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Readers' Forum

Brief discussion of previous investigations in the aerospace sciences and technical comments on papers published in the AIAA Journal *are presented in this special department. Entries must be restricted to a maximum of 1000 words, or the equivalent of one* Journal *page including formulas and figures. A discussion will be published as quickly as possible after receipt of the manuscript. Neither the AIAA nor its editors are responsible for the opinions expressed by the correspondents. Authors will be invited to reply promptly.*

Comment on "Control of Vortices on a Delta Wing by Leading-Edge Injection"

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IN Ref. 1 experimental results are presented that demonstrate the highly nonlinear character of the vortex breakdown characteristics on slender delta wings. Thus, even blowing rates below $c_\mu = 0.01$ caused a large downstream displacement of the vortex breakdown (Fig. 1). The reason for the extreme sensitivity of the breakdown location to such a small perturbation is its proximity to a critical state.[2,3] For a rolling 65-deg delta wing, the leeside wing half encounters one such critical state at 30-deg inclination of the roll axis when the roll angle enters the region $5 < |\phi| < 8$ deg. In that case the effective sweep of the leeside wing approaches 70 deg, and the vortex breakdown moves very rapidly, almost discontinuously, toward the trailing edge[4] (Fig. 2). The breakdown location for $c_\mu = 0$ in Ref. 1 is $x_{b0}/c = 0.29$ for the 75-deg delta wing, placing it very close to the critical region in Fig. 2. This explains the large effect of minuscule blowing rates in Fig. 1.

The experimental results[4] in Fig. 2 are for sharp-edged delta wings. The wing in Ref. 1 has a rounded leading edge, causing a delay of $\Delta\alpha = 3.15$ deg of the start of vortex shedding from the leading edge,[5] resulting in an effective angle of attack of $\alpha = 54 - 3.15 = 50.85$ deg for the test results[1] in Fig. 1. These coordinates, $x_{b0} = 0.29$ and $\alpha = 50.85$ deg, are represented by the symbol + in Fig. 2, indicating that the corresponding sweep angle for a sharp leading edge is somewhat above 80 deg. Assuming that crossflow separation occurs at a location half the wing thickness inboard of the leading edge gives an increment $\Delta\Lambda = 1.1$ deg of the effective leading-edge sweep. This leaves still roughly a 5-deg increment needed to reach the data point + in Fig. 2. According to the text in Ref. 1, no correction was made for the growth of the laminar boundary layer on the plate on which the delta wing half-model was mounted. Assuming that the wing was placed in the center of the plate gives an effective Reynolds number $Re \approx 2.6 \times 10^4$, producing the displacement thickness slope $\partial\delta^*/\partial x = 1.73Re^{-1/2} = 0.106 = 4.95$ deg, giving an effective leading-edge sweep of 82.25 deg, which is in almost embarrassingly good agreement with the data point + in Fig. 2.

Comparing Figs. 1 and 2, one realizes that there must be a structural difference of some sort between the breakdown of the vortex from a sharp leading edge and that of the vortex from a rounded leading edge with tangential blowing. In the case of the sharp-edged delta wing with $\Lambda = 75$ deg in Fig. 2, decreasing the angle of attack from roughly 37 to 35 deg moves the vortex breakdown all the way from 46% chord to the trailing edge. This is in sharp contrast to the results in Fig. 1, which show that the maximum downstream movement of the vortex breakdown, from $x_{b0} = 0.29$ to 0.42, was obtained for $c_\mu \approx 0.03$ and that further increase of the blowing rate moved the breakdown upstream. When searching for the source(s) of this difference in breakdown characteristics, using the information contained in Ref. 1, it could be important to con-

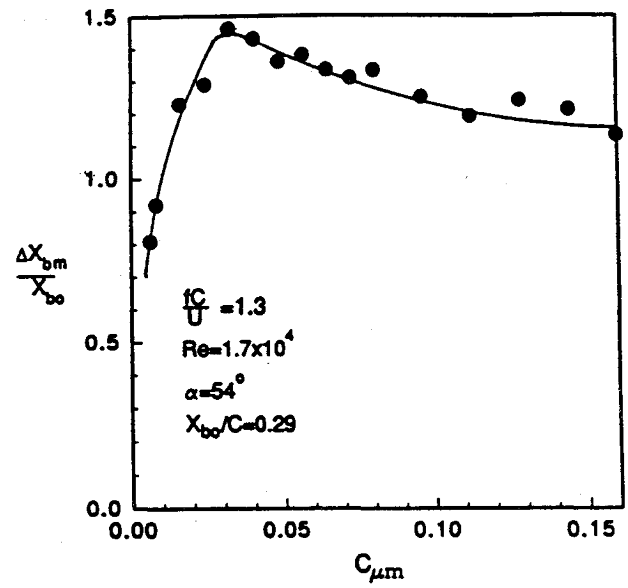

Fig. 1 Maximum attainable downstream displacement Δx_b of onset of vortex breakdown.[1]

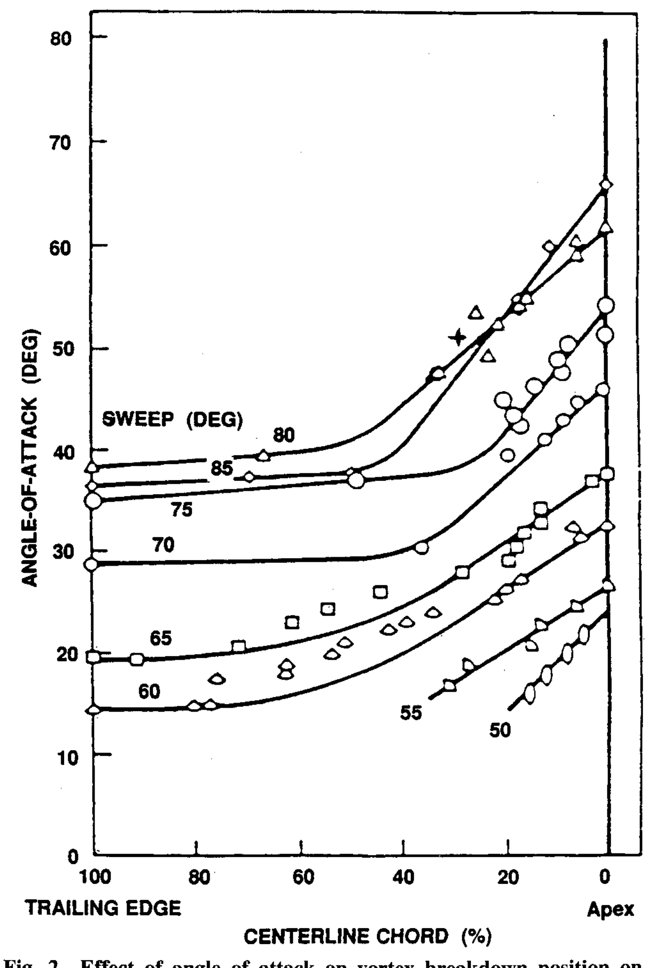

Fig. 2 Effect of angle of attack on vortex breakdown position on sharp-edged delta wings.[4]

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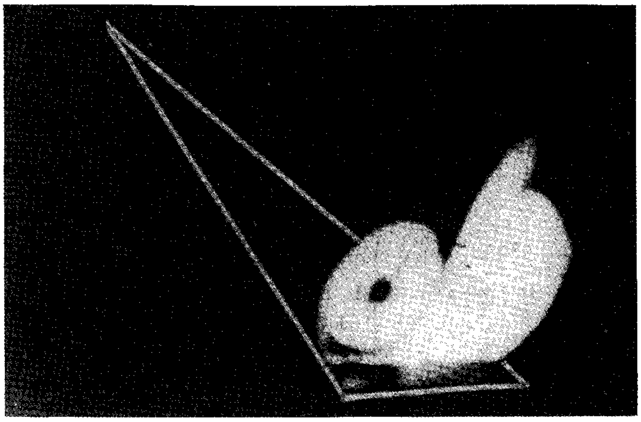

$\alpha = 35$ deg

Fig. 3 Vortex flow behind delta wing: $A = 0.56$ and $Re_c = 1.32 \times 10^5$ (Ref. 6).

sider that use of the half-model test technique eliminates the phenomenon of asymmetric vortex breakdown, illustrated in Fig. 3 already at $\alpha = 35$ deg for an 82-deg sharp-edged delta wing.[6]

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Reply by the Authors to L. E. Ericsson

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REGARDING the remarks in the first paragraph, it would indeed be insightful to study further the high sensitivity associated with proximity to a critical state. This will require an investigation of a range of angle of attack and detailed characterization of the instantaneous flowfield in terms of effective swirl and axial velocity components.

The issues of effective angle of attack and sweep angle for a rounded vs a sharp leading edge are intriguing and deserve further study. It will be appropriate to provide a basis for interpreting these effective angles in terms of the detailed structure of the leading-edge vortex for a rounded vs sharp edge.

Regarding the difference in structure between the breakdown from a sharp edge and a rounded edge with blowing, again detailed characterization of the swirl and axial velocity fields would be required. As the magnitude of the tangential blowing velocity increases, it would tend to enhance the swirl velocity, and it is expected that a limiting value of the ratio of swirl to axial velocity would be reached, for which any further increases would actually tend to enhance the onset of vortex breakdown and move its location toward the apex.

Taken as a whole, the issues raised point to the need for further studies of the quantitative structure of the flowfield. In fact, studies of the flow past a delta wing at high angle of attack subjected to various types of local control are currently under investigation in our laboratories.

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Comment on "Nonlinear Response of Asymmetrically Laminated Plates in Cylindrical Bending"

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A recent Technical Note by Carrera[1] suggested that the von Kármán large deflection plate theory[2,3] was not suitable for analysis of asymmetric composite plates. His conclusions were based on the discrepancy found in the comparison of the analytical solutions obtained by Sun and Chin[2,3] with his nonlinear finite element solutions. In his finite element analysis Carrera erroneously modeled the cylindrical bending problem as a thin laminate strip with free boundary conditions. This explains why his finite element solutions could not match the analytical solutions, thus leading him to incorrect conclusions.

References

[1]Carrera, E., "Nonlinear Response of Asymmetrically Laminated Plates in Cylindrical Bending," *AIAA Journal*, Vol. 31, No. 7, 1993, pp. 1353–1357.

[2]Sun, C. T., and Chin, H., "Analysis of Asymmetric Composite Laminates," *AIAA Journal*, Vol. 26, No. 6, 1988, pp. 714–718.

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Reply by the Author to C. T. Sun

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First of all I have to reply that in Ref. 1 I did not suggest that the von Kármán large deflection plate theory was not suitable for analysis of asymmetric composite plates. In fact I used this nonlinear theory in the FEM model empoyed in Ref. 1. Instead in my Note[1] concerning the cylindrical bending case, I mainly remarked what is in the following text:

1) The analysis in Ref. 2 is a linearized one in the sense that the load-deflection curve has the Euler buckling load as asymptote.

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