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RESEARCH MEMORANDUM

EXAMINATION OF RECENT LATERAL-STABILITY-DERIVATIVE DATA

By Frank S. Malvestuto, Jr., and Richard E. Kuhn

Langley Aeronautical Laboratory
Langley Field, Va.

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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EXAMINATION OF RECENT LATERAL-STABILITY-DERIVATIVE DATA

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INTRODUCTION

In the present paper attention is directed to the aerodynamic parameters, the so-called stability derivatives, that affect the lateral behavior of airplanes and missiles. The discussion is centered on three important quantities C_{l_β}, the effective-dihedral derivative, C_{n_β}, the directional-stability derivative, and C_{l_p}, the damping-in-roll derivative. These quantities are considered for a large angle-of-attack range at subsonic speeds. A few remarks will also be made on the sideslip derivatives at zero lift in the supersonic speed range.

DISCUSSION

For the subsonic speed range, the lateral-stability derivatives have been the subject of intensive research by the Langley high-speed 7- by 10-foot tunnel. Particular attention has been paid to the variation with Mach number in the high angle-of-attack range that is representative of flyable attitudes of many high-speed airplanes. The effective-dihedral and the directional-stability derivatives of the three complete models sketched in figure 1 are presented in figures 2 and 3. Model I is equipped with a 30° sweptback wing of aspect ratio 3; model II has a 45° swept wing of aspect ratio 4; and model III (representing the X-5 airplane) is equipped with a 60° swept wing of aspect ratio 2. To the right of each sketch in figure 1 is a plot of the model lift coefficient against angle of attack for two available Mach numbers indicative of the low and high subsonic speed range.

The effective-dihedral derivative C_{l_β}, expressed here in radians, for the three models is presented in figure 2 for the range of angle of attack and the Mach numbers indicated in figure 1. It is important to note the highly nonlinear variation of this derivative with angle of attack and the pronounced effect of Mach number on these variations. This nonlinear behavior is strongly dependent upon the separation of flow from the wings, particularly in the vicinity of the tips, and

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commences at angles of attack at which these swept wings are by no means completely stalled. Note that model I retains its positive effective dihedral (that is, $-C_{l_\beta}$) through the angle-of-attack range and increasing Mach number tended to increase this quantity at the higher angles. Models II and III have the more typical variation of C_{l_β} with angle of attack and show the decrease to zero and to negative effective dihedral at the higher angles. Configurations having this latter type of variation of C_{l_β} and the derivative C_{n_β}, to be discussed later, could easily be flying at angles at which one or the other of these derivatives becomes zero. These zero values of the derivatives could seriously affect the lateral behavior of airplanes at these higher angles of attack. The point to be observed from the data presented here is that increasing Mach number may change the angle of attack at which these derivatives become zero. As an illustration, the results of model II show that increasing Mach number increases the angle at which C_{l_β} and C_{n_β} become zero; whereas, for model III, the Mach number effect is reversed; that is, increasing Mach number decreases the angle of attack at which zero values occur.

The effects of angle of attack and Mach number on the companion derivative C_{n_β} are shown in figure 3. At the higher angles the variation of this derivative depends not only upon the tail effectiveness, that is, the difference between the tail-on and tail-off results, but also may be greatly influenced by the variation of the wing-body characteristics. As an example, for models I and II the increase in the stability of the wing-body combination at the higher Mach number tends to compensate for the reduction in tail effectiveness shown by the decrease in the increment between the tail-on and tail-off results. For model III, however, although the tail effectiveness remains appreciably constant up to large angles of attack, the decrease in the stability of the wing-body combination causes a reduction in C_{n_β} for the complete model and is the primary cause of this reduction. It is also of interest to point out for this model that the angle of attack at which C_{l_β} and C_{n_β} tend to zero is approximately the same and decreases with increasing Mach number. This similarity of the action of Mach number on C_{l_β} and C_{n_β} is not surprising since for this model the wing-body characteristics, which in the main usually control C_{l_β}, are also the controlling influence for C_{n_β} as was indicated previously. These results emphasize the need for having, through the Mach range, not only proper tail effectiveness, but equally important, proper wing-body design, incorporating satisfactory directional characteristics.

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The effects of horizontal-tail height on the directional-stability derivative C_{n_β} and also on the effective-dihedral derivative C_{l_β} for model I are shown in figures 4 and 5. The curves on the left of each figure represent horizontal-tail-off data; the next set of curves are for the horizontal tail in the low position. This arrangement is the one considered in the previous figures. The data to the right are for the horizontal tail in high position. The expected increase in the directional-stability derivative with the tail in the high position is clearly evident from these results. For the effective-dihedral derivative C_{l_β}, the relocation of the tail from the low to the high position produced again, as expected, an increase in the negative value of the derivative.

There is one additional point related to the sideslip derivatives that deserves consideration. In attempts to devise "optimum fixes" to alleviate the pitch-up conditions for various airplanes, consideration has also been given to the effect of these same fixes on the lateral derivatives. The results available so far are very limited and no specific conclusion can be made. The data of figure 6, however, illustrate for one configuration, model III, the effect of a leading-edge chord-extension on the C_{n_β} and C_{l_β} derivatives. At the lower Mach number the effect of chord-extensions in producing a linear pitching-moment variation is clearly evident, but the effect of these chord-extensions on the corresponding C_{n_β} and C_{l_β} derivatives are relatively insignificant. At the higher Mach number, although unfortunately the available chord-extension-on data are somewhat incomplete, the small effect of these chord-extensions on the derivatives is still evident, the trend for the higher Mach number being almost identical to that shown for the lower Mach number. It should be remembered, of course, that C_{l_β} did not show any pronounced breaks until angles of attack approaching stall were reached.

So far, the discussion of the lateral derivatives for the subsonic speed range has been directed toward the static effects. Recently, the characteristics in steady roll of several wings at high angles of attack in the subsonic speed range have been investigated experimentally. For a 45° swept-wing—body arrangement, the variation of the damping-in-roll parameter C_{l_p} with angle of attack and Mach number is shown in figure 7, together with the corresponding lift variations. It can be seen that at a Mach number of 0.2 the wing maintains a reasonable amount of damping at all angles of attack up to the stall. However, as the Mach number is increased, the damping-in-roll ability of the wing seriously diminishes until at a Mach number of 0.91 instability in roll is indicated at an angle of attack of 11°. Note also that this effect occurs although the lift is still increasing at this angle of attack. Similar effects occur for wings of other plan forms as indicated in figure 8. It will be noted here that all these wings indicate a serious loss in damping effectiveness in about the same angle-of-attack range. Note also that, with the exception of the unswept wing, this loss occurs although the over-all lift coefficients of the wings are still increasing. For the unswept wing, this loss in damping occurs at angles of attack corresponding to the stall, as would be expected.

One additional important point connected with these regions of poor damping is that the variation of rolling moment with rolling velocity may be very irregular as shown in figure 9. Under these conditions it is difficult to determine a representative value of the damping coefficient. The data shown in figure 9 are for a Mach number of 0.85. The variation of the rolling-moment coefficient with rolling velocity shown by the dashed curve is representative of the linear stable slope characteristic of the low angle-of-attack range. At an angle of attack of 11°, however, the variation is nonlinear and, in the case of the 32.6° swept wing, it is unstable over a very wide range of $pb/2V$. The hysteresis shown in the data for the unswept wing and the 60° triangular wing would certainly give rise to some undesirable dynamic-stability characteristics and possibly complicate the design of any automatic stabilizing equipment. The instability at small values of $pb/2V$ and the associated hysteresis loops also may have some relationship to the wing-dropping problem.

Some consideration has been given to the use of fixes in an attempt to reduce the loss of damping in roll. Since a loss in damping is associated with tip stalling, which is also a contributing factor in producing pitch-up, tests were made to determine whether devices which are known to alleviate pitch-up would also improve the damping in roll. The effect of a fence on the damping characteristics of the 45° swept wing is shown in figure 10. The fences were full chord and were located at the $0.65\ b/2$ station. For the Mach number of 0.85, the fences delayed the pitch-up by some 5° and decidedly improved the damping. At a Mach number of 0.91, however, the effect of the fences on either the damping or the pitch-up decreased considerably. Reference 1 contains a more complete discussion of the damping-in-roll characteristics of swept wings at high angles of attack and high subsonic speeds. Included also in this report is a simple procedure for estimating the load distribution in roll provided the corresponding angle-of-attack load distribution is known.

The preceding discussion of the lateral-stability derivatives at high angles of attack has of necessity been based wholly on experimental data. This discussion has been confined to the subsonic speed range. In the supersonic speed range, recent theoretical work applied to three complete configurations has demonstrated the ability of theory to predict the lateral-stability derivatives at low angles of attack. The variations of the derivatives $C_{l_{\beta}}$ and $C_{n_{\beta}}$ with Mach number for these three configurations are shown in figures 11 and 12. The theoretical results are presented for the complete arrangement, vertical-tail alone, and body or wing-body alone. The experimental results, the dark circles, are for the complete arrangement. The comparison of theory and experiment indicates that the level and trend of the experimental variations are predicted by the theory. For one of these airplanes a thorough study and prediction of all the major longitudinal and lateral derivatives has been made and is reported in reference 2.

CONCLUDING REMARKS

It has not been possible to consider all the recent information on lateral-stability derivatives. However, a bibliography of papers containing lateral-stability-derivative data has been attached. Reference 3 also contains a large number of references not included here. The following remarks are offered as an indication of the present general status of the stability-derivative field.

At low angles of attack within the subsonic speed range below the critical Mach number, it is felt that available theory permits fairly reliable predictions of the lateral-stability derivatives.

At the higher angles of attack in the subsonic and transonic ranges, the unpredictable, nonlinear characteristics of the derivatives stress the necessity for determining experimentally for a particular configuration the derivatives needed in the estimation of stability.

In the supersonic range at low angles of attack, combined theoretical and experimental studies have produced useful aerodynamic-derivative data. For the complete configurations so far considered, derivative estimates made for these conditions have met with a good measure of success.

In the supersonic range at high angles of attack there are no data available.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., August 26, 1953.

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THREE HIGH-SPEED MODELS

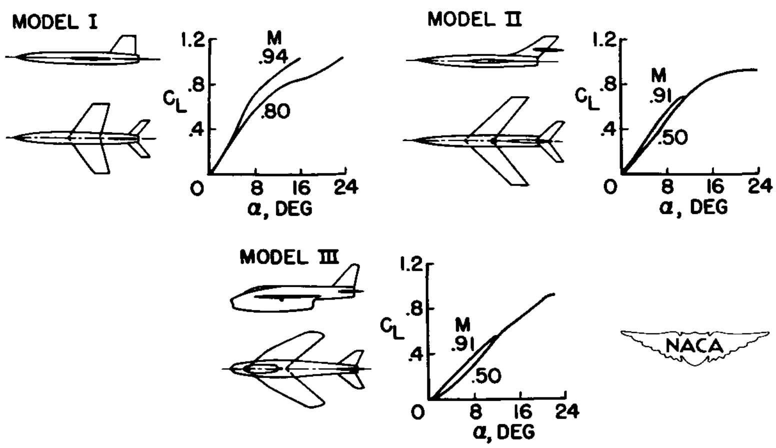

Figure 1

EFFECTIVE-DIHEDRAL DERIVATIVE C_{l_β}
FOR THREE HIGH-SPEED MODELS

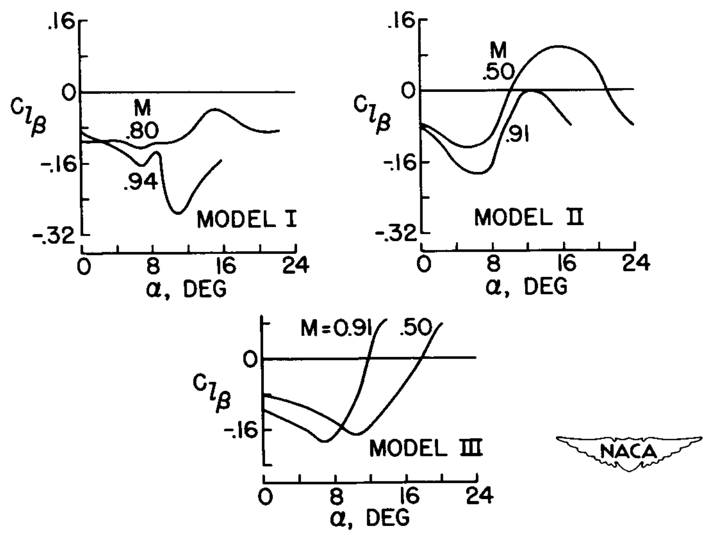

Figure 2

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DIRECTIONAL-STABILITY DERIVATIVE C_{n_β}
FOR THREE HIGH-SPEED MODELS

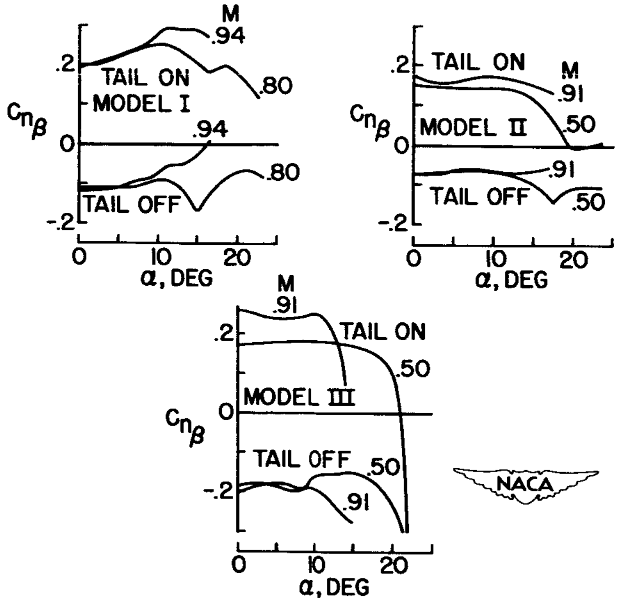

Figure 3

VARIATION OF DIRECTIONAL-STABILITY DERIVATIVE C_{n_β}
WITH HORIZONTAL-TAIL HEIGHT

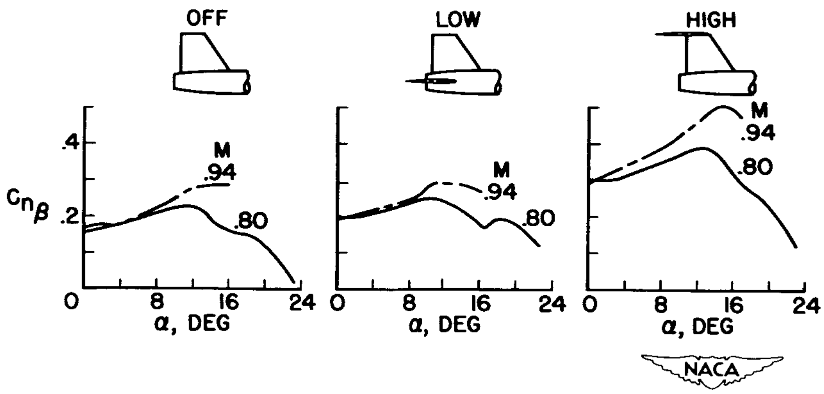

Figure 4

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VARIATION OF EFFECTIVE-DIHEDRAL DERIVATIVE C_{l_β}
WITH HORIZONTAL-TAIL HEIGHT

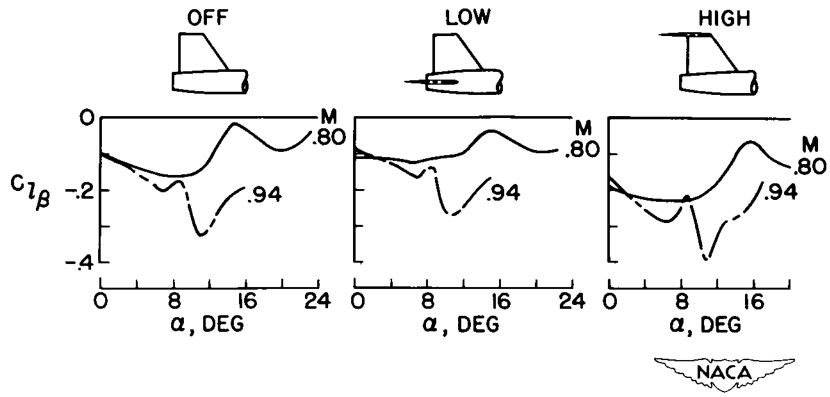

Figure 5

EFFECT OF CHORD-EXTENSIONS ON CHARACTERISTICS OF MODEL III

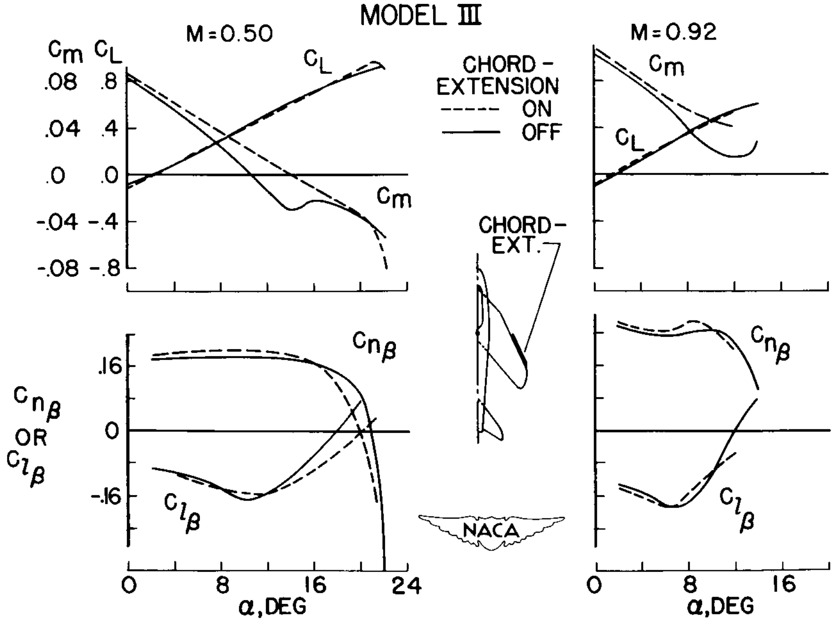

Figure 6

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VARIATION OF THE DAMPING IN ROLL C_{l_p} WITH MACH NUMBER AND ANGLE OF ATTACK

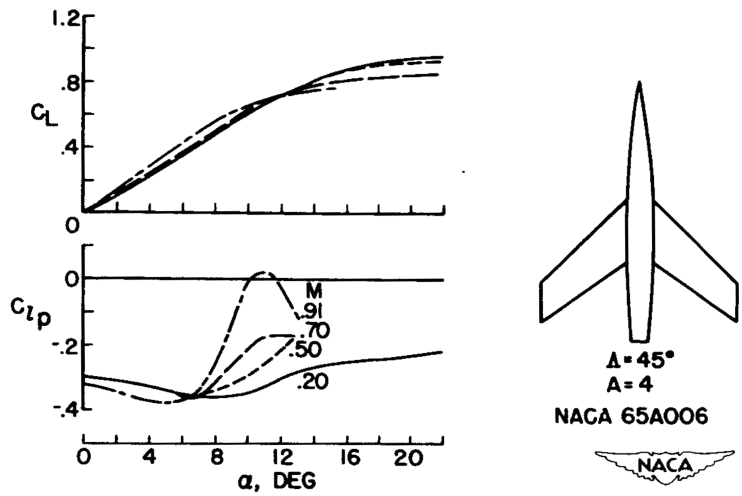

Figure 7

VARIATION OF THE DAMPING IN ROLL C_{l_p} WITH ANGLE OF ATTACK

M = 0.85

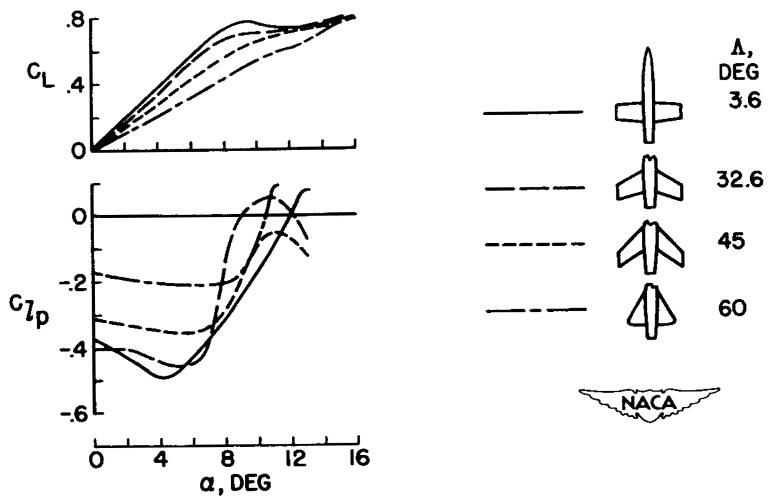

Figure 8

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TYPICAL VARIATIONS OF THE ROLLING-MOMENT COEFFICIENT C_l WITH RATE OF ROLL $\frac{pb}{2V}$

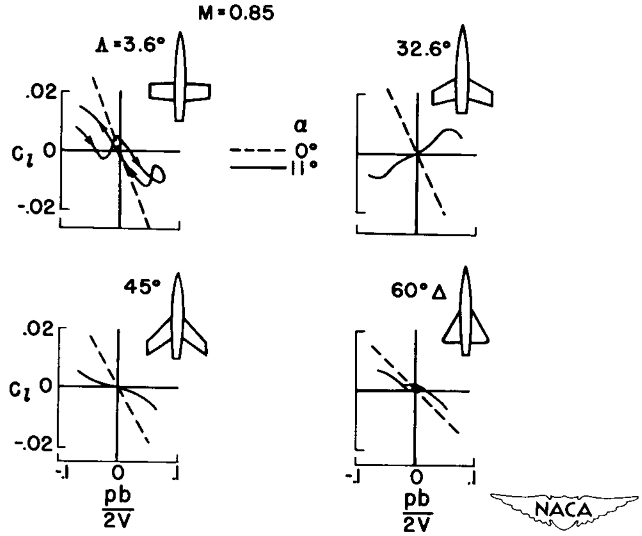

Figure 9

EFFECT OF FENCE ON CHARACTERISTICS OF A 45° SWEPT WING

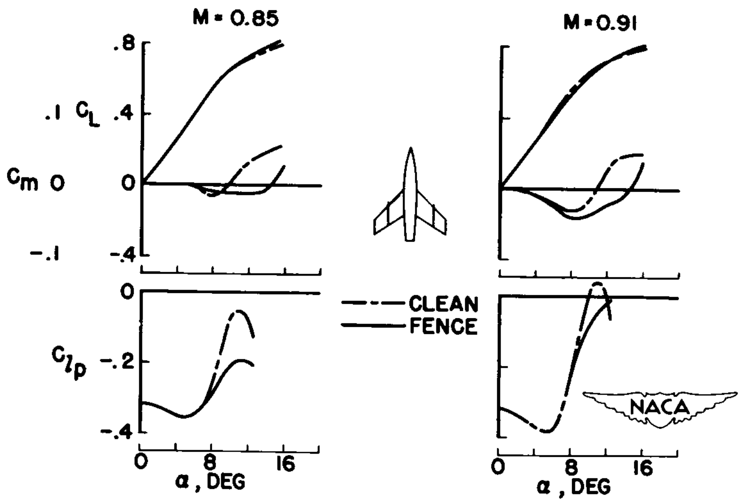

Figure 10

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C_{l_β} DERIVATIVE FOR THREE HIGH-SPEED MODELS

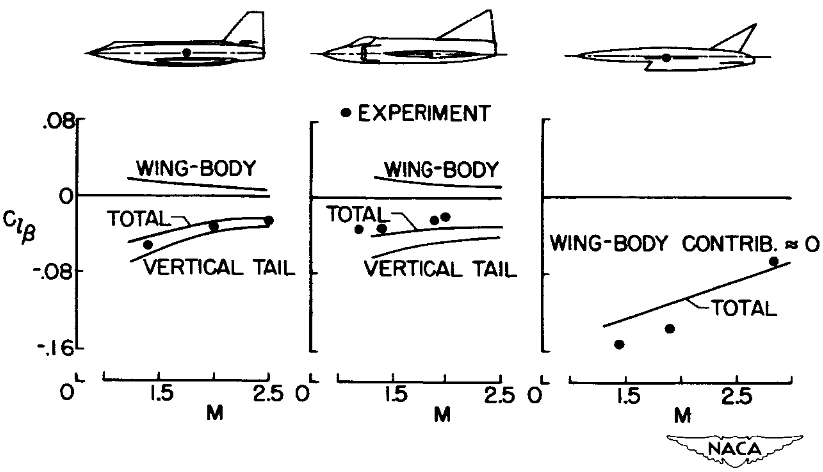

Figure 11

C_{n_β} DERIVATIVE FOR THREE HIGH-SPEED MODELS

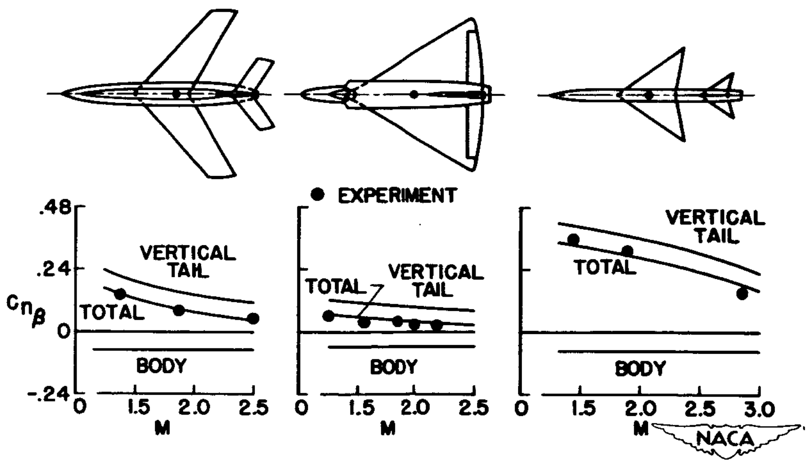

Figure 12

[redacted]

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