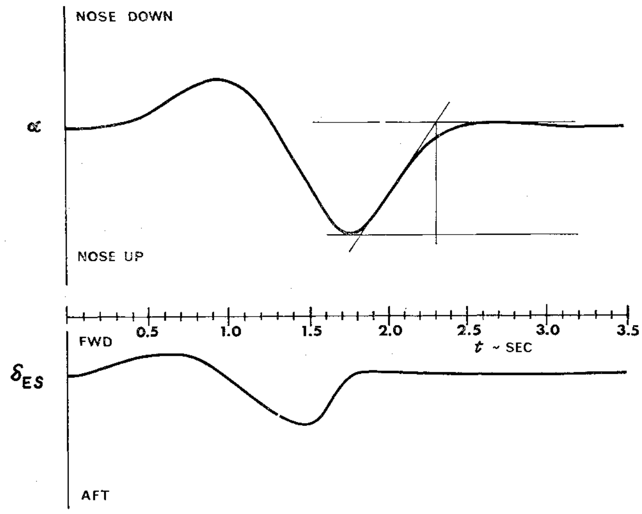

Fig. 3 Angle-of-attack response of the variable-stability T-33 to an elevator-stick doublet.

of higher-order systems when the roots are widely separated in natural frequency. The technique has particular application to identification of an airplane's short-period mode because the steady-state response need not be determined for $\zeta < 1.0$. (The steady-state response of an airplane's short-period oscillation often is masked by the presence of even small amounts of phugoid excitation).

Several other approaches to the problem of measuring airplane short-period dynamics are presented in Ref. 1, along with useful refinements of some rather well known techniques.

Reference

[1] Dolbin, B. H., "Study of some hand-computing techniques to determine the approximate short-period mode from airplane responses," Cornell Aeronautical Lab. FDM 371 (March 1966).

Supersonic and Hypersonic Lift of Highly Swept Wings and Wing-Body Combinations

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Nomenclature

Æ	=	aspect ratio
c	=	wing root chord
c_{dc}	=	cross-flow drag coefficient
C_N	=	normal-force coefficient
$C_{N\alpha}$	=	rate of change of normal-force coefficient with angle of attack
$K_{W(B)}$	=	lift ratio, wing in presence of body
$K_{B(W)}$	=	lift ratio, body in presence of wing
M	=	Mach number
S_{nose}	=	maximum cross-sectional area of body nose
S_{plan}	=	planform area
S_{ref}	=	reference area
S_{wexp}	=	exposed area of wing
t	=	wing thickness at root
α	=	angle of attack
β	=	$(M^2 - 1)^{1/2}$
ϵ	=	wing semi-apex angle
λ	=	wing taper ratio

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VARIOUS inviscid flow methods have been applied to the problem of predicting the nonlinear lift component of highly swept low aspect ratio wings as a function of angle of attack and Mach number. Such methods in their complete form are generally too unwieldy for preliminary design purposes and, when simplified, tend to be unacceptably inaccurate.

The nonlinearity in the lift of low aspect ratio swept wings is due to a characteristic viscous cross flow that is manifested as a strong vortical type of flow separation along the leading edge. This flow separation is not unlike that occurring along an inclined slender body of revolution, and it is this fact that is utilized in the method described in this note.

In Ref. 1, it is shown that the lift on an inclined cylinder due to viscous cross flow can be expressed approximately as

$$C_{N\text{vis}} = c_{dc}\,(S_{\text{plan}}/S_{\text{ref}})\,\sin^2\alpha \tag{1}$$

where c_{dc} is the drag coefficient experienced by a two-dimensional circular cylinder at a Mach number based on the cross component of velocity ($M\,\sin\alpha$). The variation of c_{dc} with cross-flow Mach number is illustrated in Fig. 1.

The total lift for a low aspect ratio wing can then be considered to be the sum of the usual linear nonviscous term and the viscous cross flow term, thus:

$$C_{NT} = (C_{N\alpha})\alpha + c_{dc}\,(S_{\text{plan}}/S_{\text{ref}})\,\sin^2\alpha \tag{2}$$

In the case of symmetrical wing-body combinations it is necessary to introduce the slender-body nose lift term and wing-body interference lift factors of Ref. 2. For a wing-body combination the lift equation becomes

$$C_{NT} = [K_{W(B)} + K_{B(W)}](C_{N\alpha})\alpha\,\frac{S_{\text{wexp}}}{S_{\text{ref}}} + 2\alpha\,\frac{S_{\text{nose}}}{S_{\text{ref}}} + c_{dc}\,\frac{S_{\text{plan}}}{S_{\text{ref}}}\,\sin^2\alpha \tag{3}$$

The planform area in the viscous lift term of Eq. (3) is the combined area of wings and body.

Equations (2) and (3) have been applied to a large number of wing-alone and wing-body configurations, and the results have been compared with wind-tunnel data. Only delta and clipped-delta wings with unswept trailing edges were considered. Although Eqs. (2) and (3) produced the proper trends, it was necessary to further correlate predicted lift values with experimental data in terms of wing semi-apex angle, angle of attack, and Mach number to obtain acceptable accuracy. This correlation is presented in Fig. 2 in the form of a correction factor to be applied to the calculated lift values. The correlating parameter $\beta\,\tan\epsilon$ is the usual supersonic linear theory similarity parameter; however, the other

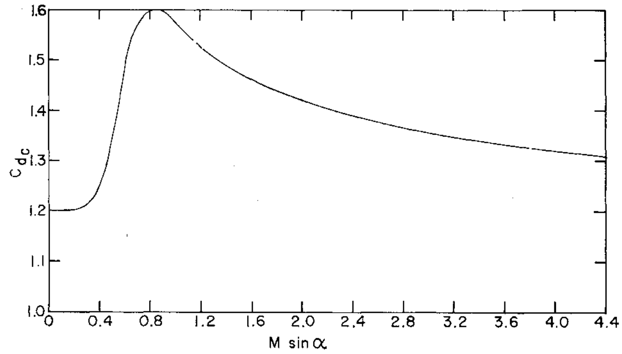

Fig. 1 Circular cylinder drag coefficient for viscous cross-flow calculations.

parameter $\beta \tan\alpha$ was intuitively evolved, and its significance is not fully understood. Evidently, $\beta \tan\alpha$ accounts for the effect of leading-edge shock detachment which occurs at fairly low angles of attack for highly swept wings (low normal Mach number).

The data presented in Fig. 2 were extracted from classified NACA and NASA reports and are therefore not identified. It is left to the reader to perform his own calculations and comparisons with test results to establish confidence in the method. The ranges of variables covered in Fig. 2 are as follows:

$$0.0938 \leq Æ \leq 1.07 \qquad 0° \leq \alpha \leq 40° \qquad 1.2 \leq M \leq 20.3$$

$$0 \leq \lambda \leq 0.24 \qquad 0 \leq t/c \leq 0.05 \qquad 1.34° \leq \epsilon \leq 15°$$

It is significant to note in Fig. 2 that the technique is equally applicable to wing-alone and wing-body combinations over a Mach number range of 1.2 to 20.3. No definite effect of taper ratio or thickness ratio was perceived over the range of values analyzed. Also, the effect of blunt and sharp leading edges was masked in the scatter of the data. For the supersonic-edge condition where wing sweep angle no longer appears in the theoretical equations, its effect is accounted for by $\beta \tan\epsilon$.

Although it has not been possible to rigorously substantiate the use of the viscous cross-flow concept and the associated lift correlation to predict the lift of highly swept wings, the large amount of experimental data that has been successfully analyzed justifies the use of the method in preliminary design parametric studies where it is necessary to rapidly obtain reasonably accurate results for a large number of configurations.

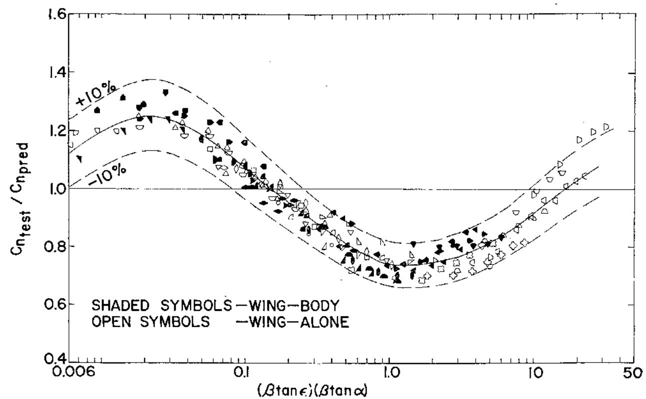

Fig. 2 Lift correlation for low aspect ratio swept wings and wing-body combinations.

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[2] Pitts, W. C., Nielsen, J. N., and Kaattari, G. E., "Lift and center of pressure of wing-body-tail combinations at subsonic, transonic, and supersonic speeds," NACA Ames Aeronautical Lab., Moffett Field, Calif., Rept. 1307 (1959).