Vortex Breakdown Measurements on a 70 Deg Sweepback Delta Wing

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An investigation of the breakdown of the leading edge vortices on a flat plate delta wing having a leading edge sweep angle of 70 deg was studied using flow visualization and surface pressure measurements. The progression of the vortex breakdown position was determined from flow visualization experiments as a function of angle of attack and sideslip angle and correlated with the force and moment data obtained from integrating surface pressure measurements. Tests were conducted at low subsonic speeds, and the Reynolds number, based upon the centerline chord, was 225,000. Vortex breakdown was observed to play a strong role in the nonlinear behavior of the rolling moment.

Abstract

In recent years there has been a renewed interest in slender wing aerodynamics, due to the quest for improved maneuverability in high performance aircraft. References 1-3 are collections of papers from three conferences devoted to high angle-of-attack vortex dominated flows. Although much is known regarding leading edge vortex phenomena on the longitudinal aerodynamic characteristics of slender wings, there is much less information available on the lateral-directional characteristics. This paper presents data on vortex breakdown position as a function of angle of attack and sideslip and its influence on the static rolling moment coefficient.

Models

Two geometrically similar models were constructed for the experiments. The pressure model has 147 pressure orifices distributed over the top and bottom surfaces. Both models had a leading edge sweep angle of 70 deg, a 406.4 mm (16 in.) chord, and an aspect ratio of 1.46. The leading edge was beveled with a 25 deg angle, so that a sharp edge was formed on the upper side of the model. The models were made 19 mm (0.75 in.) thick, primarily to house the necessary tubing associated with the pressure taps on the pressure model. This yielded a 0.047 thickness to chord ratio. Additional information on the experimental equipment and procedure can be found in Ref. 4.

Results

A laser sheet method was used both for quantitative measurements of the vortex breakdown position and qualitative flow visualization photography. Figure 1 is a sketch of the experimental setup. As this figure illustrates, the laser beam is passed through a cylindrical lens, which spreads the beam into a thin sheet of light which in turn passes through the test section. A single filament of smoke is introduced upstream of the contraction cone and positioned so that it will impinge at the apex of the delta wing. The smoke then becomes entrained into the vortices, making them visible. The photograph included in Fig. 1 is a multiple exposure showing the leading edge vortex cross sections at various positions along the wing.

The position of the breakdown was determined by the flow visualization method as a function of angle of attack and sideslip angle. A grid pattern painted on the left side of the model was used to locate the breakdown position with an accuracy of approximately 1.5% of the chord length. The weak link in the process was the determination of exactly what constituted the breakdown point. In effect, there exists a breakdown region instead of a breakdown point. Forward of

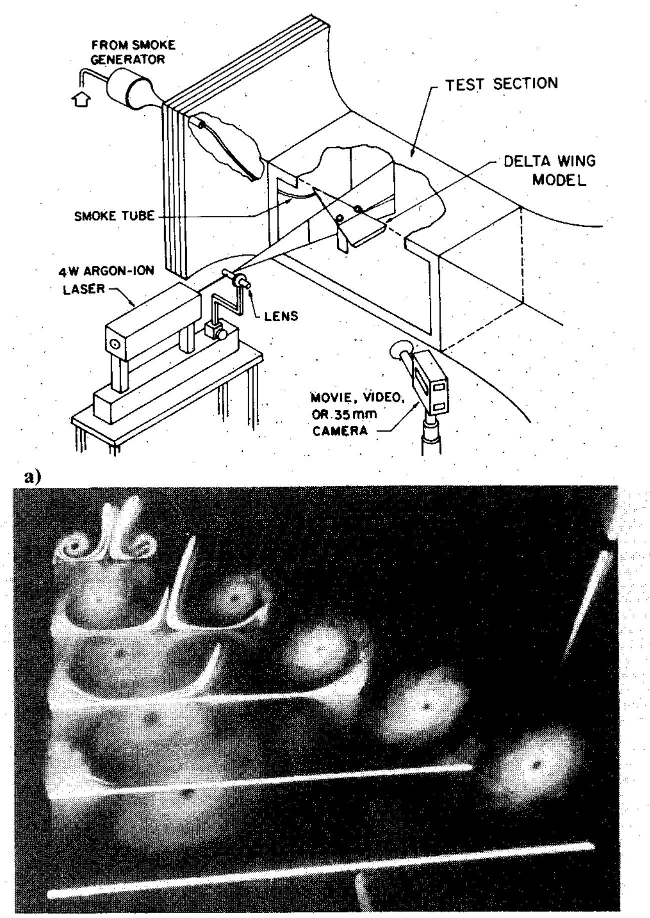

Fig. 1 Technique for measuring vortex breakdown position. a) Sketch of experimental setup, and b) photograph showing laser illuminated crossflow planes

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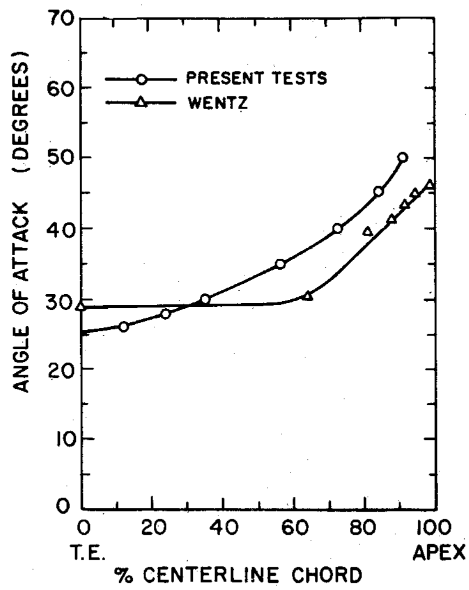

Fig. 2 Vortex breakdown position vs angle of attack. Present data $R_e = 225{,}000$, Wentz data $R_e = 1{,}000{,}000$.

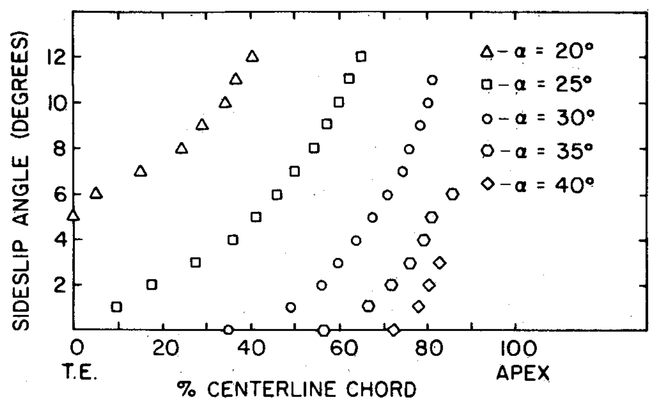

Fig. 3 Vortex breakdown position vs sideslip angle (windward vortex only), $R_e = 225{,}000$.

this region the vortex is very well defined and the vortex core is clearly discernable in the laser sheet photographs, due to the absence of smoke in the core region. Aft of the breakdown, the flow has changed dramatically; it is turbulent and the core is no longer distinguishable. Some judgment has to be made by the observer as to what point the vortex is to be considered as having experienced vortex breakdown. This introduces an inaccuracy which should be taken into account when comparing data. In this study, the breakdown location was chosen to be the initial point at which the vortex core is no longer clearly distinguishable.

Figure 2 shows a plot of the measured breakdown position as a function of angle of attack. At angles of attack between 0 and 25 deg the vortex system did not break down until some distance downstream of the wing. As the angle of attack was increased, the breakdown position moved upstream toward the trailing edge until it reached a position approximately 1/4 chord length aft of the model at an angle of attack of 25 deg. With just a slight increase of attack, the breakdown position was observed to shift from the wake up onto the model. Note that from the 25 to 26 deg angle of attack the breakdown point moves from 1/4 chord behind the wing to a position 12% ahead of the trailing edge. Wentz[5] found a similar, but even more severe, jump for his 70 deg model. The breakdown moved from well aft of the trailing edge to a position 89% ahead of the trailing edge. Although the data were taken at different Reynolds numbers, the difference is not due to a Reynolds number effect. Wentz[5] found no Reynolds number effect over a Reynolds number range of 500,000–1,500,000, and in our experiments a similar observation was made for a Reynolds number range of 85,000 to 425,000. The differences in the data are probably due to the differences in leading edge geometry and model thickness.

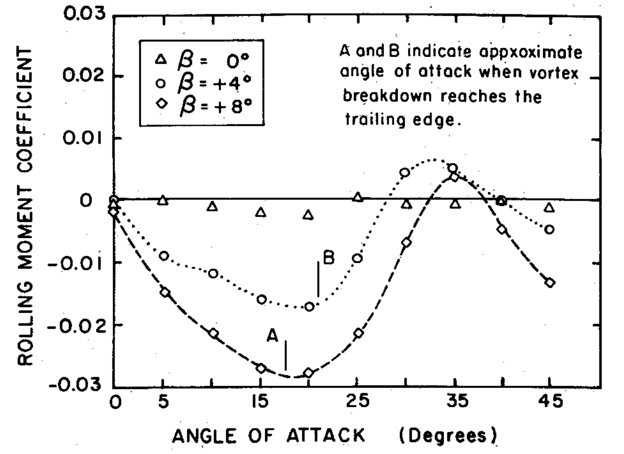

Fig. 4 Rolling moment coefficient vs angle of attack for various sideslip angles, $R_e = 225{,}000$.

A plot of the breakdown position of the windward vortex vs sideslip angle for several angles of attack between 20 and 40 deg is presented in Fig. 3. The breakdown of the windward vortex was first observed to occur over the wing at an angle of attack of 20 deg and moved forward until it became so close to the leading edge at 40 deg that no further change in position could be measured. The sideslip angle was varied from 0 and 12 deg in one degree increments. Measurements were made only for increasing sideslip angle; therefore, hysteresis effects were not investigated. The leeward vortex breakdown position is not plotted because it quickly moved off the wing and into the wake.

The surface pressure data were integrated to determine the forces and moments acting on the wing. The rolling moment curves show the effect of the asymmetrical breakdown case. Figure 4 is a plot of rolling moment (about centerline) vs angle of attack. For example, +4 deg sideslip curve shows a negative rolling moment initially. At approximately 15–20 deg angle of attack, the negative rolling moment starts to decrease. This is the effect of the windward vortex starting to break down over the wing. As the windward vortex breakdown point moves further forward with angle of attack, the rolling moment actually changes sign due to the extreme loss of lift on one side of the wing. However, as angle of attack is further increased, the leeward vortex begins to break down over the wing, causing the rolling moment curve to reverse its direction once again.

In summary, the results presented in this paper show the influence of vortex breakdown on the static rolling moment coefficient. The asymmetric breakdown of the leading edge vortices contributes to the nonlinear rolling moment characteristics with angle of attack.

References

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