Effect of Upper-Surface Blowing on Static Longitudinal Stability of a Swept Wing

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A low-speed wind-tunnel investigation was conducted on a sharp-edged 75° delta wing, to determine the effect of upper-surface blowing on static longitudinal stability characteristics. The model incorporated nozzles, located at 0.50$\bar{c}$, supplied by compressed air to provide blowing on the upper surface. A full span trailing-edge flap was also tested as an additional high-lift device. The angle of attack was varied from 0° to 24° for a range of thrust coefficients from 0 to 0.45. The results of the static force tests showed that favorable increments in static longitudinal stability and lift were obtained using upper-surface blowing.

Nomenclature‡

$\bar{c}$ = mean aerodynamic chord
C_L = lift coefficient, $F_L/q_\infty S$
Cm = pitching moment coefficient, $M_Y/q_\infty S\bar{c}$
Cm_α = $\partial Cm/\partial\alpha$, per deg
C_T = thrust coefficient, $F_T/q_\infty S$
F_L = lift force
F_T = thrust force
M_Y = pitching moment
q_∞ = freestream dynamic pressure
S = wing area
α = angle of attack, deg
δ_f = trailing-edge flap deflection, positive trailing-edge down, deg
δ_j = trailing-edge jet deflection, assumed equal to δ_f

Introduction

MANY current supersonic cruise concepts utilize a highly swept, sharp-edged delta wing. This configuration has been found to exhibit good aerodynamic performance at supersonic speeds as reported in Ref. 1. However the results presented in Ref. 2 show that at low speeds, corresponding to the takeoff and landing phases of flight, the configuration experiences static longitudinal instability, or pitch up, at relatively low angles of attack.

Considerable effort has therefore been directed towards obtaining satisfactory low-speed longitudinal characteristics through control system design,[3] and by geometric modifications.[4] The results of reference 4 indicate that the use of leading-edge flaps and wing notches, which effectively postpone the leading-edge vortex formation, can produce an increase in static longitudinal stability. However, use of these modifications were found to reduce the lift-curve slope.

The present investigation was conducted to determine whether upper-surface blowing could improve the static longitudinal stability, with additional improvements in lift characteristics, of a 75° delta wing having a moment reference center located at 0.45$\bar{c}$. The wing sweep and moment reference center were selected in order to simulate the wing planform and c.g. location of the models used in Refs. 1, 2, and 4.

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‡ The data presented herein are referred to the wind axis system. All moments are presented about a reference center located at 0.45$\bar{c}$ as shown in Fig. 1.

Model and Apparatus

A sketch of the wing and trailing edge flap used in the investigation is shown in Fig. 1. The wing was a 75° delta wing, which was constructed from 12.7-mm plywood, and beveled to 45° to obtain sharp leading edges. The model incorporated nozzles, located at 0.50$\bar{c}$, supplied by compressed air to provide blowing on the upper surface. The nozzles were constructed from 19-mm copper tubing and flattened to obtain an aspect ratio of 5. The ratio of nozzle width to wing span was 0.07. The full span flap was constructed of 1.6-mm sheet metal.

The investigation was conducted in a low-speed wind tunnel with a 3.66-m octagonal test section at the Langley Research Center. The wing was sting mounted and data were measured with a conventional strain-gage balance.

Tests

Static force tests were conducted in the low-speed wind tunnel at a Reynolds number of 0.7 × 10^6 based on the mean aerodynamic chord of the wing. During the tests measurements were made of the longitudinal force and moment components acting at 0.45$\bar{c}$.

Tests were conducted for several nozzle locations without the trailing-edge flap, and for a trailing-edge flap deflection of +40°. In all tests the angle of attack was varied from 0° to 24° for a range of thrust coefficients from 0 to 0.45. The thrust coefficients were determined by measuring the axial force coefficient, obtained when compressed air was supplied to the nozzles, with the wind off.

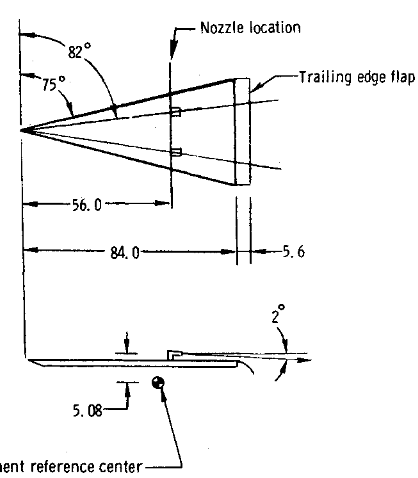


Fig. 1 Sketch of delta wing, nozzle, and flap. Dimensions are given in centimeters.

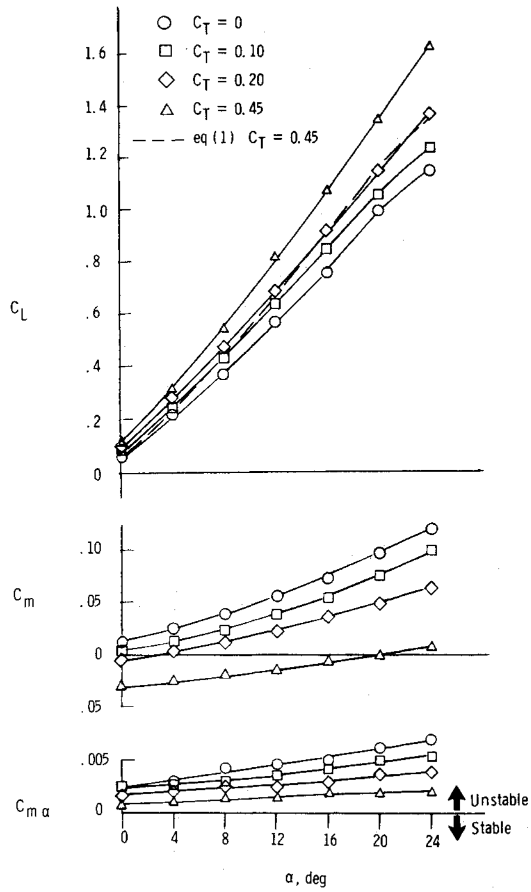
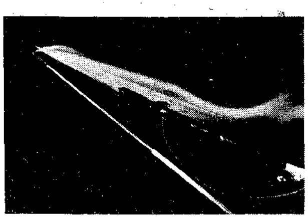


Fig. 2 Effect of upper surface blowing (δ_f = 0).

a) No thrust applied.



b) Thrust applied at 0.50 $\bar{c}$.

Fig. 3 Smoke flow visualization (α = 12°).

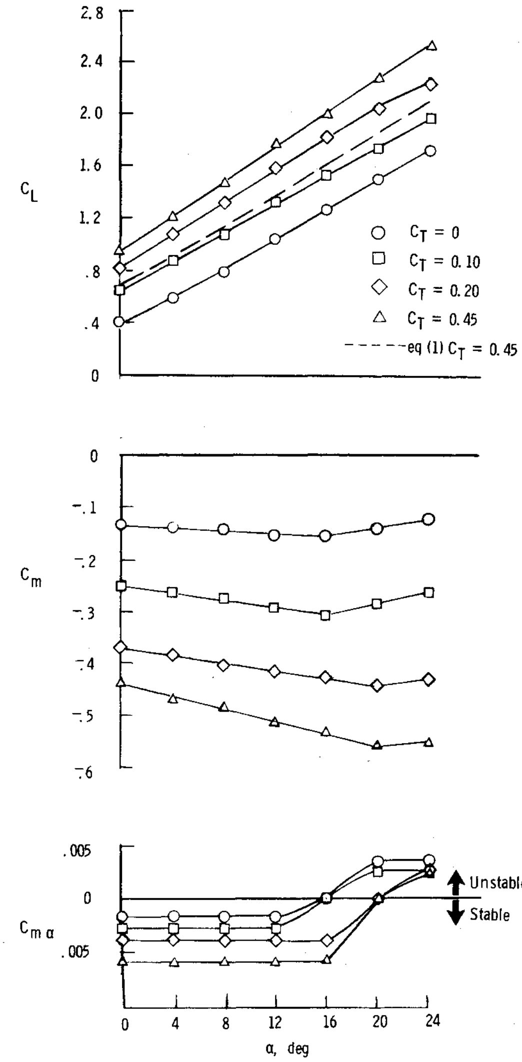


Fig. 4 Effect of upper surface blowing (δf = 40°).

Results and Discussion

The span wise nozzle location was selected in order to position the nozzles below the vortex core as determined from preliminary smoke-flow visualization studies. A brief investigation was conducted in order to select the most effective chordwise nozzle position. Based on pitching moment considerations a chordwise location corresponding to 0.50$\bar{c}$ was selected and the results presented herein.

The longitudinal data for the wing without the trailing edge flap are presented in Fig. 2. These data show that the slope of the lift curve increased with increasing thrust. Values of the lift coefficient calculated from the equation

$$C_L = C_L\big|_{C_T=0} + C_T \sin(\alpha + \delta j) \qquad (1)$$

are included for comparison and are shown to underpredict the experimentally obtained values of the lift coefficient. The nonzero values of lift at zero angle of attack are attributal to the wing support located on the lower surface (see Fig. 3). The negative displacement of the pitching moment coefficient, with increased thrust is due to the nozzles being located above the balance center.

The most remarkable effect of increased thrust was on Cm_α. While Cm_α was unstable over the angle of attack and thrust range tested, it should be noted that as the thrust was increased the level of the instability was decreased.

Although the present c.g. location is indicated in Ref. 1 to yield suitable levels of stability in the supersonic regime, the forward shift of the aerodynamic center at subsonic speeds apparently resulted in the c.g. (moment reference center) being located behind the aerodynamic center of the wing in the present low-speed investigation.

Smoke flow visualization tests shown in Fig. 3, show that when thrust is applied a downward deflection of the vortex cores occurs in the region behind the nozzles. Thus it would appear that the upper surface blowing created a low pressure region over the aft wing surface; which in turn would enhance the vortex lift (due to the close proximity of the vortex cores to the wing surface) on the aft portion of the wing. This would then account for the increased lifting properties and effective reward shift in the aerodynamic center, causing a stabilizing increment to Cm_α.

Effect of Trailing-Edge Flap Deflection

The longitudinal data for the wing with a trailing-edge flap deflection, $\delta_f = +40°$, are shown in Fig. 4. These data indicate that the lift was greatly increased by the effect of increased thrust. Calculated values of the lift coefficient are included for comparison and as in the previous case are seen to underpredict the experimentally determined values of lift. Examination of the pitching moment coefficient indicates large negative, or nose down, effects due to increased thrust. The magnitude of the nose-down moments are several times larger than those attributed to the location of the nozzle relative to the moment center. This indicates that the trailing-edge flap is extremely effective in turning the flow.

The curve of Cm_α vs α shows that a beneficial increment in static longitudinal stability was produced by upper surface blowing, and that the magnitude of the effects were somewhat enhanced by the flap deflection. These data show that a configuration which is initially longitudinally stable, benefits through the use of upper surface blowing by an increased level of static longitudinal stability, and also by an increase in angle of attack at which the instability, or pitchup occurs.

Conclusion

A low-speed wind-tunnel investigation was conducted on a sharp-edged 75° delta wing, utilizing the upper-surface blowing concept. The results show that upper surface blowing is effective in producing high values of lift and favorable increments in static longitudinal stability. Although large values of thrust were required in the present investigation, reduced thrust levels may be useful in conjunction with the methods applied in Ref. 4 for the complete aircraft configuration.

References

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