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AND USABLE-LIFT IMPROVEMENT OF A CRANKED WING

Dhanvada M. Rao

VIGYAN RESEARCH ASSOCIATES, INC.
Hampton, Virginia

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Hampton, Virginia 23665

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Dhanvada M. Rao

Vigyan Research Associates, Inc.

Hampton, Virginia 23666-1325

Abstract

An exploratory low-speed investigation of a 70 deg./46 deg. cranked-wing planform was undertaken to evaluate two vortex-control concepts aimed at alleviating a severe pitch up which limits the usable lift well below the $C_{L,max}$ of the basic wing. One concept was a strake-like extension introduced across the wing crank, whose vortex helps to stabilize the outer-wing flow and alleviate tip stall. The other was a lower-surface cavity flap employed to trap a vortex just beneath the inboard leading edge, resulting in reduced vortex lift over the inner-wing panel, i.e., forward of the moment center. Each of these concepts was shown to eliminate the high-alpha pitch up, potentially raising the maximum usable lift of the cranked wing practically to its $C_{L,max}$ value.

Nomenclature

b	Span
C_F	Flap chord perpendicular to hinge line
C_D	Drag coefficient (Drag/q.s)
C_L	Lift coefficient (Lift/q.s)
C_m	Pitching moment coefficient (Moment/q.s$\bar{c}$)
$\bar{c}$	Mean aerodynamic chord
d	Hinge line distance perpendicular to leading edge
q	Dynamic pressure
S	Reference area (= 4.90 ft^2)
α	Angle of attack
δ_F	Flap angle (perpendicular to hinge line)

Introduction

The low-speed aerodynamics of a cranked wing planform typical of highly-maneuverable supersonic fighters have been under experimental study, mainly to explore the prospects of controlling the vortex-dominated flows resulting from swept leading-edge separations. A previous report (ref. 1) described preliminary studies undertaken on a 70 deg./50 deg. cranked wing to characterize its flow development with increasing angle of attack, and also to evaluate vortex control concepts aimed at extending the usable lift range by alleviating pitch up or postponing it to a higher angle of attack. On the basis of limited pressure and flow visualization results discussed in reference 1, two leading edge devices, viz., 'folding strake' and 'cavity flaps', showed promise for improving the longitudinal characteristics. These devices were subjected to force and moment evaluation in the NASA Langley 12-ft Low Speed Tunnel on a 70 deg./46 deg. cranked wing/body model. This report presents selected results aimed at evaluating the devices in alleviating the cranked wing pitch up, in order to improve the usable lift for enhanced maneuverability and short-field landing capability. A parallel test of a 60 deg. swept wing with cavity flaps was also performed under this contract and selected results are reported in reference 2.

Model and Experimental Details

The geometry and main dimensions of the wing/body model, containing a 6-component strain gage balance, are shown in fig. 1. Details of the cranked wing, which was a flat plate with symmetrically-beveled sharp leading and trailing edges, are presented in fig. 2. The shapes and areas of the strakes, cut from thin aluminum sheet, are indicated in fig. 3. The aluminum-sheet cavity flaps, bent to desired angle δ_F, are shown in fig. 4.

The tests were performed in the NASA Langley 12-ft Low Speed Tunnel at a free-stream velocity of 70 feet per second, giving a mean-chord Reynolds number of 0.92×10^6.

Results and Discussion

Basic Wing Characteristics:

The lift and pitching-moment coefficients of the basic model as a function of angle of attack are shown in fig. 5. The lift curve exhibits two distinct breaks 'A' and 'B' before attaining $C_{L,max}$, indicative of abrupt changes in the wing flow development with increasing angle of attack. Corresponding breaks occur in the pitching moment, both in the form of 'pitch up', i.e., a relatively rapid change of the pitch-curve slope in the unstable sense. The pitch break at 'A' apparently results as the vortex lift growth on the more highly swept inner panels overtakes the rate of lift increase over the outer panels, but without appreciably altering the overall C_L curve. The event at 'B' however involves a total breakdown of flow on the outer panels producing a severe pitch up; the overall lift drops noticeably before the growing vortex lift on the inner panels restores the upward slope of the overall lift curve. The $C_{L,max}$ is reached as a result of forward movement of vortex breakdown on the wing which once again produces a nose-up pitch trend. These aerodynamic characteristics and the underlying flow mechanisms of the basic wing were studied and documented in an earlier report (ref. 1).

Even though the instability onset at 'A' could conceivably be overcome with adequate pitch authority under active control, the abruptness as well as the magnitude of nose-up moment encountered at 'B' is likely to limit the usable lift coefficient considerably short of $C_{L,max}$ on this wing. It was the specific objective of the present investigation to explore aerodynamic means of alleviating (or postponing) this terminal pitch-up and thereby raise the usable C_L closer to $C_{L,max}$.

Folding Strake:

A vortex-generating strake positioned across the crank (fig. 6) was intended to improve the tip stall, just as the wing root strakes (e.g. F-16, F-18) whose vortices help to stabilize the separated flow on a trapezoidal wing and improve its maximum lift capability. Oil flow visualizations and upper-surface pressure results presented ref. 1 indicated favorable trends with the use of the strake. The typical effect of strake addition on the lift and pitching-moment characteristics (fig. 7) is that the lift break at 'B' and the associated pitch up are eliminated, which indicates a continuous development of the outer-panel flow to a much higher angle of attack than on the basic wing. Although a reduction in the $C_{L,max}$ is incurred, the usable lift coefficient (i.e. free of pitch up) is raised nearly to 1.0 by the strakes, or an increment of 0.2 over the basic wing.

The effect of a progressive reduction of the strake area, from 8.6 percent to 4.1 percent of the exposed wing area, on the pitching moment versus lift characteristics is shown in fig. 8. These results show the 7.64 percent strake to be close to an optimum size for this wing, producing a relatively flat pitching moment curve at high angles of attack while also causing the least $C_{L,max}$ penalty. Note that in this series, increasing strake area was accompanied by a forward movement of strake apex along the inner leading edge, resulting in a more accentuated instability around $C_L = 0.4$. An optimum sized strake placed somewhat aft of the position used in this test may be preferable.

Since a 'folding' strake concept (the strake being hinged along the inboard leading edge) would permit strake deflection above or below the in-plane position, the effect if any of strake angle on the pitching moment characteristics is of interest. It is seen in fig. 9 that the 40 deg. down strake is essentially as effective in improving the usable C_L as an in-plane strake.

The drag vs. C_L characteristics shown in fig. 10 indicate an 'improvement' that can directly be attributed to the smoothening of lift curve by the strake. There is virtually no penalty in terms of lift-dependent drag up to $C_L = 1.0$. A fixed, in-plane strake suitably blended into the cranked wing profile may therefore be considered as a more practical alternative to the folding strake.

Inboard Cavity Flap:

A second approach explored for pitch-up alleviation was to moderate the inboard leading edge vortex growth with increasing angle of attack in order to avoid the rapid lift-away of the outboard leading edge vortex, which was suggested in reference 1 to be the cause of the abrupt outer-panel stall. The 'cavity flap' proposed for this purpose (fig. 11) attempts to 'trap' a vortex in a spanwise cavity created underneath the leading edge. The induced effect of this vortex assists in turning the external flow around the leading edge, thus curtailing leading edge separation and reducing the vortex strength on the inboard wing panel. It is envisaged that the hinge line may also be translated perpendicular to the leading edge to allow an optimum fraction of the flap chord to project forward of the wing. Both these 'non-extended' and 'extended' versions of cavity flap were included in the present investigation of a preliminary assessment of their pitch-up alleviation capability.

The lift and pitching-moment characteristics of the cranked wing with and without inboard cavity flaps are shown in fig. 12. The 'extended' cavity flap is seen to have smoothed out the break in the lift curve above $\alpha = 10$ deg. and the corresponding pitch up. Contrasting the strake effect (fig. 7), the cavity flap produces a progressive lift reduction at the higher angles of attack, which is in accord with its hypothesized leading-edge vortex reduction capability. The pitching moment data show the 'non-extended' cavity flap to be relatively less effective below $\alpha = 20$ deg., but having a positive influence between $\alpha = 20$ deg. and 35 deg.

The angle-of-attack range of cavity flap effectiveness would be a function of flap deflection angle as well as the degree of forward extension, variables which require more detailed evaluation than was possible in the present investigation. Some data obtained on a 60 deg. swept wing (ref. 2) are of relevance in this context.

Conclusion

Results have been presented of exploratory investigations to validate two vortex-control concepts proposed for alleviating the severe pitch up of a 70/46 deg. cranked wing due to outer panel stall, which limits its usable lift coefficient significantly below $C_{L,max}$. A planar strake placed across the crank, having less than 8 percent of the exposed wing area, strongly influences the longitudinal characteristics and relieves the pitch up; similar result is achieved with a cavity flap deployed underneath the inboard leading edge. Both these vortex control concepts appear capable of extending the maximum usable lift coefficient practically to $C_{L,max}$. Since the two devices are mechanically non-interfering and influence different regions of the wing flow field, their combined application may allow a powerful means of tailoring the cranked-wing pitch characteristics for maximizing its usable lift range. The demonstrated vortex-control capability of the strake and cavity flap also warrants an investigation of their possible benefit to high-alpha lateral/directional stability, which is another well-known area of concern of highly swept wings.

References

1. Rao, Dhanvada, M.: Subsonic Flow Investigations on a Cranked Wing Designed for High Maneuverability. NASA CR 178046, Feb. 1986.

2. Rao, Dhanvada, M.: Towards an Advanced Vortex Flap System - The 'Cavity' Flap. Vortex Flow Aerodynamics Conference, Vol. 1, NASA CP 2416, 1986.

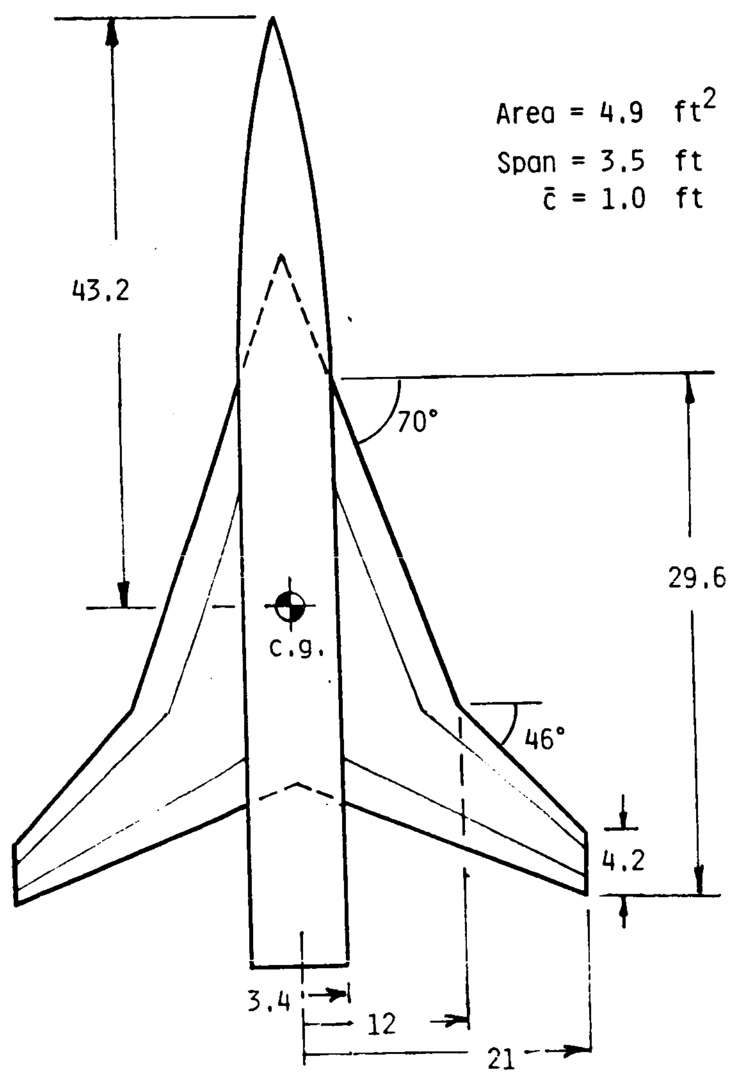

Fig. 1. Plan View of Cranked Wing Model Showing Major Dimensions (in inches).

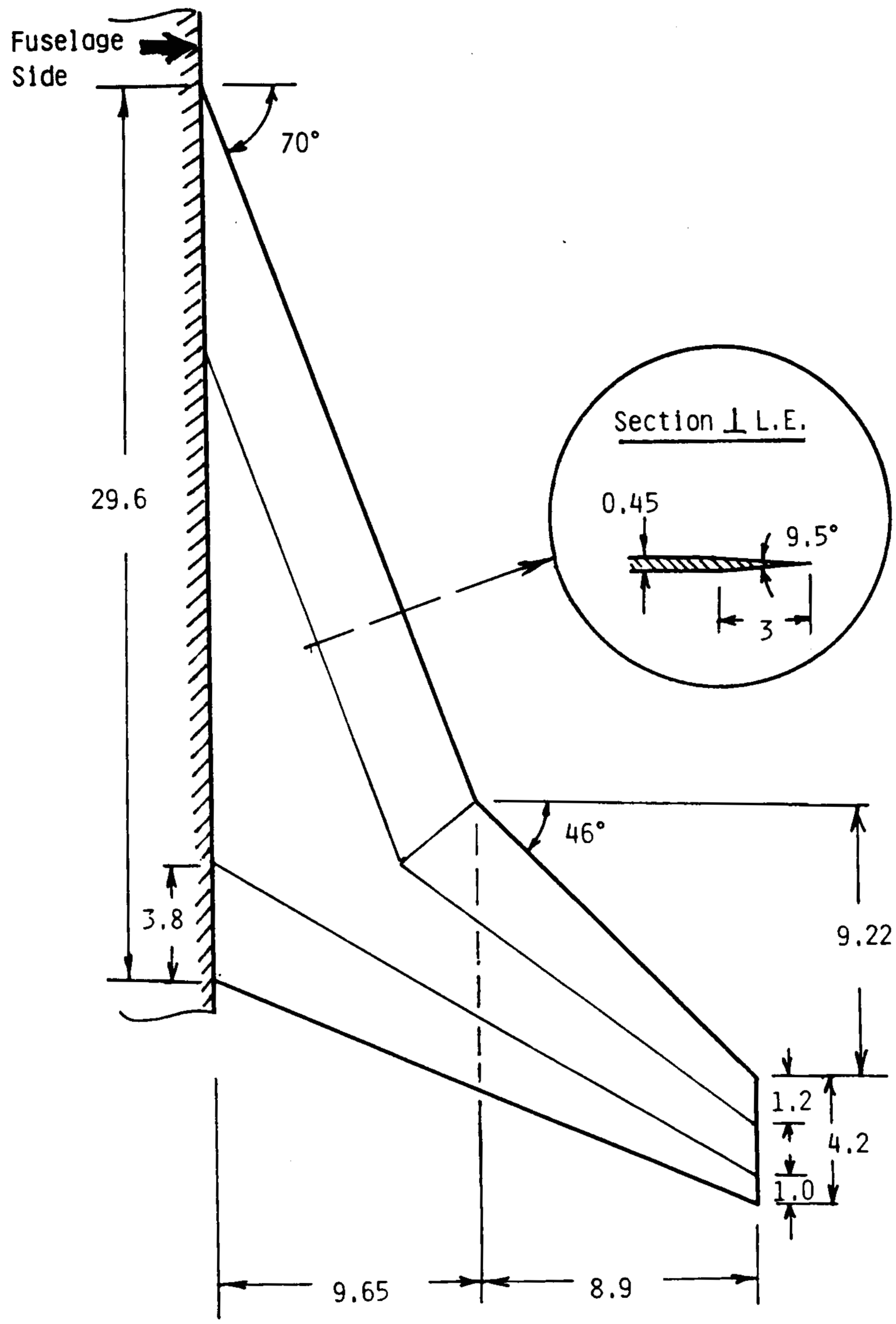

Fig. 2. Cranked Wing Exposed Panel Geometry and Major Dimensions (in inches).

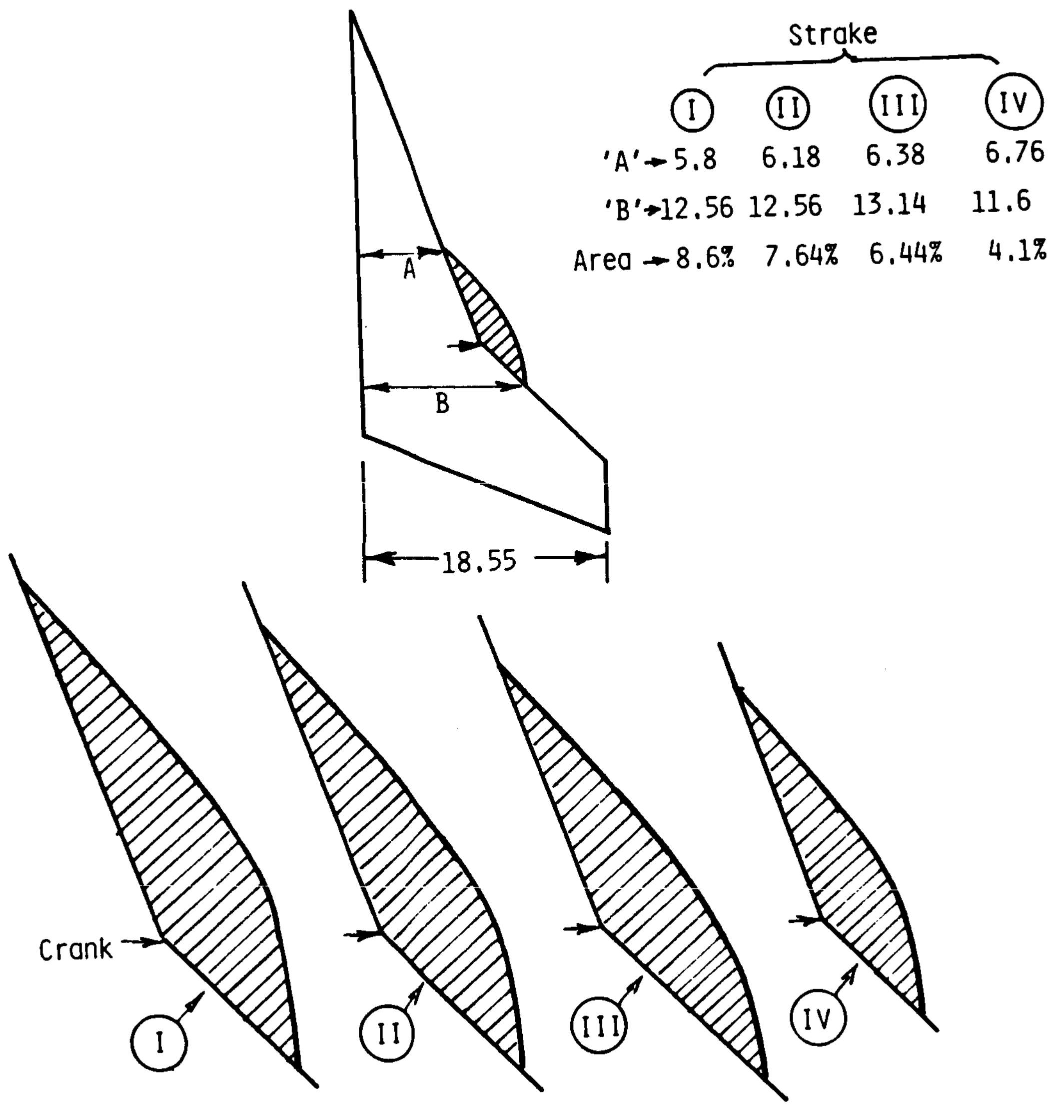

Fig. 3. Geometrical Characteristics of Strakes (Dimensions in Inches).

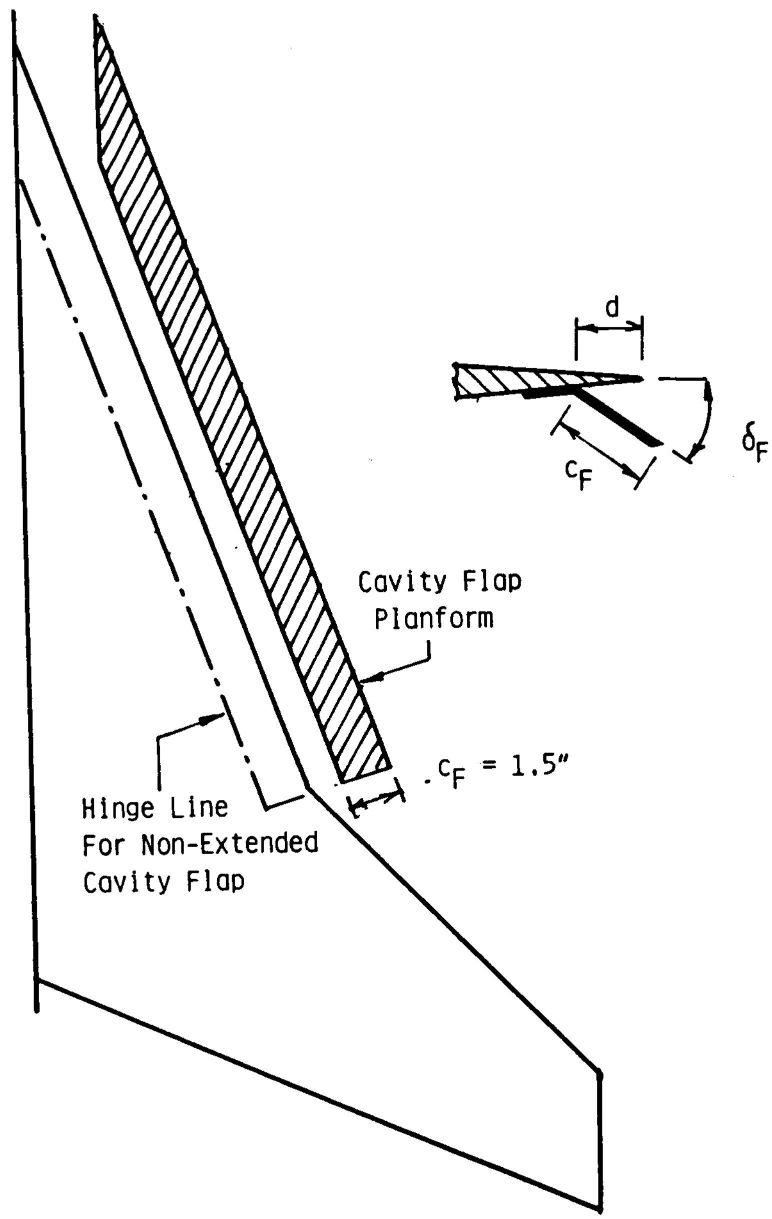

Fig. 4. Geometry of Cavity Flap.

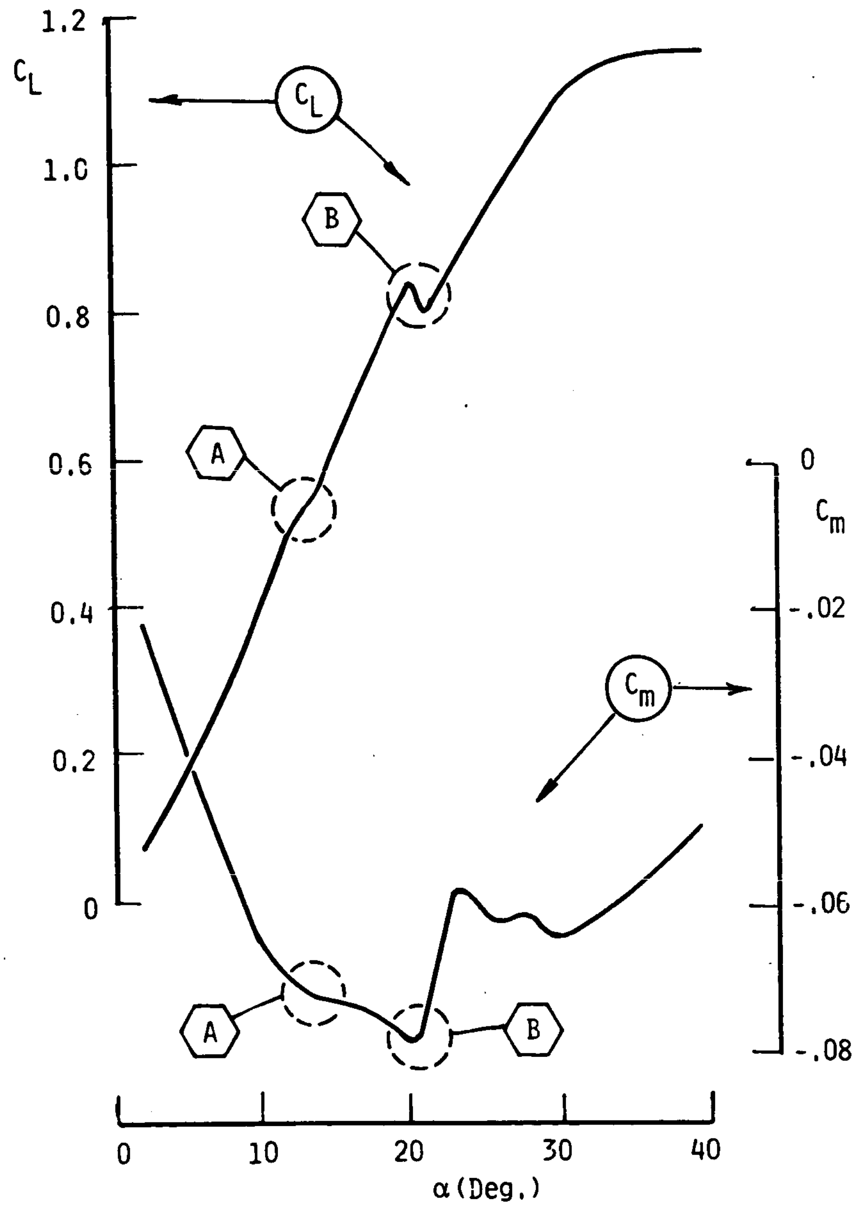

Fig. 5. Lift and Pitching-Moment Characteristics of Basic Model.

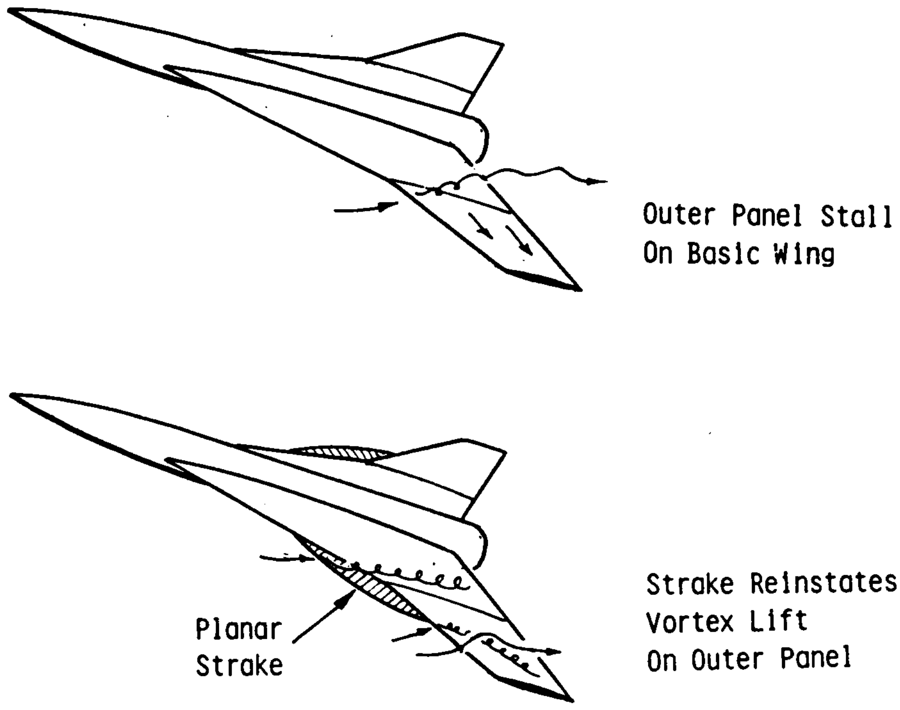

Fig. 6. Cranked Wing Strake Concept.

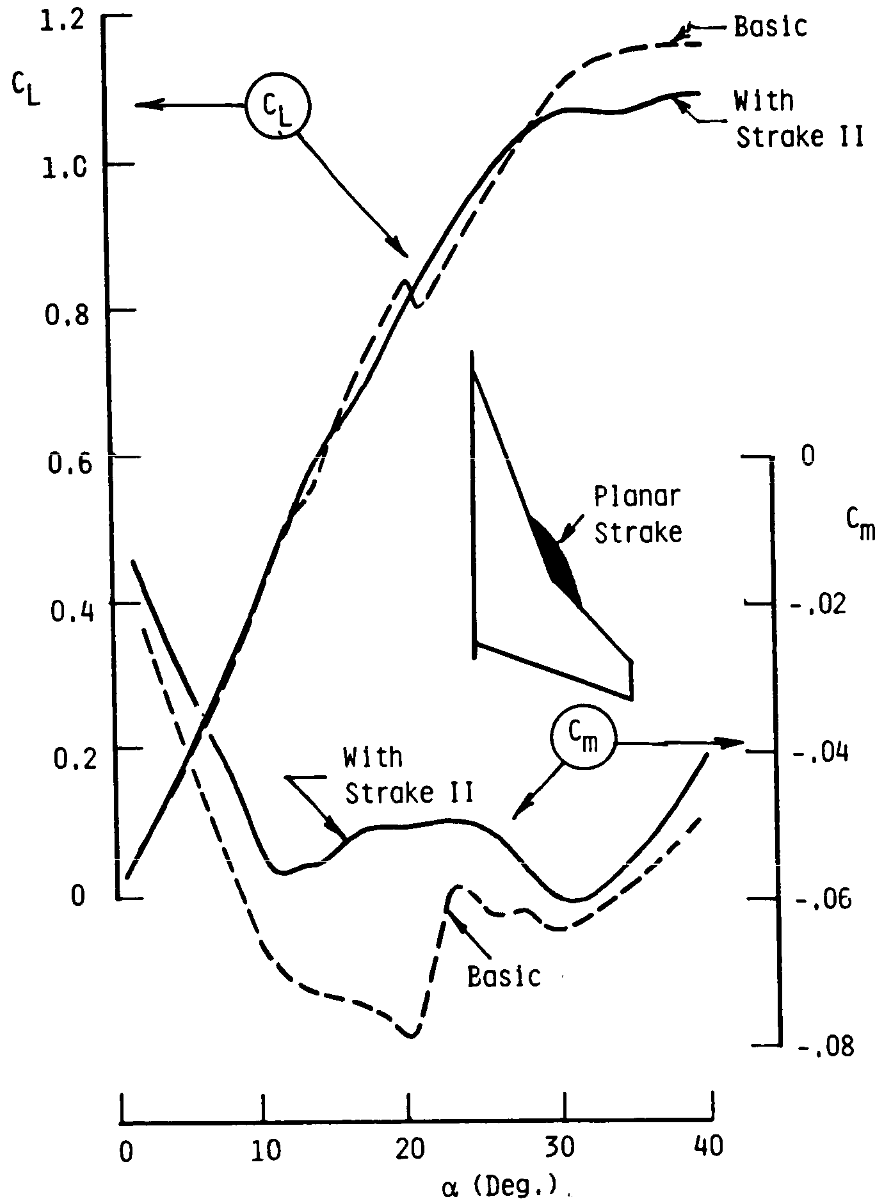

Fig. 7. Typical Strake Effect on Cranked Wing Lift and Pitching Moment Characteristics.

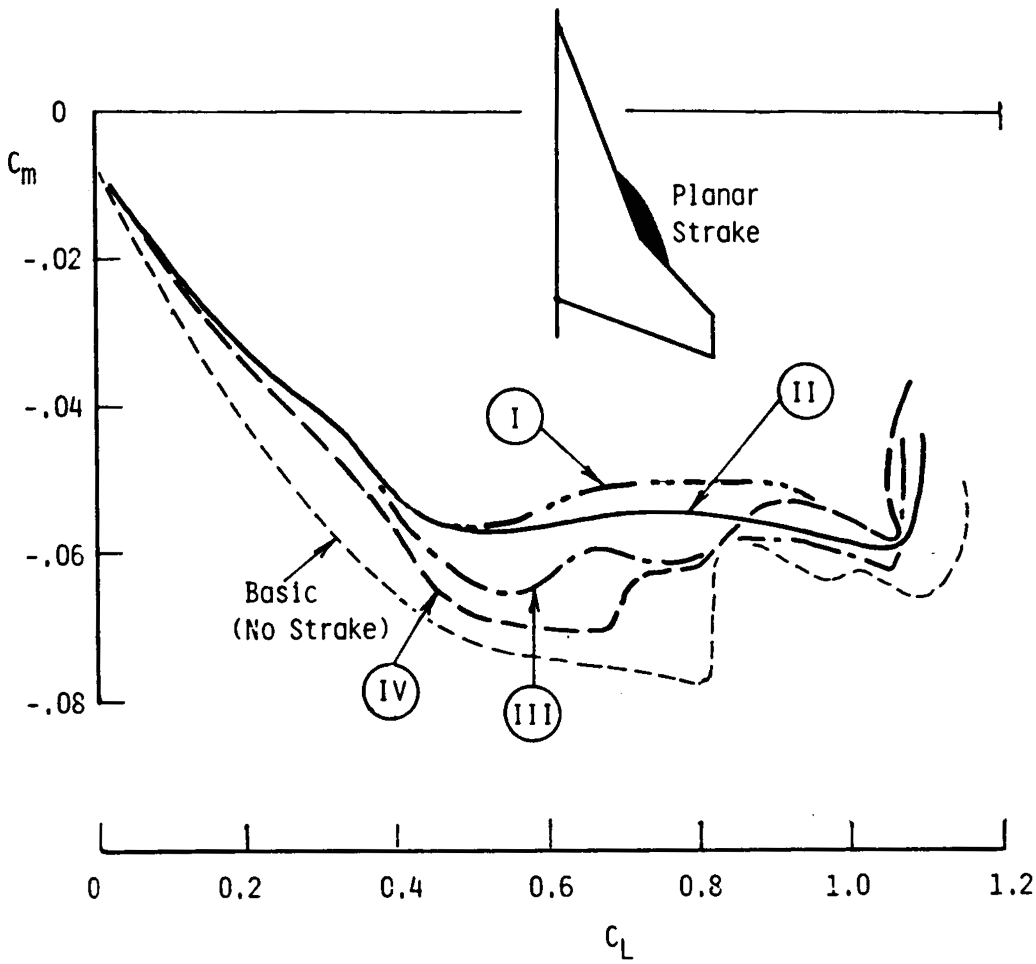

Fig. 8. Effect of Strake Size Variation on Pitching-Moment Characteristics.

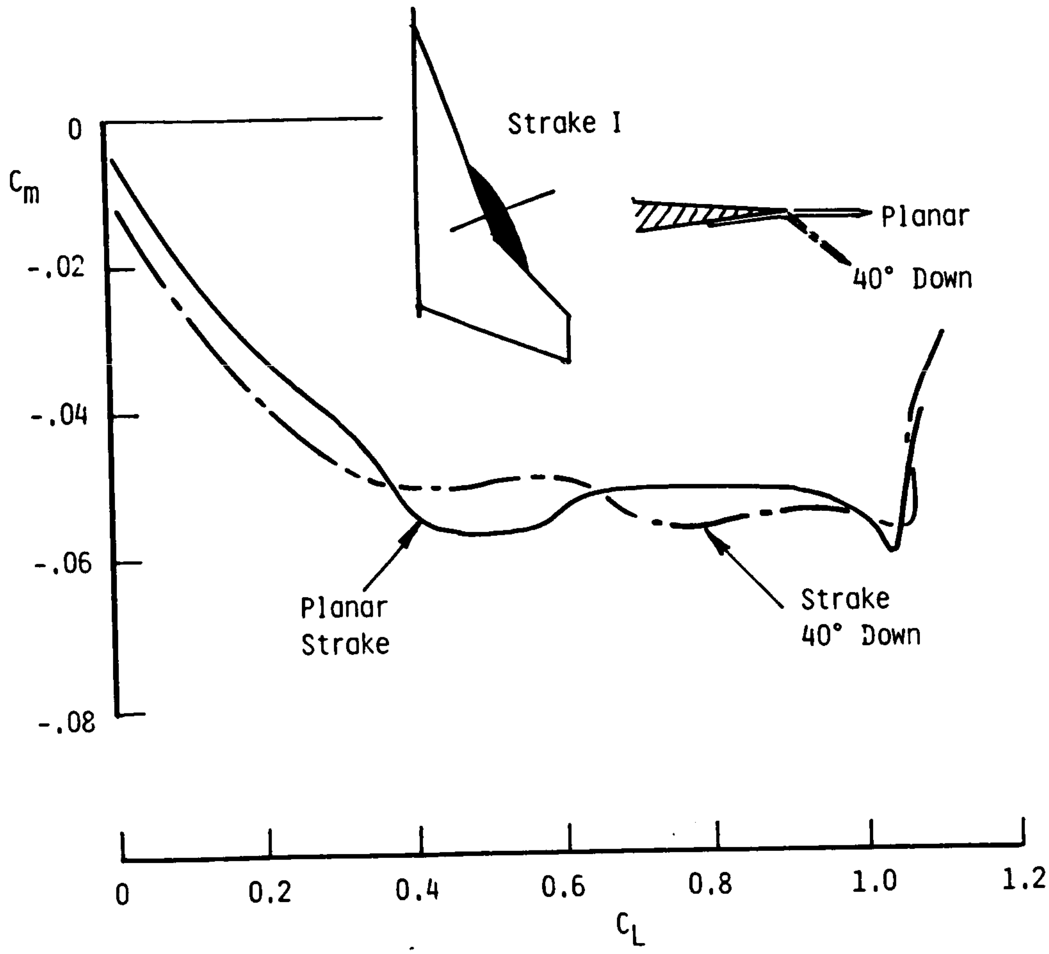

Fig. 9. Effect of Strake Deflection on Pitching-Moment Characteristics.

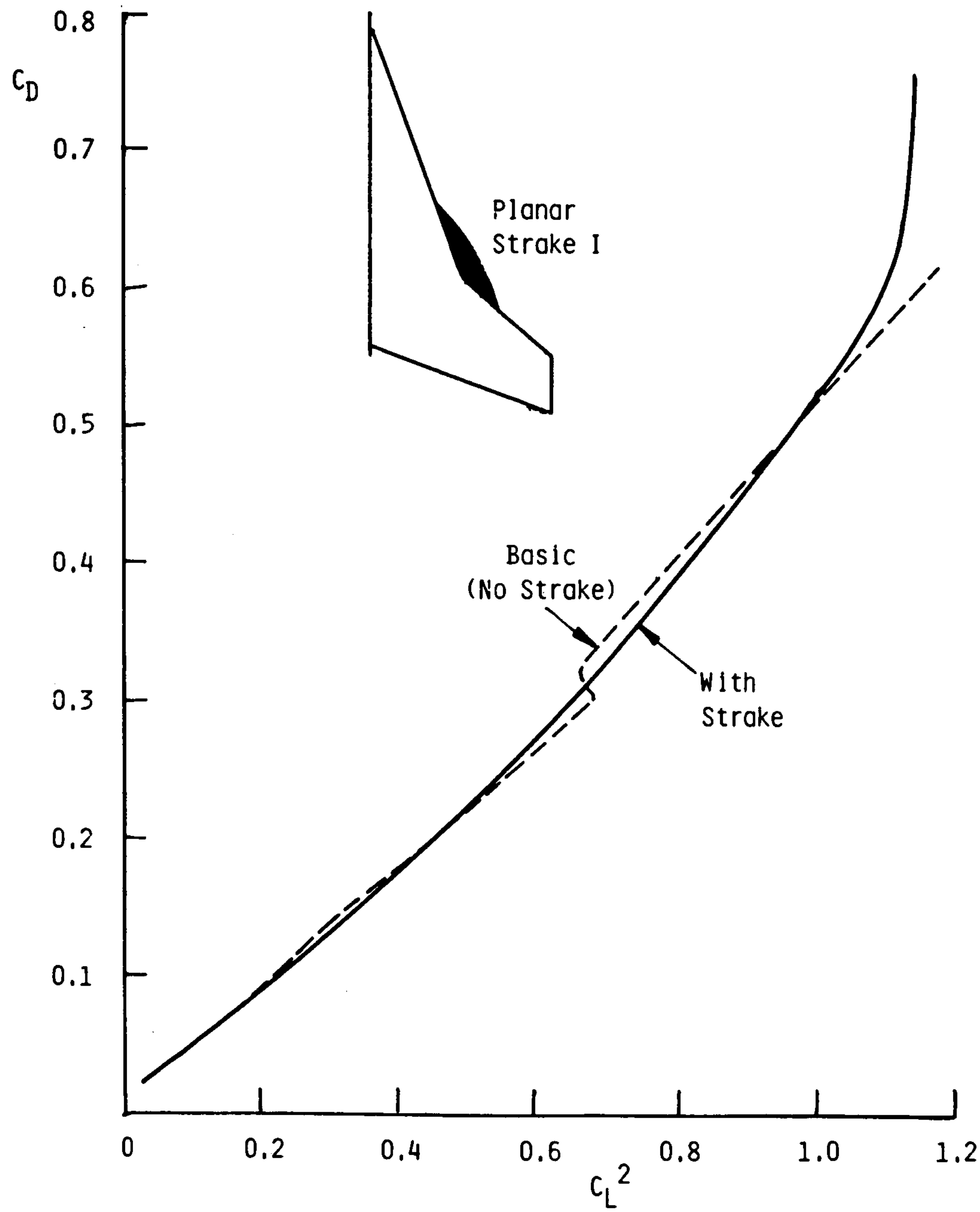

Fig. 10. Typical Strake Effect on Drag Versus Lift Characteristics.

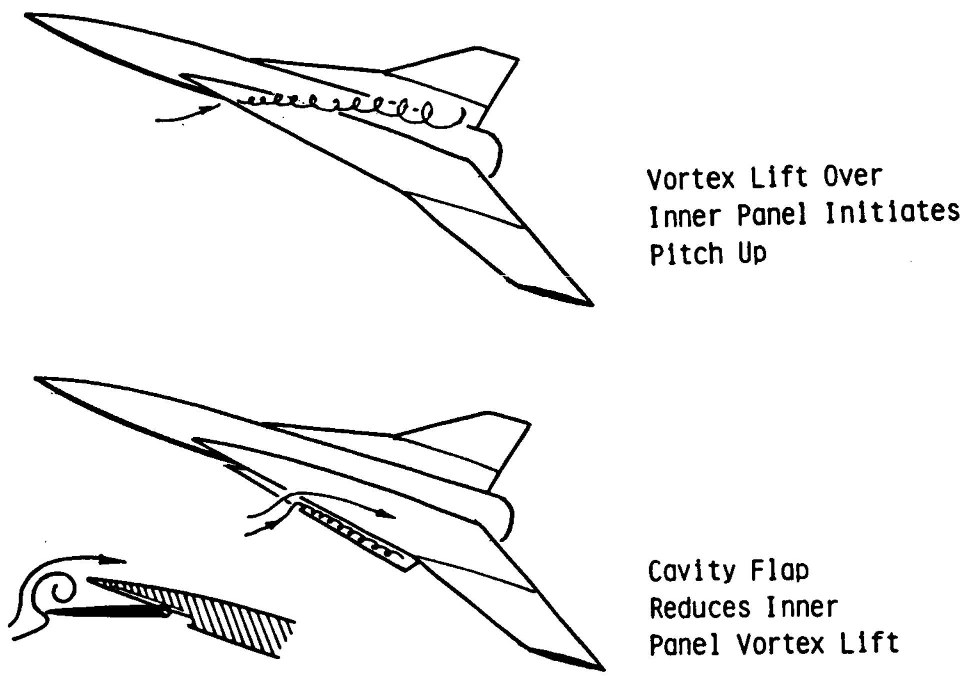

Fig. 11. Cavity Flap Concept Applied to Cranked Wing.

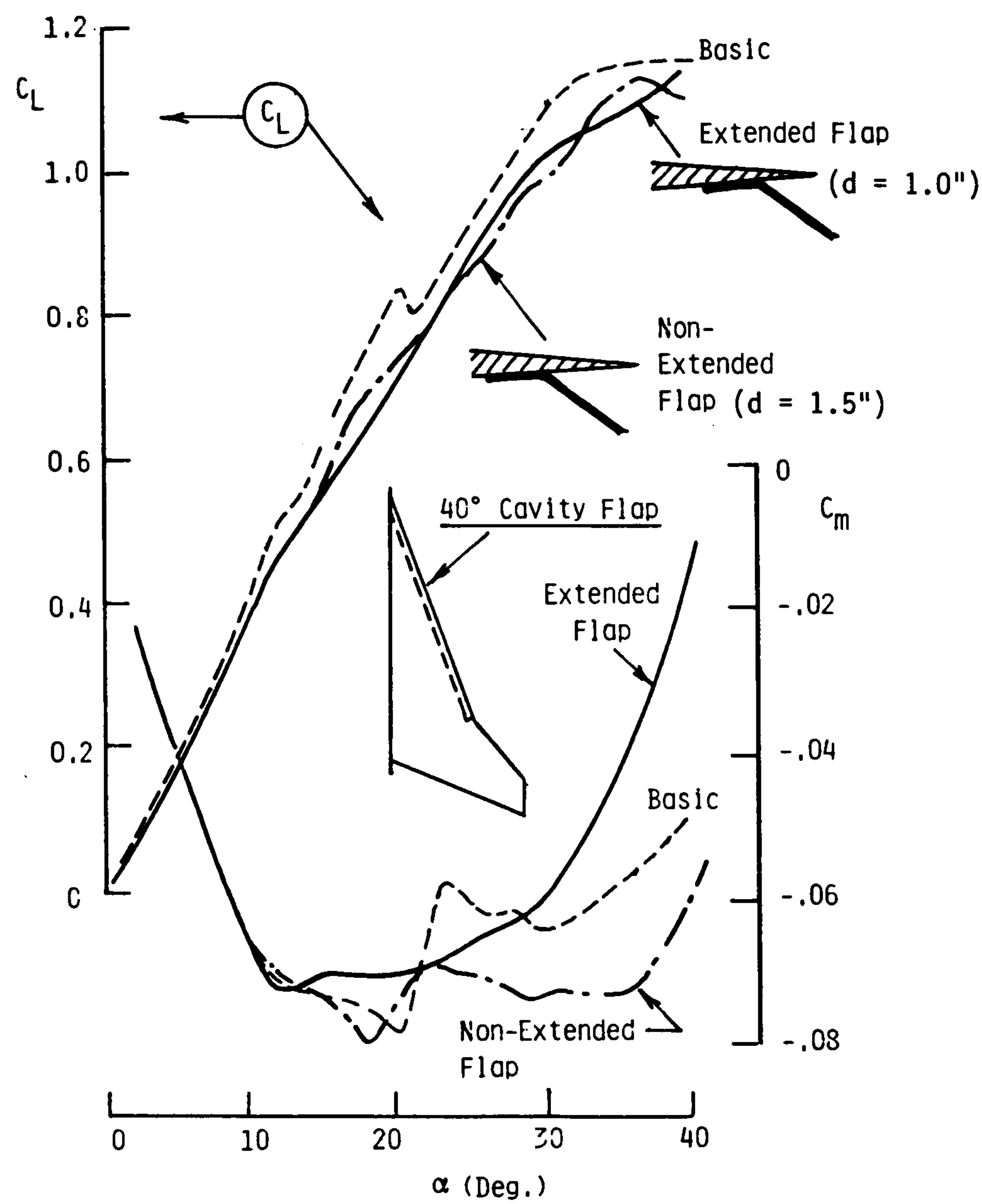

Fig. 12. Typical Cavity Flap Effects on Lift and Pitching-Moment Characteristics.

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15. Supplementary Notes

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