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EFFECTS OF SWEEP ON CONTROLS

II - HINGE MOMENTS

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INTRODUCTION

In the discussion by Lowry, an empirical method for predicting the effectiveness of swept control surfaces has been presented. There is not sufficient high-speed data available as yet for developing a reliable method of predicting hinge moments of control surfaces in the transonic-speed region. Efforts to approach the problem theoretically have not yielded satisfactory results because of the lack of a suitable approach which accounts for the many variables, such as effects of the viscosity of the air, boundary layer, and separation. High-speed data furnish the best guide for use in control surface design and for estimating the high-speed characteristics of surfaces. Although there has only been a limited amount of hinge-moment data thus far obtained in the transonic-speed range, the existing data have given several definite results, the more significant of which will be discussed, first with respect to unbalanced control surfaces, and then with respect to aerodynamically balanced surfaces.

UNBALANCED CONTROL SURFACES

Sweep.- Sweep has been shown to be very useful in delaying the effects of compressibility on the effectiveness of control surfaces and in decreasing the magnitude of the changes when they occur. The same general trends exist in the hinge-moment characteristics

In figure 1 are presented the variations of the aileron hinge-moment parameters C_{h_α} and C_{h_δ} with Mach number for three wings having varying degrees of sweep. (See reference 1.) C_{h_α} and C_{h_δ} are the variations of hinge-moment coefficient with angle of attack and control-surface deflection, respectively. It will be noted, as it was in the case with effectiveness, that the main effects of sweep on hinge moments are to delay the effects of compressibility to a higher Mach number and to decrease the magnitude of the changes when they occur. In the results shown here, C_{h_α} and C_{h_δ} are both negative, and the effect of sweep is to reduce the absolute value of the hinge-moment parameters with increasing sweep. In other tests in the Ames 16-foot high-speed tunnel of a model having a large

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trailing-edge angle, C_{h_α} and C_{h_δ} were positive for the unswept configurations, and sweeping the wing back tended to reduce the positive values of the parameters. Thus, in these and other investigations, sweeping the model tended to reduce the magnitude of C_{h_α} and C_{h_δ}, whether the parameters were positive or negative for the unswept configuration. Such an effect is to be expected because the magnitudes of the hinge-moment parameters are directly related to the lift or loading parameter C_{L_δ}, which has been shown to decrease roughly as the cosine of the angle of sweep.

Trailing-edge angle.- The importance of control-surface profile aft of the hinge line on the high-speed control-surface characteristics has been fully realized only relatively recently (reference 2). In many high-speed wind-tunnel and flight investigations, drastic changes in control-surface characteristics were unexpectedly encountered at high Mach numbers. In some cases, the unusual characteristics were found to be associated with bulges and in others with the trailing-edge angle of the control surface. Analysis of the results indicated that adverse effects generally came with the larger trailing-edge angles (which for bulged and cusped surfaces are best measured between the maximum tangents to the surface.) The larger the trailing-edge angle, the more positive became C_{h_α} and C_{h_δ} and the greater the increase of these parameters with increasing Mach number. This trend occurs for both unswept and swept control-surface combinations.

In figure 2 are presented the variations of C_{h_α} and C_{h_δ} with Mach number for three swept models having different trailing-edge angles. The trailing-edge angles indicated in the figure are those measured parallel to the wind stream. It can be seen that increasing the trailing-edge angle increases C_{h_α} and C_{h_δ} and leads to adverse changes with increasing Mach number. The large positive C_{h_δ} above .6 Mach number of the control surface having the greatest trailing-edge angle did not extend over the entire control-surface-deflection range but did cover the useful operating range as shown in figure 3. (See reference 3.) Although the aileron had a radius nose, considerable balancing effect was produced by the large trailing-edge angle at all Mach numbers, the degree of balance increasing rapidly at the higher Mach numbers, the ailerons then becoming overbalanced. At the same time the control effectiveness changed in a similar manner, reversed effectiveness occurring in the same general range as the positive C_{h_δ}. The airfoil section perpendicular to the quarter-chord line was the NACA 0011-64 section. Extension of the chord and reduction of the trailing-edge angle as indicated in figure 3 materially improved the hinge-moment characteristics as well as causing a similar improvement in the effectiveness of the control surface and in the stability characteristics of the wing.

These results indicate that the trailing-edge angle should be kept to a minimum, preferably below 14°. In doing so, flat-sided control surfaces may be generally preferable to cusped surfaces both from a structural standpoint and because a cusp tends to heavy the hinge moments by negatively increasing C_{h_δ}. Bulges and bevels are definitely not suitable for high-speed use because of the accompanying large trailing-edge angles. Special care should be taken when using elliptical plan forms or curved trailing edges in order that the trailing-edge angles be kept uniformly small along the entire span of the control surface.

AERODYNAMICALLY BALANCED CONTROL SURFACES

Overhang.- Aerodynamic balancing of control surfaces is often desirable even where boosts are employed in the system (reference 2). The most common type of balance is the nose overhang, shown on three models in figure 4. The variations of C_{h_α} and C_{h_δ} with Mach number are presented for each of the three models, all of which had trailing-edge angles of 14° or less. Only the first model displayed an objectionable increase in C_{h_α} and C_{h_δ} with increasing Mach number over the test range. This was caused by the larger thickness of the overhang forward of the hinge line. These results and other similar data indicate that overhang balances can be used up to a Mach number of at least .85 and probably higher, provided the nose shape is properly formed and the thickness-to-chord ratio and trailing-edge angles are kept small. There is very little data on internal nose balances above .8 Mach number, but the same general remarks apply.

Tabs.- In figure 5 is shown the effect of sweep on tab effectiveness. Existing data on tabs indicate that the tab effectiveness generally decreases at high Mach numbers in a manner similar to that of the flap-effectiveness parameter C_{L_δ}, since the same factors, such as separation, influence both. The results show that sweeping the hinge line back 45° reduced the tab effectiveness at lower Mach numbers as might be expected but also resulted in a more favorable variation with Mach number. These effects of sweep on tab effectiveness are very similar to the effects of sweep on C_{L_δ}, which have already been discussed.

Horn balance.- In figure 6 is shown a collection of hinge-moment data (reference 4 and unpublished data) for horn balances on swept tail surfaces. Results are shown for a 35° swept-back model with and without the horn obtained from wing-flow tests and for a 45° swept model with a horn from wind-tunnel tests. It can be seen that the values of C_{h_δ} for the 35° and 45° swept tails having horn balances are very nearly constant with Mach number below a Mach number of .9. At the low Reynolds number of about $.8 \times 10^6$, the horn on the 35° swept model loses effectiveness rather rapidly above a Mach number of .9; but at a higher Reynolds number, the effectiveness appears to hold at least to the speed of sound. The results for the horn on the 45° swept model at the left of figure 6, which was at a Reynolds number of about 6×10^6, shows the same trend as the high Reynolds number data on the 35° swept wings. The large Reynolds number effects, such as shown here, make it difficult to predict the characteristics at full-scale Reynolds number from tests of relatively small models because of the large influence of separation and boundary layer on trailing-edge type of controls.

The values of C_{h_α} for the horn balance on both the 35° and 45° swept tails are positive. It should be noted, however, that the unbalanced flap on the 35° swept wing gave almost zero C_{h_α} and most types of aerodynamic balance, with some exceptions, would be expected to give some positive increments of C_{h_α}.

The data presented indicate that the horn-type of balance apparently balances C_{h_δ} through Mach numbers of 1 but that the increasingly positive values of C_{h_α} with increasing Mach number might prohibit its use except for truly irreversible control systems where, for example, oscillations such as snaking offer no problem. In any case, the balancing power of the horn would be reduced by the positive C_{h_α}, which tends to heavy the controls during maneuvers because the combination of C_{h_α} and C_{h_δ} determined the resulting hinge moments and control forces in flight.

The results which have been presented indicate that favorable balancing characteristics can be obtained up to a Mach number of .9 and probably higher. The pronounced effects of sweep and trailing-edge angle on hinge moments in the transonic-speed range have also been demonstrated. The general remarks may be interpreted as applying to horizontal and vertical tails and to trailing-edge control surfaces on wings.

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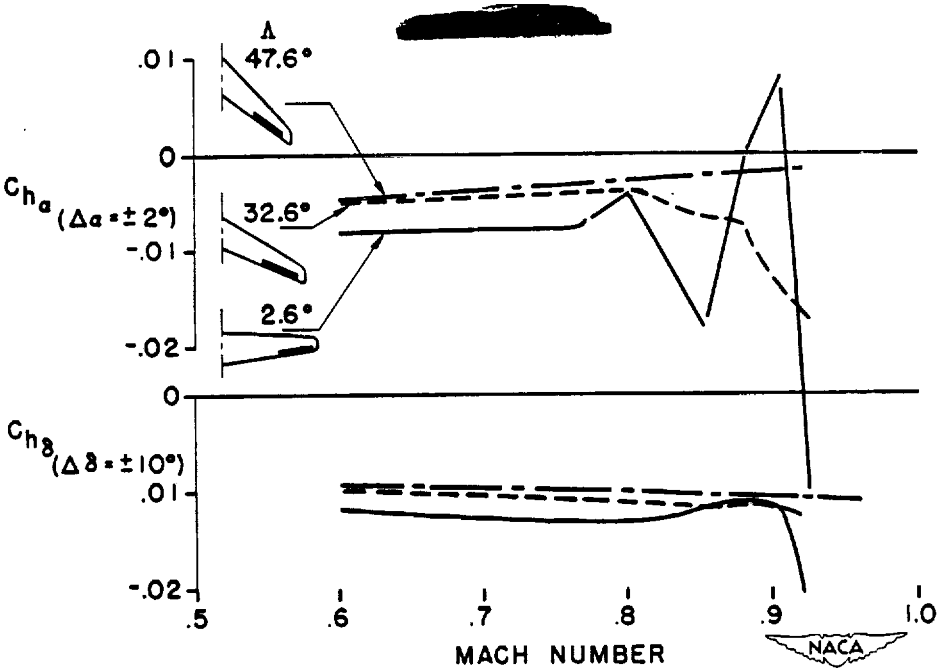
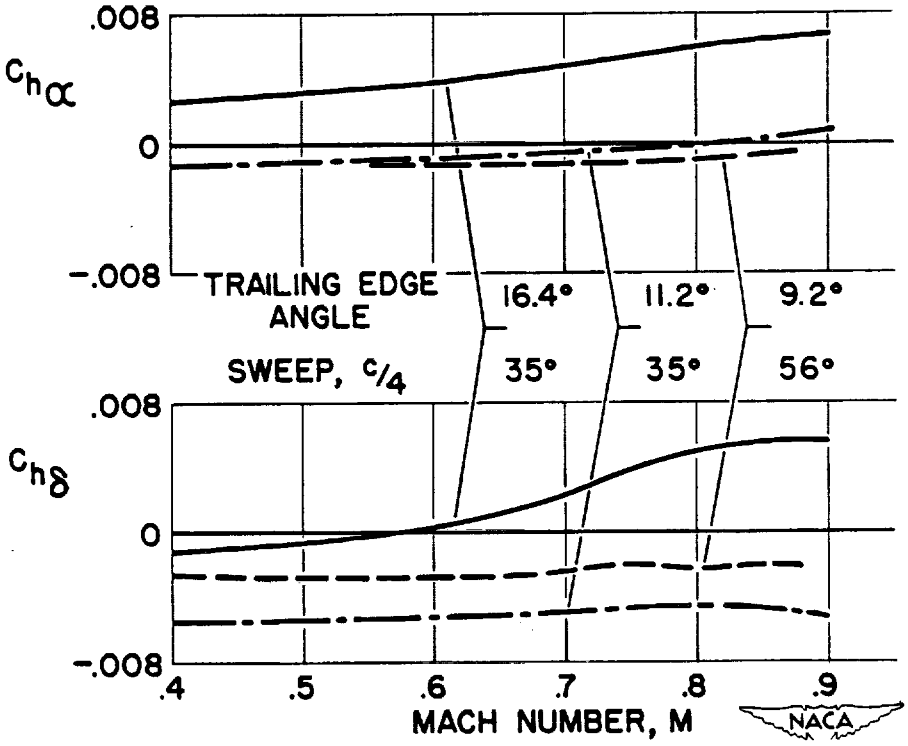


AILERON HINGE-MOMENT PARAMETERS AT HIGH SUBSONIC SPEEDS

Figure 1.



Effect of Trailing-Edge Angle on Hinge-Moment Parameters.

Figure 2.

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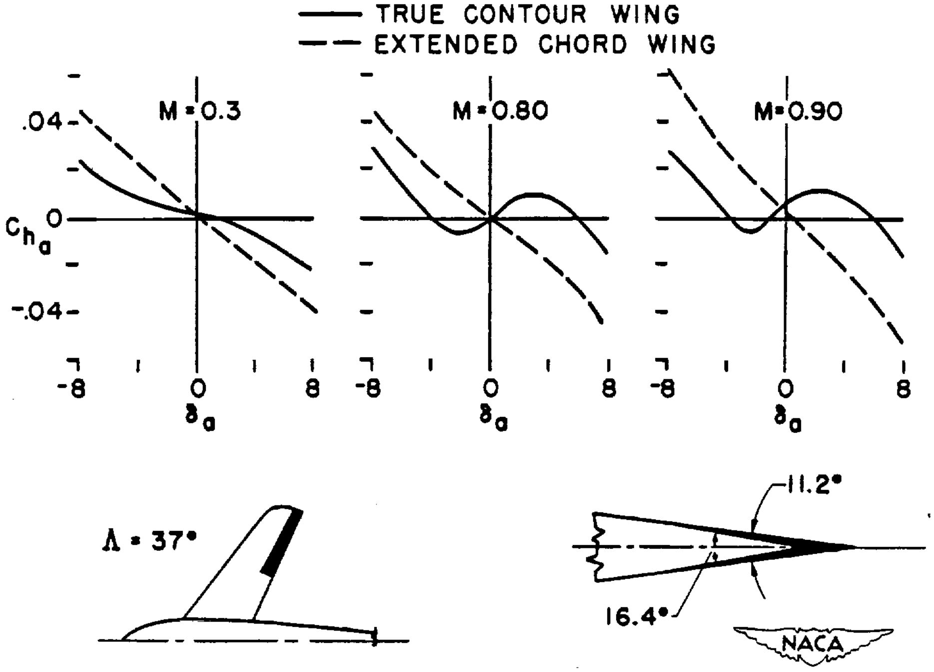
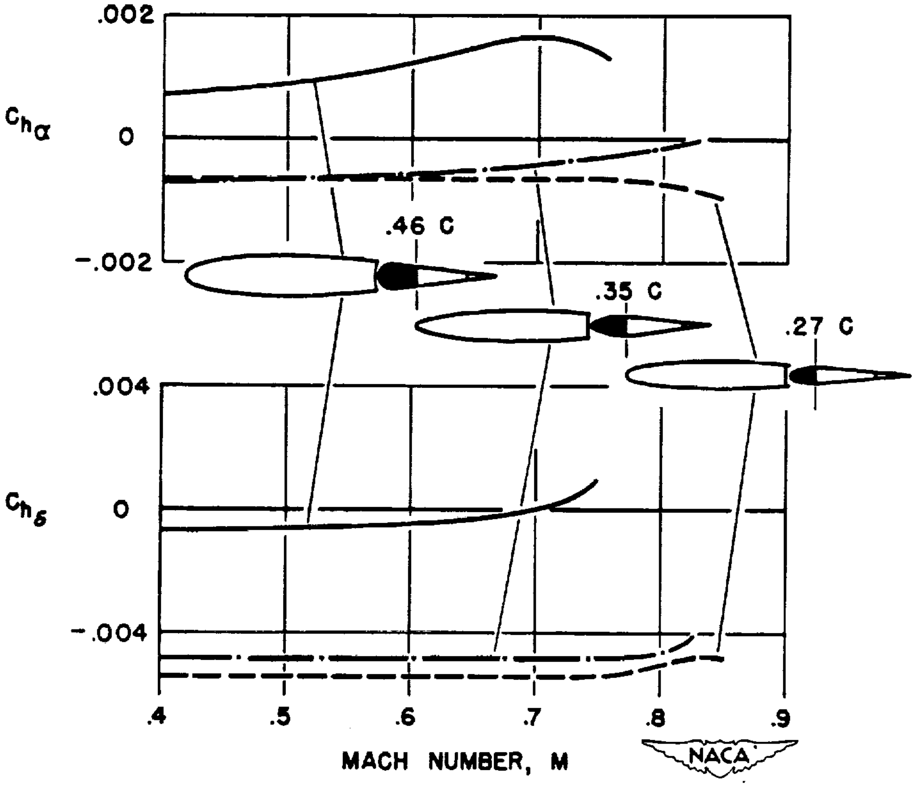


EFFECT OF TRAILING-EDGE ANGLE AT HIGH SUBSONIC SPEEDS

Figure 3.



Effect of Nose Balance on Hinge-Moment Parameters.

Figure 4.

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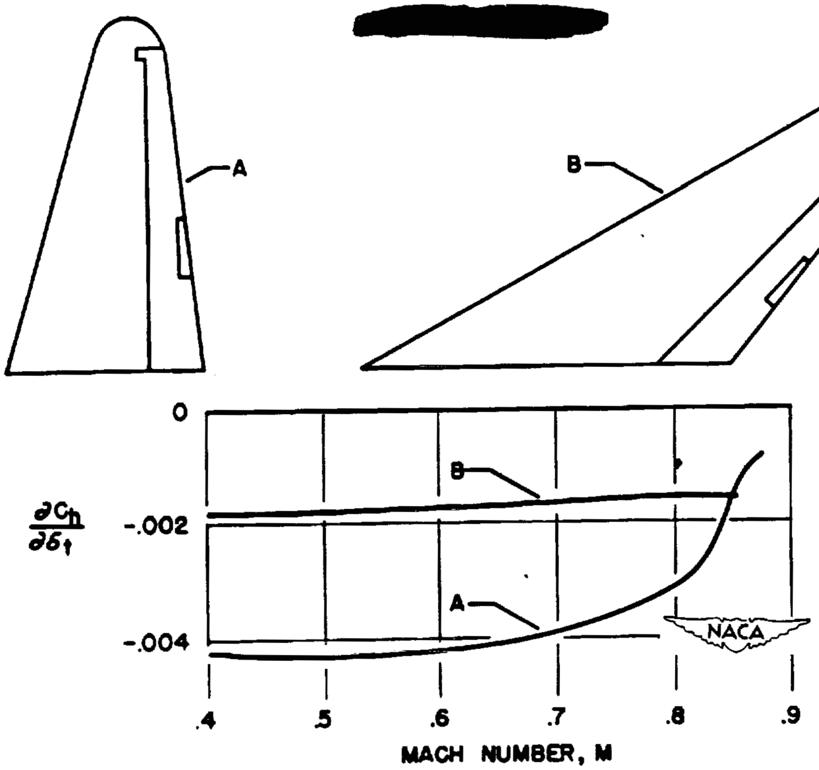
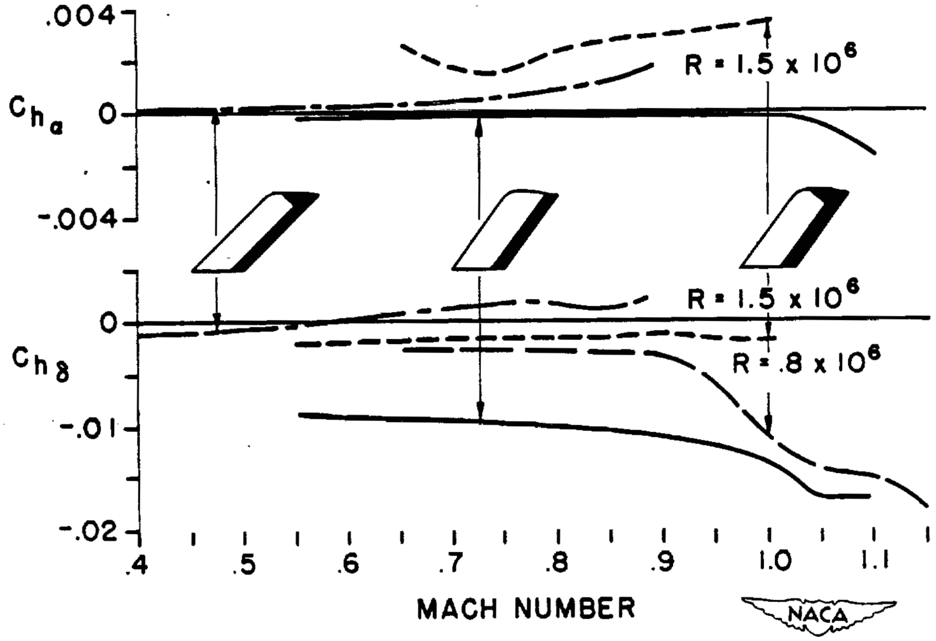


Effect of Sweep on Tab Effectiveness.

Figure 5.



HINGE-MOMENT PARAMETERS AT TRANSONIC SPEEDS

Figure 6.

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