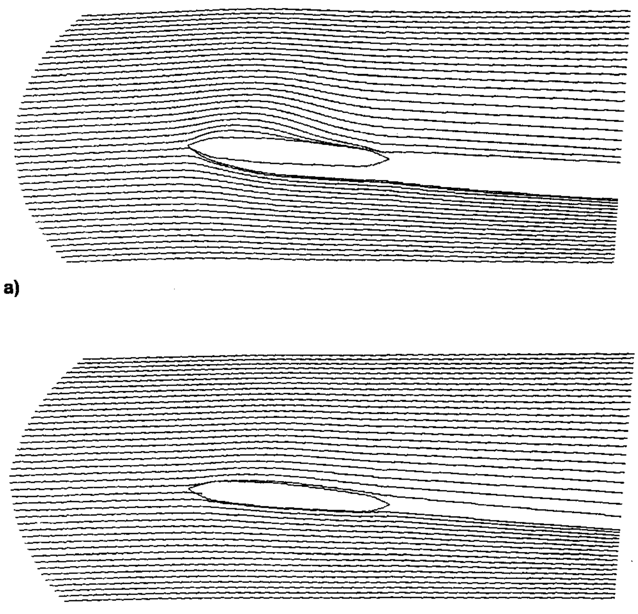

Fig. 4 Influence of sidewall boundary layer on root plane streamline pattern (M_∞ = 0.8860, α = 8.24 deg): a) viscous sidewall computation and b) free-air computation.

Conclusions

A numerical investigation of the interaction between a wind-tunnel sidewall boundary layer and a thin low-aspect-ratio wing has been performed for transonic speeds and flight Reynolds numbers. A three-dimensional Navier-Stokes code was applied to calculate the flowfields. The results indicated that the sidewall boundary layer had a strong influence on the flowfield around the wing. The low momentum of the sidewall boundary layer resulted in higher pressures in the juncture region, which decreased the favorable spanwise pressure gradient. This significantly decreased the spanwise migration of the wing boundary layer. The computations which modeled the sidewall boundary layer were found to be in better agreement with experimental data.

Acknowledgments

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Experimental Investigation of Vortex Flaps on Thick Delta Wings

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Introduction

MOST modern fighter airplanes and missiles use the "so called" nonlinear-lift. Swept sharp leading edges generate additional lift. The leading-edge separation rolls up the leading-edge vortex and rotates the leading-edge suction that normally points upstream, to a direction normal to the wing surface. However, the increased normal force adds a significant drag component.[1]

Vortex flaps have been introduced as a means to reduce the additional drag. It was postulated that a downward deflection of the leading edge to parallel the freestream direction will redirect the vector of the vortex suction.[2] The postulation was found in this work to be oversimplified. The deflected flap created cambered profiles of smaller geometrical and effective angles of attack, and transformed the flat delta wing into a cambered wing with a dihedral. The flowfield also became more complicated than that of a flat delta wing, with two additional vortices generated at the flap hinges.[3] These changes in the flowfield reduced the leading-edge suction, and resulted in both the lift and the drag forces being smaller. However, the aerodynamic efficiency of the wing, defined by the lift/drag ratio, has improved on occasion. This improvement has been the main goal of several works.[4–14] The aerodynamic coefficients of configurations with vortex flaps were measured experimentally,[3,15–17] and predicted theoretically,[18,19] Most of these works dealt with very thin wings. Although Rao[10] reports on the adverse effect of the thickness on the performance of vortex flaps, the current investigation is of delta wings with substantial thickness. This thickness, being more realistic, also made possible the design of an actual hinge geometry, rather than the virtual hinge used in prior experiments, as well as the observation of the effect of the leading-edge shape.

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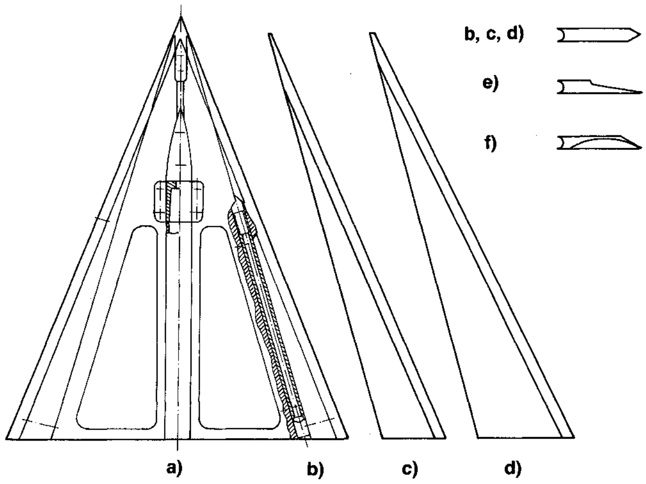

Fig. 1 Model description: a) generic wing and b–f) the flaps.

Test Model

The generic delta wing is shown in Fig. 1. Its dimensions are 400 mm root chord, 240 mm span, and 12.7 mm thickness. Three different symmetrical flaps (Figs. 1b–1d) now mounted on the wing through hinges along the wing leading edge, resulting in delta wings of aspect ratios 1.6, 1.8, and 2.1. The hinges were designed to be replaced by secondary balances for measuring the aerodynamic loads on the flaps. The flap could be deflected continuously through 70 deg. A six-component sting balance was housed in the midsection of the wing. The wing apex was interchangeable, so that the leading-edge slopes for the various flaps at different deflection angles could be matched. Two additional vortex flaps were investigated to observe the leading-edge shape effect. One asymmetric with a flat bottom (Fig. 1e), and one with a concave bottom (Fig. 1f) similar to a leading-edge droop.

The wing was tested in the 1 × 1 m low-speed wind tunnel, at a velocity of 32 m/s ($R_e \cong 5\text{–}10^5$ based on the root chord). Each configuration was tested at angles of attack from −20 to 40 deg. Six force and moment components were measured. The force and moment coefficients calculation was based on the projected area of each configuration at zero angle of attack, an area that changes with each flap, and flap deflection.

Test Results

The physical size of the vortex flap does not affect the character of the flap effect. The same basic phenomena are repeated with all the symmetrical flaps of different aspect ratios. It does, however, increasingly affect the magnitude of the flap influence on the lift curve slope, the drag coefficient, and the aerodynamic efficiency, as the flaps grow larger.

The lift variation with angle of attack is shown in Fig. 2 for the largest symmetrtical flap (aspect ratio 2.1 is representative of the other two). Flap deflections of up to 45 deg have almost no effect on the lift curve slope. Flap deflections of 60 and 70 deg reduce this slope, the reduction is more evident with the smaller flap.

Flap deflection increases the zero lift angle α_{0L}. This increase becomes larger with growing deflection angles and the size of the flap. Maximal α_{0L} for the largest flap deflected 70 deg is approximately 6 deg. The larger α_{0L} reduces the lift coefficient at each angle of attack. However, as the flap deflection postpones the stall angle, the maximal lift coefficient $C_{L_{\max}}$ can be increased on some configurations. This increase was of the order of 10% ($\Delta C_{L_{\max}} \approx 0.15$). On some configurations the stall angle was postponed beyond 45-deg angle of attack.

Figure 3 is representative of the drag variations with the three symmetrical flaps. It shows a substantial reduction in the drag at angles of attack larger than 8 deg, with all the flaps. This reduction increases consistently with increasing deflection angle, except at 70 deg. Explanation of this phenomenon by the reduction of the effective angle of attack is supported by the drag polars (C_L vs C_D). The large differences between the drag coefficients of the different configurations almost vanish when the angle of attack is no longer a param-

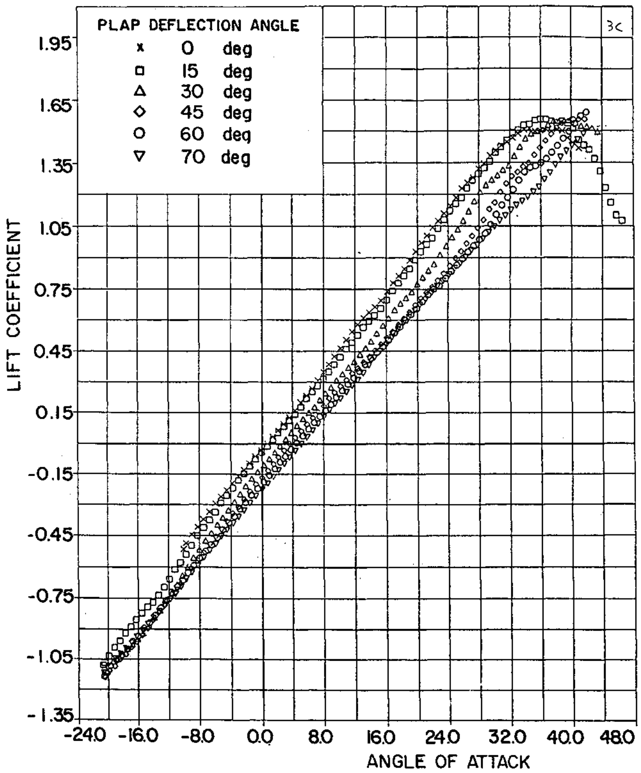

Fig. 2 Lift variation vs angle of attack, flap "d," AR = 2.1, deflections 0 ÷ 70 deg.

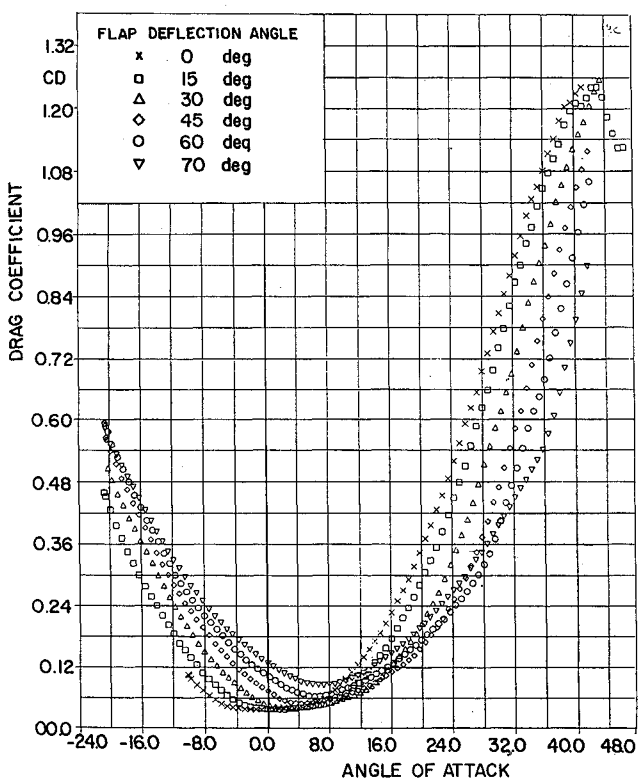

Fig. 3 Drag variation vs angle of attack, flap "d," AR = 2.1, deflections 0 ÷ 70 deg.

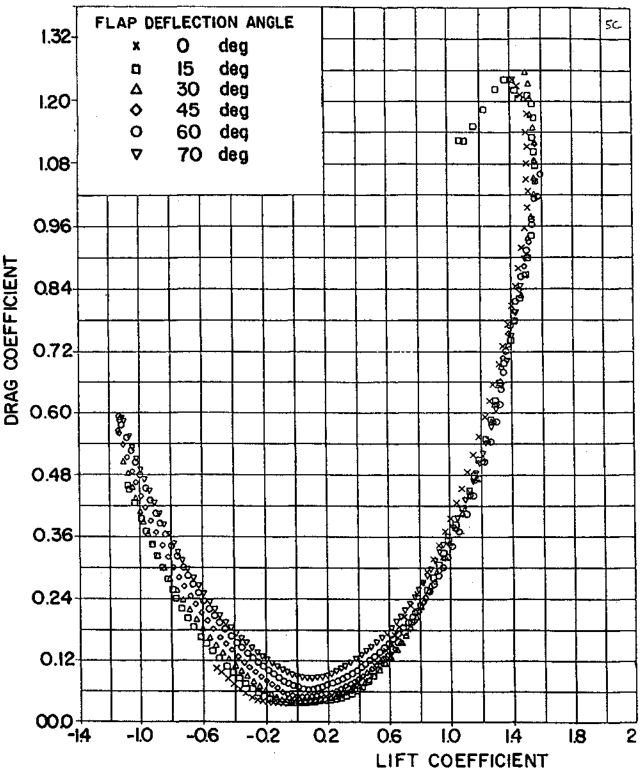

Fig. 4 Drag polar (C_D vs C_L) flap "d," AR = 2.1, deflections 0 ÷ 70 deg.

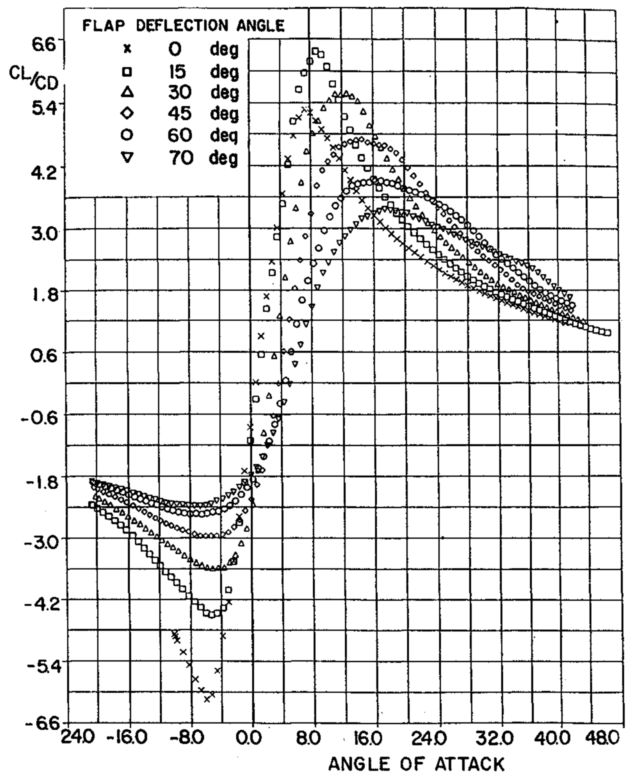

Fig. 5 Aerodynamic efficiency (C_D/C_L) vs angle of attack, flap "d," AR = 2.1, deflections 0 ÷ 70 deg.

eter (Fig. 4). However, there still remains a difference between the performances of the wings with positive lift and those with negative lift that will be discussed later.

The aerodynamic efficiency of the vortex flaps is demonstrated by the plot of C_L/C_D vs the angle of attack (Fig. 5). Up to angles of attack of approximately 8 deg, the flat wings produce the highest efficiency. However, at larger angles of attack a local maximum efficiency can be correlated with a given specific deflection angle. As the angles of attack increase, larger deflection angles are required to achieve this maximum.

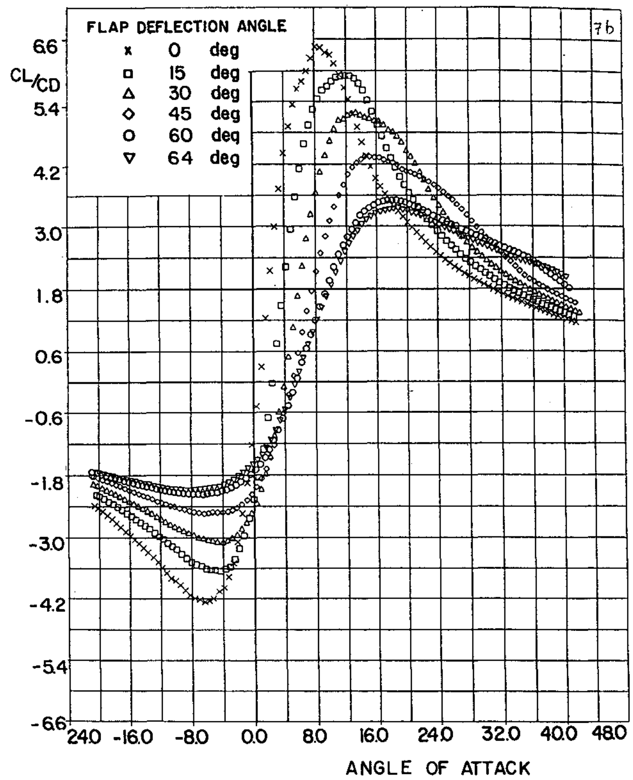

Fig. 6 Aerodynamic efficiency, asymmetric leading edge.

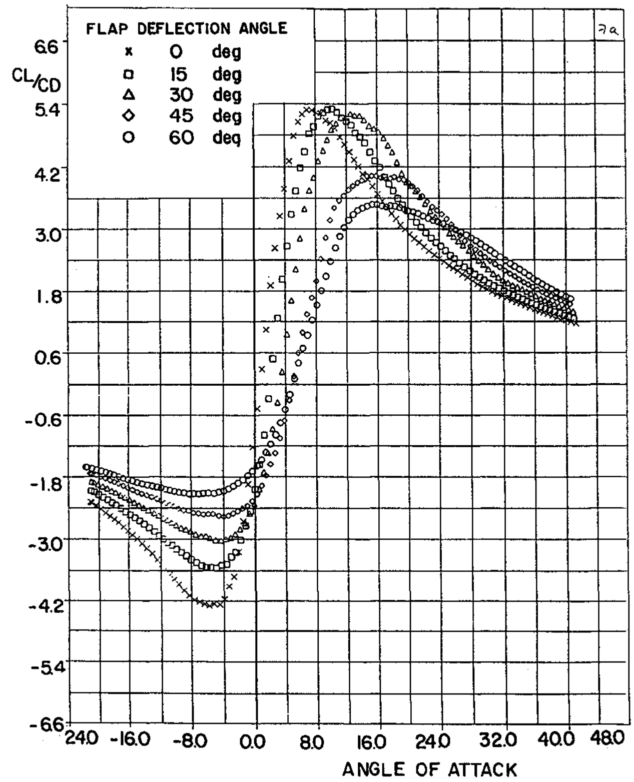

Fig. 7 Aerodynamic efficiency, concave leading edge.

The effect of the leading-edge shape was investigated with two large flaps, one asymmetric and one with a concave bottom. Generally speaking, the leading-edge shape had little or no effect on the performance of the flap. However, it did affect the characteristics of the various wings at vanishing or small flap deflection angles. The asymmetric leading edge had a lower aerodynamic efficiency (Fig. 6) than the symmetric one (Fig. 5), whereas the concave leading edge increased the aerodynamic efficiency at positive angles of attack (Fig. 7).

The difference between the aerodynamic characteristics of the flapped wings at negative and positive angles of attack, as mentioned before, and Rao's suggestion that leeward deflections could improve the wing performance, led to the investigation of the inverted flapped wing, because the flap hinges were not designed for large upward, or leeward, deflections. Although the wing was not designed to operate in an upside-down position, it was assumed, that as the leading-edge shape affect was small, the trends of leeward-deflection effects could be at least qualitatively evaluated. Generally speaking, the results of the leeward flap deflection were antisymmetrical to those of the downward deflection that were described above. α_{0L} became negative which caused the lift at positive angles of attack to increase. The drag increased significantly with all the flaps at angles of attack above 4 deg. The maximum aerodynamic efficiency was obtained when the flaps were not deflected. The aerodynamic efficiency of the configurations with windward deflections was higher than those with the leeward flap deflections. However, this result must be qualified because the generic wing is asymmetrical, and has different efficiencies at negative and positive angles of attack.

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Study of Dynamic Stall Using Real-Time Interferometry

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Introduction

CONTROL and utilization, or alleviation, of the dynamic-stall-induced aerodynamic loads which appear on helicopter rotor blades, and on rapidly moving conventional aircraft wings or control surfaces, will require a much greater understanding of the character of the unsteady flowfield that occurs on these aerodynamic surfaces than is currently available. The complexity and rapidity of the flow development during dynamic stall as well as the large pressure gradients that form near the leading edge make quantitative measurement very challenging and difficult; the need for a clearer understanding of the effect of compressibility on the dynamic stall process further complicates this difficult task. However, traditional experimental techniques for analyzing aerodynamic flows are limited at compressible flow speeds; experimental data at these conditions on dynamically stalling airfoils has usually been restricted to surface measurements of pressure and skin friction. Interferograms showing the flow away from the surface of rapidly pitching airfoils have been obtained using holographic techniques.[1] However, the post-

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