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Surface Shaping to Suppress Vortex Breakdown on Delta Wings

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I. Introduction

IN an accompanying Note[1] we presented evidence of vortex-breakdown suppression by reconfiguring the planform of a delta wing from straight leading edges to a shaped form. The underlying rationale for such a change in wing geometry is based on the so-called self-induction mechanism[1,2] of vortex breakdown for the straight leading edge: in the transient formative stage of vortex breakdown, self-induction in the shear layers spiraling around the straight vortex core causes the pile up of vorticity, which in turn induces backflow and radial enlargement of stream surfaces (Fig. 1).

If the proposed self-induction mechanism of vortex breakdown, which hinges on the straightness of the vortex core, is indeed correct, one may be able to suppress the vortex breakdown by forcing the path of the core to deviate from a straight line (Fig. 2). In the preceding Note[1] this was achieved by shaping the leading edge of a delta wing that resulted in a spanwise perturbation to the vortex core.

Even for a delta wing with straight leading edges, a requisite disturbance may be generated by wing surface shaping or bulges. Such bulges would create a perturbation normal to the wing surface, which induces similar deviation of the core from a straight line.

The effectiveness of such surface bulges in inducing vortex breakdown is illustrated in this Note.

II. Experiments

The tests were conducted in the water tunnel[1] at the University of Washington. The baseline delta wing with straight leading edges is the same as the one used in the tests described in Ref. 1. Here two bulges are placed on one side of the wing, as shown in Fig. 3.

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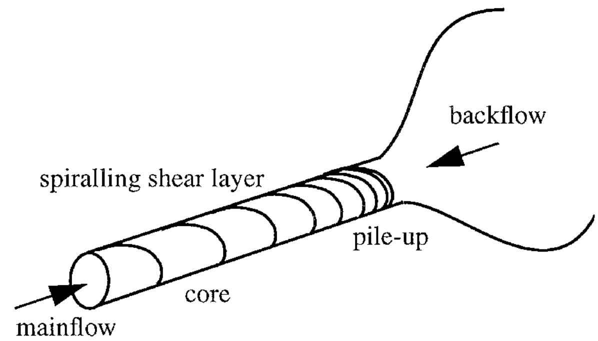


Fig. 1 Vorticity pile up by self-induction.

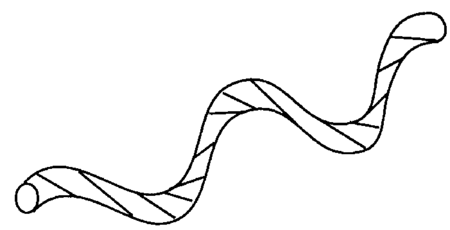


Fig. 2 Departure of the core from a straight line.

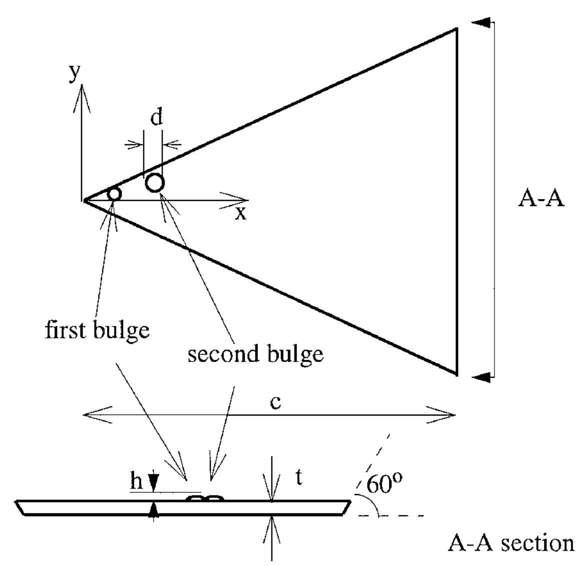
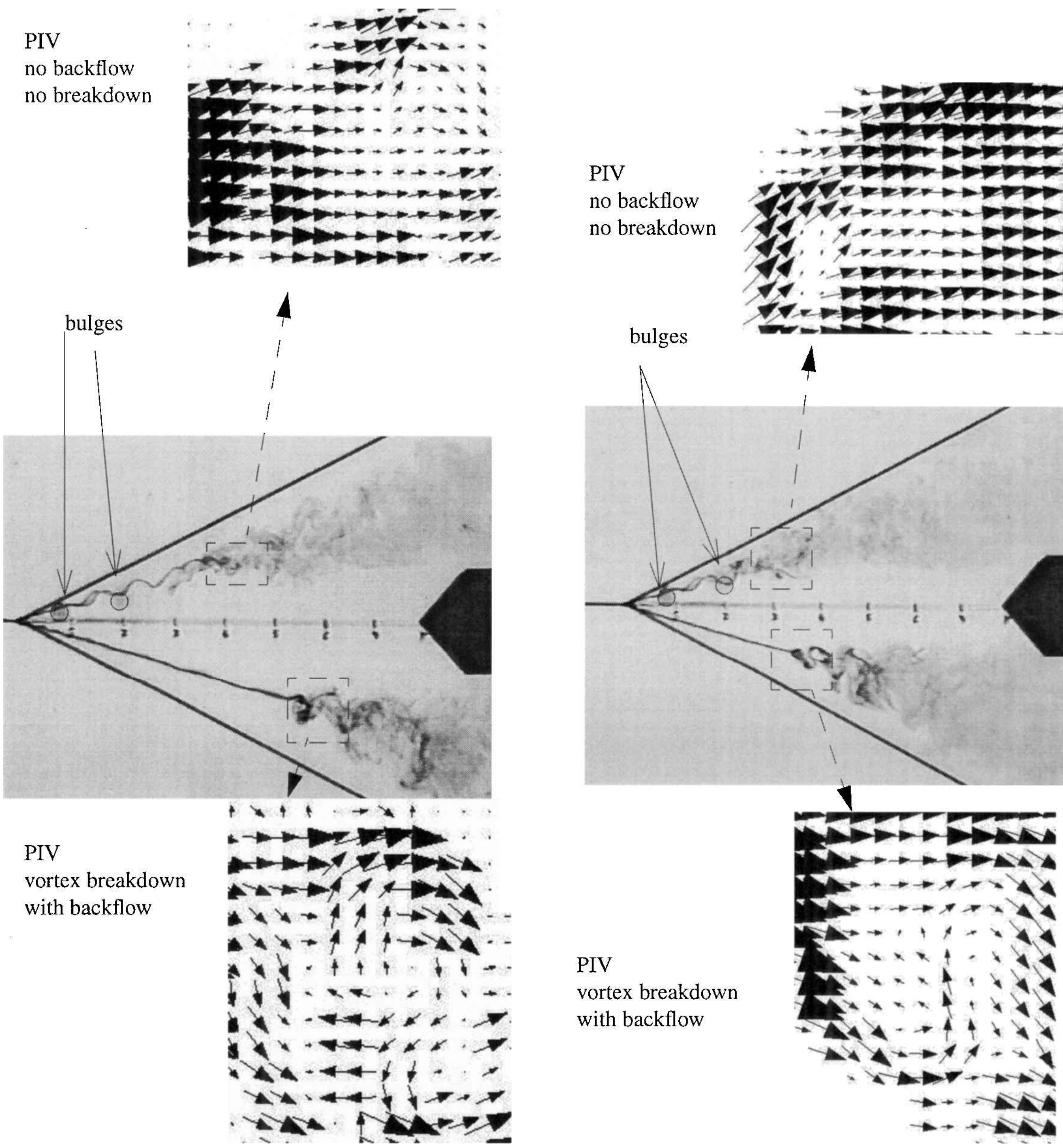


Fig. 3 Bulges.

The center of the first bulge is located at $x_1 = 0.079c$ and $y_1 = 0.0198c$; its diameter $d_1 = 0.033c$, and its height $h_1 = 0.0066c$. The center of the second bulge is located at $x_2 = 0.1914c$ and $y_2 = 0.0495c$; its diameter $d_2 = 0.046c$, and its height $h_2 = 0.0066c$. The chord c is 303 mm, the thickness 6 mm, and the sweep angle 65 deg. The freestream velocity is 4 cm/s, and the estimated accuracy of the particle image velocimetry (PIV) data is 10%. In obtaining PIV measurements the position of the laser sheet is not exactly parallel to the upper surface: the laser sheet touches the apex, and at the trailing edge it is separated from the upper surface by a distance of 0.13c.

In Fig. 4, for the lower part of the wing without bulges, the core is straight, and vortex breakdown with characteristic backflow is present, as observed from PIV data taken over a region shown in a box. For the upper part of the wing with bulges, the core is deflected by the disturbance generated by the bulges, and although the dye becomes diffused, there is no backflow observed in the PIV data. Because of the swirling nature of the flow, the perturbation imparted initially normal to the wing surface by the bulges is seen to induce simultaneously spanwise deviation of the core from the original



a) Angle of attack = 25 deg **b) Angle of attack = 30 deg**

Fig. 4 Effect of two bulges.

straight line. The effect of bulges appears to persist above a 40-deg angle of attack.

III. Conclusions

Based on a self-induction mechanism where the spiraling shear layer and its linear alignment are considered to be the cause of the vortex breakdown, it is demonstrated that the vortex breakdown can be suppressed by installing slender bulges on the upper surfaces of conventional delta wings with straight leading edges.

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