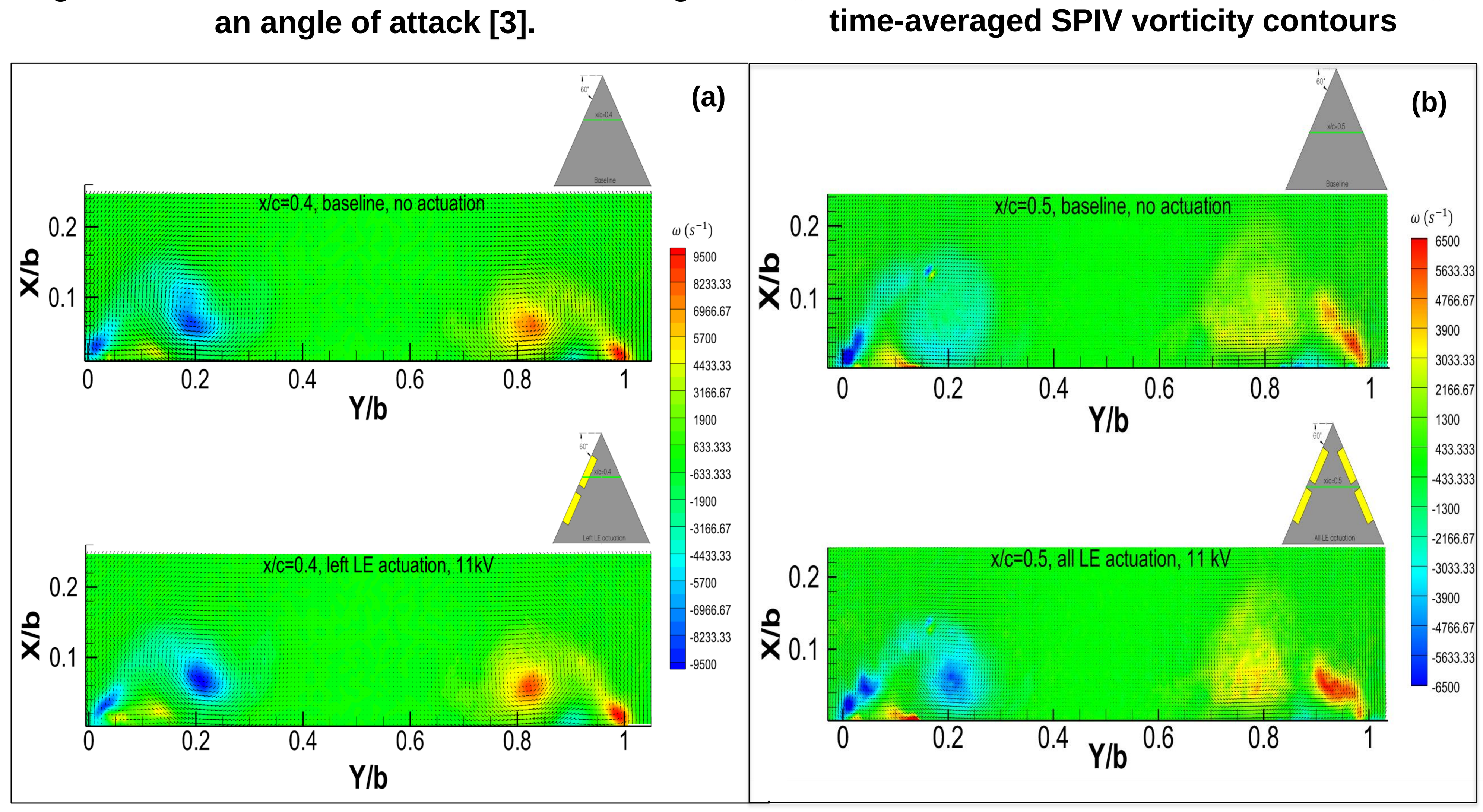

Fig. 7 – Time-averaged vorticity contours for LE vortex – (a) x/c=0.4, left LE actuation, 11 kV p-t-p, (b) x/c=0.5, symmetrical LE actuation, 11 kV p-t-p, at $\alpha = 20°$, $\Lambda = 60°$, *Re = 57,000*.

Impact

Selective control of vortex breakdown through DBD actuation can significantly alter a delta wing's rolling moment aiding maneuverability at low flight speeds.

Application of DBD actuators on delta wing flow control platforms such as engine strakes can significantly strengthen the LE vortex over an aircraft's wing.

References

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2. Shen, L., and Wen, C.-Y., "Leading Edge Vortex Control on a Delta Wing with Dielectric Barrier Discharge Plasma Actuators," Applied Physics Letters, vol. 110, 2017, p. 251904.
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