Ground Effect on Slender Wings at Moderate and High Angles of Attack

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Abstract

THE effect of ground proximity on a 60-deg swept delta wing at angles of attack of 10-31 deg is studied by means of surface pressure measurements and oil flow visualization tests. Results show that ground effect increases the magnitude of the low pressure regions on the upper surface of the wing, induced by the leading-edge vortices. This increase diminishes at high incidence where the effect of vortex breakdown is dominant. On the lower surface, ground effect increases the pressure. This increase becomes larger as the angle of attack increases. The overall result of ground effect is an increase in the normal force.

Contents

One of the most critical phases of powered flight is takeoff, where weight is largest and speeds are low. Thus, high angles of attack at which nonlinear effects are significant are required in close proximity to the ground. It is therefore important to know the effects of ground proximity on the aerodynamics of the wing and the mechanism by which they are produced. These effects are studied on a slender delta wing on the basis of static surface pressures, normal force, and pitching moment acting on the wing, as well as oil flow visualizations.

The tests were carried out on a thin 60-deg swept delta wing equipped with 130 pressure points. The static pressures on the suction and pressure sides of the wing were measured for angles of attack ranging from 15-35 deg. In this range, which is typically encountered in landing and takeoff situations, the leading-edge vortices generated on the wing are affected by vortex breakdown. The range of proximity ratios tested was ($\bar{h}$ = height/max semi-span) $\bar{h}=2.336$ (which simulated ground free conditions) to $\bar{h}=0.365$.

The ground was simulated by a flat board 150 cm long with a sharp leading edge, spanning the width of the wind tunnel (100 cm) parallel to its floor. The experiments were carried out with the wing trailing edge placed about four chords (110 cm) downstream from the leading edge of the board. The airspeed in these experiments was 30 m/s.

In a typical experiment the wing was set at a prescribed angle of attack, and pressure measurements on the upper surface were performed for a series of ground heights. The wing was then turned over so that the pressure measurement surface became the lower surface, and data were taken for the same series of heights. This procedure was repeated for a series of angles of attack to obtain the full data set. The flow on the ground plate was visualized by means of a fluorocentric oil emulsion (Fig. 1). A detailed account of the experimental system and the results obtained are given in Ref. 1.

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The characteristic effects of ground proximity on the static pressures at the wing surfaces are shown in Figs. 2 and 3. On the upper (suction) side, the pressure decreases with increasing ground proximity. The magnitude of this decrease is largest underneath the leading-edge vortices. These results are consistent with a simple model that considers the effect of ground proximity as the interaction of the wing leading-edge vortices and their image in the ground (Fig. 4). The image leading-edge vortices displace the real ones upward and

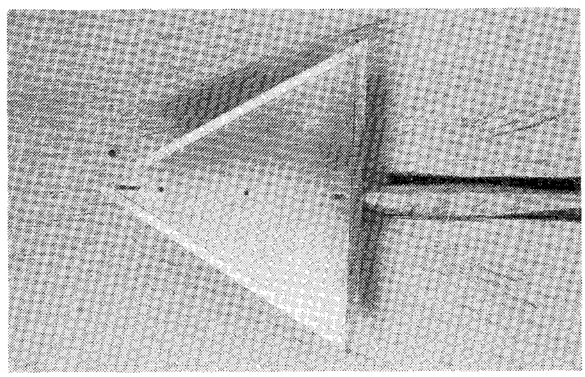

Fig. 1 Oil flow pattern on the ground plate; the wing is placed at $\bar{h}=0.365$ and $\alpha=1.75$ deg.

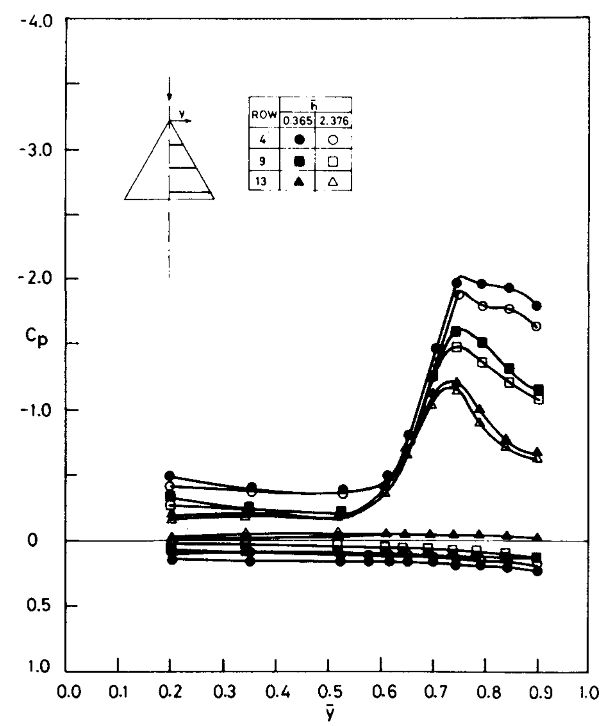

Fig. 2 Spanwise pressure distributions at $\alpha=10$ deg.

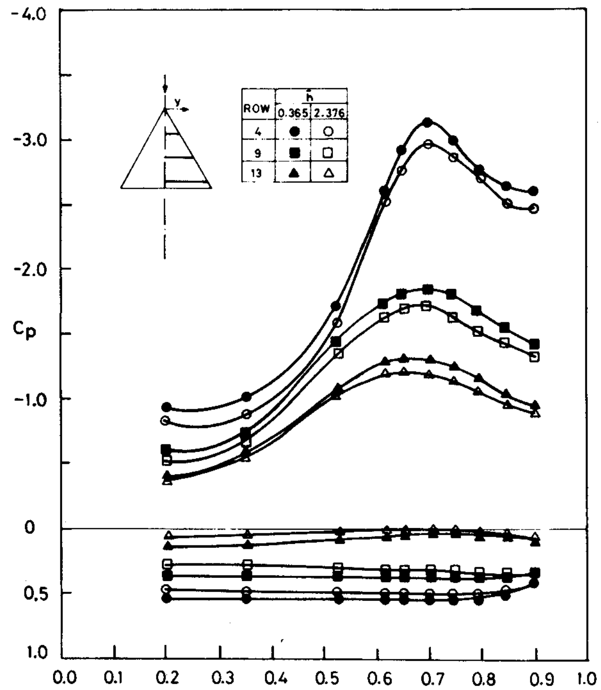

Fig. 3 Spanwise pressure distributions at $\alpha = 25$ deg.

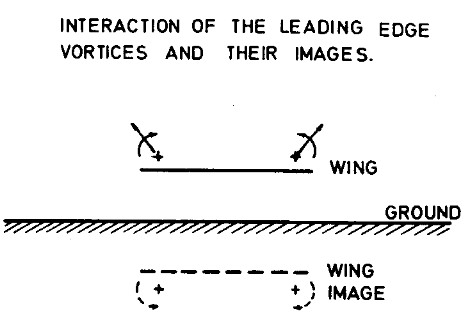

Fig. 4 Schematic rear view of the wing with its leading-edge vortices and their image in the ground. The directions of the displacements of the real vortices due to the mutually induced velocities are denoted by the straight arrows.

outboard. The upward displacement of these vortices has been shown[2] to signify an increase in their circulation and the suction they induce on the wing.

The increased suction due to ground effects is unique to slender wings where the leading-edge vortices are located over the wing surface and affect the flow directly. In two-

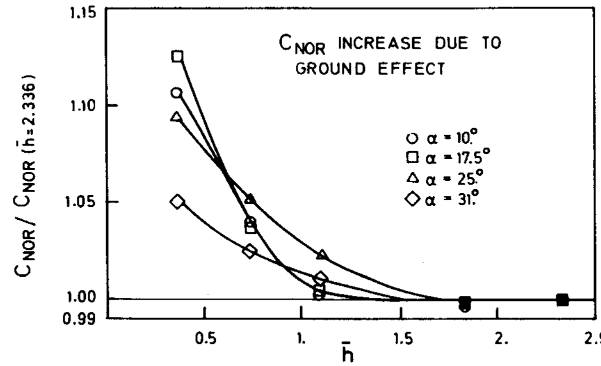

Fig. 5 Effects of ground proximity on the normalized C_{NOR}, which is computed by integration from the pressure measurements.

dimensional flow on high-aspect-ratio wings, for example, the suction is reduced due to ground effect.[3] This reinforces the aforementioned model, which associates the increased suction due to ground effect in delta wings with interaction of the leading-edge vortices and their image.

On the windward side of the wing the pressure coefficients are in general positive and increase both with increasing angle of attack and ground proximity (Figs. 2 and 3). The spanwise C_p profiles on this side near the trailing edge are characterized by a dip, which is located underneath the suction peaks of the upper side and the leading-edge vortices. This dip also appears, in a weak form, in the ground-free tests and becomes more pronounced as the wing approaches the ground.

This phenomenon is probably associated with the effect of the leading-edge vortices in the ground-free case, in addition to the effect of their image in the ground, when ground proximity affects the wing. Apparently the suction induced by the leading-edge vortices on the suction side "leaks" into the trailing-edge region on the pressure side. When the ground effect exists, the image vortices induce additional suction in this region, in a manner similar to the effect of the leading-edge vortices on the suction side.

In conclusion, ground proximity increases the suction on the upper surface and the pressure on the lower surface. This combination results in an increase of both the normal force (Fig. 5) and the nose-down pitching moment.

References

[1]Er-El, J. and Weihs, D., "Ground Effect on Slender Wings at Moderate and High Angles of Attack," ICAS Paper 84.2.8.2, Sept. 1984.

[2]Smith, J. H. B., "Improved Calculations of Leading Edge Separation from Slender, Thin Delta Wings," *Proceedings of the Royal Society of London,* Ser. A, Vol. 306, 1968, pp. 67-90.

[3]Bagley, J. A., "The Pressure Distribution on Two Dimensional Wings Near the Ground," ARC R and M 3238, 1961.