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RESEARCH MEMORANDUM

PRELIMINARY INVESTIGATION AT TRANSONIC SPEEDS OF THE EFFECT OF BALANCING TABS ON THE HINGE-MOMENT AND OTHER AERODYNAMIC CHARACTERISTICS OF A FULL-SPAN FLAP ON A TAPERED 45° SWEPTBACK WING OF ASPECT RATIO 3

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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PRELIMINARY INVESTIGATION AT TRANSONIC SPEEDS OF THE EFFECT OF BALANCING TABS ON THE HINGE-MOMENT AND OTHER AERODYNAMIC CHARACTERISTICS OF A FULL-SPAN FLAP ON A TAPERED 45° SWEPTBACK WING OF ASPECT RATIO 3

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SUMMARY

An investigation was made at transonic speeds of the control balancing characteristics of three tabs on a full-span flap on an aspect-ratio-3, 45° sweptback wing. The investigation was made in the Langley high-speed 7- by 10-foot tunnel utilizing the high-velocity flow field generated over a reflection plane on the side wall of the tunnel.

The results indicated that all the tabs tested, inset, attached, or detached, would balance the flap hinge moments throughout the speed range. The inset tab showed the greatest loss in lift and the detached tab generally showed the least loss in lift and would have the most constant ratio of tab deflection to flap deflection throughout the speed range.

INTRODUCTION

The lack of information on the aerodynamic balancing of controls in the transonic-speed range has led to the installation of powerful boosts in the control system of airplanes to enable the performance requirements to be met. The power-boosted control, although quite successful from the standpoint of effectiveness, has some disadvantages: The required mechanism occupies considerable space which with the thinner wings could become critical, considerable power is required to operate the control system, and a manually operated control system must often be provided in addition to the power boost for positive control in the event of boost failure. It is quite possible that the size of the boost might be materially reduced or even eliminated entirely if more information were available on methods of aerodynamically balancing controls at transonic speeds. The National Advisory Committee for Aeronautics is engaged, at the present time, in a research program designed to provide more information on this subject. One method of balance which has been successful at low speeds and which might be adapted to present-day high-speed aircraft is the balancing tab. It was the purpose of this investigation to determine whether a balancing tab would maintain its effectiveness through the transonic-speed range. No attempt has been made to provide design information by varying the tab geometry other than to change the chordwise location of the tab.

The three tabs used in the investigation had the same plan form which consisted of a rectangular lifting surface attached to or near the flap trailing edge. The half-span tabs were centered along the flap span. The chordwise positions in which the tabs were tested are indicated by their respective names: inset tab, one which lies within the plan form of the main control; attached tab, one attached to the control trailing edge; and detached tab, one which is located behind the control and supported by booms.

Lift, rolling-moment, and hinge-moment characteristics were obtained over a limited angle-of-attack and deflection range at Mach numbers from 0.7 to 1.1.

COEFFICIENTS AND SYMBOLS

C_L lift coefficient (Twice semispan lift/qS)

C_{h_f} flap hinge-moment coefficient
(Flap hinge moment about hinge line of flap/q2M')

C_l rolling-moment coefficient about axis parallel to relative wind and in plane of symmetry
(Rolling moment of semispan model/qSb)

S twice wing area of basic semispan model, 0.202 square foot

twice span of basic semispan model, 0.778 foot

mean aerodynamic chord of basic wing, 0.269 foot $\left(\frac{2}{S}\int_0^{b/2} c^2 dy\right)$

M' area moment of flap (within the basic-wing contour) behind hinge line about hinge line for semispan wing, 0.000692 foot cubed.

q effective dynamic pressure over span of model, pounds per square foot $\left(\frac{1}{2}\rho V^2\right)$

c local wing chord parallel to plane of symmetry, feet

y spanwise distance from plane of symmetry, feet

ρ mass density of air, slugs per cubic foot

V free-stream velocity, feet per second

M effective Mach number over span of model $\left(\frac{2}{S}\int_0^{b/2} cM_a\, dy\right)$

M_a average chordwise local Mach number

M_l local Mach number

R Reynolds number of wing based on $\bar{c}$

α angle of attack, degrees

δ_f flap deflection relative to wing-chord plane, measured in a plane perpendicular to flap hinge axis (positive when flap trailing edge is down), degrees

δ_t tab deflection relative to flap-chord plane measured in a plane perpendicular to flap trailing edge (positive when tab trailing edge is down), degrees

Parameters

$$C_{h_{f_\alpha}} = \left(\frac{\partial C_{h_f}}{\partial \alpha}\right)_{\delta_f=\delta_t=0^\circ}$$ (based on the increment between $\alpha = 0^\circ$ and 4°)

$$C_{h_{f_{\delta_f}}} = \left(\frac{\partial C_{h_f}}{\partial \delta_f}\right)_{\alpha,\delta_t=0^\circ}$$

$$C_{h_{f_{\delta_t}}} = \left(\frac{\partial C_{h_f}}{\partial \delta_t}\right)_{\alpha, \delta_f = 5^\circ} \left[\frac{\left(C_{h_f}\right)_{\text{tab deflected}} - \left(C_{h_f}\right)_{\text{tab undeflected}}}{\delta_t}\right]$$

$$C_{L_{\delta_f}} = \left(\frac{\partial C_L}{\partial \delta_f}\right)_{\alpha, \delta_t = 0^\circ}$$

$$C_{L_{\delta_t}} = \left(\frac{\partial C_L}{\partial \delta_t}\right)_{\alpha, \delta_f = 5^\circ} \left[\frac{\left(C_L\right)_{\text{tab deflected}} - \left(C_L\right)_{\text{tab undeflected}}}{\delta_t}\right]$$

$$\left[C_{L_\delta}\right]_{\left(C_{h_{\delta_f}} = 0\right)} = C_{L_{\delta_f}} + \left(\frac{\delta_t}{\delta_f}\right)\left(C_{L_{\delta_t}}\right)$$ (net lift parameter for zero-flap hinge moment)

$$C_{l_{\delta_f}} = \left(\frac{\partial C_l}{\partial \delta_f}\right)_{\alpha, \delta_t = 0^\circ}$$

$$C_{l_{\delta_t}} = \left(\frac{\partial C_l}{\partial \delta_t}\right)_{\alpha, \delta_f = 5^\circ} \left[\frac{\left(C_l\right)_{\text{tab deflected}} - \left(C_l\right)_{\text{tab undeflected}}}{\delta_t}\right]$$

$$\left[C_{l_\delta}\right]_{\left(C_{h_{\delta_f}} = 0\right)} = C_{l_{\delta_f}} + \left(\frac{\delta_t}{\delta_f}\right)\left(C_{l_{\delta_t}}\right)$$ (net roll parameter for zero-flap hinge moment)

where

$$-\frac{\delta_t}{\delta_f} = \frac{C_{h_{f_{\delta_f}}}}{C_{h_{f_{\delta_t}}}}$$

The subscripts outside the parentheses indicate the factors hold constant during the measurement of the parameters.

MODEL AND APPARATUS

The semispan steel model used in the investigation had a quarter-chord sweep angle of 45.58°, an aspect ratio of 3, a taper ratio of 0.5, and an NACA 64A010 airfoil section measured in a plane at 45° to the plane of symmetry. The pertinent dimensions of the basic wing are given in figure 1. The wing was equipped with a full-span plain flap-type control of 25.4 percent of the chord measured parallel with the plane of symmetry. The flap was supported by four hinges along its span, two of which were within the reflection-plane fairing. The gap between the nose of the flap and the rearmost part of the wing was approximately 0.15 percent of the wing chord.

The three tabs which were used in the investigation had the same plan form and were centered along the span of the flap as shown in figure 2. The inset tab was formed by milling a 0.031-inch slot in the bottom surface of the flap. The groove was filled with a cement to eliminate the break in flap contour when the tab was deflected. The attached tab was made from 0.005-inch brass sheet bent double and attached in the same location as the inset tab. Deflection of the tab was assumed to be about the flap trailing edge. The detached tab was a 0.031-inch-thick piece of steel rounded on the leading edge and mounted on booms at a distance of about 63 percent of the local flap chord at midspan behind the flap trailing edge. The hinge line of this tab was slightly ahead of its leading edge. The chords of the tabs were approximately 30 percent of the flap chord at its midspan. The tab area was about 15 percent of the flap area for all tabs.

The investigation was conducted in the Langley high-speed 7- by 10-foot tunnel by using a small reflection-plane setup on the side wall which gives local supersonic flow when the tunnel was near maximum velocities. The reflection plane is mounted a few inches from the side wall as shown in figure 1. The model was mounted through a turntable in the reflection plane as shown in figure 3. A gap of about 1/16 inch was maintained between the wing root-chord section and the reflection-plane turntable. A sponge seal was fastened to the wing butt to minimize flow through the gap.

The model was mounted on an electrical strain-gage balance attached to the side of the tunnel and the moments and forces were indicated by self-balancing potentiometers. A strain-gage beam which was attached to the end of the flap along the hinge line was used for measuring flap hinge moments.

TESTS

The tests were conducted over a Mach number range from 0.70 to 1.10. For Mach numbers below 0.95, there was practically no gradient in the vicinity of the reflection plane. At higher Mach numbers, however, the presence of the reflection plane created a high-local-velocity field which allowed testing the model up to $M = 1.10$ before choking occurred in the tunnel. The variations of local Mach numbers are shown in figure 4. Effective test Mach numbers were obtained from contour charts similar to those shown in figure 4 by the relationship

$$M = \frac{2}{S} \int_0^{b/2} cM_a \, dy$$

For the investigation, a Mach number gradient of generally less than 0.02 was obtained between Mach numbers of 0.95 and 1.04 and increased to about 0.06 at the highest test Mach number of 1.10. It will be noted that the Mach number gradient is principally chordwise. The estimated boundary-layer thickness on the reflection plane was 0.16 inch based on a value of 95 percent of the free-stream velocity. This value corresponds to about 3.4 percent of the wing semispan. A typical Reynolds number variation with Mach number is shown in figure 5.

CORRECTIONS

A reflection-plane correction, which accounts for the carry-over of load to the other wing, has been applied to the parameters $C_{l_{\delta_f}}$ and $C_{l_{\delta_t}}$ throughout the Mach number range tested. (No corrections have been applied to the measured rolling moments of the wing.) The correction factor K which is applied as given in the following equation is 0.67 for the full-span control and 0.74 for both the inset tab and the attached tab.

$$C_{l_{\delta_f}} = KC_{l_{\delta_{f_{measured}}}}$$

These factors were obtained from an unpublished low-speed experimental and theoretical investigation. The aileron-effectiveness parameters presented herein represent the aerodynamic effects on a complete wing produced by the deflection of the control on only one semispan of the complete wing. Although the corrections are based on incompressible conditions, it is believed that the results obtained by applying the corrections gives a better representation of the true conditions than the uncorrected data. Application of the correction factors to the data in the manner given results in the values of C_{l_δ} being undercorrected at subcritical Mach numbers and probably overcorrected in the transonic Mach number ($M > 0.95$) range.

No reflection-plane correction factor was applied to the data from the detached tab as it was thought that the tab would not significantly affect the lift distribution over the model.

In view of the small size of the model relative to the tunnel test section, jet boundary and blockage corrections are believed to be insignificant and were not applied to the data.

Flap deflections were corrected for angle changes due to strain-gage beam deflections under load.

RESULTS AND DISCUSSION

Typical plots of hinge-moment, lift, and rolling-moment coefficients against flap deflection are given in figure 6 for a Mach number of 0.8 for various angles of attack. Variations of the hinge-moment coefficient with angle of attack for various Mach numbers are shown in figure 7. From these and similar data the parameter values of the flap and tab, figures 8 to 14, were determined. The values of the slopes of the coefficient curves are those existing between approximately 0° and 10° flap deflection and 0° and 20° tab deflection. These slopes may differ from those which might exist if small deflections had been tested near $\delta_f = 0^{\circ}$. The absolute value of the parameters, therefore, is subject to this consideration but inasmuch as the data for all tabs were secured under similar conditions, the comparison between tabs should be valid.

The slopes of the hinge-moment-coefficient curves resulting from flap deflection are greater the farther to the rear the tab is placed, as the parameter $C_{h_{f_{\delta_f}}}$ in figure 8 indicates, which is as expected, because of the effective chord extension on the attached tab and the longer moment arm on the detached tab.

Likewise the tab effectiveness $C_{h_{f_{\delta_t}}}$ is increased as the tab location is moved rearward. The ratio of $C_{h_{f_{\delta_f}}}$ to $C_{h_{f_{\delta_t}}}$ is an indication of the tab deflection required to balance out the hinge moments per degree of flap deflection. The ratio of tab deflection to flap deflection δ_t/δ_f (fig. 9) indicates that it is possible with any of the tab configurations to balance out the flap hinge moments through the range of these tests. The inset tab, however, shows a very wide range of ratios required (1.5 to 5.0) for trim through the Mach number and angle-of-attack range. These ratio variations make the inset tab an impractical balancing control for a geared balancing mechanism. The attached tab shows trends of δ_t/δ_f with Mach number and angle of attach similar to that of the inset tab but the values of δ_t/δ_f are of smaller magnitude. In contrast to these tabs the detached tab indicates very little variation in δ_t/δ_f with either Mach number or angle of attack. The extreme values of δ_t/δ_f appear to be about 1.25 to 1.70, the average variation with Mach number is less. A single value of δ_t/δ_f, perhaps 1.5, would come close to balancing the flap hinge moments throughout the Mach number range for this flap-tab configuration.

The ratios of tab deflection to flap deflection presented in figure 9 take no account of the effect of $C_{h_{f_\alpha}}$ on the control; therefore these data may represent an overbalanced condition. In maneuvering flight, the negative values of $C_{h_{f_\alpha}}$ shown in figure 14 would aid in reducing the hinge moments of the controls and therefore less tab deflection would be required resulting in greater lift or roll effectiveness than shown by the parameters $\left[C_{L_\delta}\right]_{\left(C_{h_{\delta_f}}=0\right)}$ and $\left[C_{l_\delta}\right]_{\left(C_{h_{\delta_f}}=0\right)}$. The attached and detached tabs show greater negative values of $C_{h_{f_\alpha}}$ than those of the inset tab (fig. 14) therefore the effect of maneuvering flight would be more pronounced on the attached and detached tabs than on the inset tabs. For steady flight the negative values of $C_{h_{f_\alpha}}$ might either reduce or increase the hinge moments depending on the trim and stability characteristics.

The tab arrangement investigated represents a rather unusual tab-linkage mechanism, that is, one in which no tab moments are transmitted outside of the flap. An example of such an arrangement is one in which an electric motor within the flap actuates the tab proportional to flap deflection. For the more conventional arrangements, a knowledge of the tab hinge moments is necessary before any tab balancing system can be evaluated. It is probable that the magnitude of the tab hinge moments at transonic speeds may be such that aerodynamic balancing of the tab will be required if the system is to be manually operated.

An indication of the amount of useful control that can be accomplished from these tab configurations is given in figure 10 by the parameter $\left(C_{L_\delta}\right)_{C_{h_f}=0}$. The inset tab appears to be an ineffective device at angles of attack of 0°, 2°, and 4° as the lift retained after balance has been achieved is small particularly at Mach numbers of 1.0 or above. This loss in lift effectiveness is in agreement with the two-dimensional theory of reference 1 which shows that when an inset tab is used to make $C_{h_\delta} = 0$ at supersonic speeds it also results in $C_{L_\delta} = 0$.

Because the lift effectiveness of the flap with the attached tab $C_{L_{\delta_f}}$ is generally greater through the range of test conditions than for the other two tab configurations, it might be expected that this configuration would have the most lift retained for useful control. The large ratios of δ_t/δ_f required for trim, however, materially reduce the value of the parameter $\left(C_{L_\delta}\right)_{C_{h_f}=0}$. The detached tab because of its comparatively small values of δ_t/δ_f generally results in having the maximum lift available for control, particularly in the transonic-speed range.

The efficiency of the controls in lift which is given by the ratio of $\left[C_{L_\delta}\right]_{\left(C_{h_{\delta_f}}=0\right)}$ to $C_{L_{\delta_f}}$ is compared in figure 11. The detached tab shows the greatest efficiency which is about 80 percent for the range of test conditions investigated. Values of the efficiency for the other two tabs are generally less and show considerable variation with Mach number.

The rolling-moment parameters presented in figures 12 and 13 indicate about the same results as the lift parameters except perhaps that the parameter $\left(C_{l_{\delta_f}}\right)_{C_{h_f}=0}$ is about equal for the attached and detached tab.

CONCLUSIONS

An investigation at transonic speeds to determine the balancing characteristics of an inset, an attached, and a detached tab on a full-span flap of a sweptback wing indicated the following conclusions:

1. All three tabs were capable of reducing to zero the flap hinge moments resulting from deflections of the control.

2. The inset tab showed the greatest variation in tab-flap deflection ratios and the greatest loss in lift for zero flap hinge moment; whereas the detached tab showed the lowest values of and the least variation in tab-flap ratios and also showed generally the least loss in lift for zero flap hinge moment.

3. The hinge-moment variations with angle of attack for the attached and detached tab were much greater than those of the control with the inset tab and the variations were in the direction to reduce the control forces in maneuvers.

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REFERENCE

1. Tucker, Warren A.: Notes on Geared Tabs at Supersonic Speeds. NACA RM L7L04, 1948.

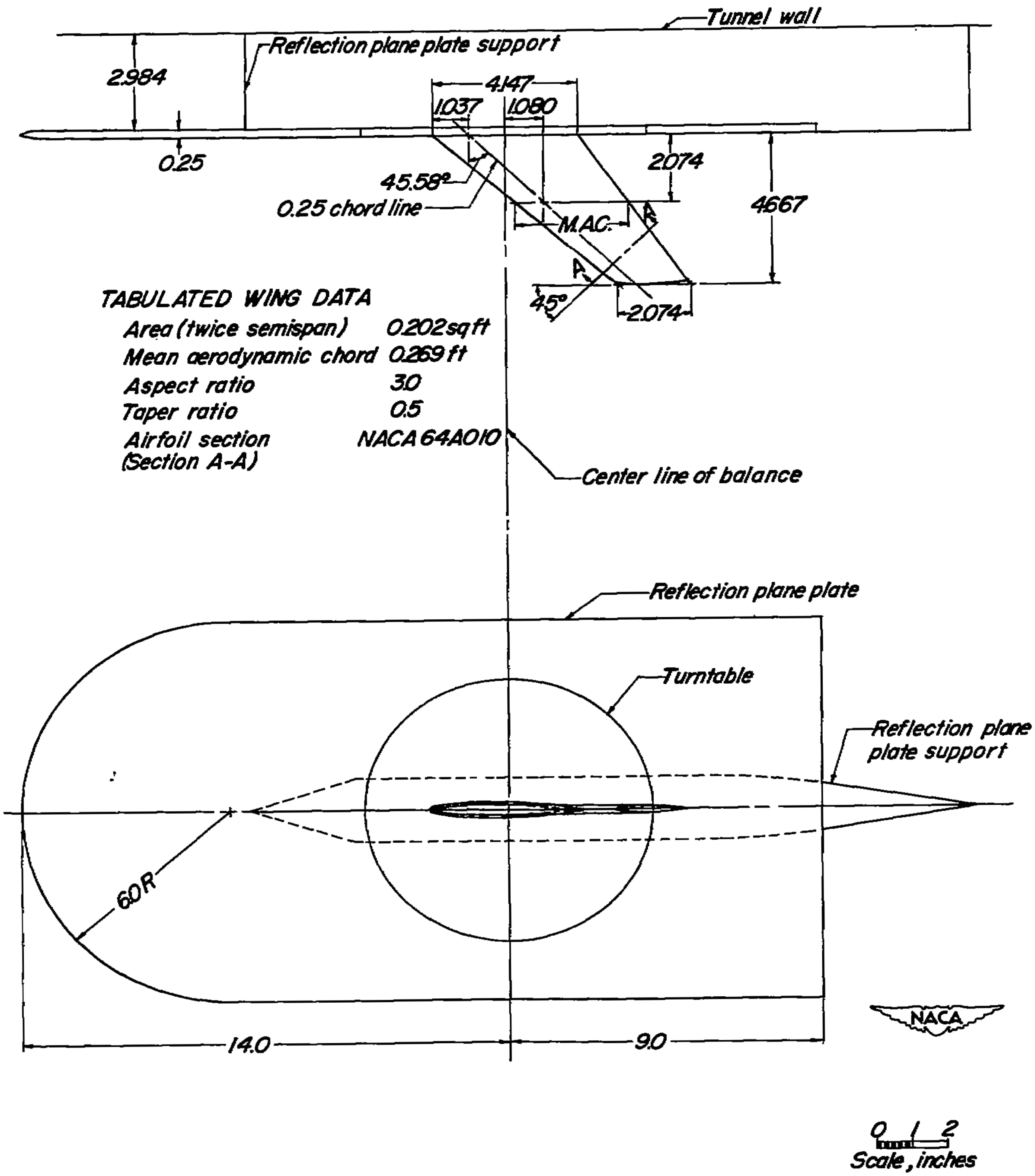


Figure 1.- Basic wing model mounted on the reflection plane in the Langley high-speed 7- by 10-foot tunnel.

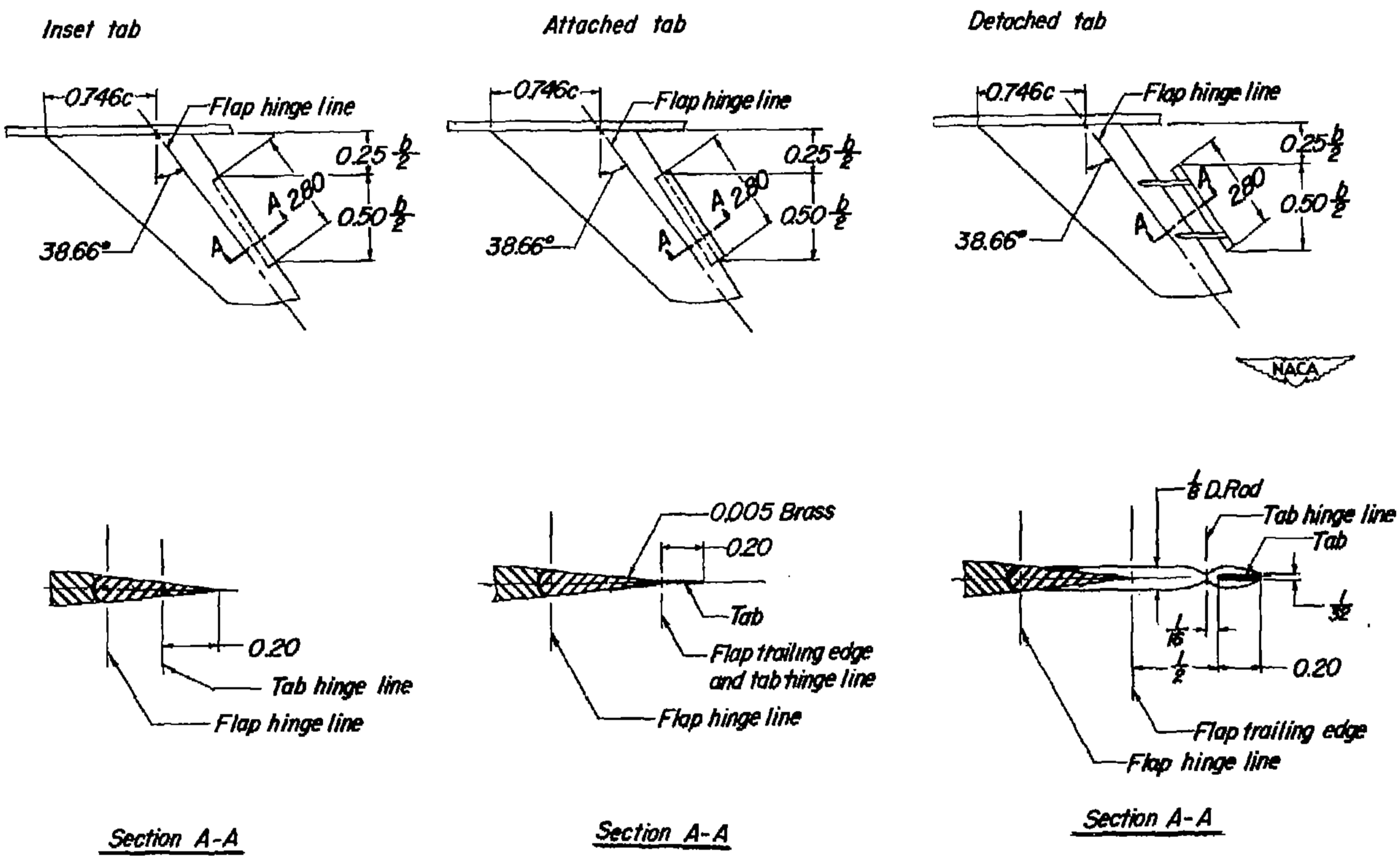


Figure 2.- Details of the controls tested. (All dimensions are in inches.)

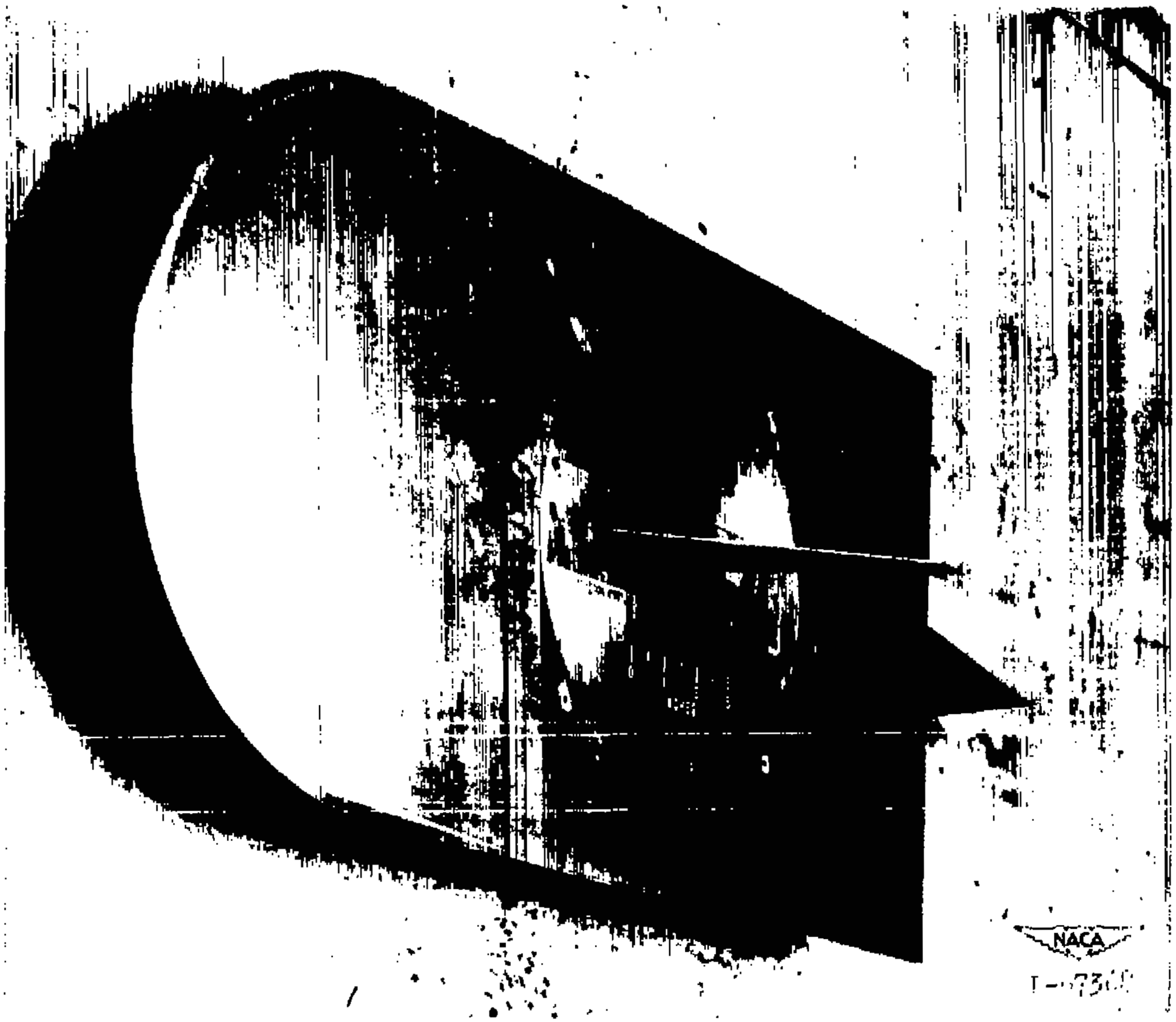


Figure 3.- View of typical model mounted on the reflection plane in the Langley high-speed 7- by 10-foot tunnel.

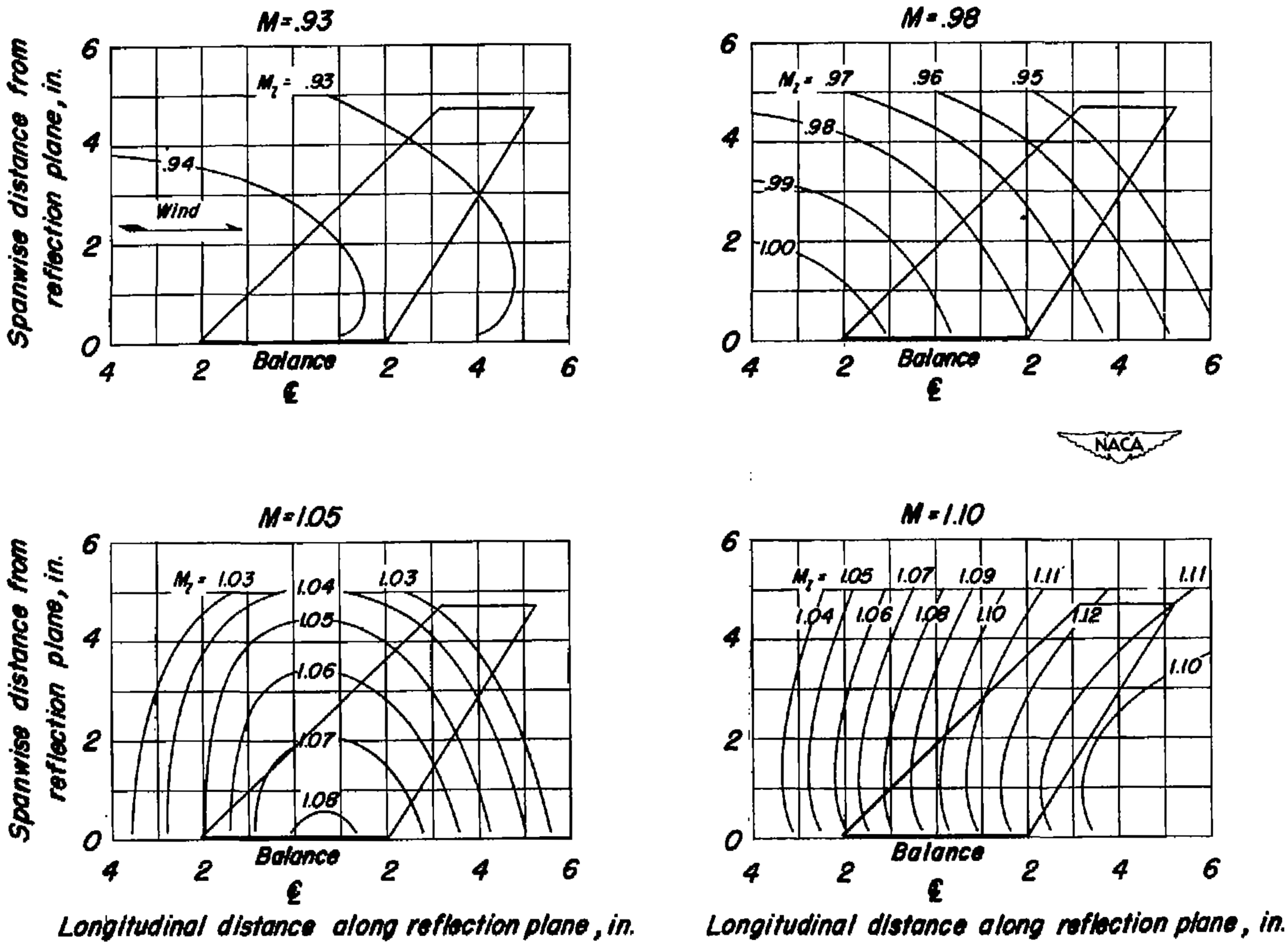


Figure 4.- Typical Mach number contours over the side-wall reflection plane in region of model location.

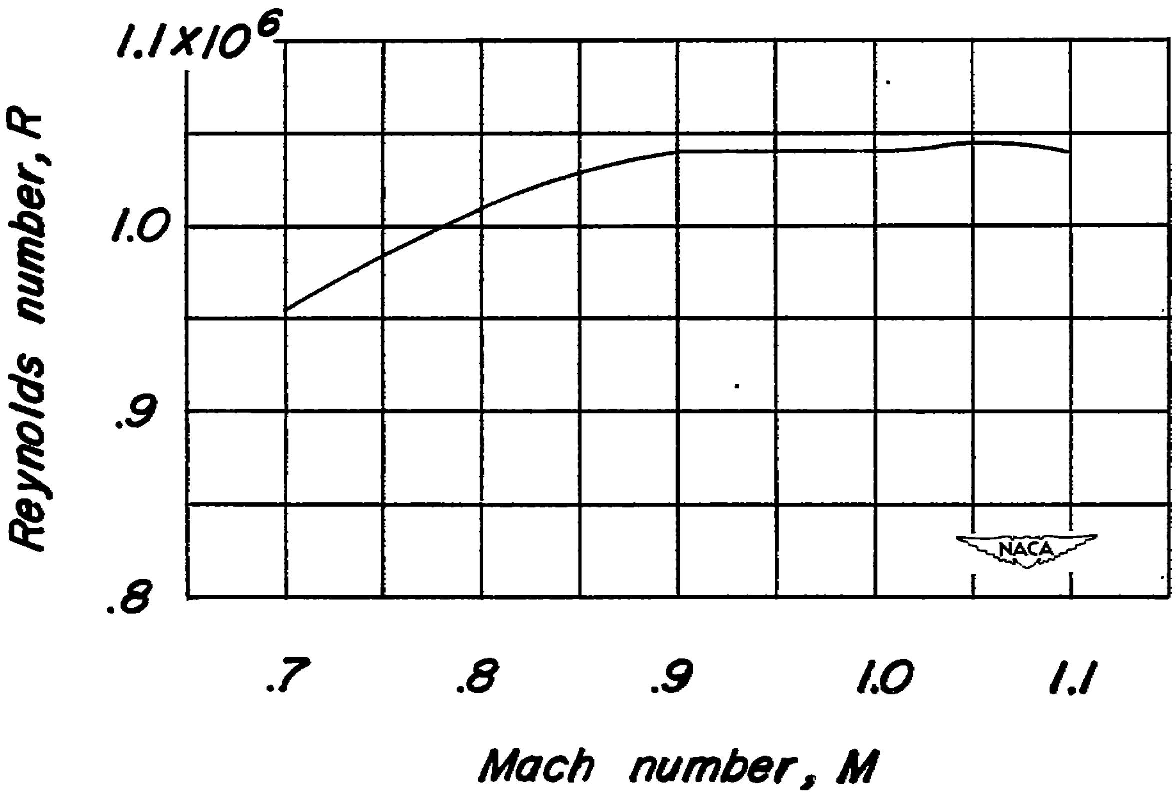
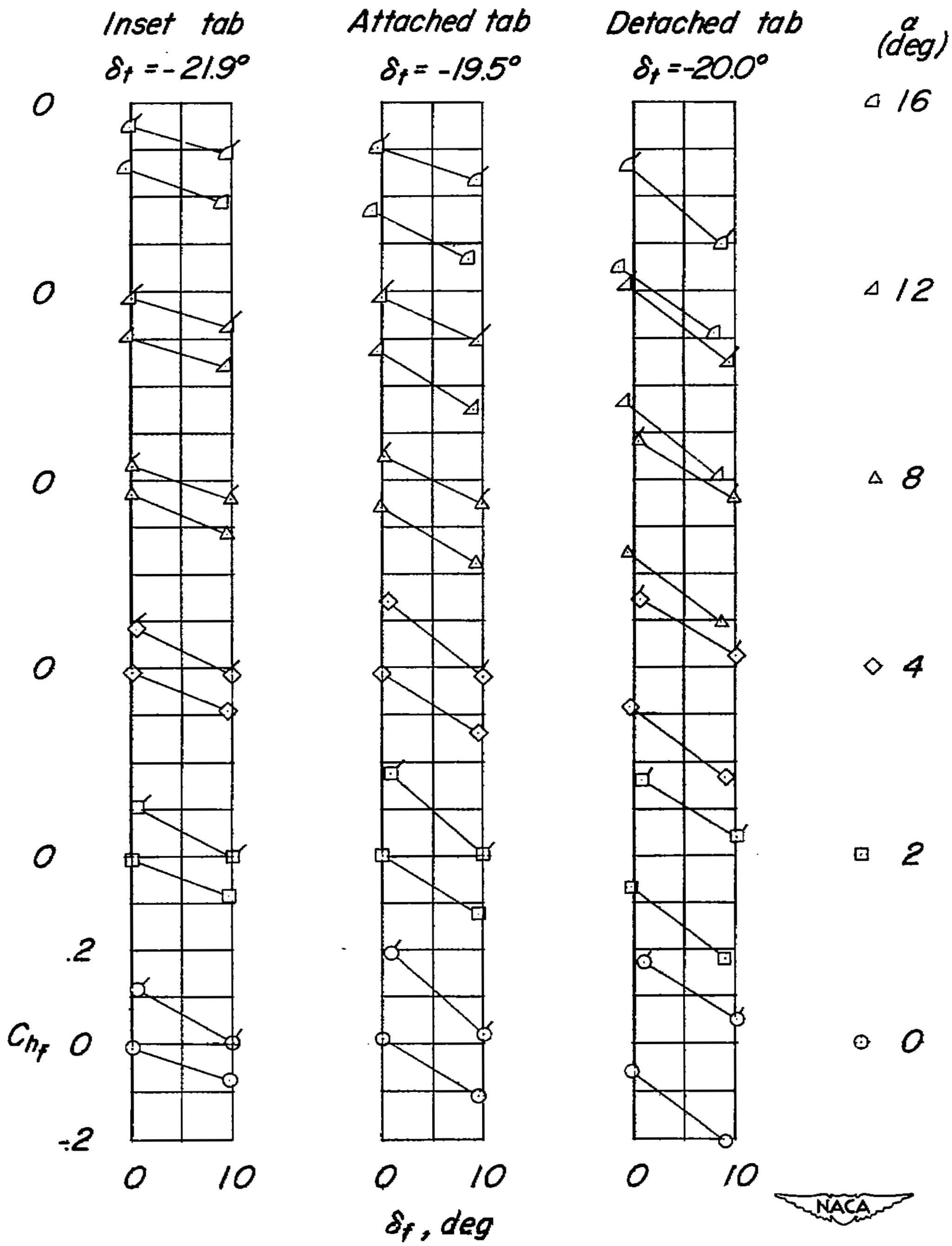
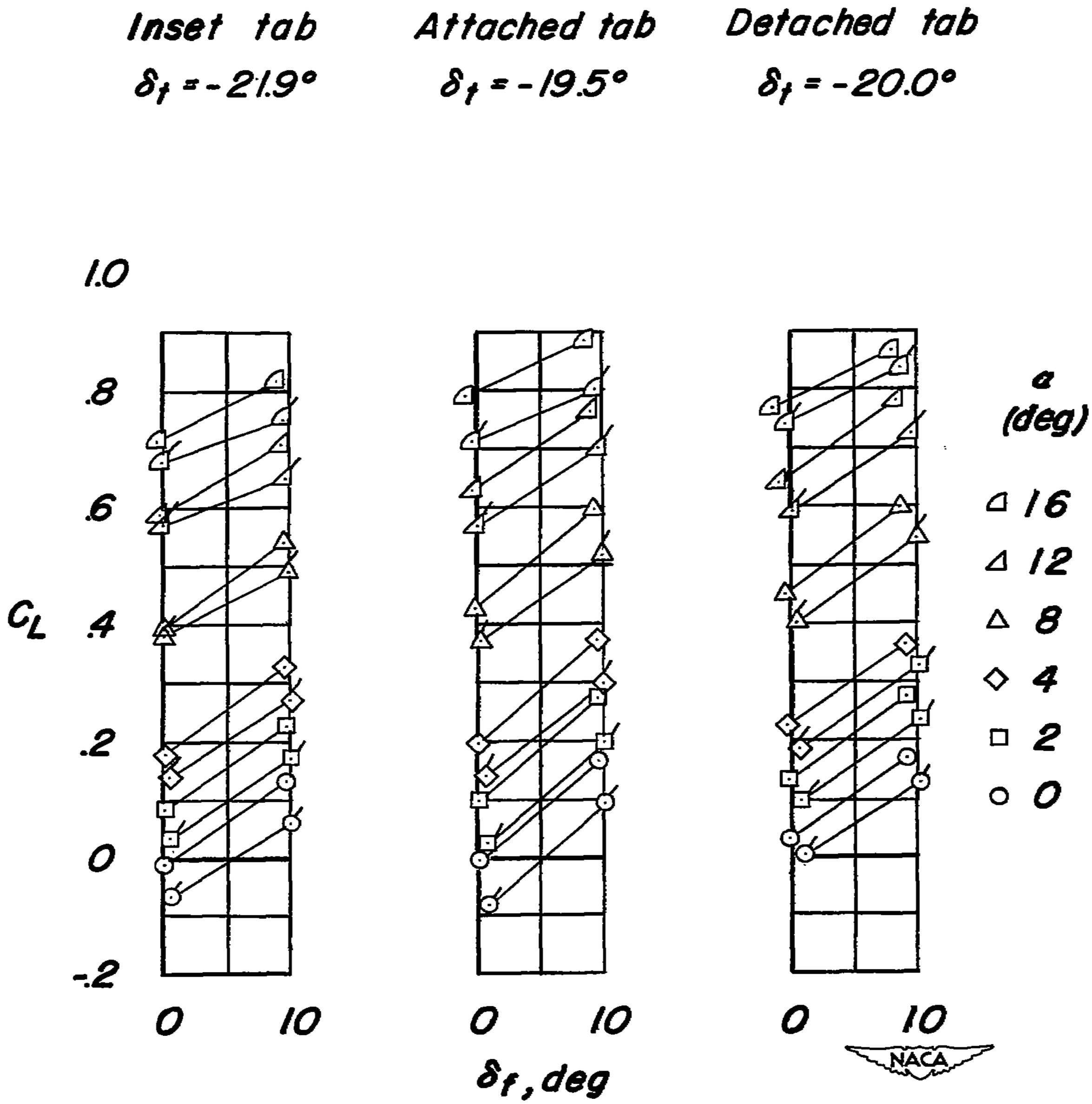


Figure 5.- Typical variation of Reynolds number with test Mach number through the transonic-speed range.



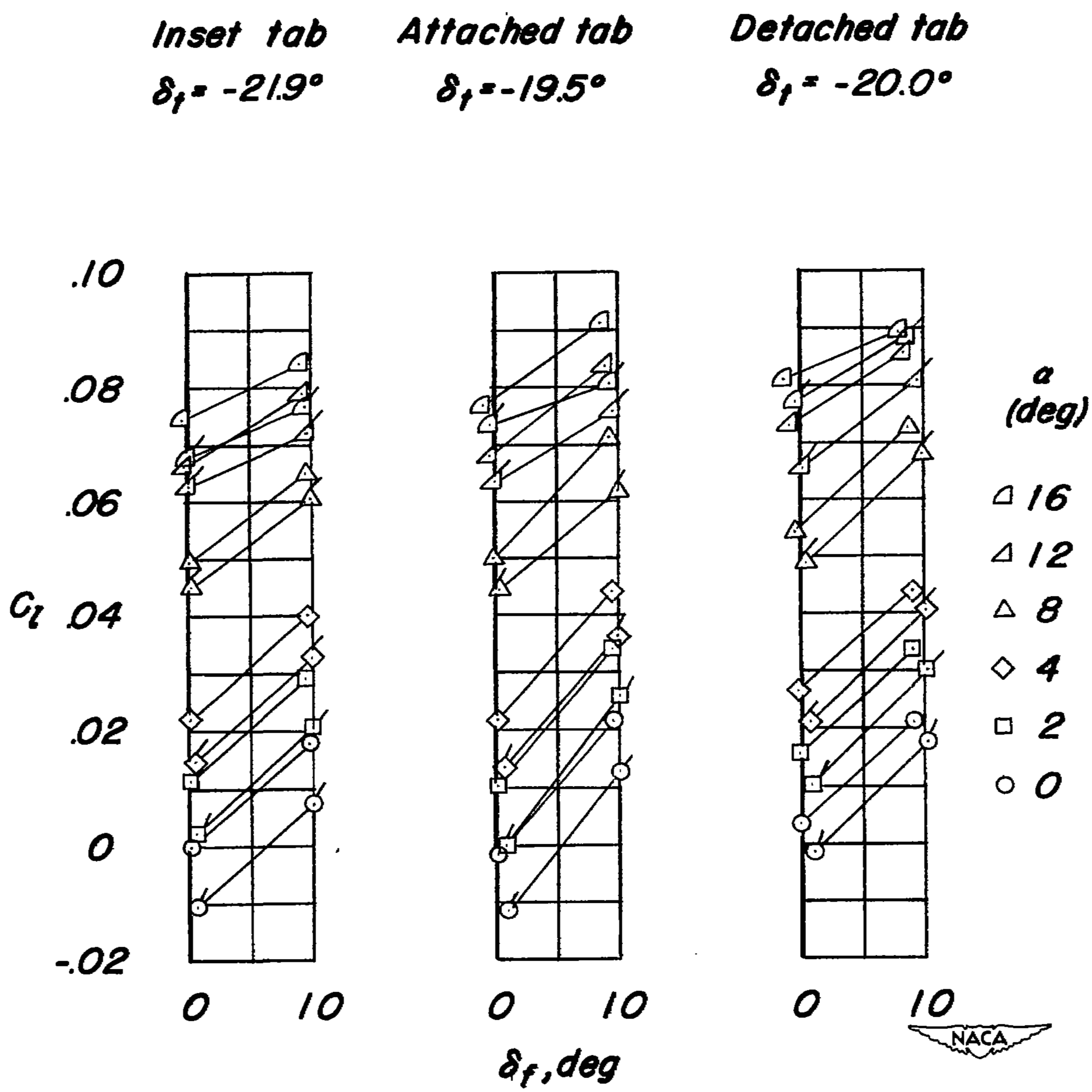
(a) C_h against δ_f

Figure 6.- Typical data plots from which the lift, hinge-moment, and rolling-moment parameters were determined. M = 0.80. Flagged symbols indicate data obtained with the tab deflected.



(b) C_L against δ_f.

Figure 6.- Continued.



(c) C_l against δ_f.

Figure 6.- Concluded.

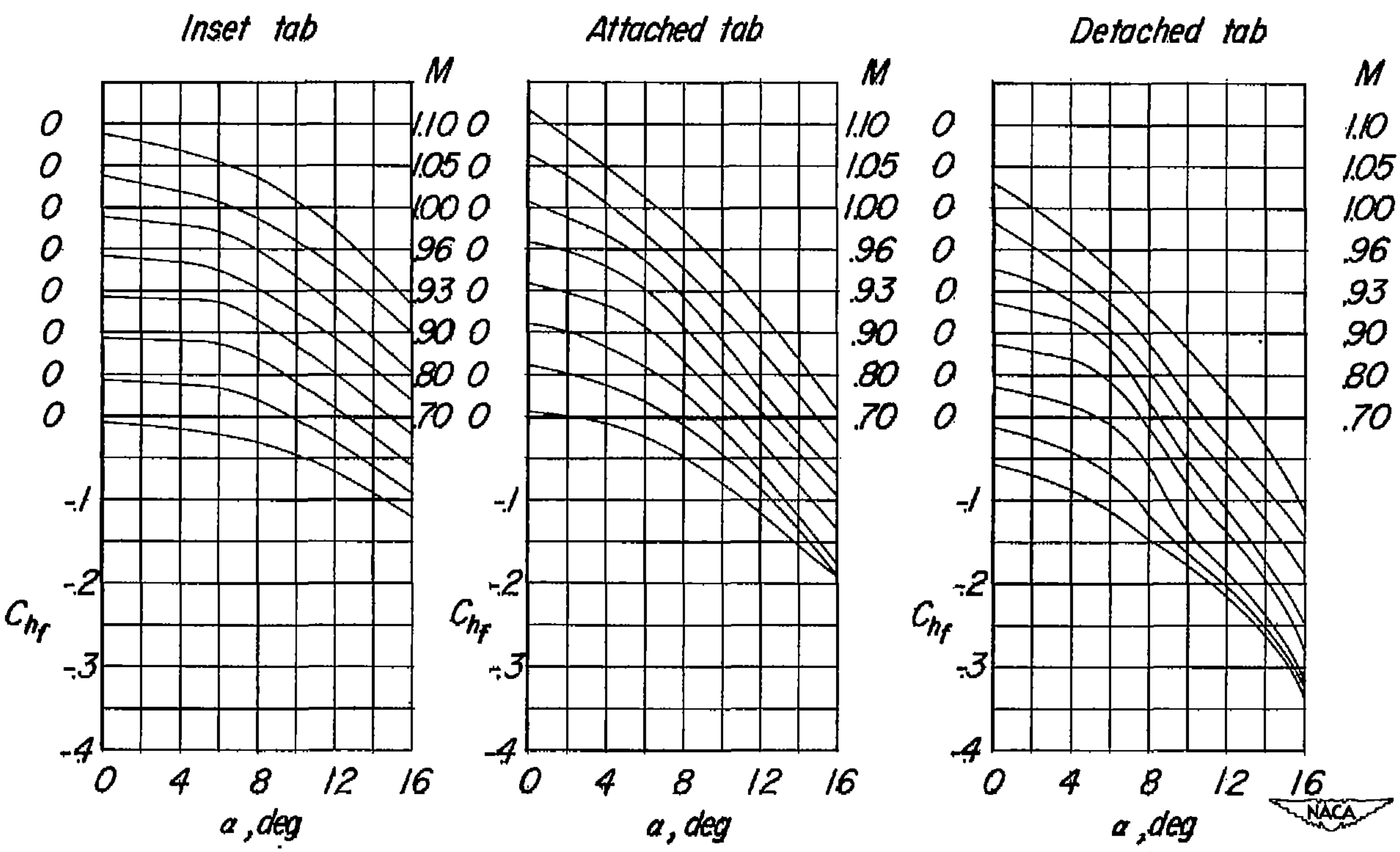


Figure 7.- Variation of flap hinge-moment coefficient with angle of attack. $\delta_f = \delta_t = 0$.

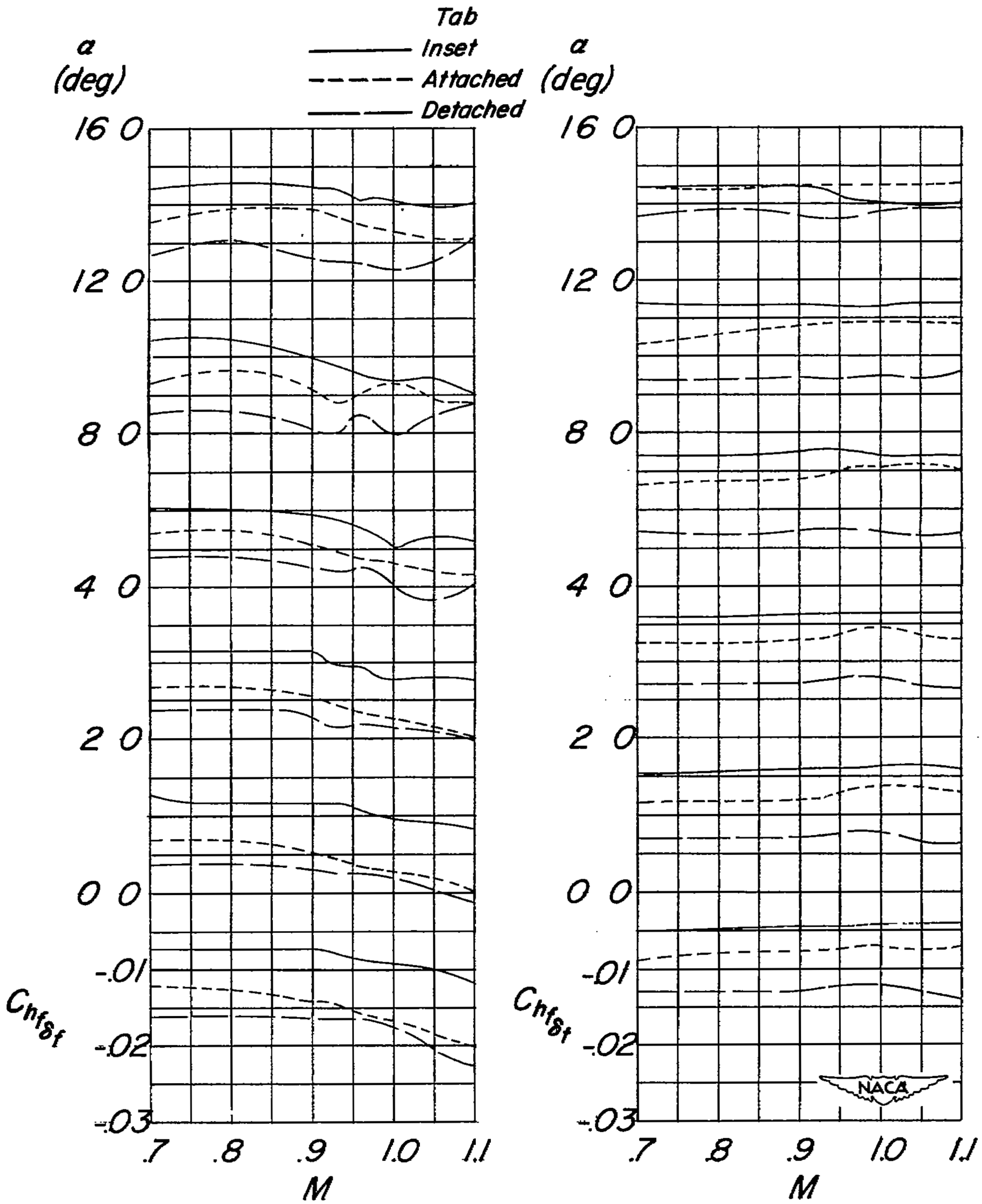
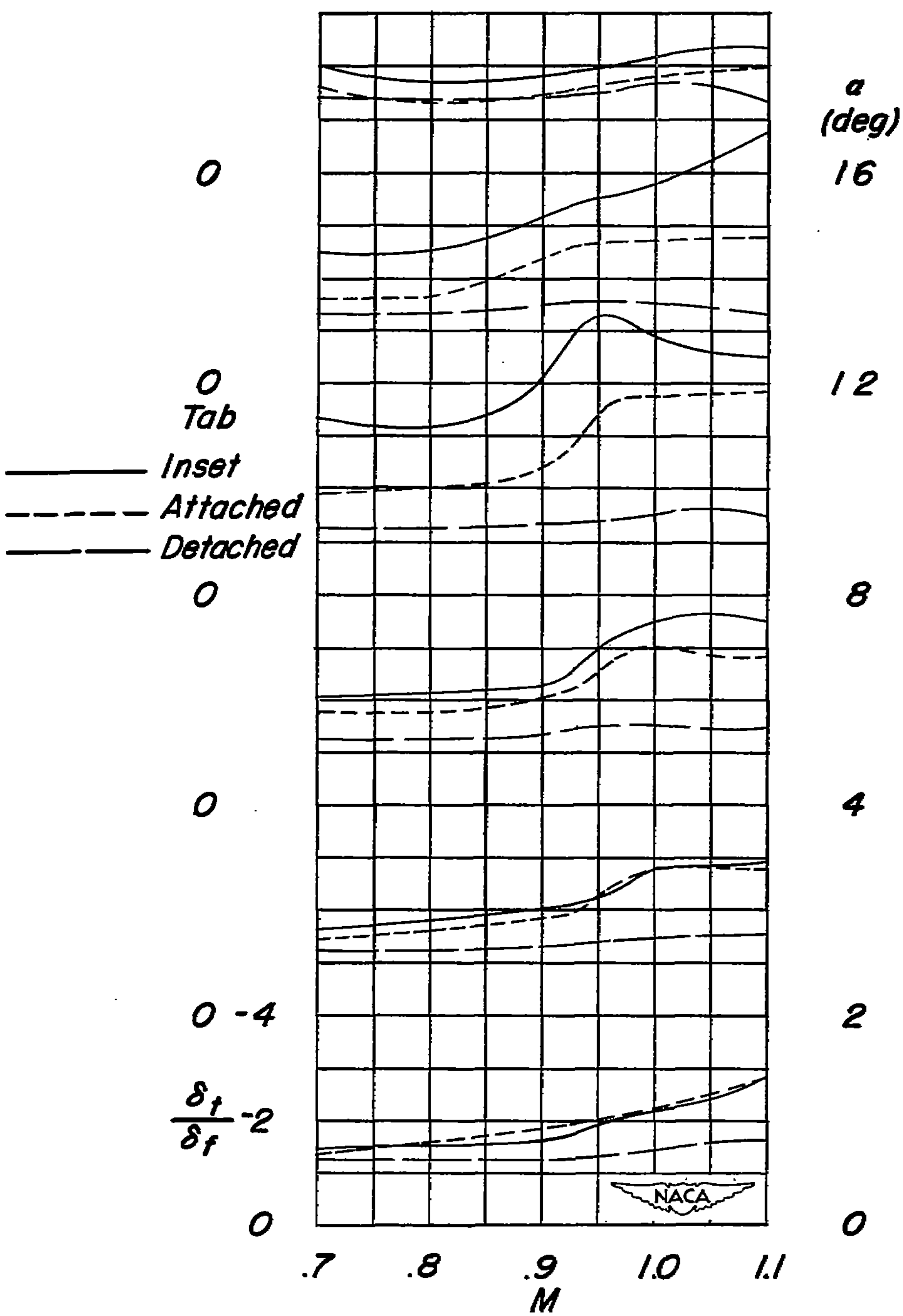
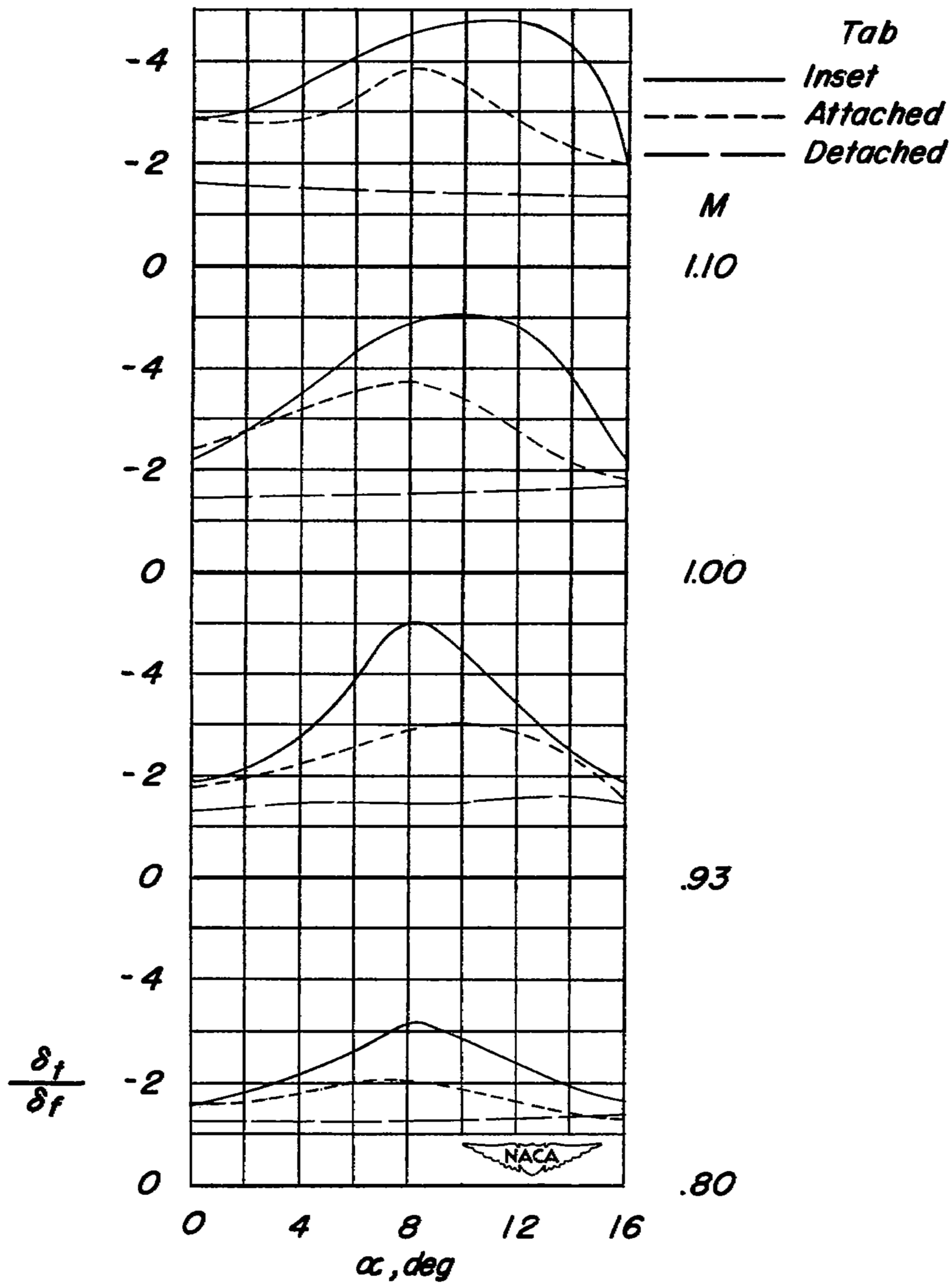


Figure 8.- Variation of the flap hinge-moment parameters with Mach number.



(a) δ_t/δ_f against M.

Figure 9.- Ratio of tab deflection to flap deflection required for $C_{h_{\delta_f}} = 0$.



(b) δ_t/δ_f against α.

Figure 9.- Concluded.

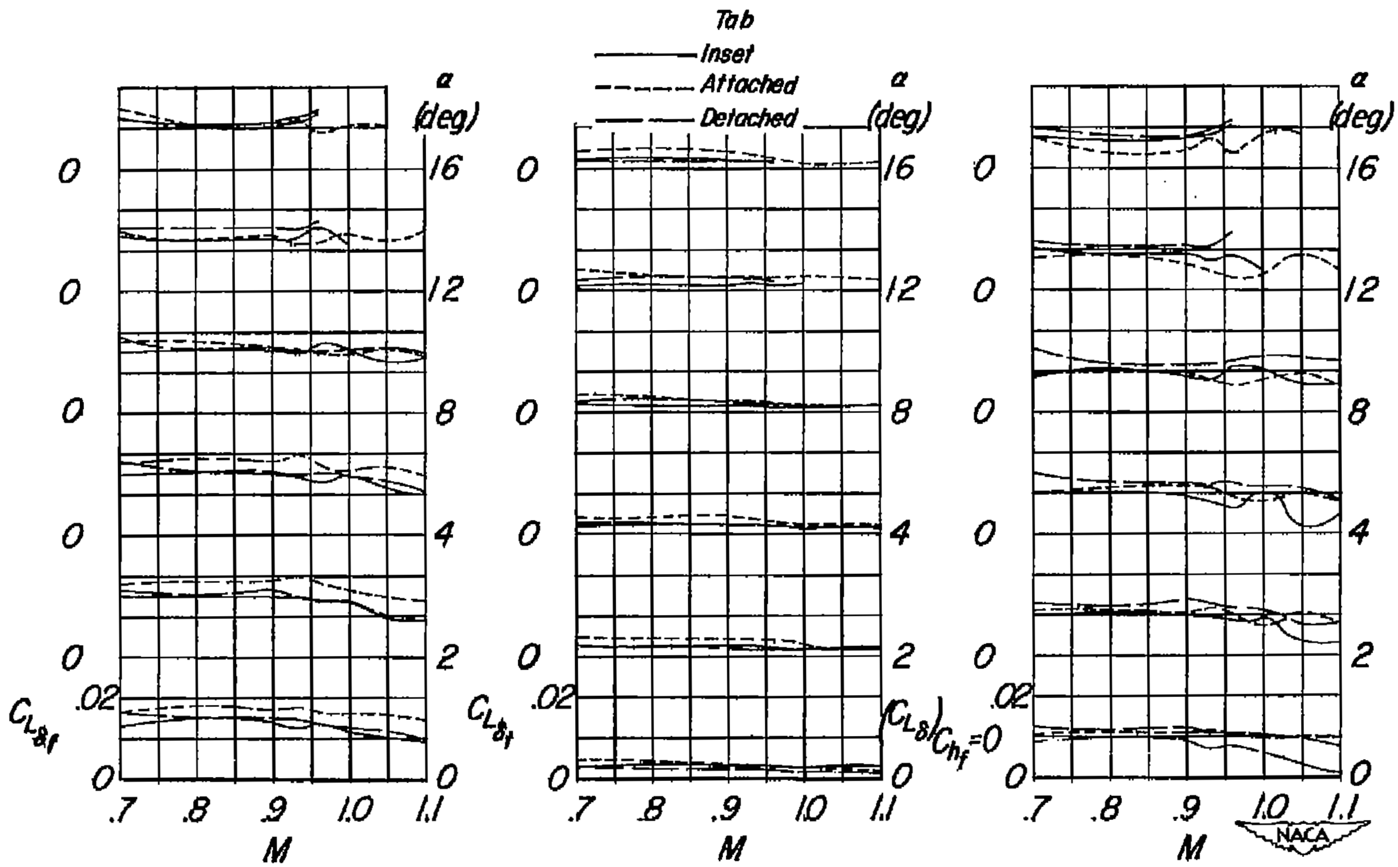


Figure 10.- Variation of the flap and tab lift parameters with Mach number.

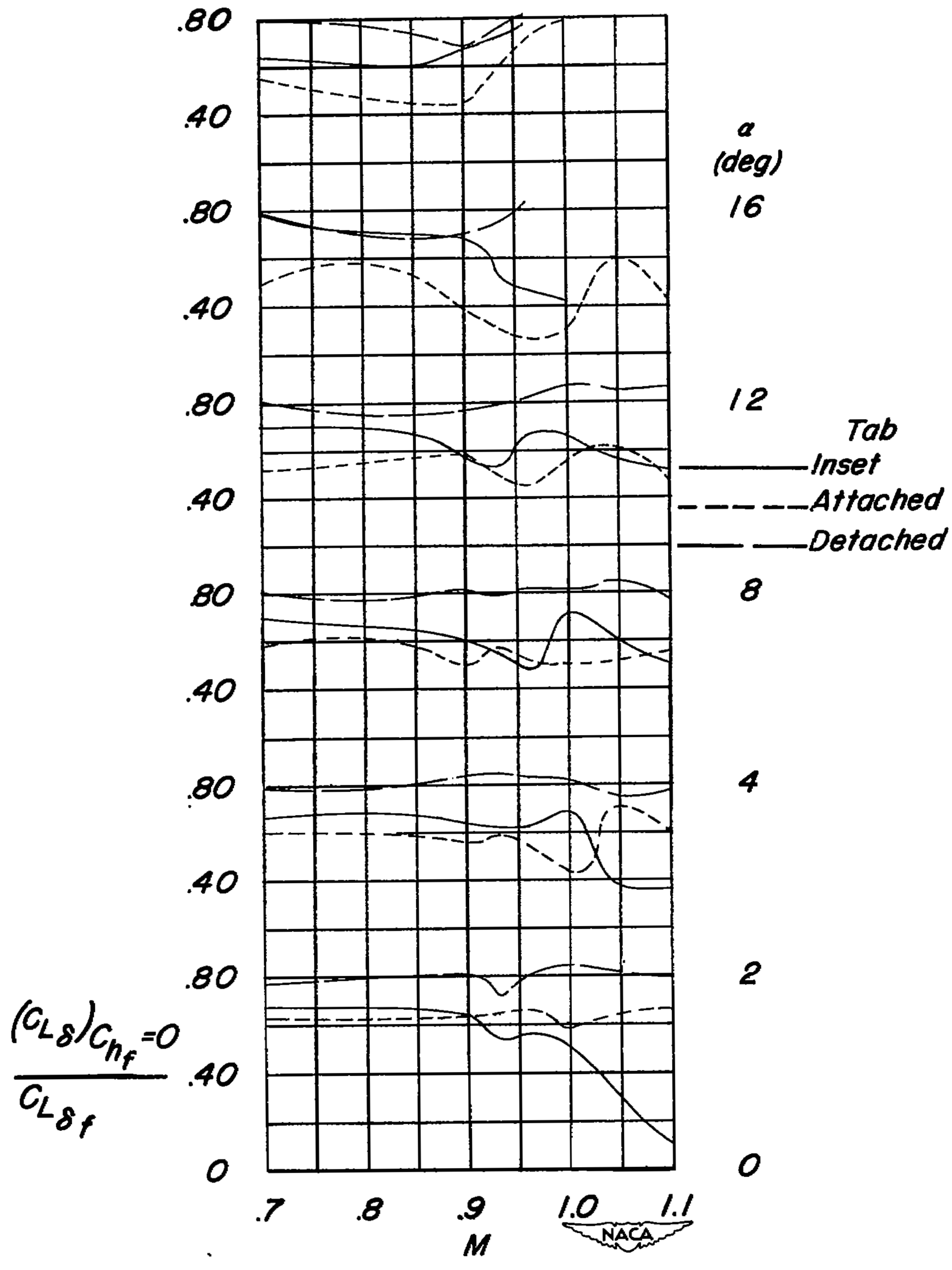


Figure 11.- Ratio of the lift parameter of the flap with tab deflected to give $C_{h_{\delta_f}} = 0$ to that of the flap with the tab undeflected.

[redacted]

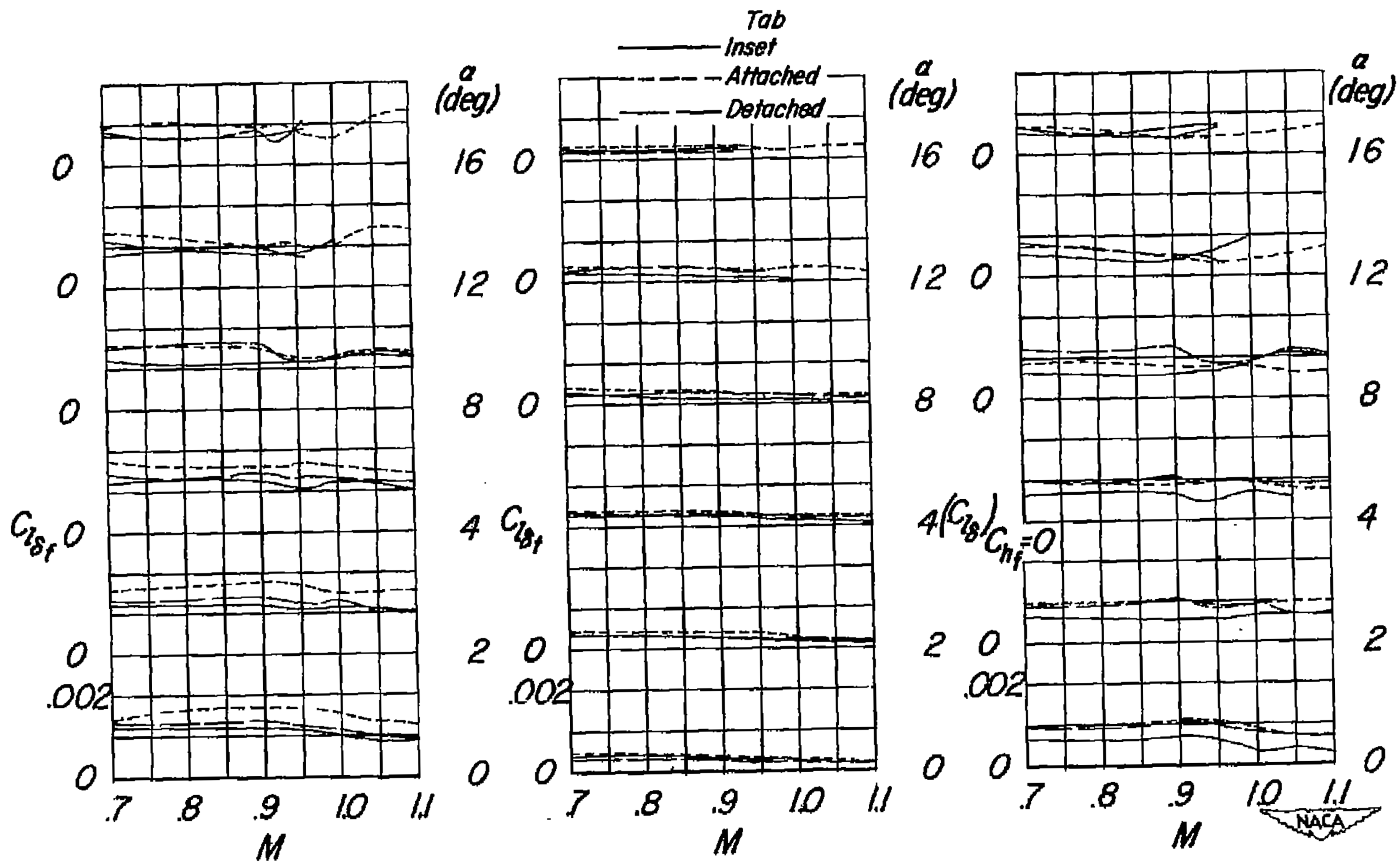


Figure 12.- Variation of the flap and tab rolling-moment parameters with Mach number.

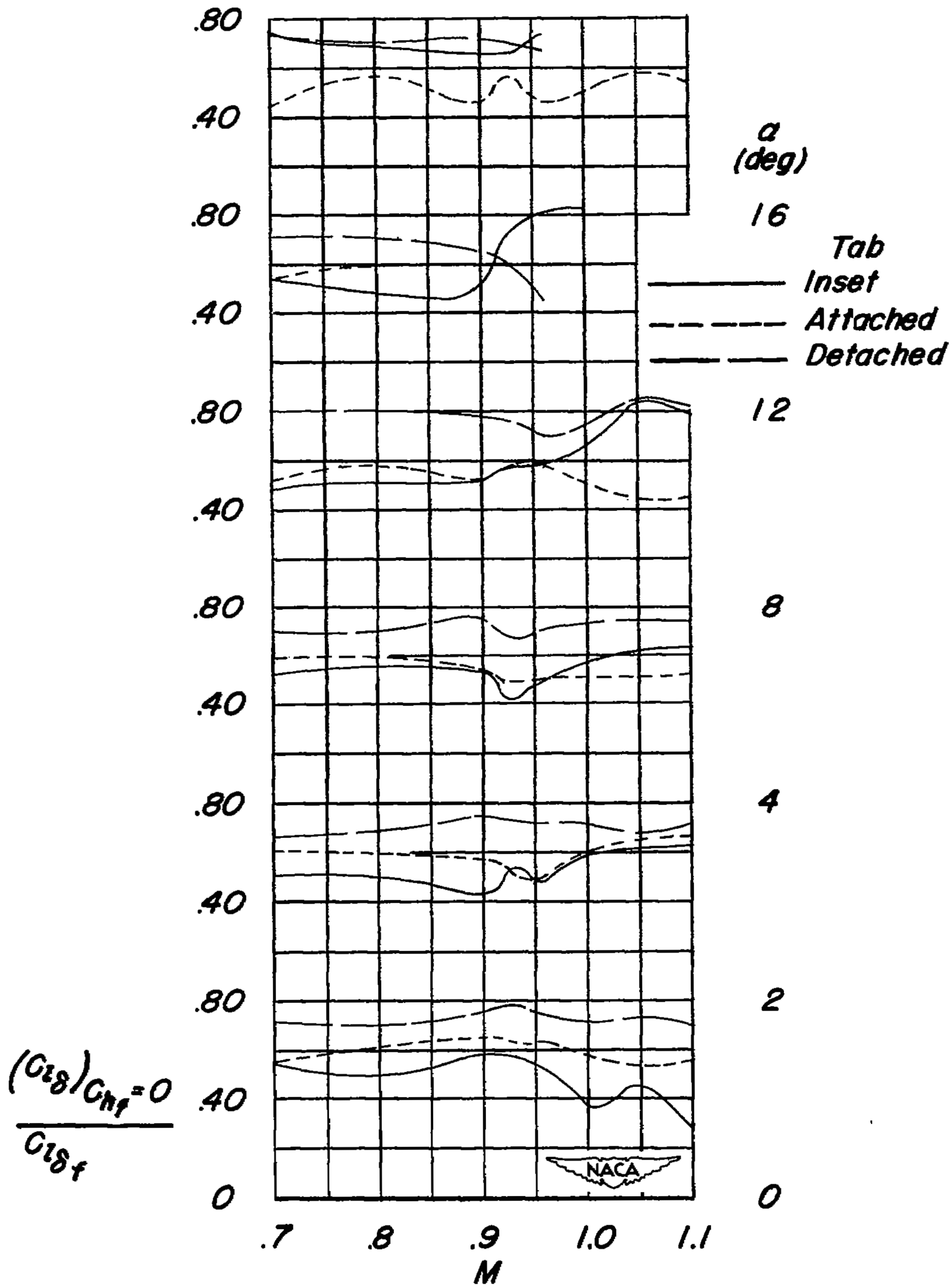


Figure 13.- Ratio of the rolling-moment parameter of the flap with the tab deflected to give $C_{h_{\delta_f}} = 0$ to that of the flap with the tab undeflected.

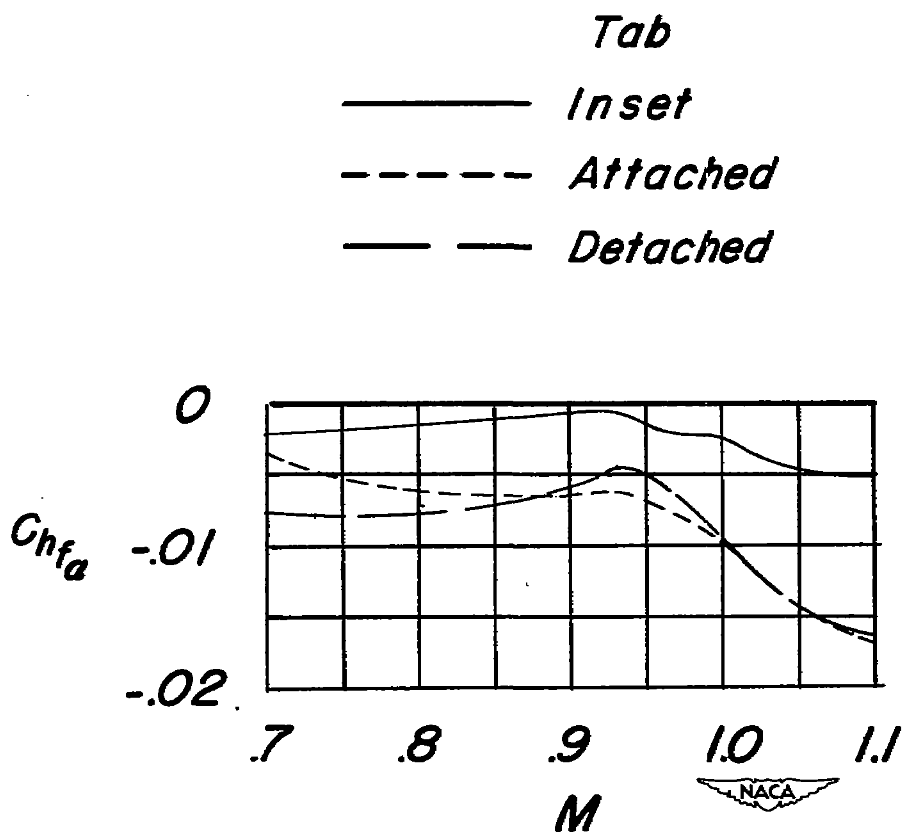


Figure 14.- Variation of the hinge-moment parameter $C_{h_{f_\alpha}}$ with Mach number. $\delta_f = \delta_t = 0^\circ$; $\alpha = \pm 4^\circ$.

[redacted]

[redacted]