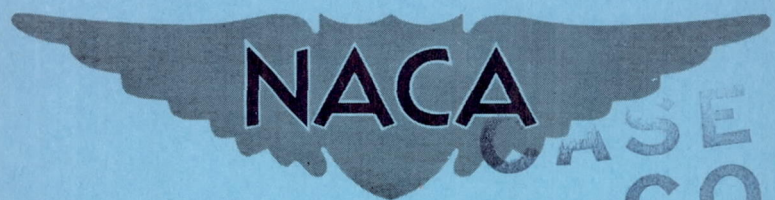


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RESEARCH MEMORANDUM

INVESTIGATION OF THE EFFECTS OF
WING AND TAIL MODIFICATIONS ON THE LOW-SPEED STABILITY
CHARACTERISTICS OF A MODEL HAVING A THIN 40° SWEEP WING
OF ASPECT RATIO 3.5

By Joseph Weil, William C. Sleeman, Jr.,
and Andrew L. Byrnes, Jr.

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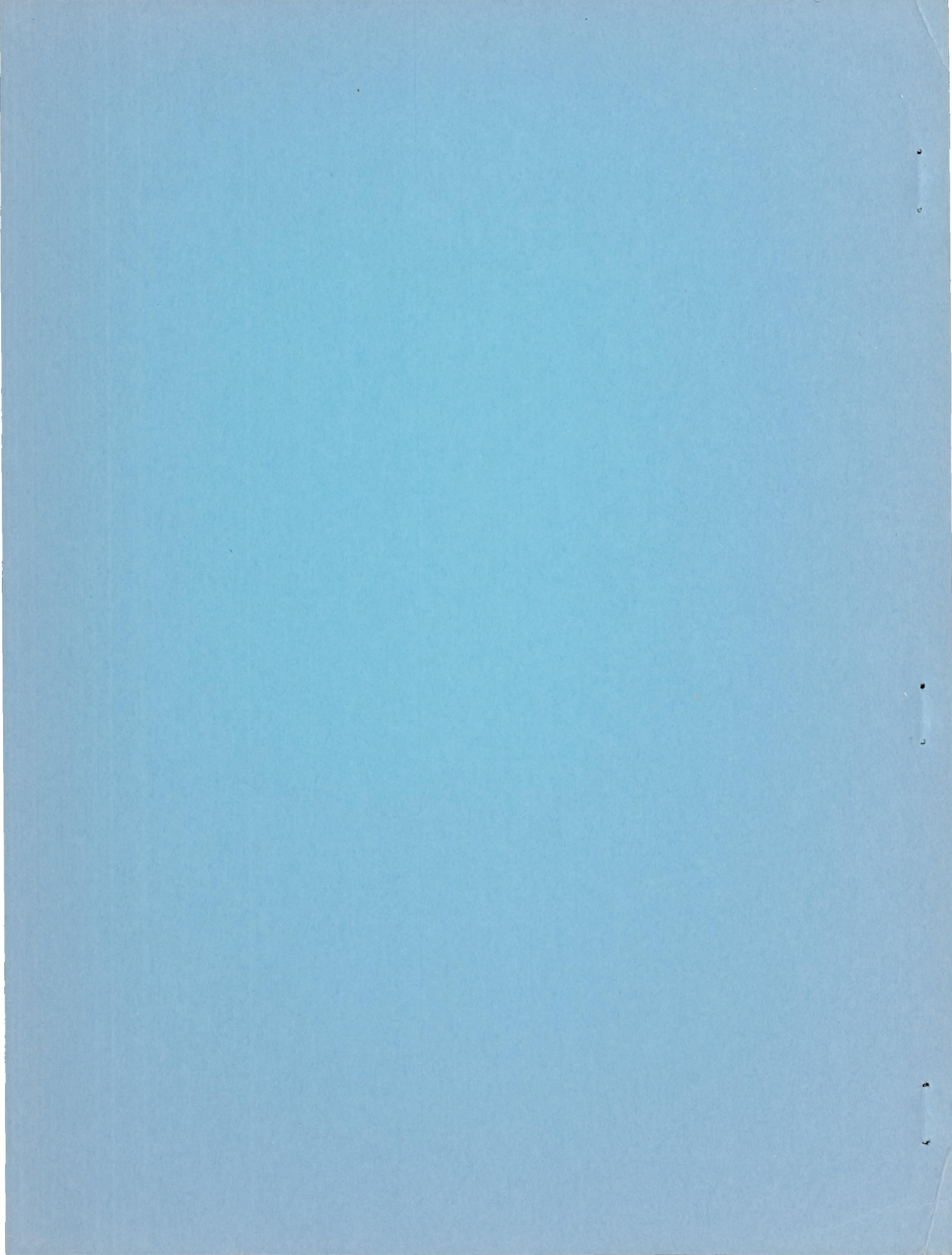
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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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April 28, 1953

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SUMMARY

An investigation has been made of the effects of wing and tail modifications on the low-speed stability characteristics of a model having a thin 40° swept wing of aspect ratio 3.5. The scope of this investigation was influenced to a large degree by the problem of obtaining a remedy for undesirable longitudinal stability characteristics observed in flight on several airplanes with similar wing geometry. Although some lateral stability and control data were obtained, this paper deals primarily with longitudinal characteristics of the model.

Longitudinal stability characteristics of the original configuration were considered good with the flaps down and slats extended; however with flaps and slats retracted, longitudinal instability was present in the angle-of-attack range between 11° and 16° . The use of either a horizontal-tail location below the fuselage center line or an optimum wing leading-edge chord-extension essentially eliminated the longitudinal instability. Neither the optimum fence configuration developed nor the highest tail position studied (0.65 semispan above the fuselage center line) were quite as effective in improving the longitudinal stability characteristics as the aforementioned modifications. By drooping the portion of the leading edge occupied by the retracted slat and chord-extension, it was possible to obtain almost the same usable lift coefficient with flaps down that was available without chord extension but with slats extended.

Enlarging the wing root inlet accentuated the undesirable longitudinal characteristics encountered with the original configuration and rendered it less responsive to modifications found beneficial with the smaller inlet. A tail location below the fuselage center line appeared to offer the most effective means of providing satisfactory longitudinal stability with the larger root inlet.

INTRODUCTION

An investigation of the effects of wing and tail modifications on the low-speed stability characteristics of a model having a thin 40° swept wing of aspect ratio 3.5 has been made in an attempt to find means of improving the longitudinal stability characteristics observed in flight on several airplanes with similar wing geometry.

Information is also presented to show effects of wing modifications (such as fences and leading-edge chord-extensions) and changes in horizontal-tail location on the stability characteristics of the model. Longitudinal-stability data were also obtained with an enlarged root inlet with several wing and tail modifications.

SYMBOLS

The system of stability axes employed, together with an indication of the positive forces, moments, and angles is presented in figure 1. The symbols used in this paper are defined as follows:

| | |
|-------|--|
| C_L | lift coefficient, $Lift/qS$ |
| C_X | longitudinal-force coefficient, X/qS |
| C_Y | lateral-force coefficient, Y/qS |
| C_l | rolling-moment coefficient, L/qSb |
| C_m | pitching-moment coefficient, $M/qS\bar{c}$ |
| C_n | yawing-moment coefficient, N/qSb |
| X | longitudinal force along X-axis (Drag = $-X$), lb |
| Y | lateral force along Y-axis, lb |
| Z | force along Z-axis (Lift = $-Z$), lb |
| L | rolling moment about X-axis, ft-lb |
| M | pitching moment about Y-axis, ft-lb |
| N | yawing moment about Z-axis, ft-lb |

| | |
|----------------|--|
| q | free-stream dynamic pressure, $\frac{\rho V^2}{2}$, lb/sq ft |
| σ | tail effectiveness parameter, $\frac{(\partial c_m / \partial i_t)_{\text{wing on}}}{(\partial c_m / \partial i_t)_{\text{max wing off}}}$ |
| S | wing area, sq ft (excluding area of inlet ducts) |
| \bar{c} | wing mean aerodynamic chord, ft |
| c | local streamwise chord, ft |
| b | wing span, ft |
| V | free-stream velocity, ft/sec |
| A | aspect ratio, b^2/S |
| ρ | mass density of air, slugs/cu ft |
| α | angle of attack of fuselage center line, deg |
| β | angle of sideslip, deg |
| ϵ | effective downwash angle at tail, deg |
| Λ | angle of sweep of quarter-chord line, deg |
| i_t | angle of incidence of stabilizer with respect to fuselage center line (positive when trailing edge down), deg |
| δ_{a_L} | left-aileron deflection (positive with trailing edge down), deg |
| δ_f | flap deflection, deg |
| δ_s | slat deflection, deg |
| δ_1 | deflection of leading edge between 48 and 65 percent semispan, deg |
| δ_2 | deflection of leading edge between 65 and 94 percent semispan, deg |

Subscripts:

β denotes partial derivative of a coefficient with respect to sideslip; for example, $C_{l\beta} = \frac{\partial C_l}{\partial \beta}$

max maximum

MODEL AND APPARATUS

Description of Model and Airplane

Details of the physical characteristics of the model are presented in figures 2 and 3 and table I.

Inasmuch as no provision was made to allow air flow through the model inlet, the forward portion of the inlet was faired to afford a good aerodynamic shape. (See fig. 2.)

Various modifications to the wing and tail geometry were made to study their effects on the longitudinal stability characteristics of the proposed configuration.

Tail modifications.- Six alternate tail locations were investigated in addition to the original position. (See fig. 4.) The primary variable in this study was tail height; however, some increase in tail length occurred when the horizontal tail was raised on the swept vertical tail.

Wing modifications.- A fairly systematic series of fence and leading-edge chord-extension configurations was investigated. The scope of this study is indicated in figures 5 and 6. Two segments of the portion of wing originally occupied by the retracted slat (including the chord-extensions) were drooped various amounts, pivoting about the lower wing surface at the 15-percent-chord station. (See fig. 7.)

In order to determine the effect of inlet size on the various aerodynamic characteristics, a glove conforming to a large inlet was fashioned out of soft wood and placed over the original inlet. The differences between the two inlet configurations are shown in figure 8. Some of the most beneficial fence and chord-extension configurations investigated with the smaller inlet were also studied with the wing having the larger inlet. Additional modifications attempted with the larger inlet alone consisted of a large fence at the outboard edge of the inlet and a spoiler on the inlet nose (fig. 8).

Flow Studies

The effects of wing modifications on the flow over the upper wing surface were obtained from photographs of wool tufts placed on the wing surface.

The effects of wing modifications on the flow field at the tail plane were determined by use of the tuft grid described in reference 1. For these studies, the tail surfaces were replaced by unswept $\frac{1}{8}$ -inch rods to indicate the position occupied by the vertical tail and also the proposed and extreme horizontal-tail positions investigated. The tuft grid was placed approximately 1.5 wing semispans behind the wing quarter-chord line and extended over the tunnel cross section except for the supporting frame. Photographs of the tuft grid were obtained with a camera mounted 75 feet downstream of the grid and approximately on the tunnel center line. Further details of the tuft-grid technique can be found in reference 2.

TESTS AND CORRECTIONS

Tests

The tests were conducted in the Langley 300 MPH 7- by 10-foot tunnel at a dynamic pressure of 40 pounds per square foot which, for average test conditions, corresponds to a Mach number of about 0.17 and a Reynolds number of approximately 2.0×10^6 , based on the wing mean aerodynamic chord of 1.67 feet.

The lateral-stability derivatives of the model were determined from tests through the angle-of-attack range at sideslip angles of $\pm 5^\circ$.

In all instances the tricycle landing gear was in the extended position when the trailing-edge flaps were deflected. Unless otherwise noted, a tail height of 25 percent wing semispan above the fuselage center line was used.

Corrections

The angle-of-attack, drag, and pitching-moment results have been corrected for jet-boundary effects, computed on the basis of unswept-wing theory by the method of reference 3. Independent calculations have shown that the effects of sweep on these corrections are negligible.

No systematic tare evaluation has been made. It is felt, however, on the basis of limited data and past experience that appreciable tare effects were present only in minimum drag and longitudinal trim. It was estimated from reference 4 that the blockage correction to the measured dynamic pressure was of the order of 1 percent. This correction has not been applied to the data.

PRESENTATION OF RESULTS

The figures presenting the results are grouped as follows:

Longitudinal Characteristics

| | Figure |
|--|-----------|
| Basic longitudinal data: | |
| Wing off | 9 |
| Wing on | 10 and 11 |
| Analysis | 12 |
| Effect of slats | 13 |
| Modifications to proposed configuration: | |
| Effect of tail height | 14 to 16 |
| Effect of wing fences | 17 to 20 |
| Effect of chord-extensions | 21 to 26 |
| Effect of drooped chord-extensions | 27 to 31 |
| Characteristics with enlarged root inlet: | |
| Basic data | 32 and 33 |
| Modifications | 34 to 36 |
| Tuft-grid and surface-tuft photographs | 37 to 41 |

Lateral Characteristics

| | |
|---|-----------|
| Aileron characteristics | 42 to 44 |
| Lateral-stability derivatives | 45 and 46 |

DISCUSSION

Basic Longitudinal Characteristics

The data of figure 10 with $\delta_f = 0^\circ$ indicate longitudinal stability characteristics at about $\alpha = 10^\circ$ which might cause the airplane

to be uncontrollable and to pitch up to undesirably high angles of attack in certain flight conditions. For this configuration, the cause of the higher-lift instability is clearly traceable to the extremely large increase in $\partial\epsilon/\partial\alpha$ (fig. 12) arising from the inward and upward displacement of the center of wing vorticity. (See tuft-grid photographs, fig. 37.) The untapered horizontal-tail plan form also places a large portion of the tail outboard in a region of higher downwash slope. It is perhaps of some interest that the fuselage alone contributes only about 0.14 to $\partial\epsilon/\partial\alpha$ in the range of greatest instability.

At the highest angles of attack the stabilizer effectiveness, as indicated by the parameter σ , is reduced to about 50 to 75 percent of the maximum wing-off value (fig. 12). This adverse stability effect, however, is more than counteracted by the large stabilizing decrease in downwash slope.

With the flaps deflected 40° and slats extended, acceptable stability characteristics are indicated. (See fig. 11.) The desirable flow characteristics obtained over the tip wing sections in this configuration are shown in figure 38.

A short study was made to determine the effect of the slat and slat modifications on the lift coefficient attainable at moderately high angles of attack with the flaps deflected 40° . It is seen (fig. 13) that the slat was very effective in delaying the wing stall and contributed as much as 0.3 to the available lift coefficient at moderately high angles of attack. The data of figure 13 indicate, furthermore, that the lift characteristics are essentially unaffected by slat gap. Reducing the slat deflection from 21.7° to 14.5° effected only a slight reduction in maximum lift but produced less desirable longitudinal stability characteristics above $\alpha = 14^\circ$.

Modifications Designed to Improve

Longitudinal Characteristics

The longitudinal-stability difficulties encountered with the basic configuration, $\delta_f = 0^\circ$, were considered serious enough to warrant the study of various means for alleviating the pitch-up tendency. In the interpretation of the effects of the modifications it was felt that, although the variation of C_m with C_L provides a direct indication of the stability characteristics below stall, it usually does not produce data in a convenient form for a quantitative evaluation of the pitch-up that occurs at or near the stall. The motion associated with this type of instability can produce high angular acceleration of the airplane without necessarily causing excessive load factors and is

considered very undesirable by pilots. It appeared that a linear variation of C_m with α on the other hand would result in close to optimum stability characteristics with little overshoot or pitch-up apt to occur in either maneuvers or 1 g flight near stall and this attainment is the goal of the various modifications.

Although the data are presented about the rather far forward center-of-gravity location (0.15 \bar{c}), every attempt will be made to discuss the results in a fairly general manner.

Effect of tail height.- The effect of relocating the horizontal tail is shown in figures 14 to 16. Raising the tail to 36 percent $b/2$ above the fuselage center line actually resulted in increased severity of the break although the instability was delayed to a slightly higher lift coefficient. With the tail located on top of the vertical tail (65 percent $b/2$ above the fuselage center line) the lift coefficient at which pitch-up might be expected is delayed to $C_{L_{max}}$, but this configuration might still produce undesirable overshoot at the stall. The instability above $\alpha = 17^\circ$ for the highest tail location (fig. 14) results from the unfavorable downwash variation encountered as the tail approaches the plane of the rolled-up wing vortices. (See tuft-grid photographs, fig. 37.)

Lowering the tail to 19 percent $b/2$ above the fuselage center line or use of an inverted vee tail (root and tip chords 19 and 2 percent semispan above fuselage center line, respectively, fig. 4) produced little beneficial effect on the pitch-up tendency (see fig. 15). When the tail was lowered to 7 percent semispan below the fuselage center line, however, the longitudinal stability seems acceptable throughout the angle-of-attack range probably because the tail is emerging from the wake in this condition.

With flaps deflected 40° and slats extended, no serious longitudinal stability problems would appear to exist for any of the raised tail locations although some pitch-up tendency is indicated for the highest tail location at angles of attack greater than 20° . (See fig. 16.) No force data were obtained for the lowest tail investigated with flaps deflected. The tuft-grid photographs (fig. 38), however, show very unsteady flow in the region of the lowest tail which might indicate a buffet problem.

Use of fences.- Fences have frequently been used in the past to improve the longitudinal stability characteristics of swept wings. A number of fence configurations were studied on the subject model (fig. 5) and the results are shown in figures 17 to 20. With the flaps undeflected, fence 2 was located at various spanwise stations from 65 to 80 percent $b/2$. The data (fig. 17) indicate that the high-lift longitudinal stability was considerably improved by the fence at all

locations. None of the fence installations was successful in producing a configuration free from pitch-up in the angle-of-attack range below 20° ; however, a fence location at 75 percent $b/2$ appeared slightly superior to some of the other locations.

The sensitivity of the pitching-moment characteristics to fence size was determined for the 75-percent - $\frac{b}{2}$ location. (See fig. 18.)

It is seen that there are relatively minor changes in stability brought about by using a fence larger than fence 4. This result appears to be reasonable in view of the leading-edge separation encountered on thin swept wings. A small inboard leading-edge spoiler added as a means of providing a sharp leading edge (fig. 5) and used in conjunction with fence 2 improved the over-all stability somewhat (fig. 18). Several multiple-fence installations were investigated in the flap-retracted condition (fig. 19). The results showed that in neither instance did the use of two fences add to the gains obtained through use of a single well-placed fence. (See figs. 17 and 19.)

With flaps and slats extended it is seen (fig. 20) that the lift coefficient in the angle-of-attack range between 12° and 16° is reduced by from 0.04 to 0.08 when fences 1 and 2 are used; moreover, the gains in ΔC_L attributable to slat deflection in the same angle-of-attack range are about halved. The multiple fences did not change the already satisfactory pitching-moment variations obtained with slats extended. In the high angle-of-attack range with slats retracted, however, the use of fences 1 and 2 did improve the longitudinal stability.

Undrooped chord-extensions. - Another means of securing improved high-lift longitudinal stability on thin-, swept-wing airplanes is afforded by the use of leading-edge chord-extensions. A systematic investigation of various chord-extension configurations (see fig. 6) was undertaken and the results are presented in figures 21 to 26. The effects of varying the inboard end of a $0.10c$ extension with $\delta_f = 0^\circ$ are shown in figure 21. The improvement in the pitching-moment characteristics is similar to, but somewhat greater than, that obtained with fences at a given spanwise location (cf. figs. 21 and 17). This is particularly true of the 65- and 70-percent - $\frac{b}{2}$ inboard-end locations where the variations of C_m with both α and C_L indicate essentially no pitch-up tendency in the practical angle-of-attack range ($\alpha < 20^\circ$).

It is generally conceded that the gains derived from use of chord-extensions are dependent to a large extent on the action of the vortex shed from the inboard edge, which is of such direction as to retard the spread of low-energy air over the outboard wing sections and, consequently, maintain a greater proportion of the total lift over the tip.

Thus, the effects of the chord-extension in some respects are the aerodynamic counterpart of the physical barrier created by the use of a fence. This line of reasoning is illustrated by a comparison of photographs made of surface tufts with and without a chord-extension (cf. figs. 37 and 39).

From figure 21 it was evident that 65 to 70 percent $b/2$ represented the optimum inboard extension location for the configuration under study. A further investigation was made to determine the effect of spanwise extent of the chord-extension with the inboard end fixed at 65 percent $b/2$. The results (fig. 22) show that an outboard location of 80 percent $b/2$ did not produce the abrupt instability at $\alpha = 24^\circ$ that existed when the extension was carried to 94 percent $b/2$. In the practical angle-of-attack range, however, there would appear to be very little difference between the two installations, particularly with a large initial static margin present. Moving the outboard end of the extension in to the 75-percent- $\frac{b}{2}$ location resulted in longitudinal stability characteristics that were definitely inferior (above $\alpha = 10^\circ$) to those for the larger span extensions previously discussed. A similar comparison for an inboard location of 70 percent $b/2$ showed that a span of 0.24 $b/2$ (70 to 94 percent $b/2$) produced somewhat more desirable results than a span of 0.10 $b/2$ (cf. figs. 21 and 22).

Increasing the overhang of the leading-edge chord-extension from 0.10c to 0.15c produced very little effect up to $\alpha = 20^\circ$ but delayed and reduced the magnitude of the abrupt pitch-up tendency at very high angles of attack. (See fig. 23.)

A fairly complete set of data was obtained for one of the more promising chord-extension configurations evolved (extension of 0.10c from 70 to 94 percent $b/2$) and the results are presented in figures 24 and 25. A comparison of these results with those obtained for the original configurations (figs. 10 and 11) are presented in figure 26. It is evident that for $\delta_f = 0^\circ$ the gains in stability in the angle-of-attack range from 12° to 16° are less attributable to a more rearward wing-fuselage aerodynamic center than to the reduction in $\partial\epsilon/\partial\alpha$. The stability characteristics with flaps deflected 40° are about equally satisfactory with either the original extended slats or chord-extensions.

Drooped chord-extensions.- In order to realize maximum landing performance, it is desirable to obtain the highest possible lift at reasonable angles of attack (12° to 16°). The lift characteristics pertinent to the landing problem have been summarized in figure 31; the values are for trimmed flight about the 0.15 \bar{c} center-of-gravity location. When a chord-extension was used in combination with $\delta_f = 40^\circ$, the usable

$C_{L_{max}}$ was about 0.15 less than that obtained for the original configuration with slats extended. In order to increase the usable $C_{L_{max}}$, it was decided to droop the area forward of $0.15c$ and outboard of the 48-percent $-\frac{b}{2}$ station (including the chord-extension) by various amounts (see fig. 7). Note that the region of the wing drooped corresponded to the portion of the wing occupied by the retracted slat. It is apparent from figure 31 that a leading-edge droop of 10° provided substantially the same $C_{L_{max}}$ as with slats extended but at the expense of somewhat deteriorated higher-lift stability characteristics (fig. 27). Drooping the chord-extension alone weakened the stability and produced essentially no gain in $C_{L_{max}}$. (See fig. 28.)

The effect of leading-edge droop was obtained with flaps neutral (fig. 30) on the assumption that a small amount of permanent droop could be tolerated in the high-speed condition. It is evident that even 5° of leading-edge droop seriously reduced the effect of the chord-extension on the stability in the angle-of-attack range between 10° and 12° .

Longitudinal Stability Characteristics With Enlarged Inlet

Basic configuration.- It is seen from figure 32 that increasing the size of the root inlet does not alter the angle of attack for instability. However, the model with the original inlet was unstable in the angle-of-attack range from 11° to 16° , primarily because of the extremely high values of downwash slope encountered. The instability of the model with the larger inlet persisted to $\alpha = 19^\circ$ because of the pronounced unstable tendency of the wing-fuselage combination in conjunction with the later occurrence of peak $\partial\epsilon/\partial\alpha$. (See figs. 32 and 33.)

The more unfavorable wing-fuselage pitching-moment characteristics obtained with the larger inlet probably stem from two sources. It would appear from a comparison of the tuft photographs in figures 37 and 41 that the vortices shed from the outboard edge of the large inlet might be responsible for an accentuation of spanwise boundary-layer flow which promotes earlier tip separation. At $\alpha = 13^\circ$ and 17° , although the flow over the most of the outboard wing sections is almost completely stalled with either inlet, the flow near the leading edge appears to be somewhat better for the smaller inlet. In addition to this indirect effect of the larger inlet, a further inspection of the tuft photographs shows that the larger inlet, acting much like a low-aspect-ratio wing, remained unstalled even at very high angles of attack and this effect is probably responsible for a direct destabilizing increment in lift of perhaps 0.1 to 0.2 C_L .

Modifications to model.- The results of some attempts to improve the pitching-moment characteristics of the model with the larger inlet are presented in figures 34 to 36. A chord-extension from $0.65b/2$ to $0.94b/2$ (which was so effective when used with the smaller inlet) reduced the severity of the pitch-up tendency in the angle-of-attack range from 11° to 18° (fig. 34), but the characteristics indicated are far from desirable. Lowering the tail to 19 percent $b/2$ above the fuselage reference line with chord-extensions (fig. 35) caused no additional improvement in the stability characteristics. The addition of either a large fence at the outboard edge of the inlet or a spoiler located 2 inches behind the inlet leading edge for the model equipped with chord-extensions actually produced less desirable pitching-moment characteristics than were obtained with chord extensions alone. (See fig. 34.) The use of fences 1 and 2 at 75 and 40 percent $b/2$, respectively, had little effect on the characteristics of the basic model with the larger inlet.

Placing the horizontal tail 7 percent $b/2$ below the fuselage center line resulted in pitching-moment characteristics that probably would be acceptable (fig. 36).

Aileron Characteristics

The results of aileron-effectiveness tests are presented in figures 42 and 43 for the original configurations and for the wing with chord-extensions from 70 to 94 percent $b/2$. The lateral-control data for the basic configuration indicate that about two-thirds of the low-lift effectiveness is maintained in the high angle-of-attack range. The data of figure 42(b) also show an abrupt roll-off tendency on the left wing at the initiation of stall with flaps deflected, which might indicate extreme sensitivity to small model asymmetry in this attitude. This same sensitivity is also shown with flaps up (fig. 42(a)) by the presence of double-value points at $\alpha = 13^\circ$ for the up-aileron settings.

When the wing was modified with chord-extensions from 70 to 94 percent $b/2$ the abruptness of roll-off at stall was considerably reduced for the flaps-deflected condition (without slats), and no unstable flow conditions, as indicated by double-value points, were observed in the flaps-retracted condition. (See fig. 43.) The effects of chord-extensions on the aileron control effectiveness at several angles of attack are shown in figure 44. The use of chord-extensions did not alter the aileron effectiveness much with flaps deflected or at low angles of attack with flaps neutral, but the effectiveness of the down-going aileron is improved with flaps neutral at very high angles of attack.

Lateral-Stability Derivatives

$C_{n\beta}$.- For all complete-model configurations investigated the directional stability is high (generally greater than 0.004) below the stall. (See figs. 45 and 46.) The tail contribution to $C_{n\beta}$ was estimated to be 0.0062 by the method of reference 5 and lift-effectiveness charts of reference 6. This compares with 0.0052 from wing-off tests at zero lift and an average value of 0.0065 with flaps down and drooped chord-extensions. The greater effectiveness with the wing on is probably attributable to stabilizing sidewash effects. There was not much effect of either chord-extension configuration on $C_{n\beta}$ below the stall. At the stall a large decrease in weathercock stability was always present; however, a small degree of positive stability was retained at the highest test angle of attack. The loss in effectiveness at high angles of attack is probably traceable to the blanketing of the vertical tail by fuselage separation inasmuch as the wing-off configuration showed a similar, although more gradual, decrease in $C_{n\beta}$ with α . (See fig. 45.)

$C_{l\beta}$.- In the high angle-of-attack range and with flaps down, the drooped chord-extensions (fig. 46) would appear to prevent the occurrence of neutral or slightly negative dihedral effect which was present for the original slats-out condition and with the undrooped chord-extension (fig. 45(b)). In the flaps-neutral condition the use of the chord-extension increased $C_{l\beta}$ in the higher angle-of-attack range. (See fig. 45(a).)

CONCLUSIONS

An investigation of the effects of wing and tail modifications on the low-speed stability characteristics of an airplane configuration having a thin 40° swept wing of aspect ratio 3.5 indicated the following conclusions:

1. Longitudinal instability was present for the basic model configuration with flaps neutral at angles of attack between 11° and 16° . With flaps down and slats extended the longitudinal stability was considered good.
2. The use of slats with flaps down contributed as much as 0.3 to the lift coefficient at moderately high angles of attack and was to a large extent responsible for the desirable longitudinal stability characteristics. Slat gap was found to be unimportant for this configuration.

3. Raising the horizontal tail to 65 percent semispan above the fuselage center line (highest tail position investigated) delayed the onset of instability from an angle of attack of 11° to 17° . A tail location of 7 percent semispan below the fuselage center line resulted in acceptable pitching-moment characteristics with flaps neutral throughout the test angle-of-attack range.

4. Although the longitudinal stability characteristics at higher angles of attack were considerably improved by the use of outboard wing fences, none of the fence installations were successful in producing a configuration free from flat spots or instability below an angle of attack of 20° . In no instance did the gains obtained with two fences add to the improvement obtainable through use of a single well-placed fence.

5. Leading-edge chord-extensions were more effective in improving the pitching-moment characteristics than fences. An extension of 0.10 local chord extending from 0.70 to 0.94 semispan, for example, essentially eliminated the pitch-up tendency.

6. Replacing the wing slats with leading-edge chord-extensions in the landing condition resulted in a loss of 0.15 lift coefficient in the usable range of landing attitudes. Drooping that portion of the leading edge occupied by the retracted slat and the chord-extension 10° provided substantially the same lift characteristics as with slats extended and deflected 21.7° , at the expense, however, of somewhat deteriorated higher-lift stability characteristics.

7. With an enlarged wing root inlet and flaps neutral, the attitude at which longitudinal instability occurred was not altered, but the instability was extended over a considerably greater angle-of-attack range than with the smaller inlet. The use of a leading-edge chord-extension reduced the severity of pitch-up tendency in the angle-of-attack range from 11° to 18° but the resultant characteristics would still appear unacceptable. The addition of various wing fences or spoilers located near the inlet leading edge had no beneficial effect. Lowering the horizontal tail to a position 7 percent semispan below the fuselage center line produced what would appear to be acceptable pitching-moment characteristics throughout the lift range with flaps neutral.

8. About two-thirds of the low-lift aileron effectiveness is maintained at the highest angles of attack for the basic configuration. The use of chord-extensions did not materially alter the aileron effectiveness but improved the flow stability near the stall (flaps neutral) and reduced the abruptness of roll-off with flaps deflected.

9. In the higher angle-of-attack range and with flaps down, the drooped chord-extensions prevented the occurrence of neutral or slightly

negative dihedral effect which was present for the original slats-out condition and with undrooped chord-extensions.

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TABLE I
SUMMARY OF BASIC MODEL GEOMETRY

Wing:

| | |
|--|-------------|
| Area (not including inlet area), sq ft | 9.03 |
| Span, ft | 5.59 |
| Sweepback of quarter-chord line, deg | 40 |
| Aspect ratio | 3.45 |
| Taper ratio | 0.578 |
| Dihedral | -3° 30' |
| Incidence | 2° 30' |
| Geometric twist, deg | 0 |
| Mean aerodynamic chord, ft | 1.67 |
| Airfoil section (normal to quarter-chord line) | NACA 64A010 |
| Root chord, ft | 2.063 |
| Tip chord, ft | 1.195 |

Flap:

| | |
|-----------------------------------|---------------------|
| Type | Plain trailing edge |
| Area (one flap), sq ft | 0.420 |
| Span, ft | 1.009 |
| Hinge line, percent c | 75 |
| Maximum deflection, deg | 40 |

Aileron:

| | |
|--|------|
| Area (one aileron), sq ft | 0.38 |
| Span, ft | 1.24 |
| Hinge line, percent c | 75 |
| Maximum deflection (normal to hinge line), deg | ±18 |

Leading-edge slat:

| | |
|--|-------|
| Span of one slat (normal to model center line), ft | 1.33 |
| Ratio of slat chord to wing chord (normal to c/4) | 0.140 |
| Inboard edge (from model center line), ft | 1.347 |
| Forward extension of slat, percent c | 8.4 |
| Downward extension of slat, percent c | 7.24 |

Horizontal tail:

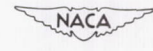
| | |
|--|-------------|
| Type | All-movable |
| Area, sq ft | 1.55 |
| Span, ft | 2.36 |
| Sweepback (quarter chord), deg | 40 |
| Taper ratio | 1.0 |
| Dihedral, deg | 0 |
| Chord, ft | 0.67 |



TABLE I.- Concluded

SUMMARY OF BASIC MODEL GEOMETRY

| | |
|---|-----------------|
| Maximum deflection, deg | -6 to 15 |
| Airfoil section | NACA 64A009 |
| Vertical tail: | |
| Area, sq ft | 1.73 |
| Span, ft | 1.815 |
| Sweepback of quarter-chord line | 41° 16' 10" |
| Aspect ratio | 1.90 |
| Taper ratio | 0.34 |
| Mean aerodynamic chord, ft | 0.955 |
| Airfoil section | NACA 64(10)A011 |



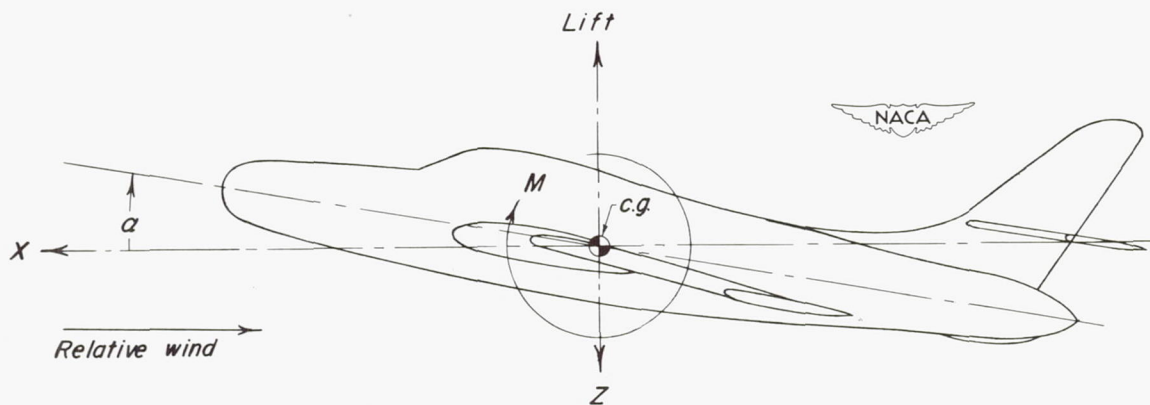
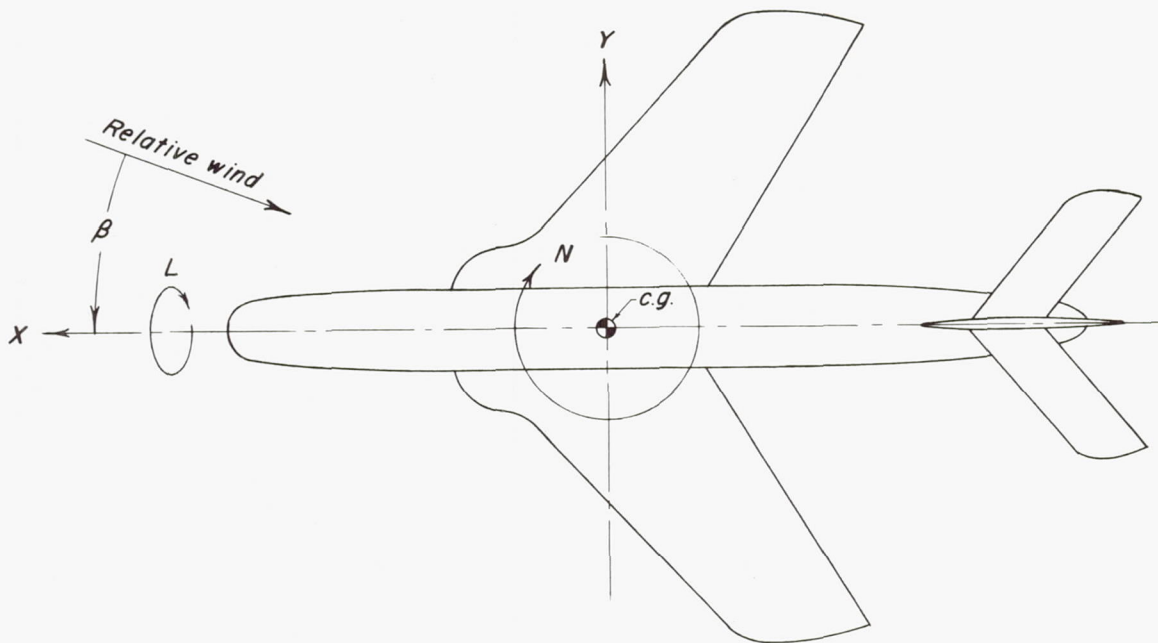


Figure 1.- System of axes and control-surface deflections. Positive values of forces, moments, and angles are indicated by arrows.

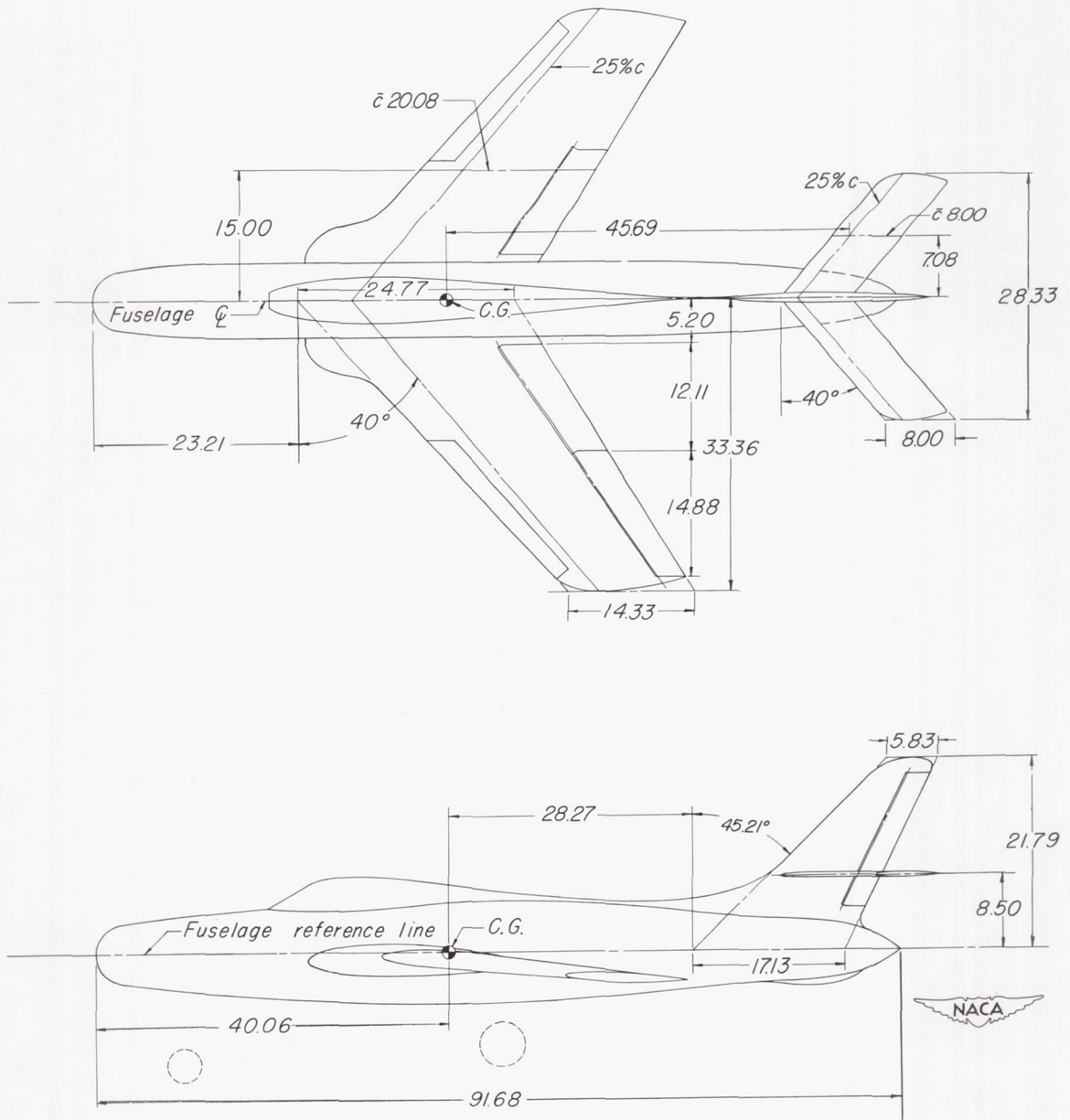


Figure 2.- Two-view drawing showing details of basic model. All dimensions in inches.

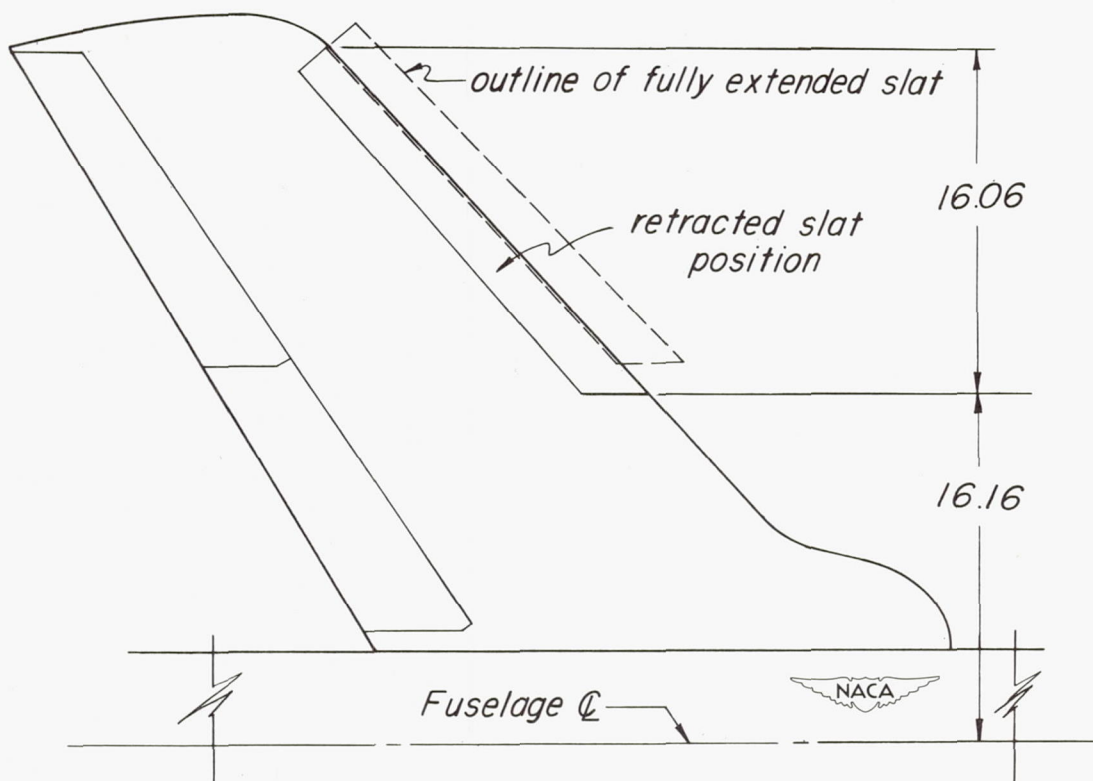
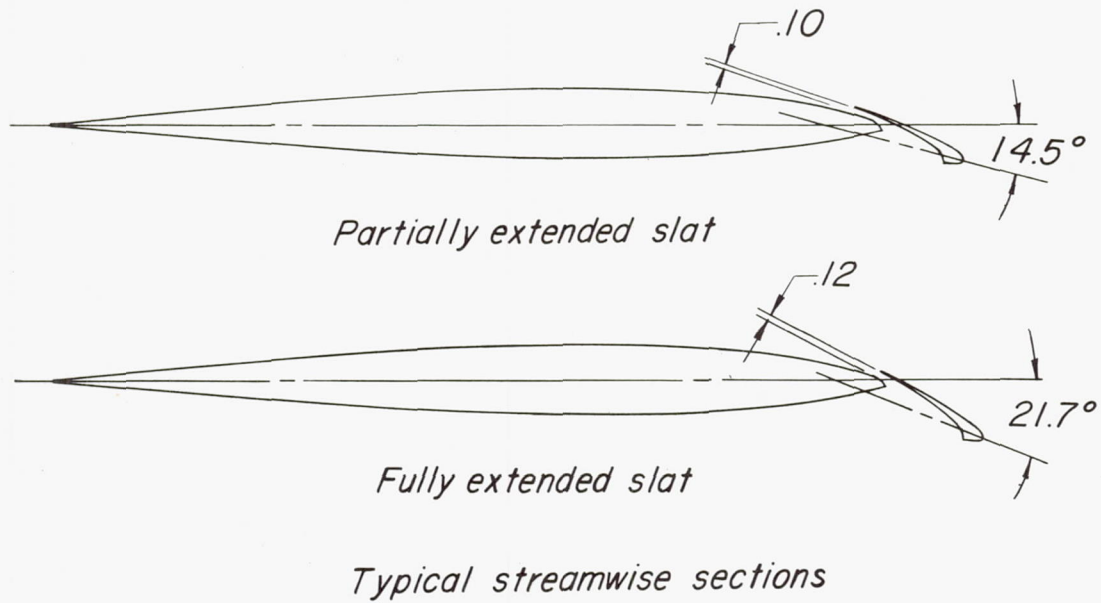
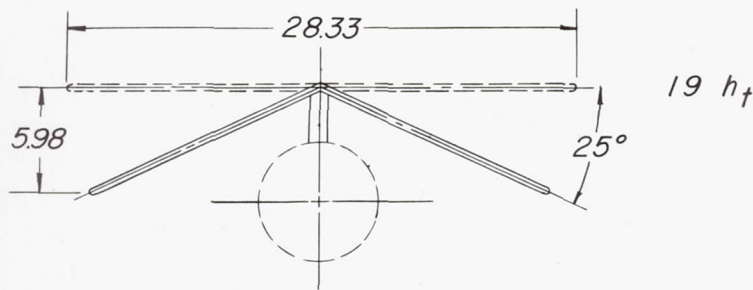
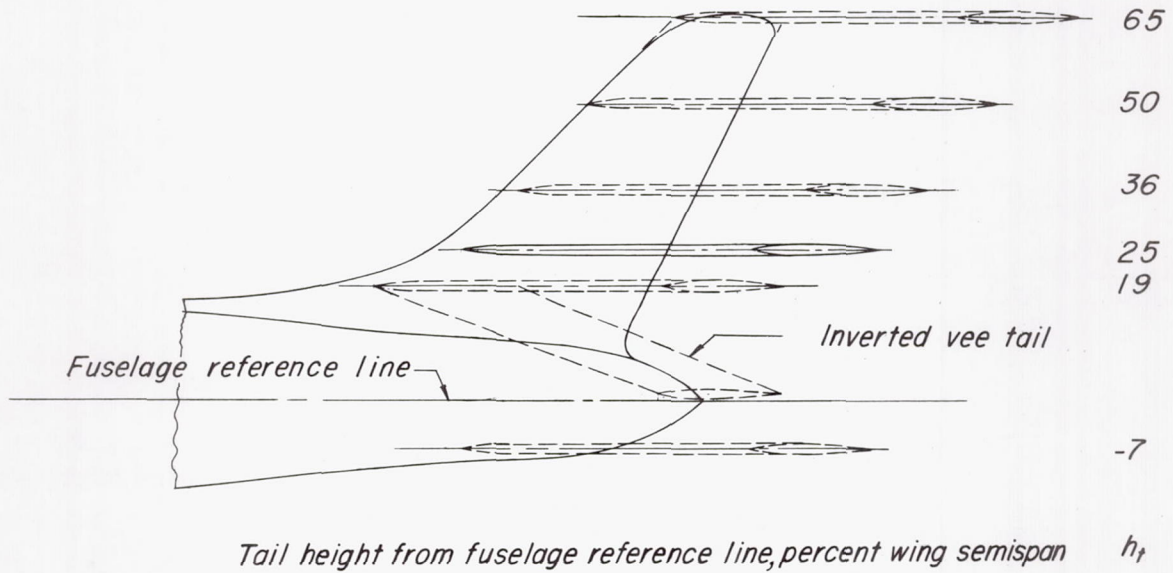


Figure 3.- Details of slat configurations investigated. All dimensions in inches.

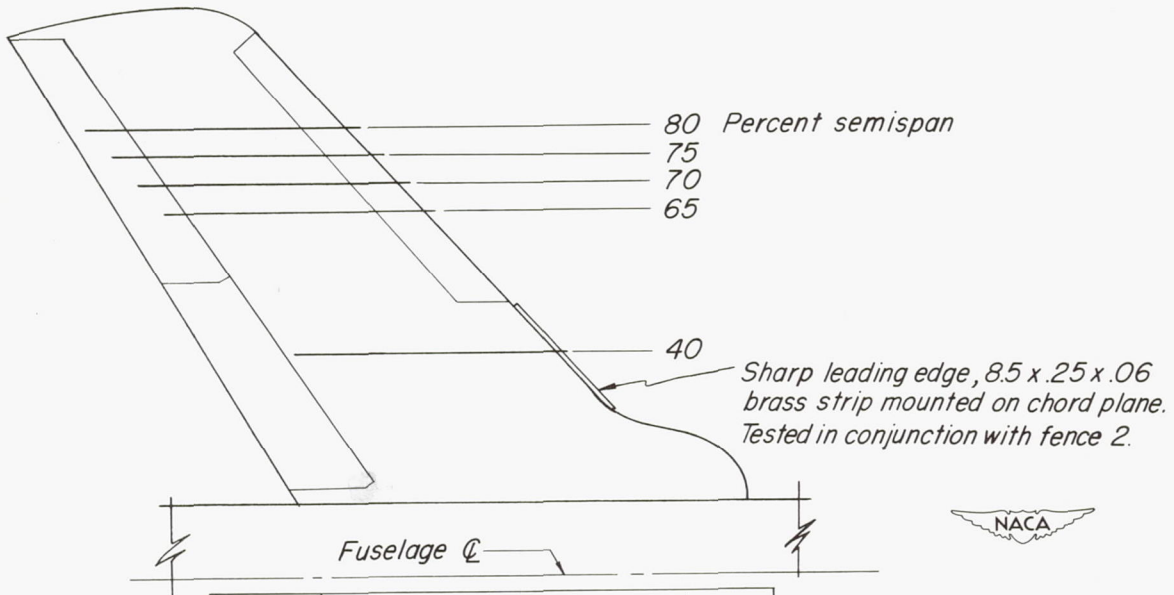
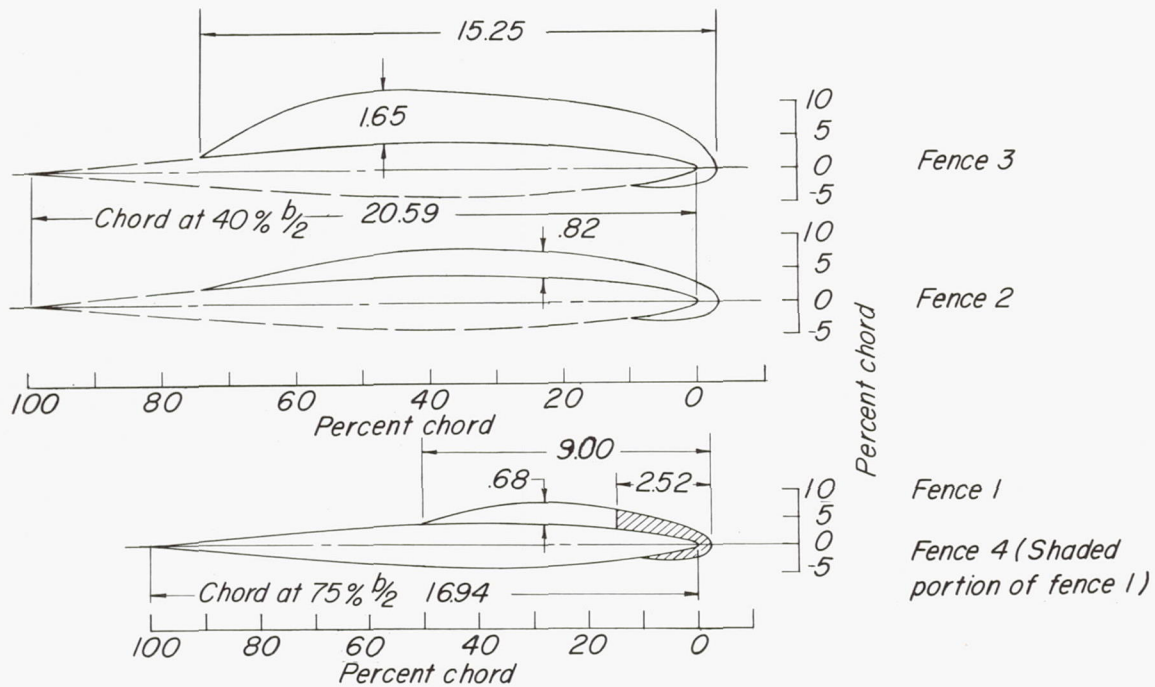


Front view of inverted vee tail



| | | | | | | |
|--|-----|-----|-----|-----|-----|-----|
| <i>Tail length, percent \bar{c}</i> | 228 | 202 | 228 | 243 | 262 | 286 |
| <i>Tail height, percent semispan</i> | -7 | 19 | 25 | 36 | 50 | 65 |

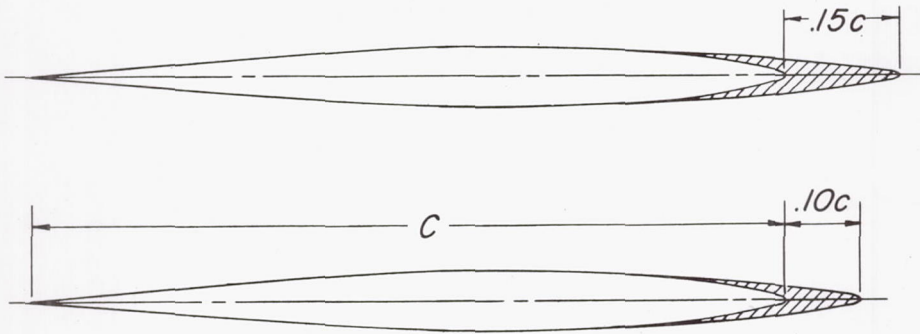
Figure 4.- Summary of horizontal-tail configurations investigated.



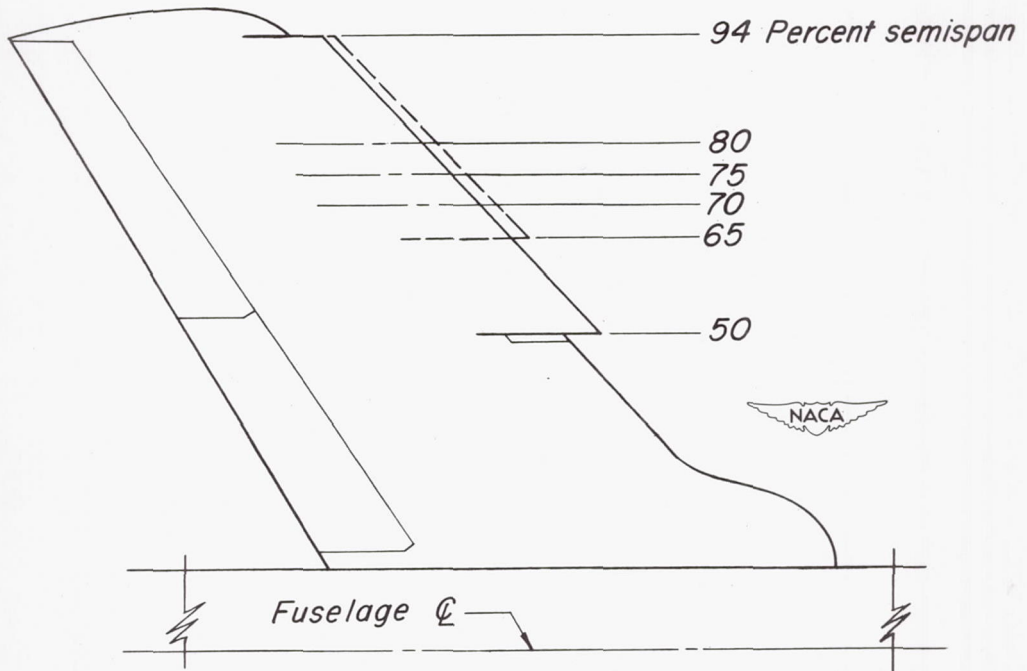
| Fence no. | Spanwise location, percent $b/2$ | | | | | | | |
|-----------|----------------------------------|----|----|----|----|----|----|----|
| 1 | | | | | 75 | 75 | 80 | 75 |
| 2 | 65 | 70 | 75 | 80 | | 40 | 65 | |
| 3 | | | | | | | | 40 |
| 4 | | | | | 75 | | | |



Figure 5.- Details of fence configurations investigated. All dimensions in inches unless otherwise specified. All fences made from 1/8-inch aluminum sheet.



Typical streamwise sections of wing with leading-edge extension



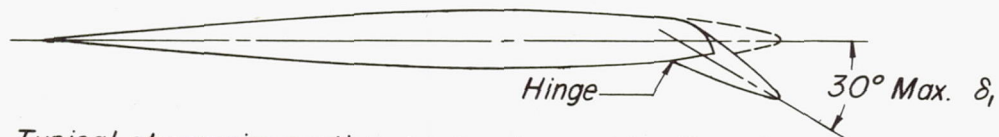
Spanwise extent of chord-extensions tested, Percent semispan

| Chord-extension | 10% c | | | | | | | | 15% c | |
|-----------------|-------|----|----|----|----|----|----|----|-------|----|
| Inboard edge | 50 | 65 | 70 | 75 | 80 | 65 | 65 | 70 | 65 | 65 |
| Outboard edge | 94 | 94 | 94 | 94 | 94 | 80 | 75 | 80 | 94 | 80 |

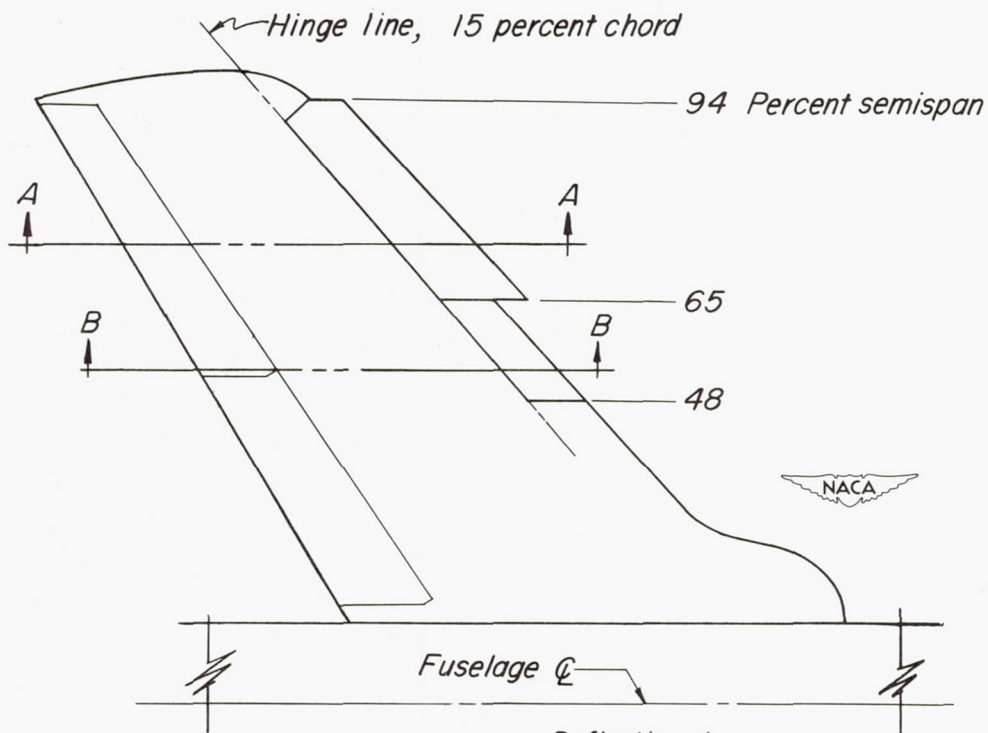
Figure 6.- Details of leading-edge chord-extensions investigated.



Typical streamwise section showing wing with drooped 10% c leading-edge extension
A-A



Typical streamwise section showing drooped leading edge
B-B



| | | Deflection, deg | | | | | | |
|-------------------------|------------|-----------------|----|---|----|----|----|--|
| Drooped chord-extension | δ_1 | 0 | 0 | 5 | 10 | 20 | 30 | |
| Combinations tested | δ_2 | 0 | 10 | 5 | 10 | 20 | 30 | |

Figure 7.- Details of drooped leading-edge chord-extensions investigated.

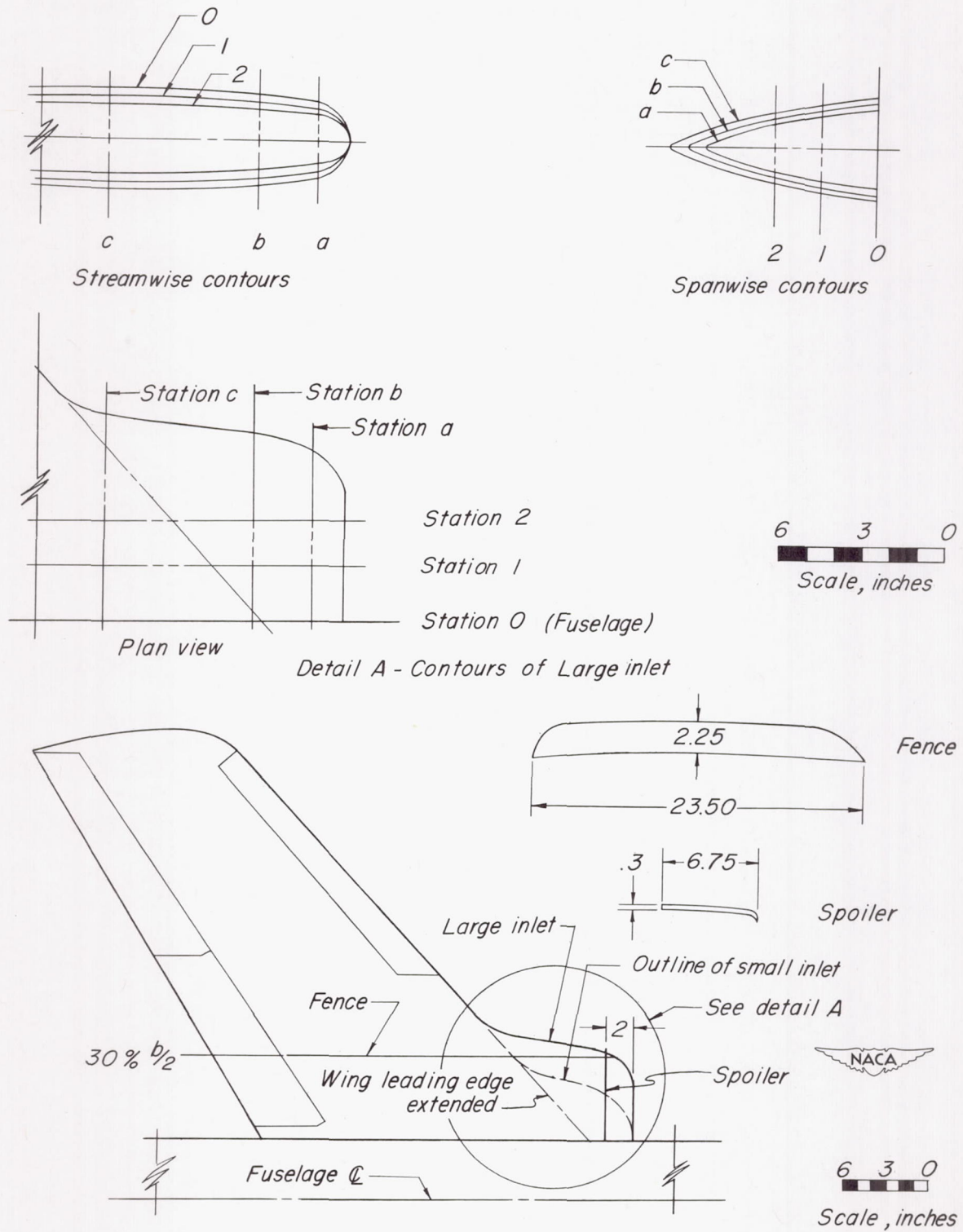


Figure 8.- Details of enlarged inlet and several wing modifications used in conjunction with enlarged inlet.



Figure 9.- Wing-off aerodynamic characteristics.

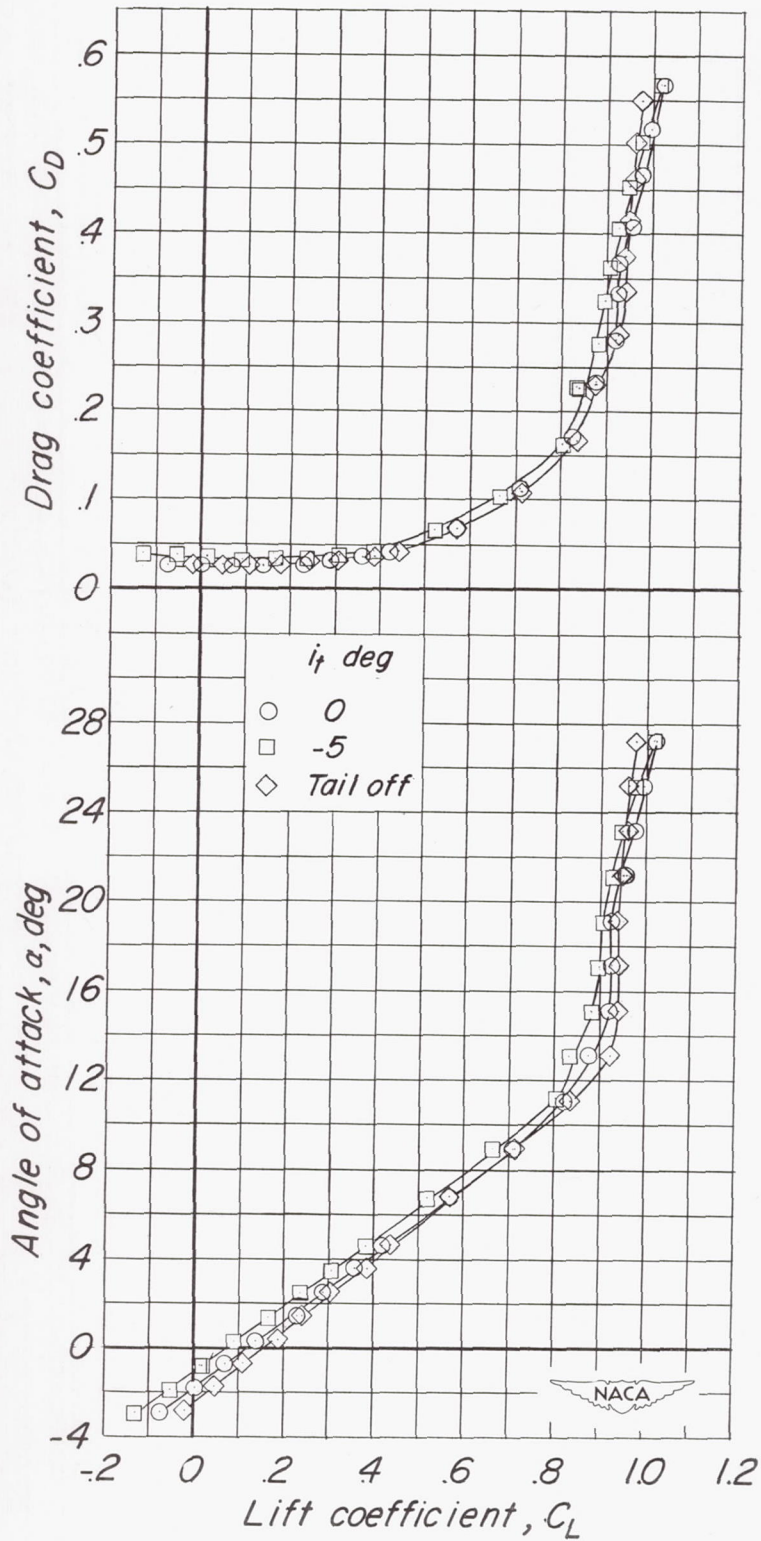


Figure 10.- Effect of stabilizer deflection on the aerodynamic characteristics of the basic model. $\delta_f = \delta_s = 0^\circ$.

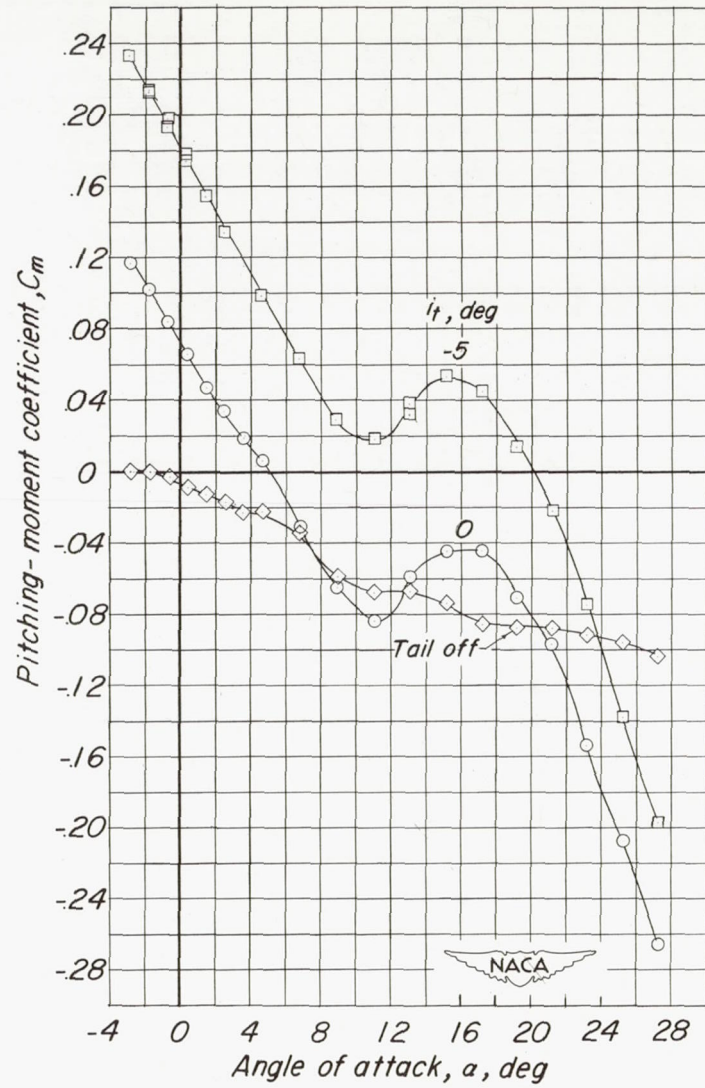
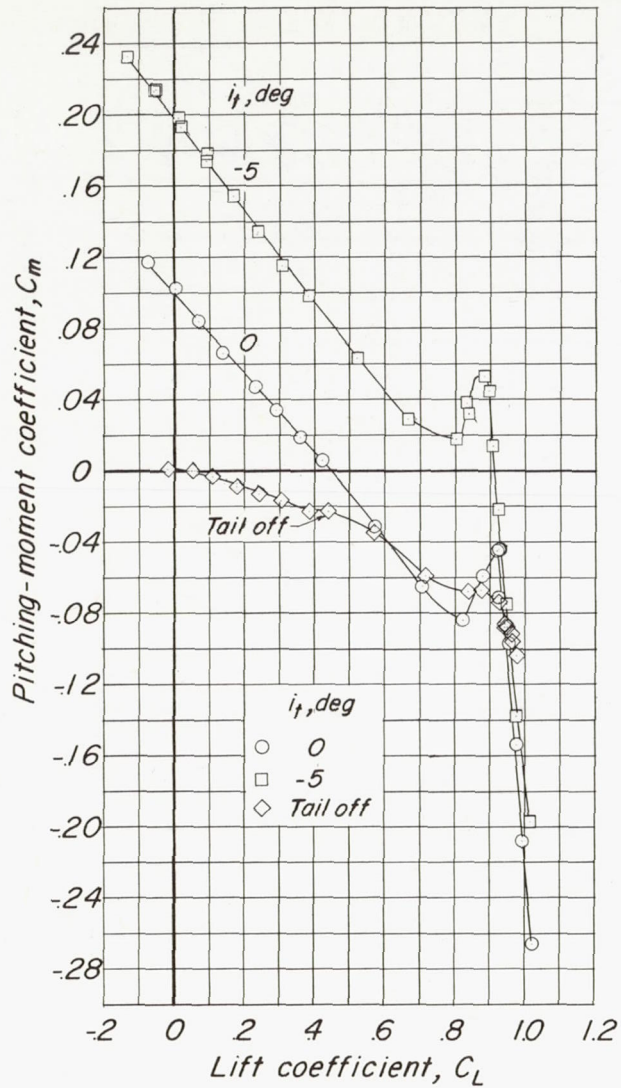


Figure 10.- Concluded.

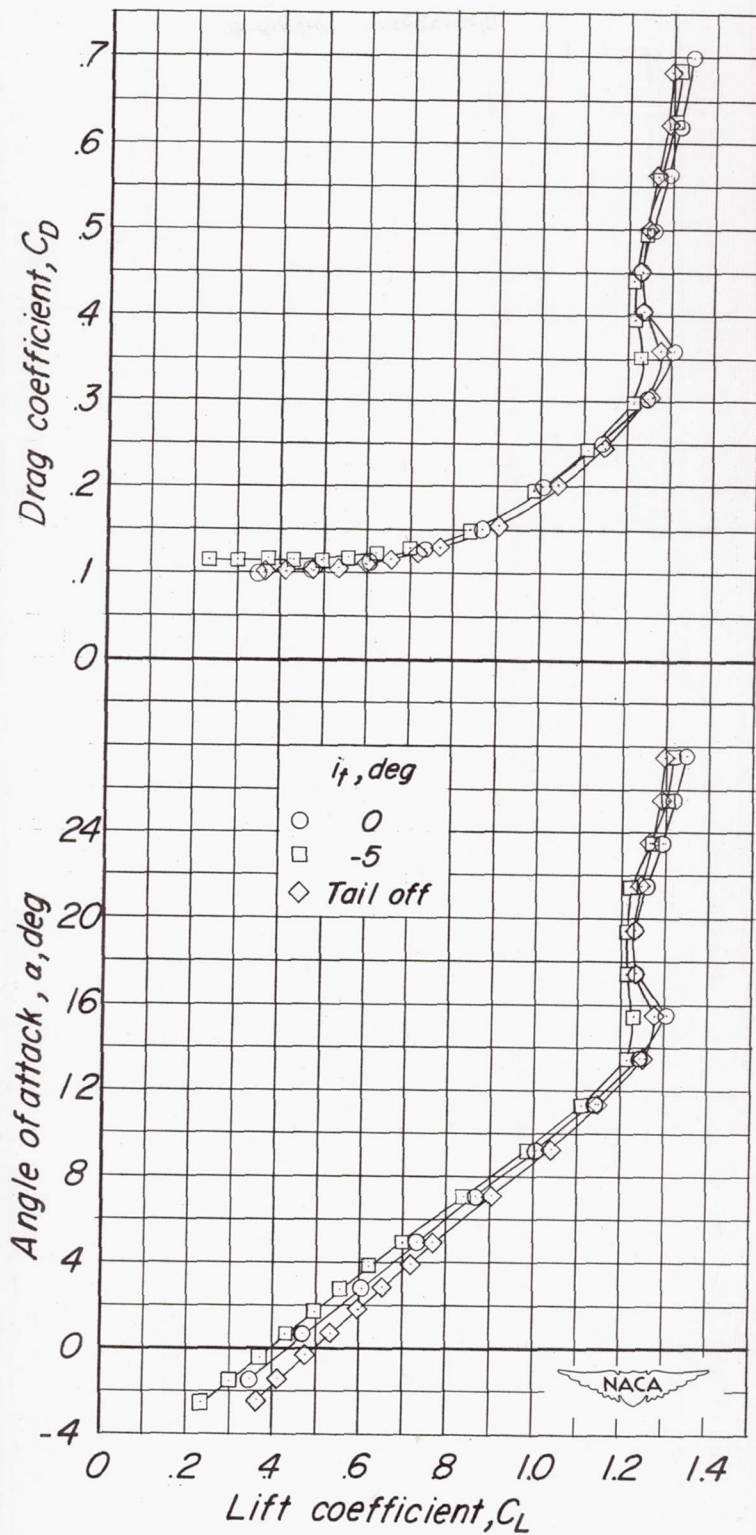


Figure 11.- Effect of stabilizer deflection on the aerodynamic characteristics of the basic model. $\delta_f = 40^\circ$; $\delta_s = 21.7^\circ$.

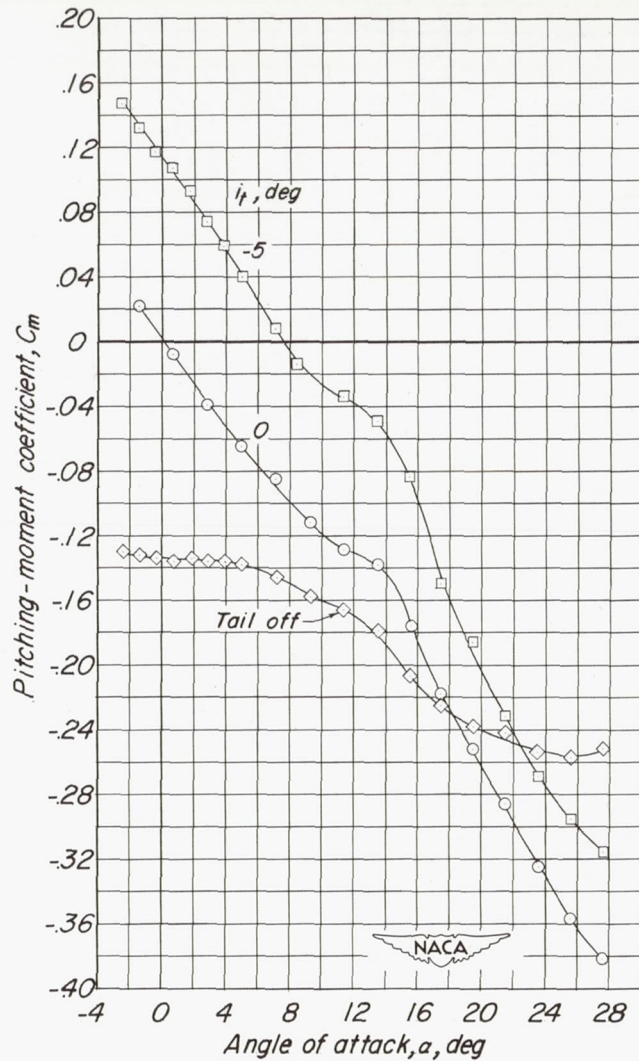
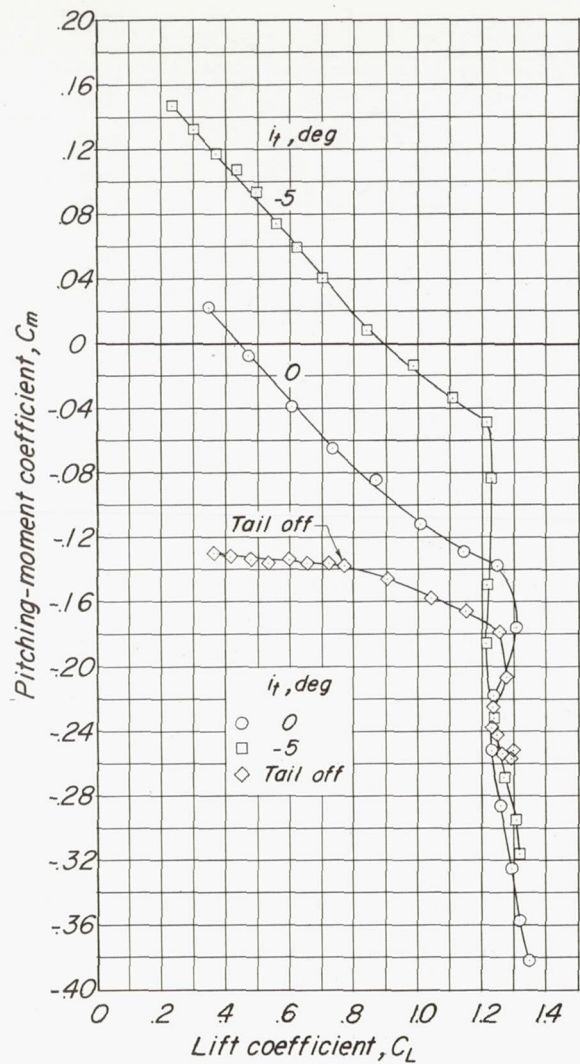


Figure 11.- Concluded.

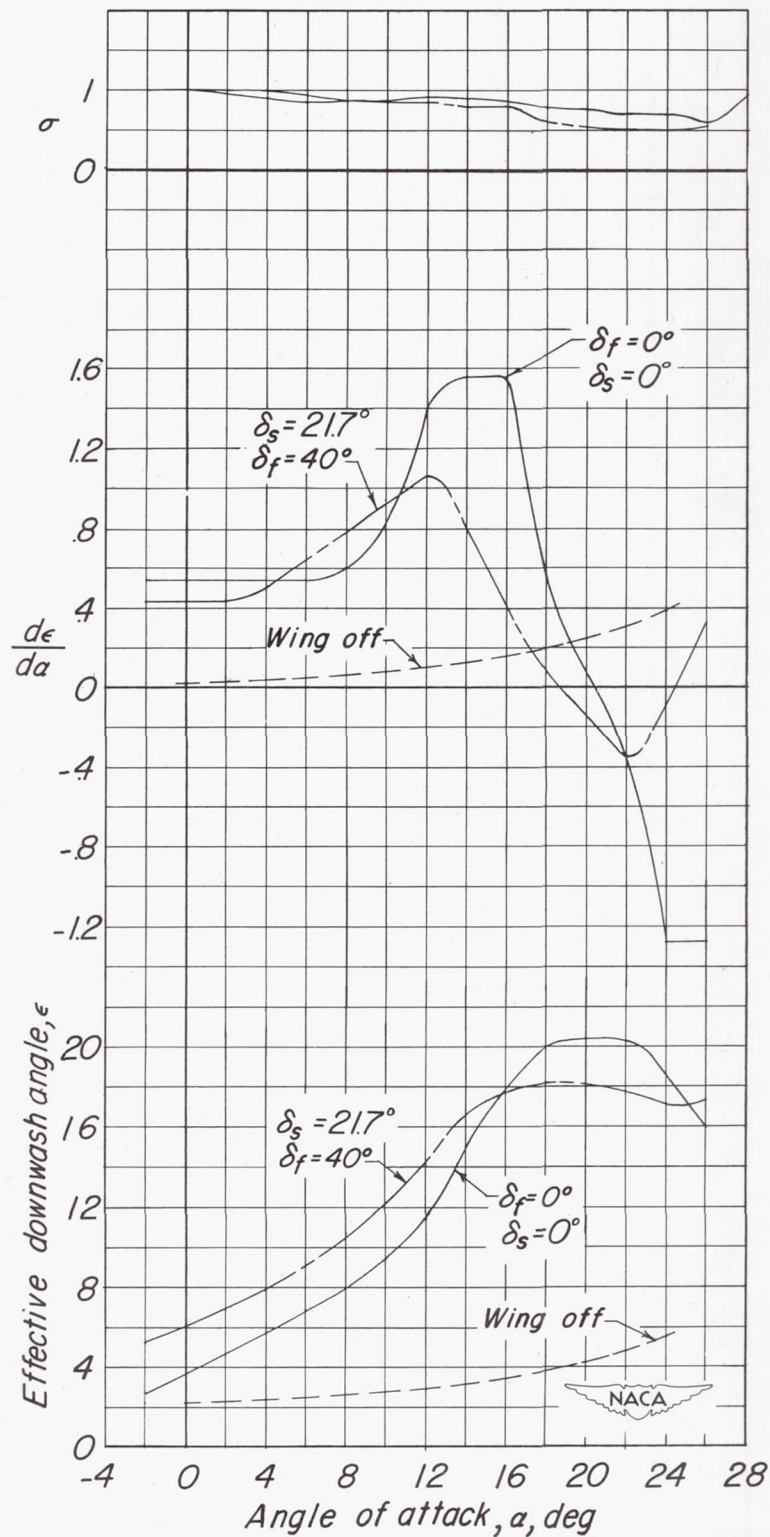


Figure 12.- Summary of effective downwash and tail effectiveness parameter for basic model.

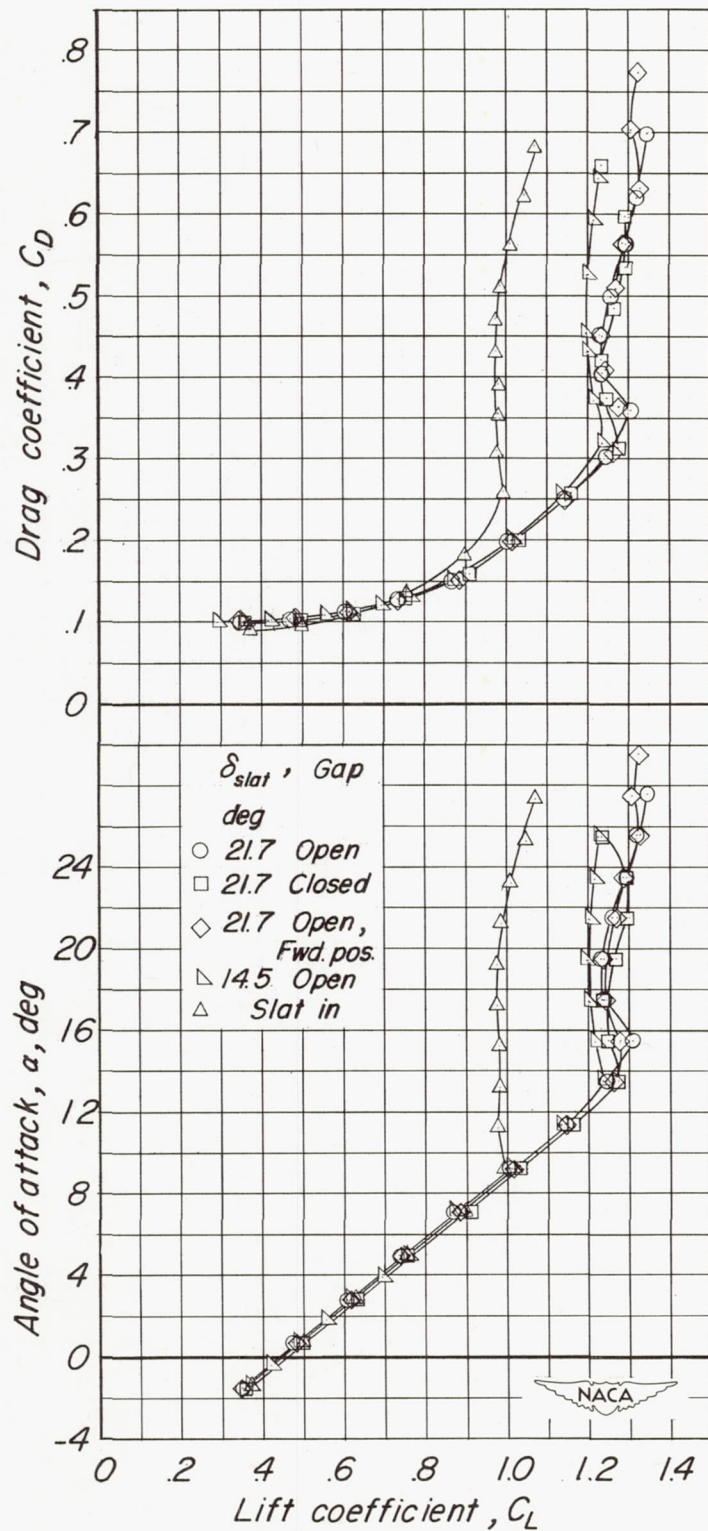


Figure 13.- Effect of slat deflection and modifications. $\delta_F = 40^\circ$; $i_t = 0^\circ$.

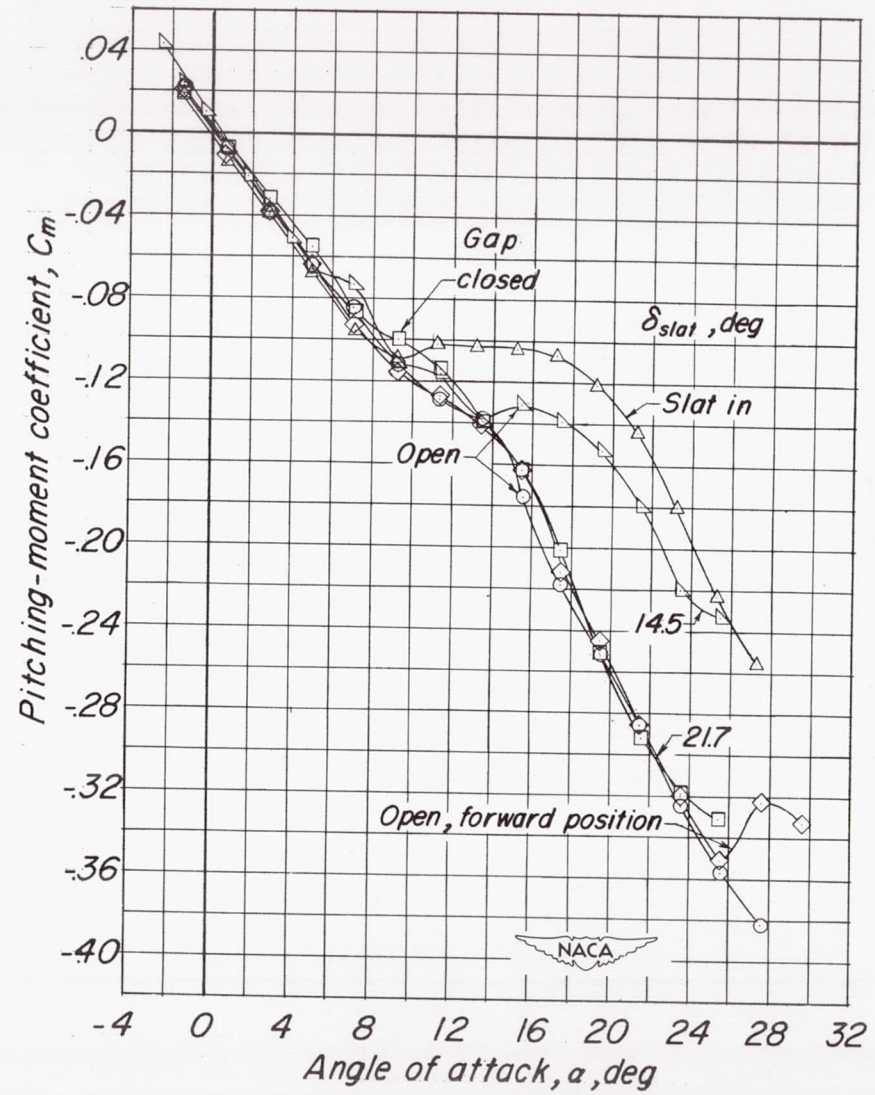
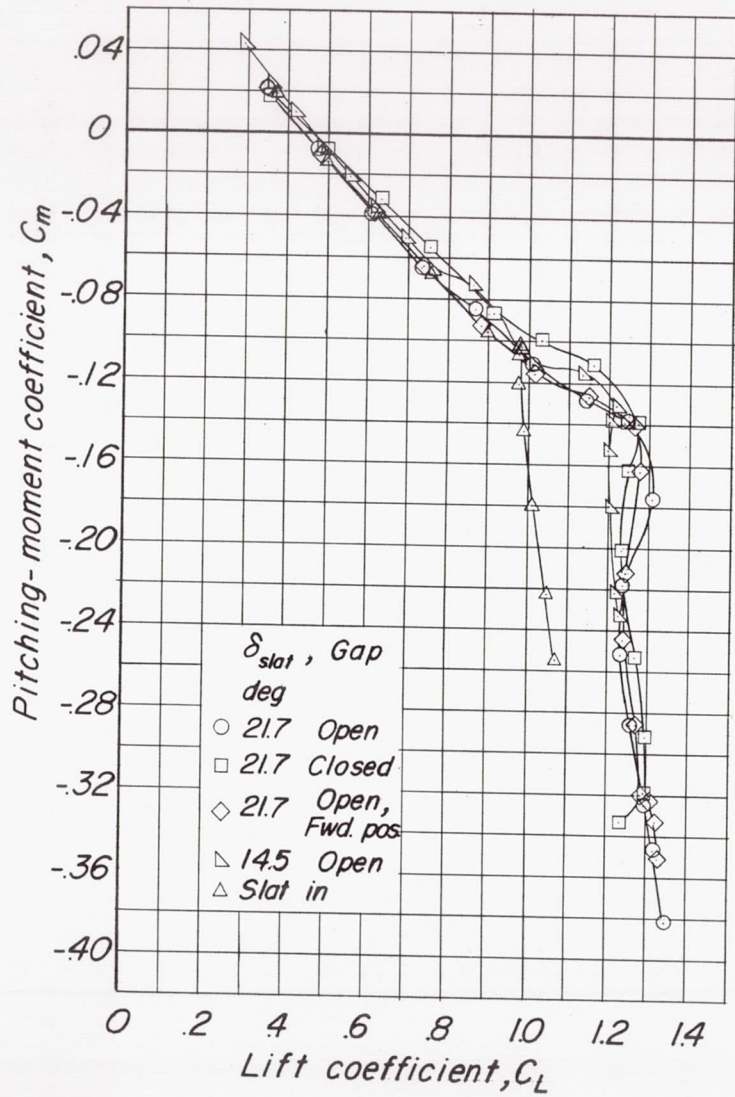


Figure 13.- Concluded.

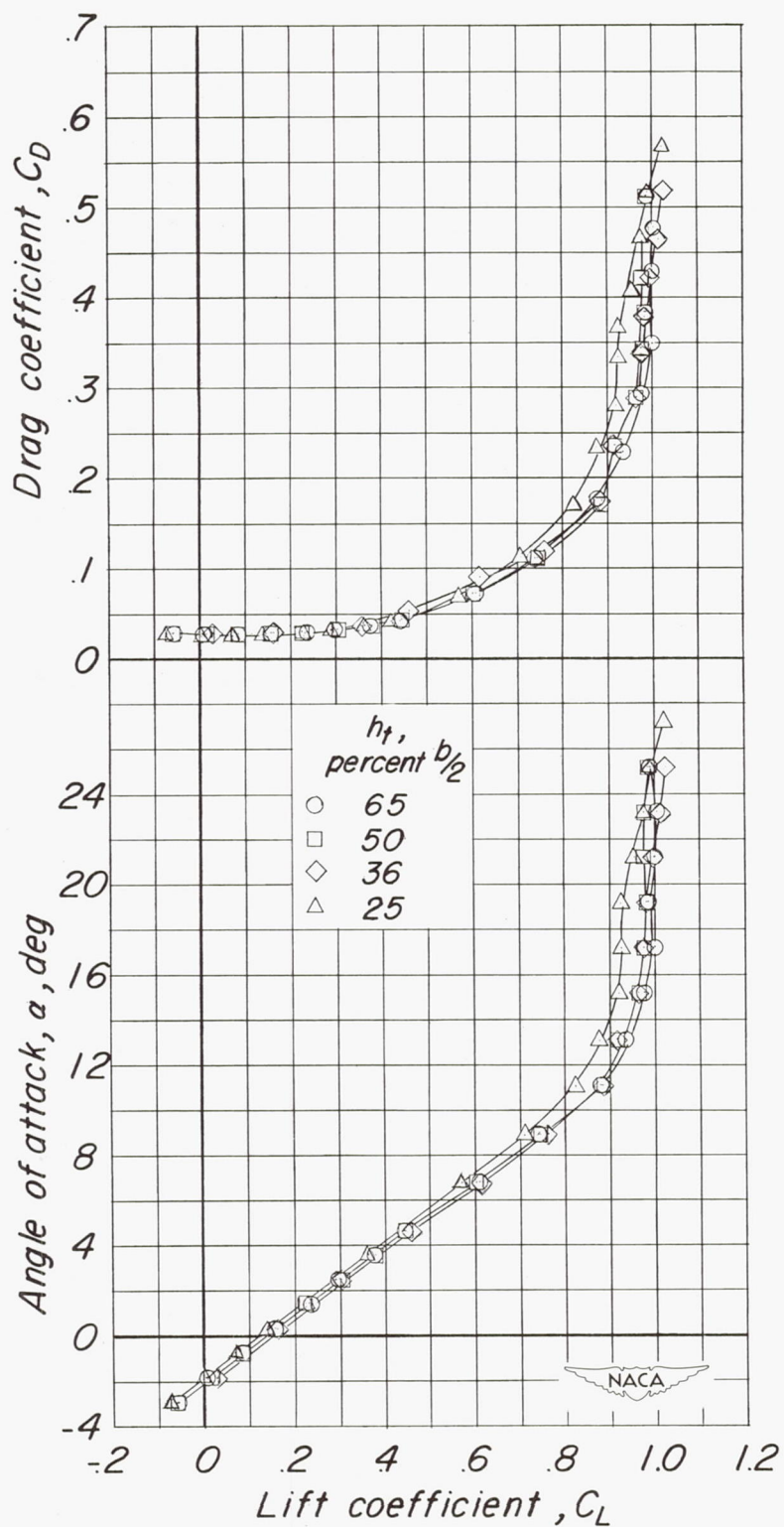


Figure 14.- Effect of raising the horizontal tail on the aerodynamic characteristics of the model. $\delta_f = \delta_s = i_t = 0^\circ$.

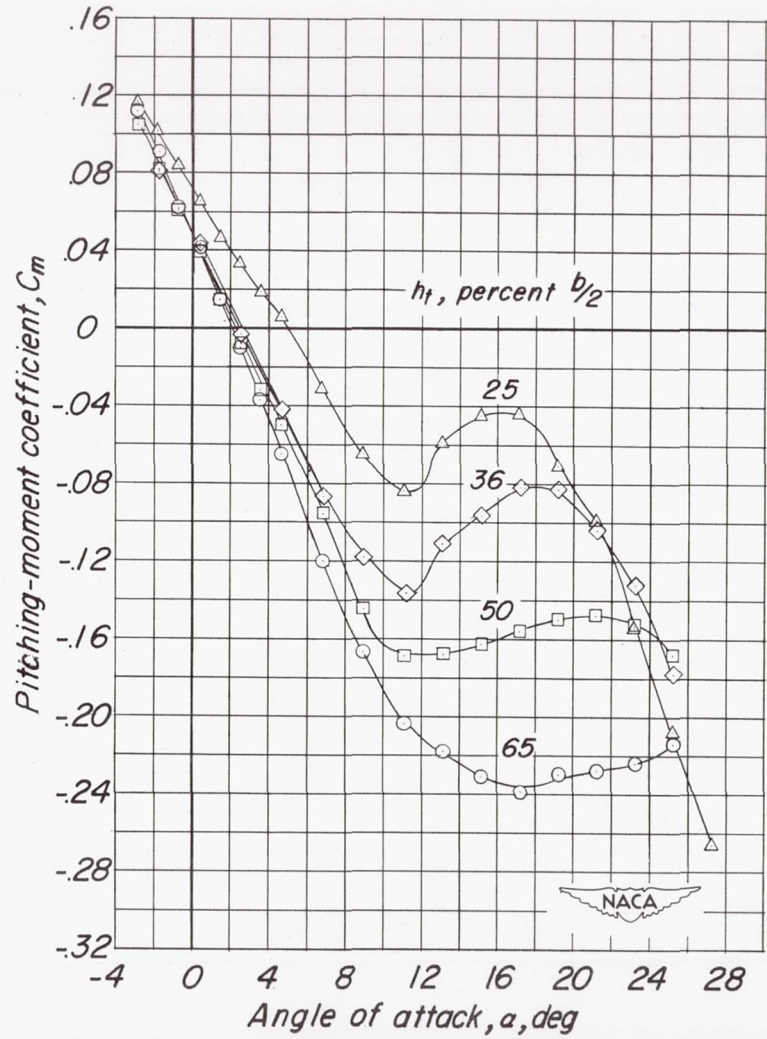
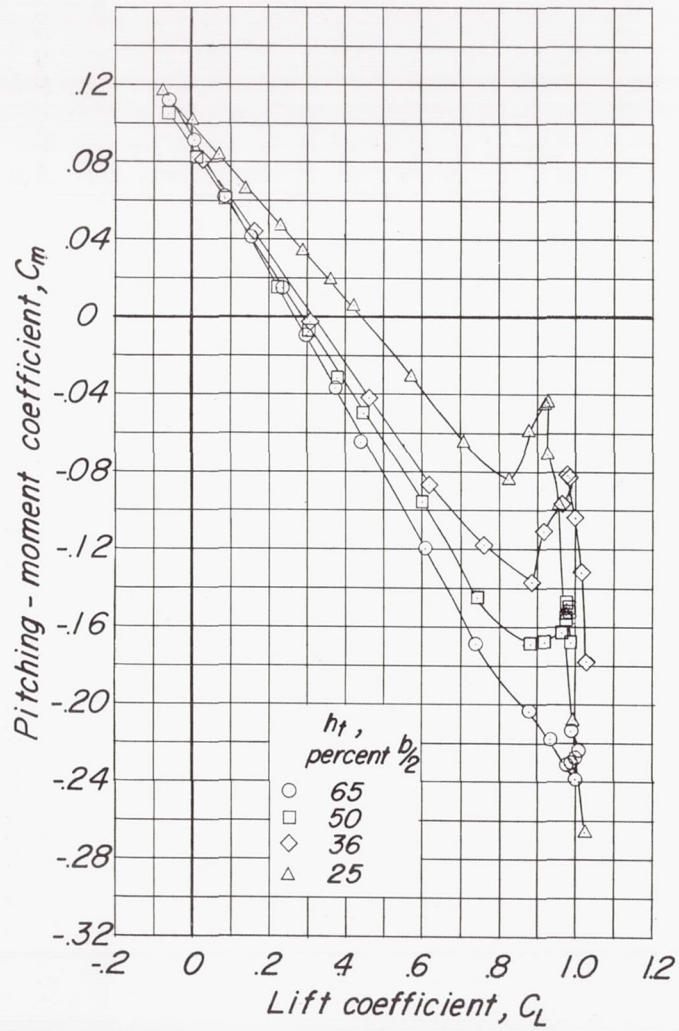


Figure 14.- Concluded.

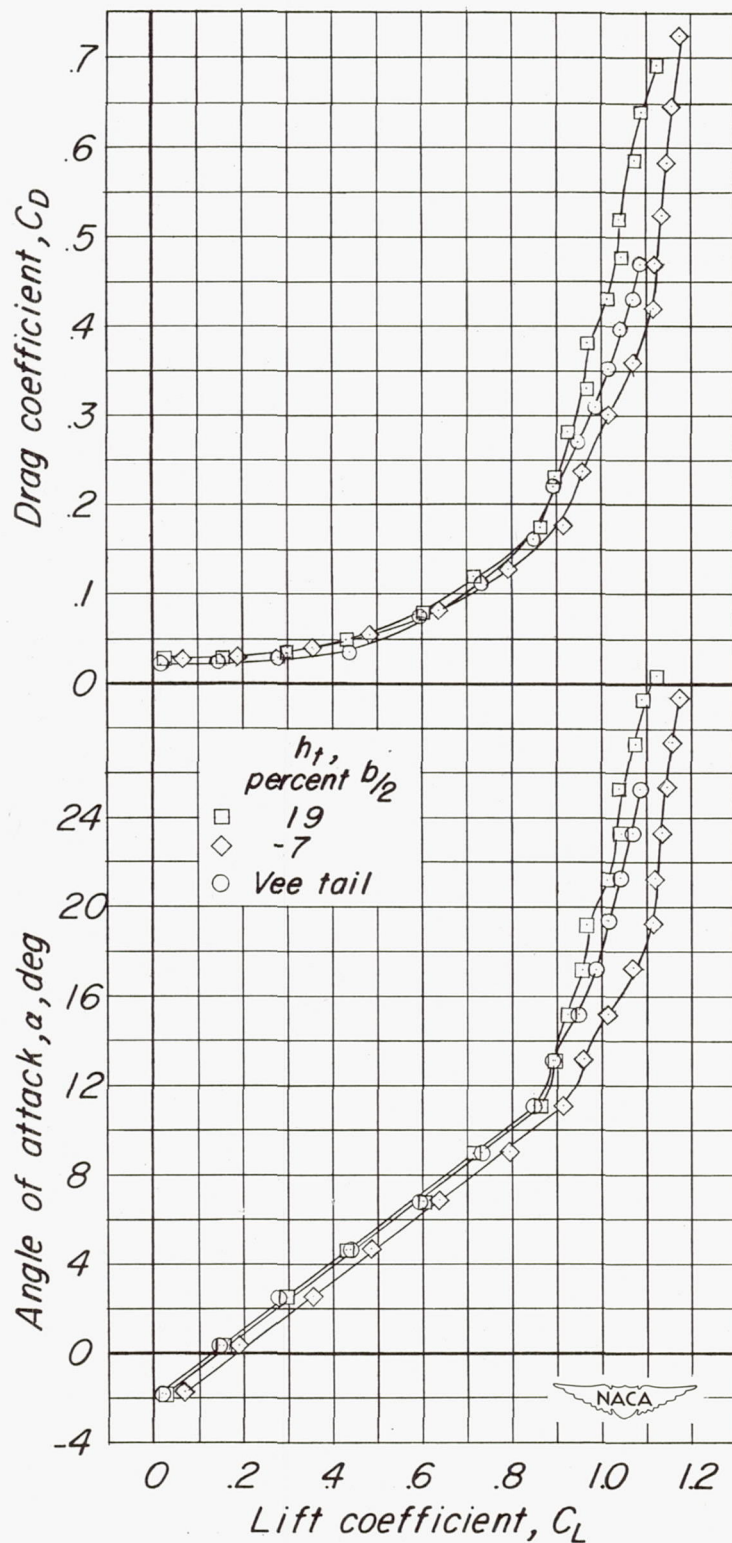


Figure 15.- Effect of lowering the horizontal tail on the aerodynamic characteristics of the model. $\delta_f = \delta_s = i_t = 0^\circ$.

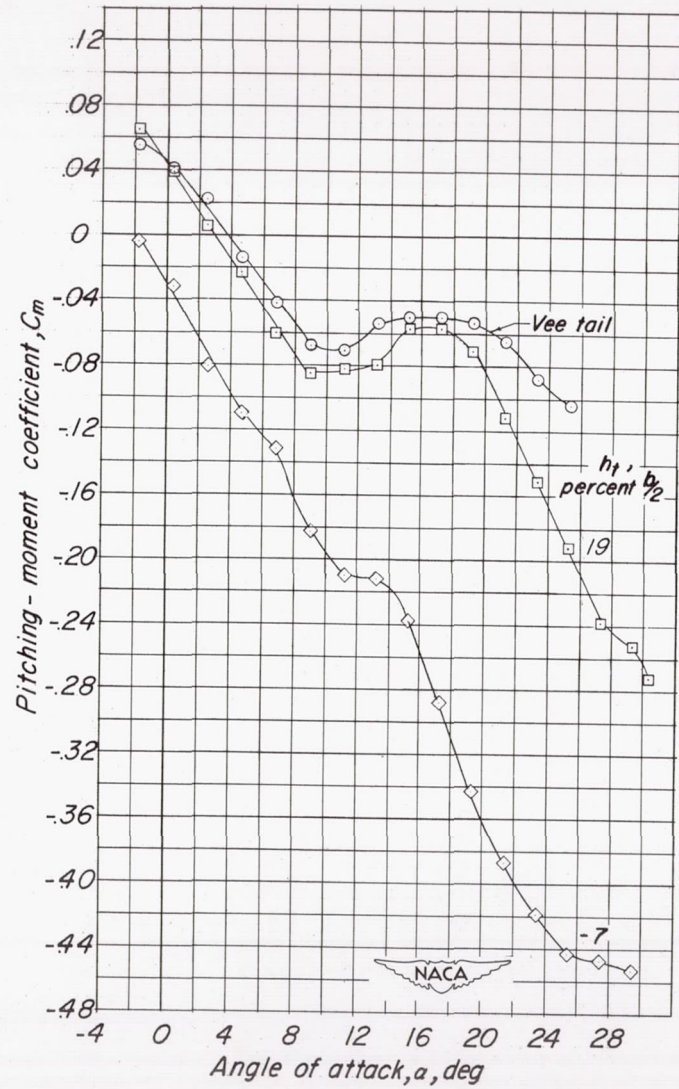
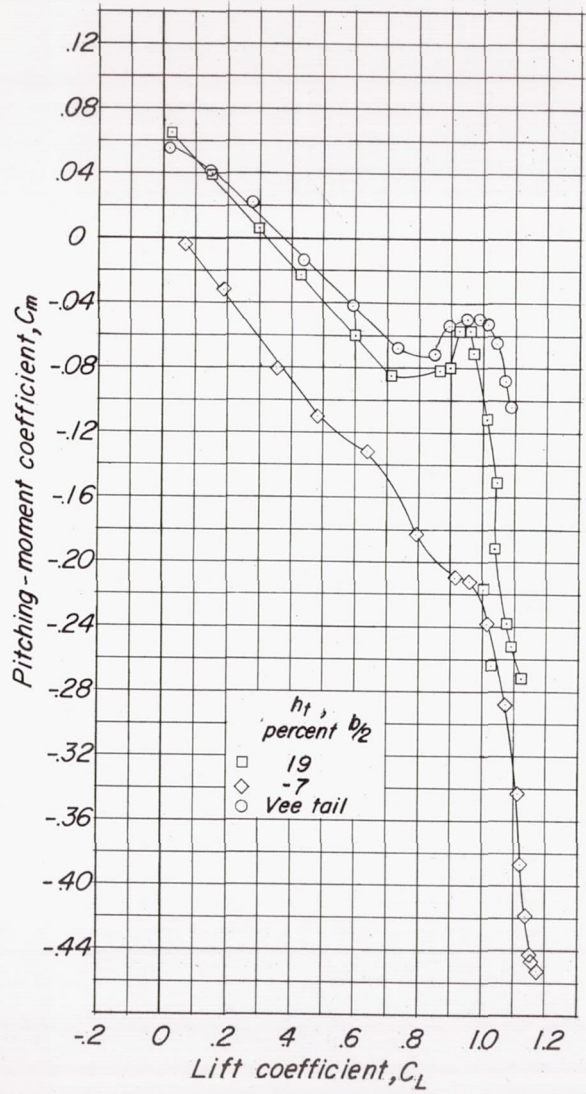


Figure 15.- Concluded.

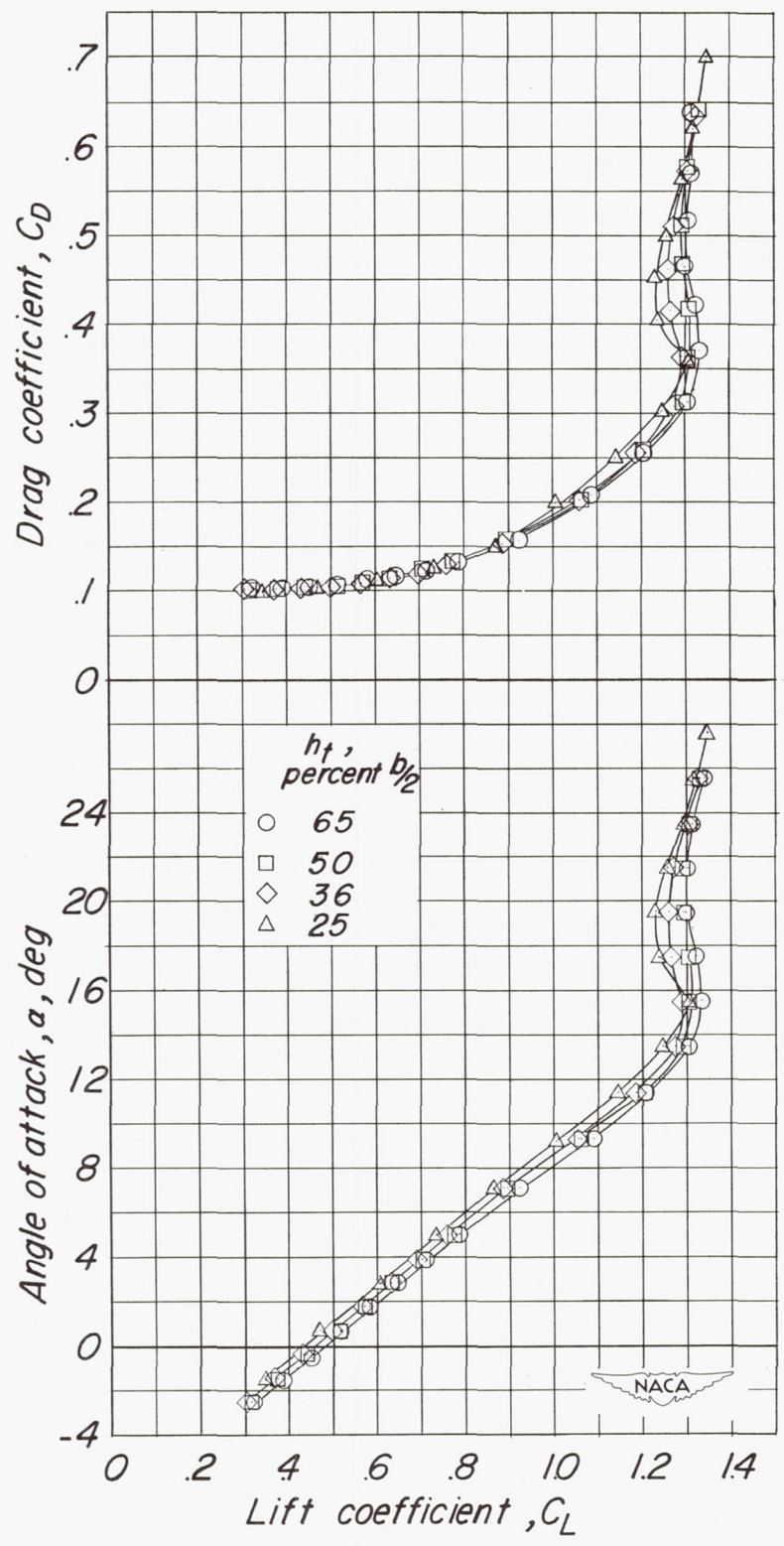


Figure 16.- Effect of raising the horizontal tail on the aerodynamic characteristics of the model. $\delta_f = 40^\circ$; $\delta_s = 21.7^\circ$; $i_t = 0^\circ$.

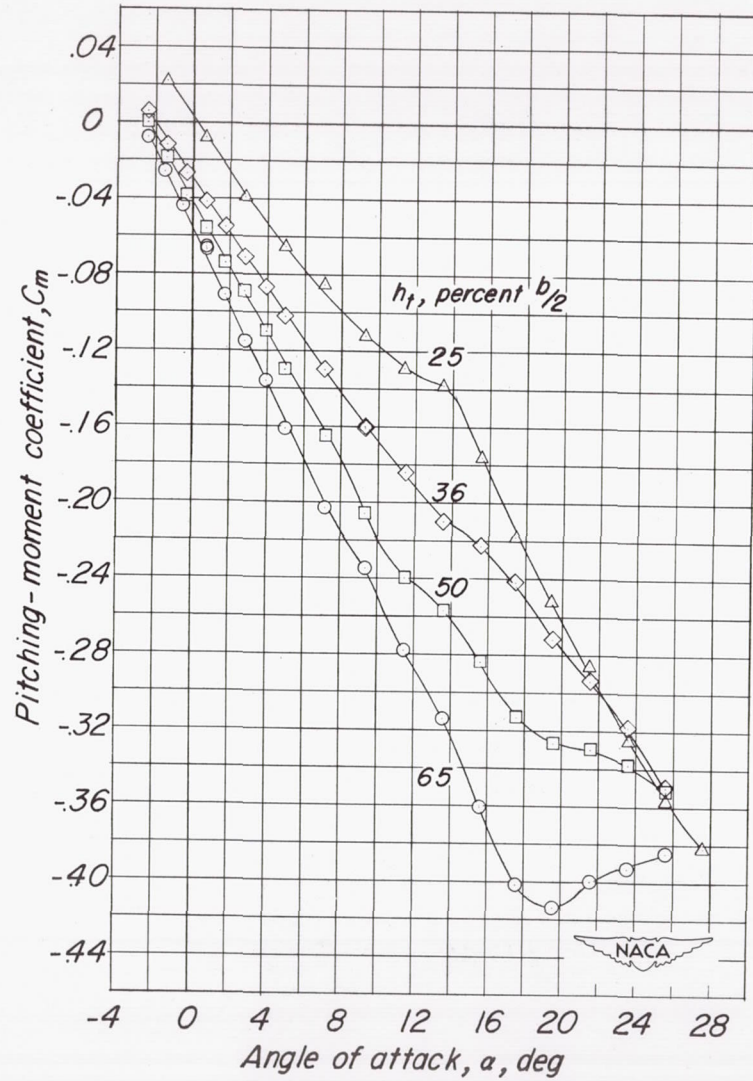
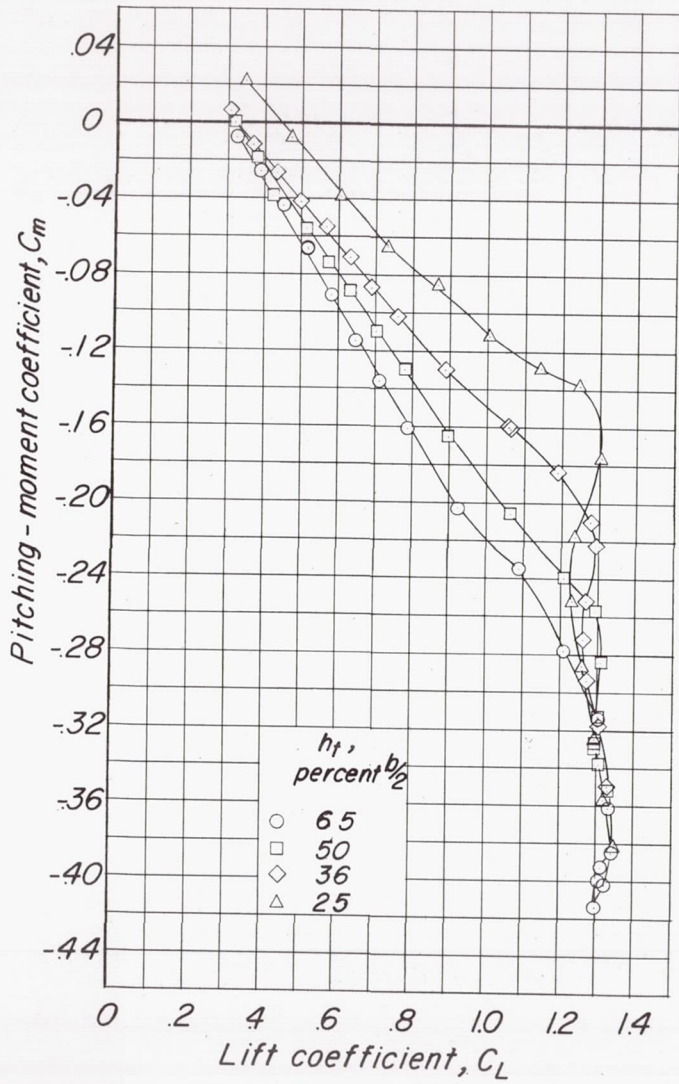


Figure 16.- Concluded.

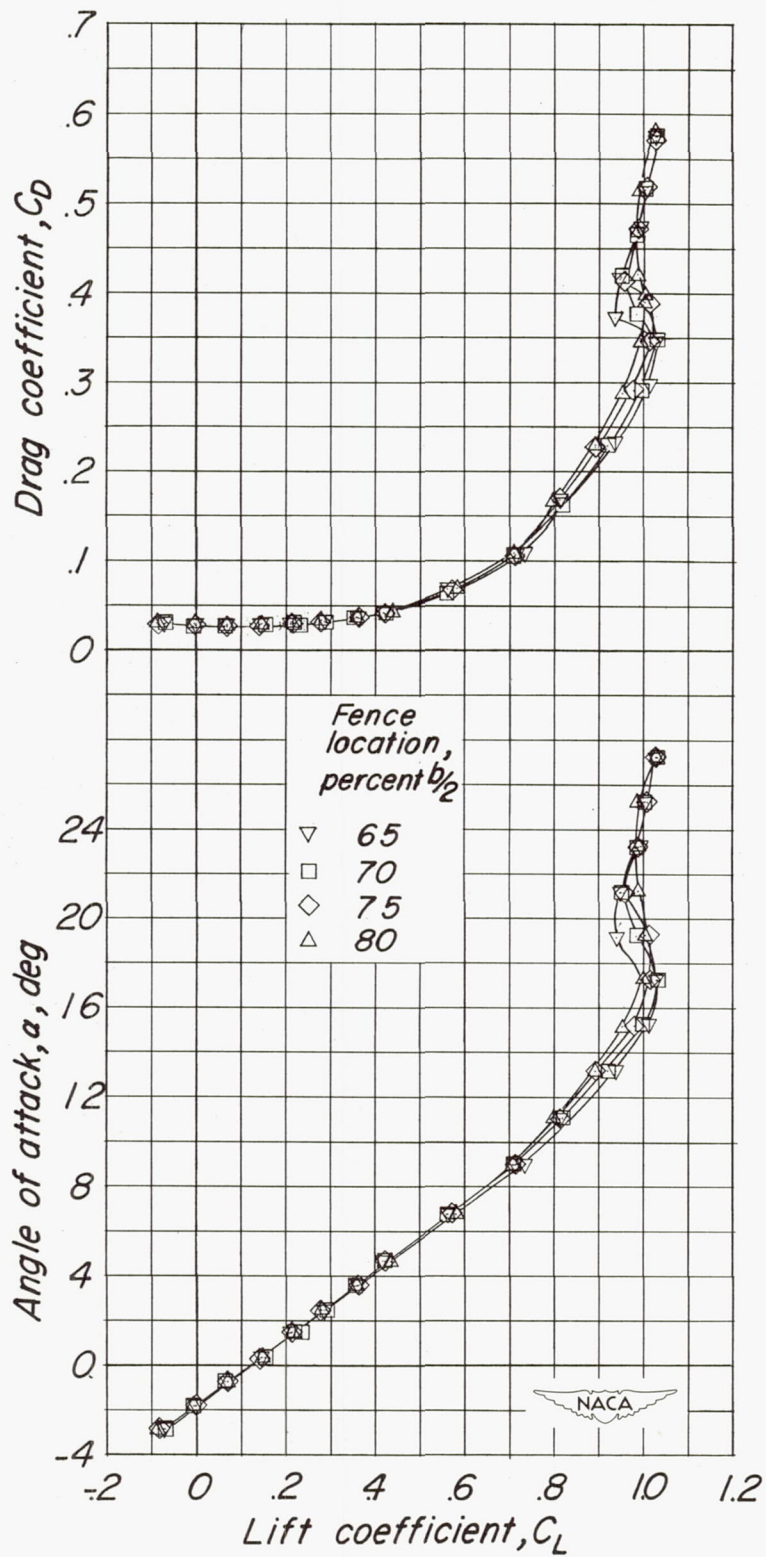


Figure 17.- Effect of spanwise location of wing fence 2. $\delta_f = \delta_s = i_t = 0^\circ$.

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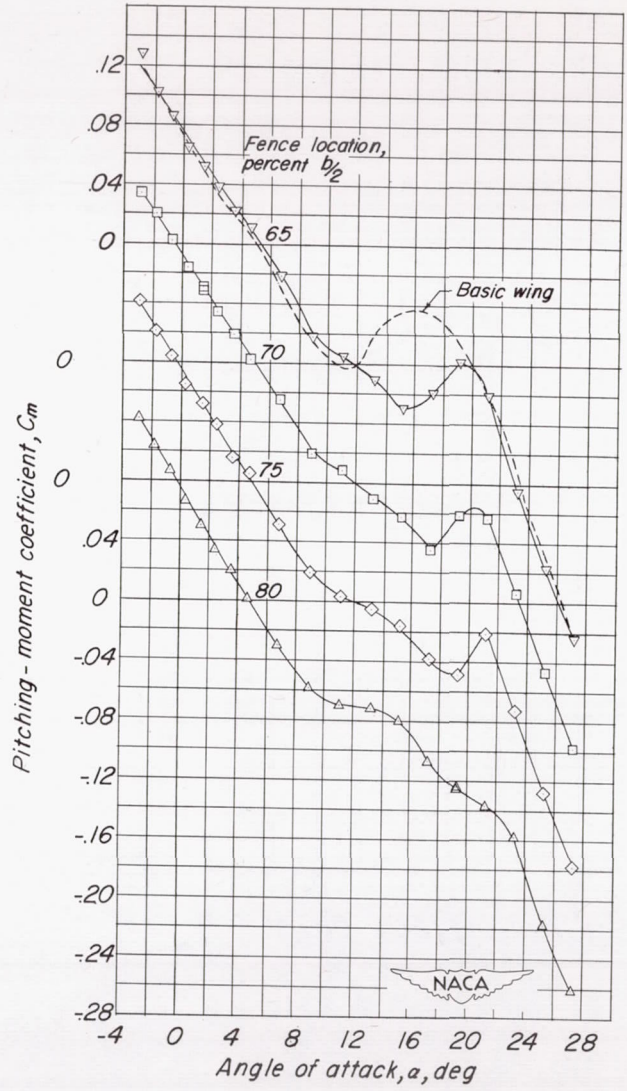
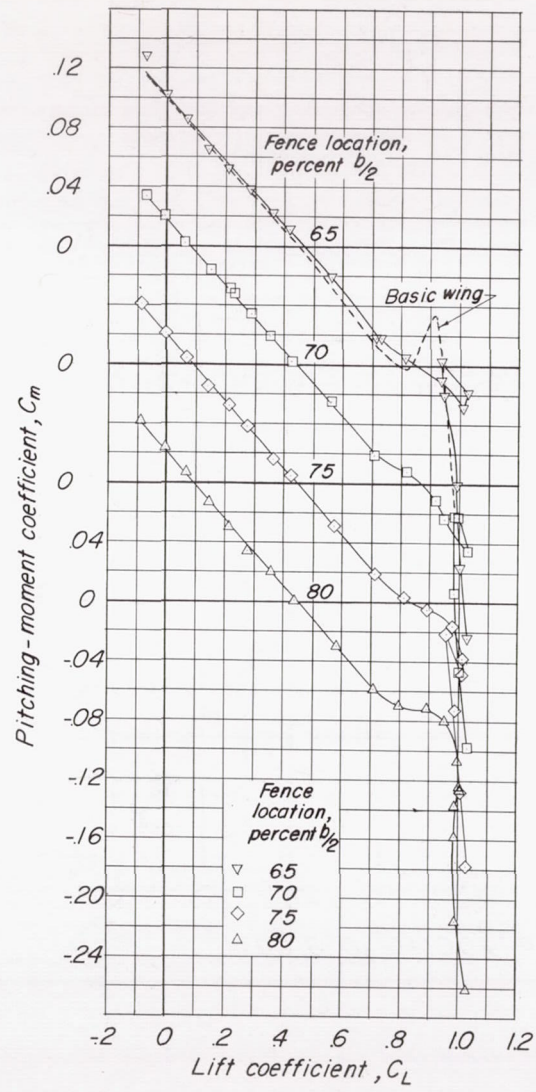


Figure 17.- Concluded.

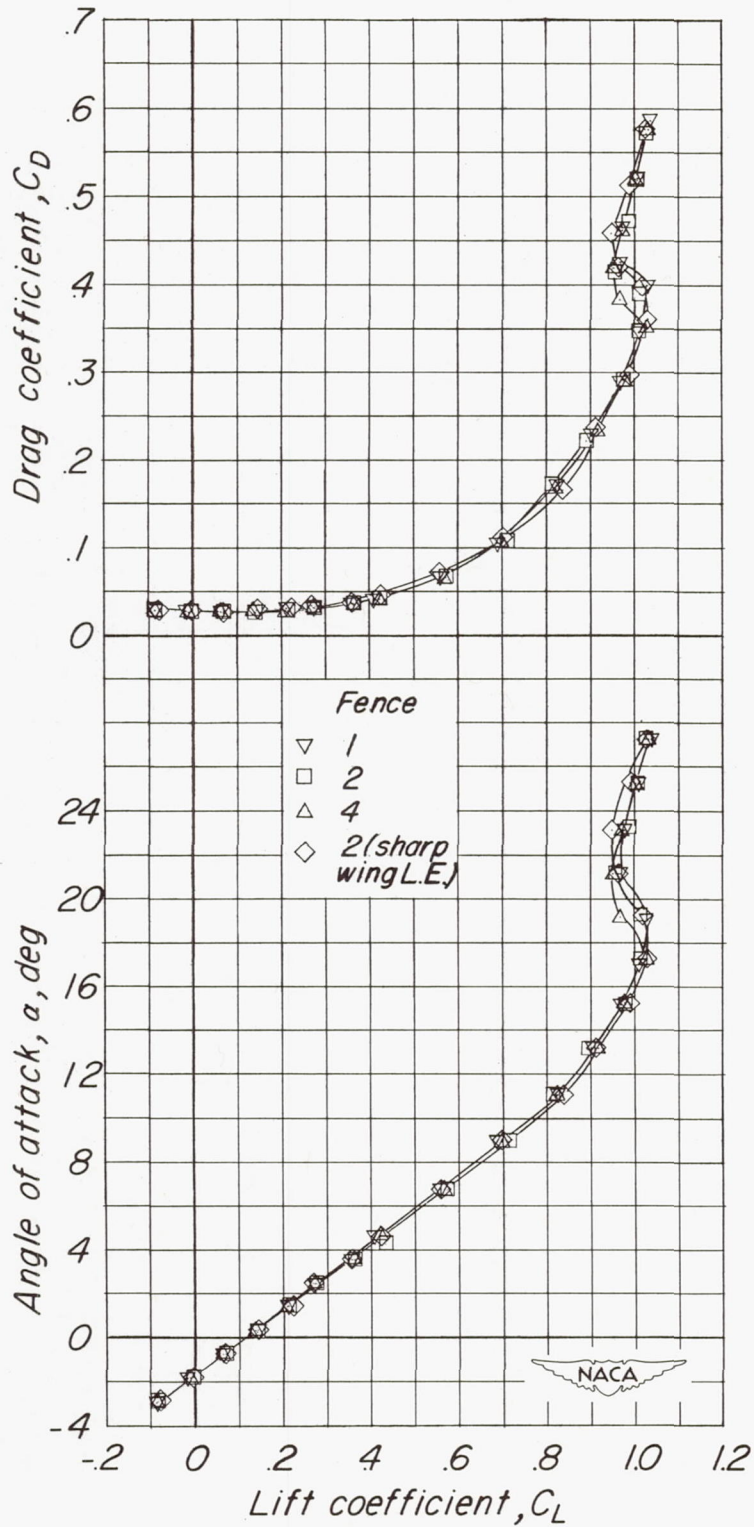


Figure 18.- Effect of fence size with fences located at 75 percent semispan.
 $\delta_f = \delta_s = i_t = 0^\circ$.

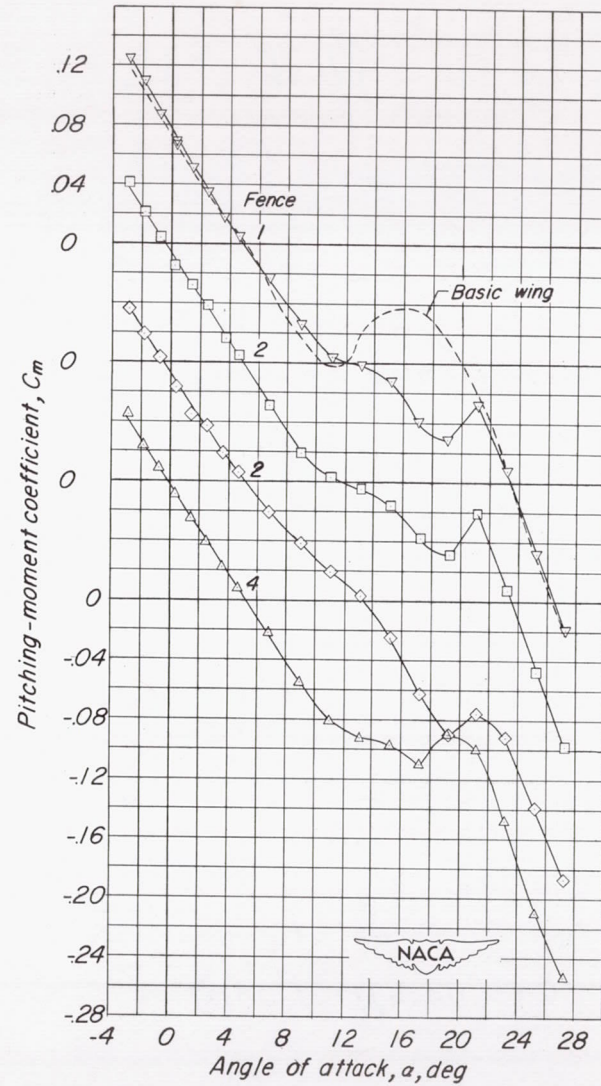
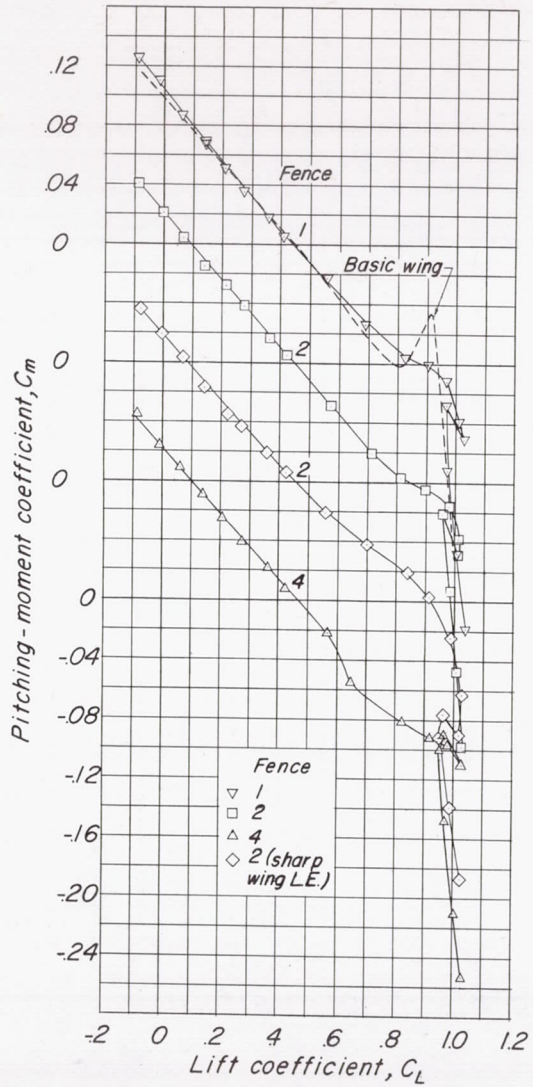


Figure 18.- Concluded.

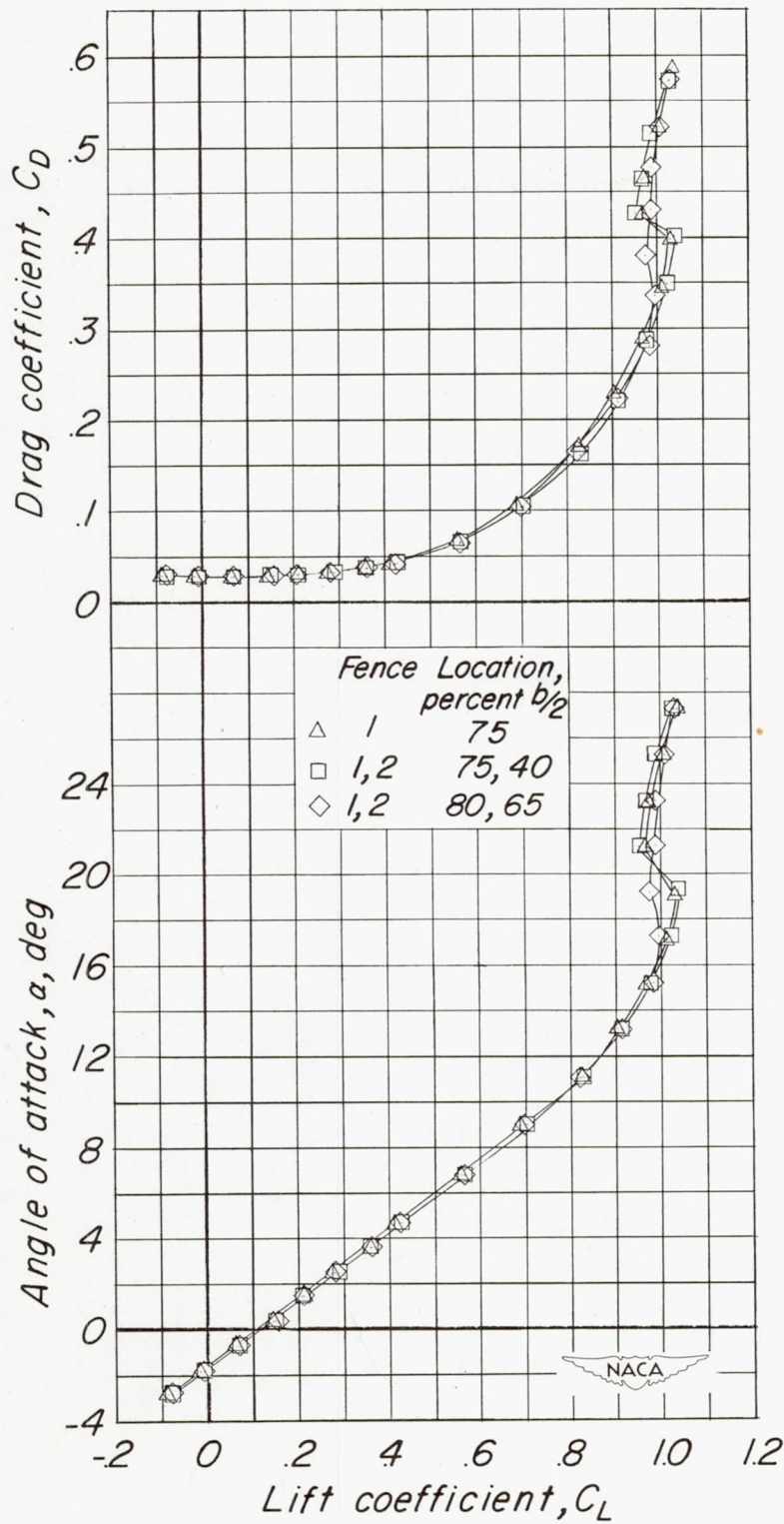


Figure 19.- Effect of multiple fences and spanwise location of fences.
 $\delta_f = \delta_s = i_t = 0^\circ$.

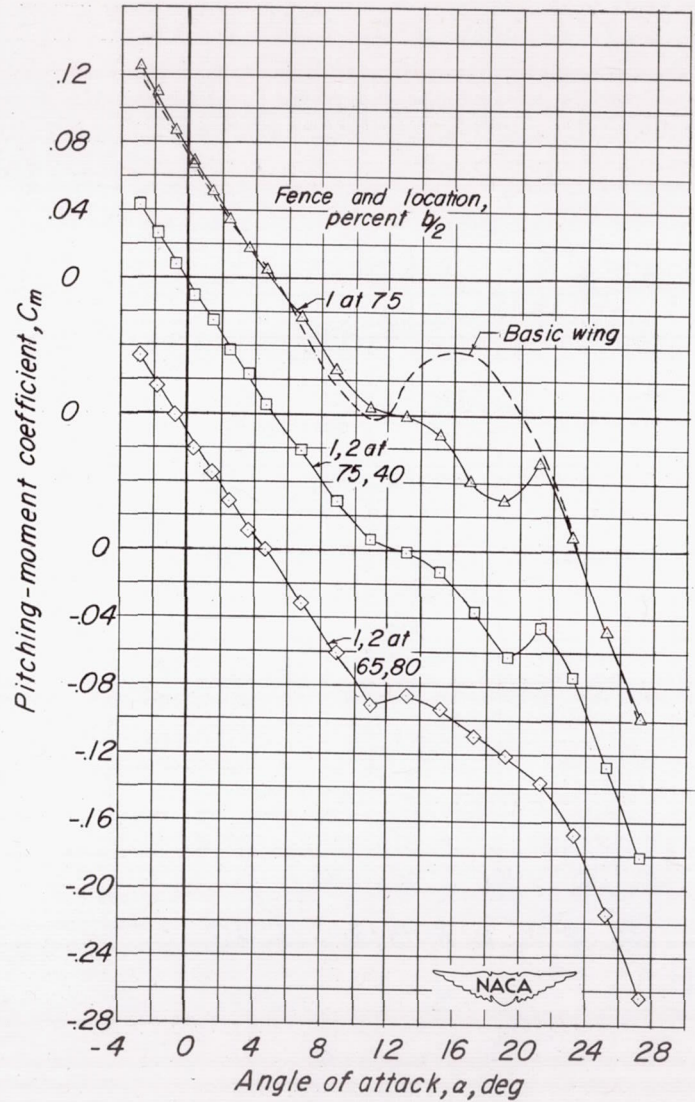
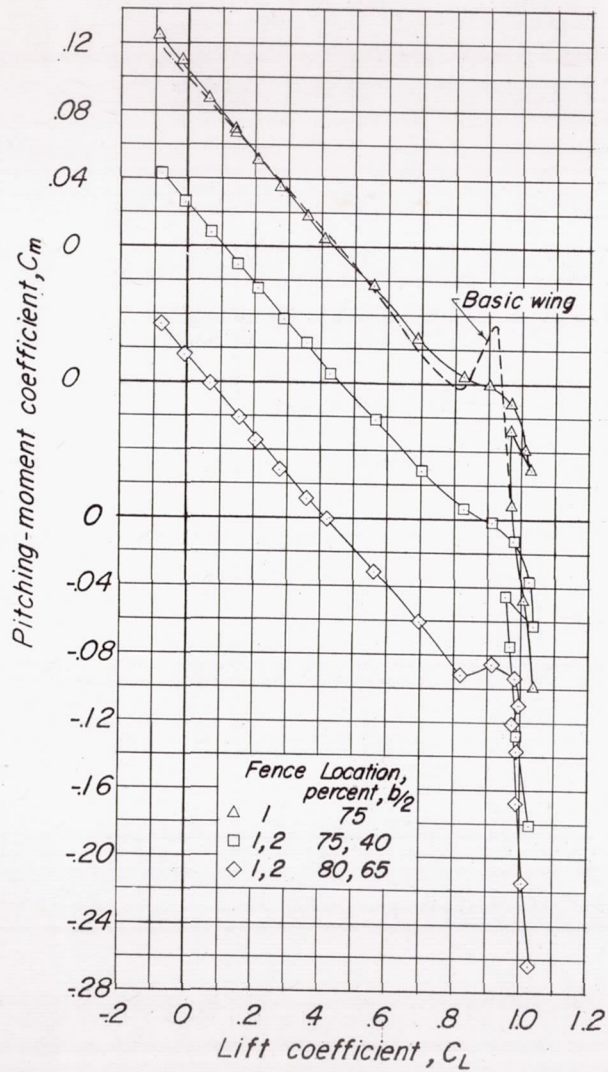


Figure 19.- Concluded.

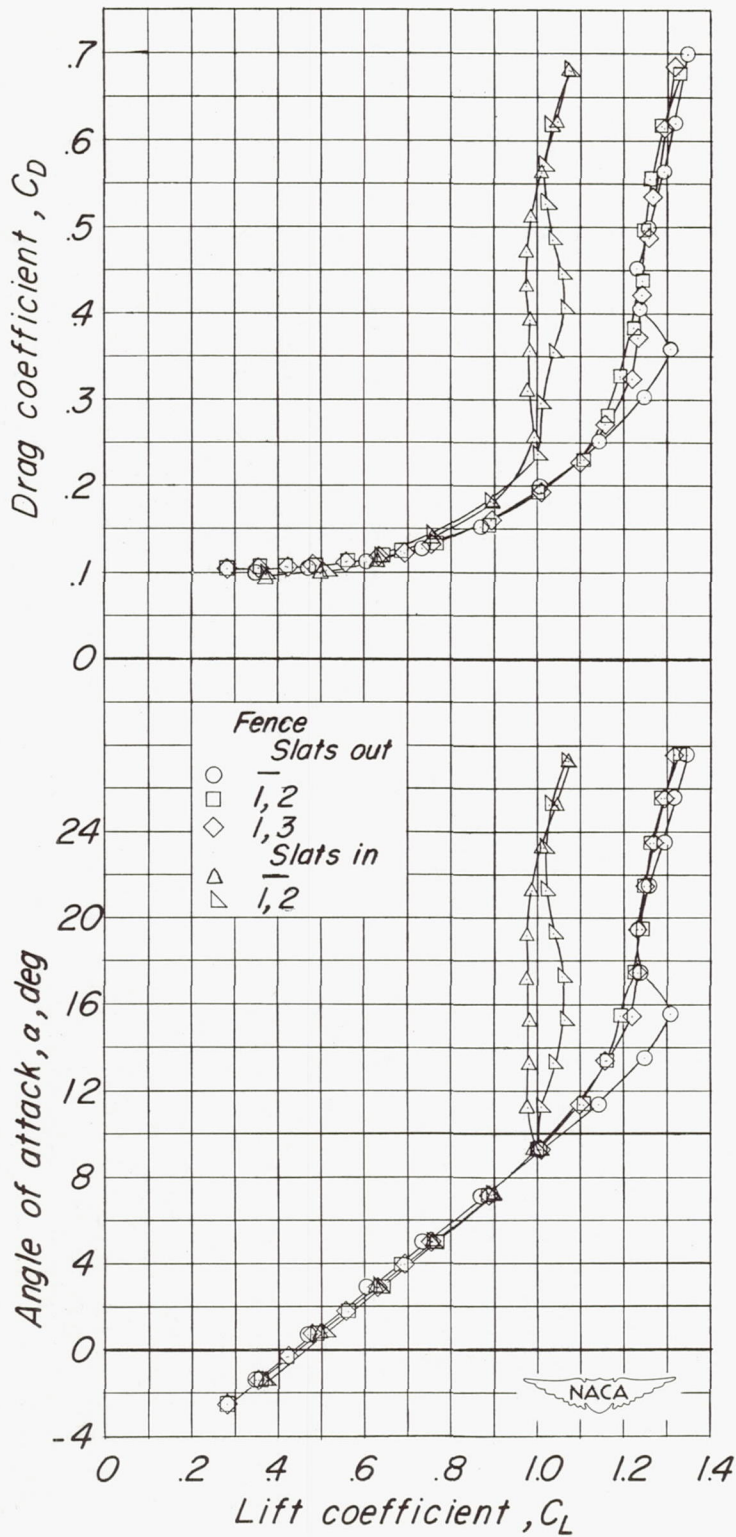


Figure 20.- Effect of multiple fences located at 75 and 40 percent semispan.
 $\delta_f = 40^\circ$; $\delta_s = 21.7^\circ$; $i_t = 0^\circ$.

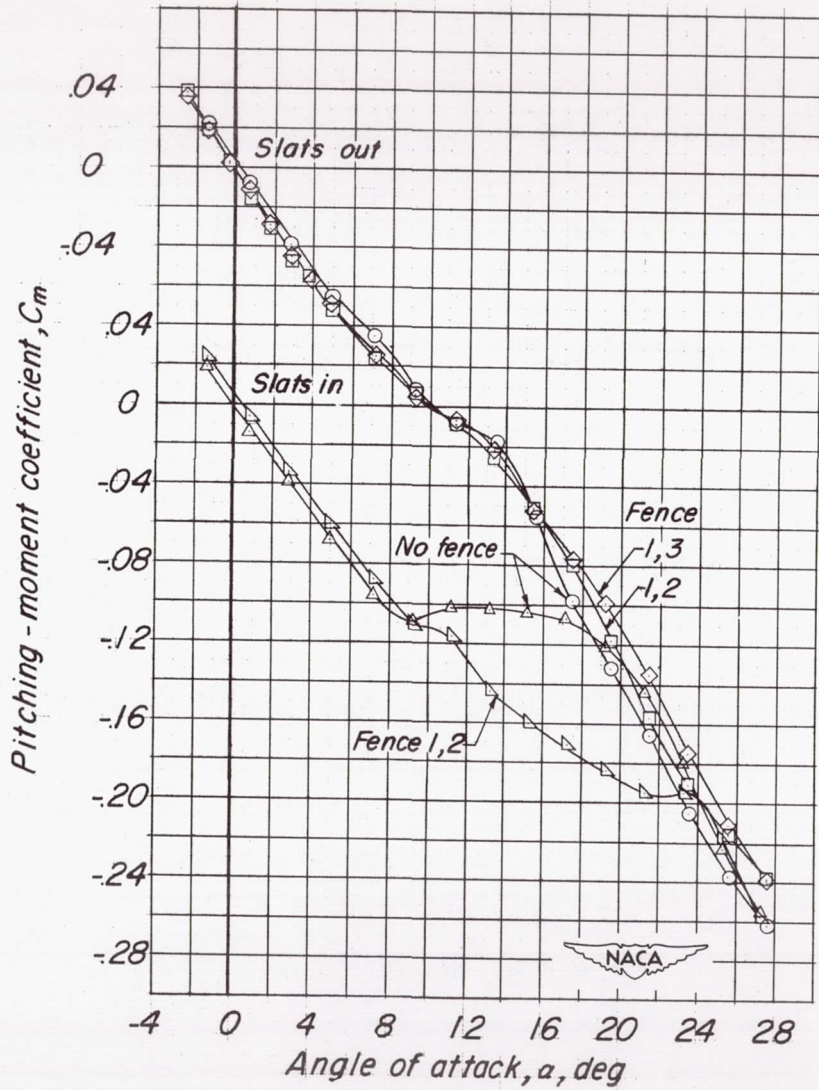
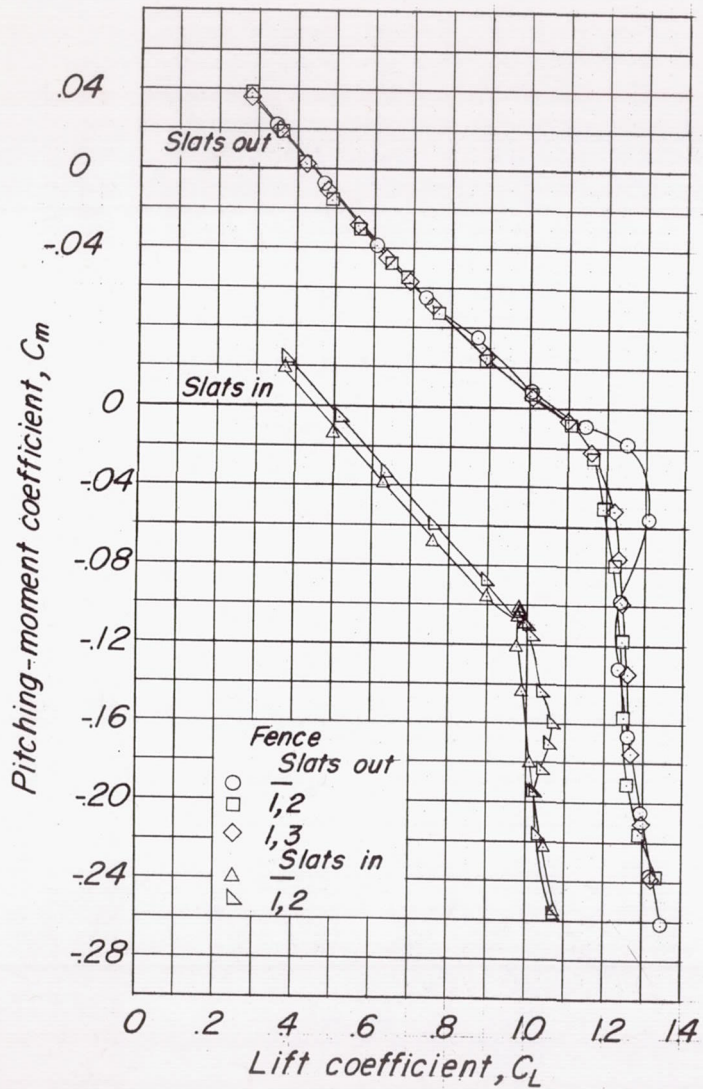


Figure 20.- Concluded.

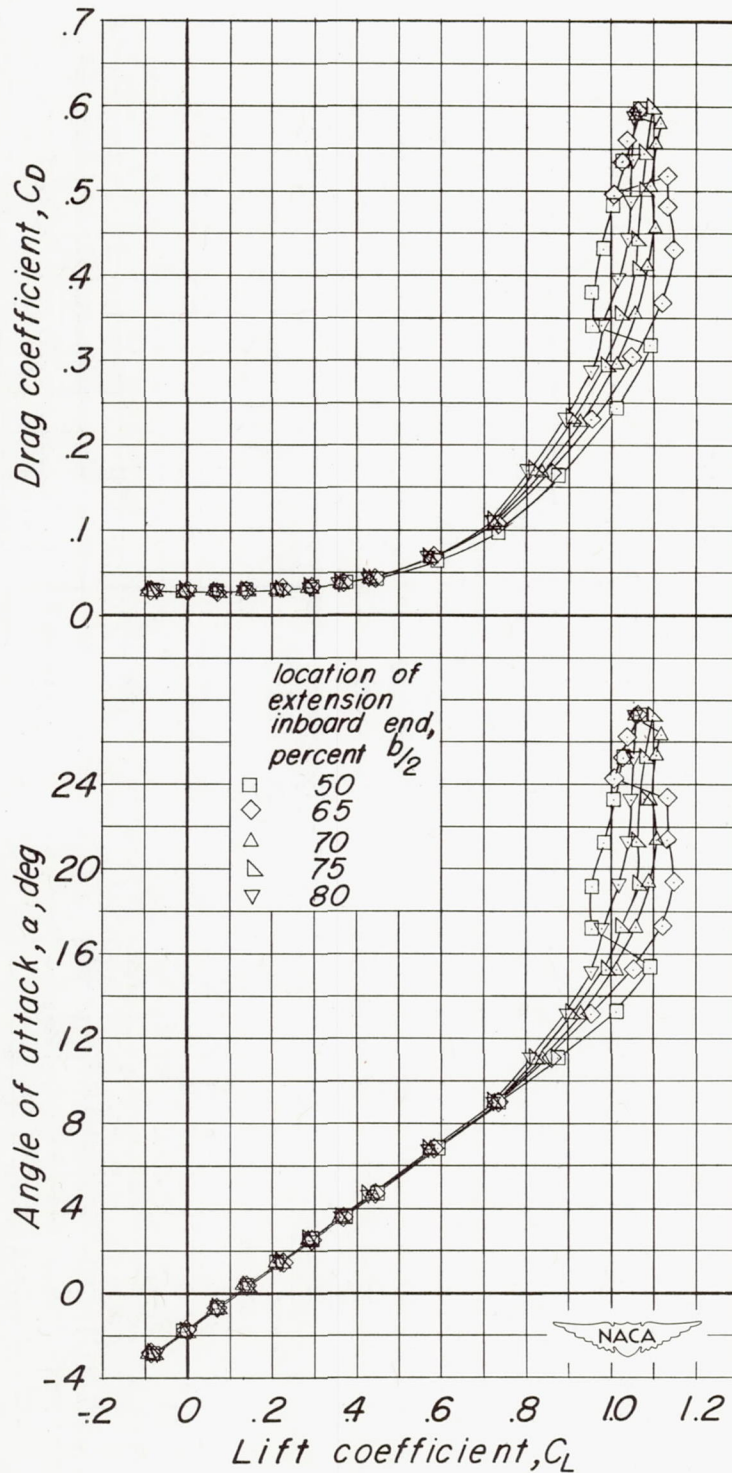


Figure 21.- Effect of inboard-end location of 0.10c leading-edge chord-extensions having the outboard end at 94 percent semispan. $\delta_f = \delta_s = i_t = 0^\circ$.

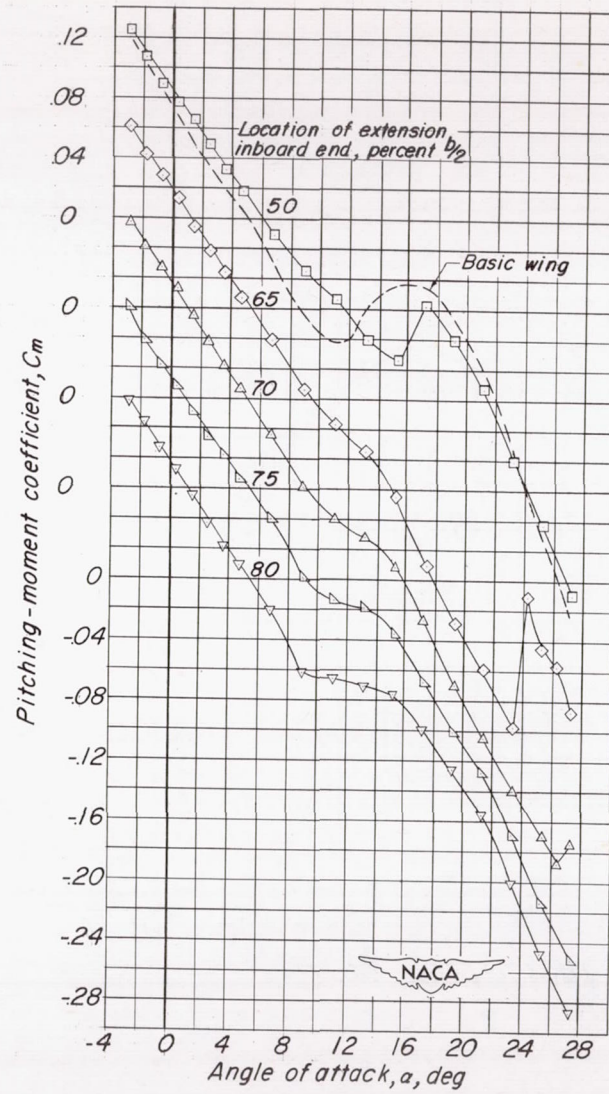
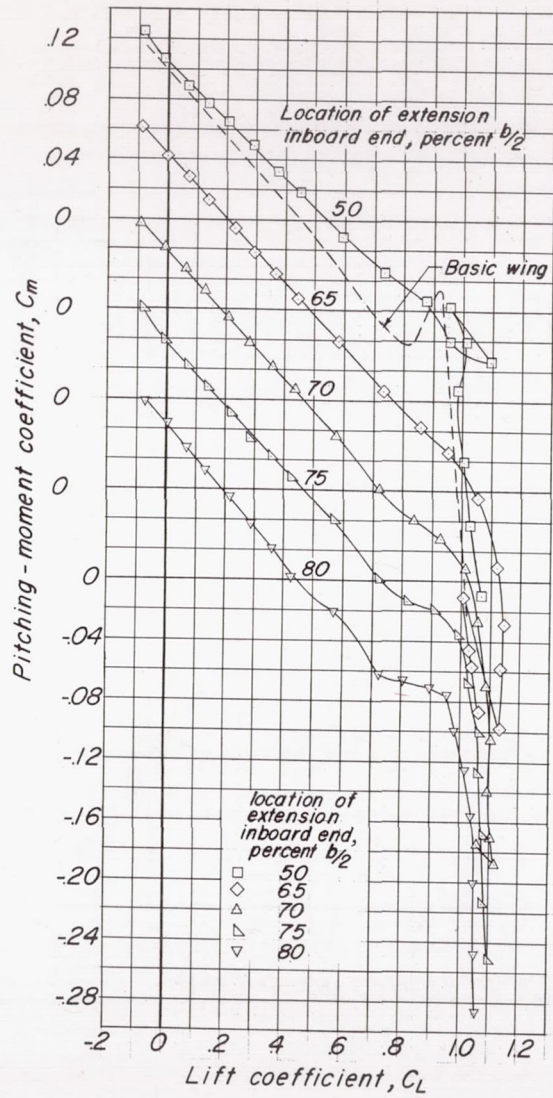


Figure 21.- Concluded.

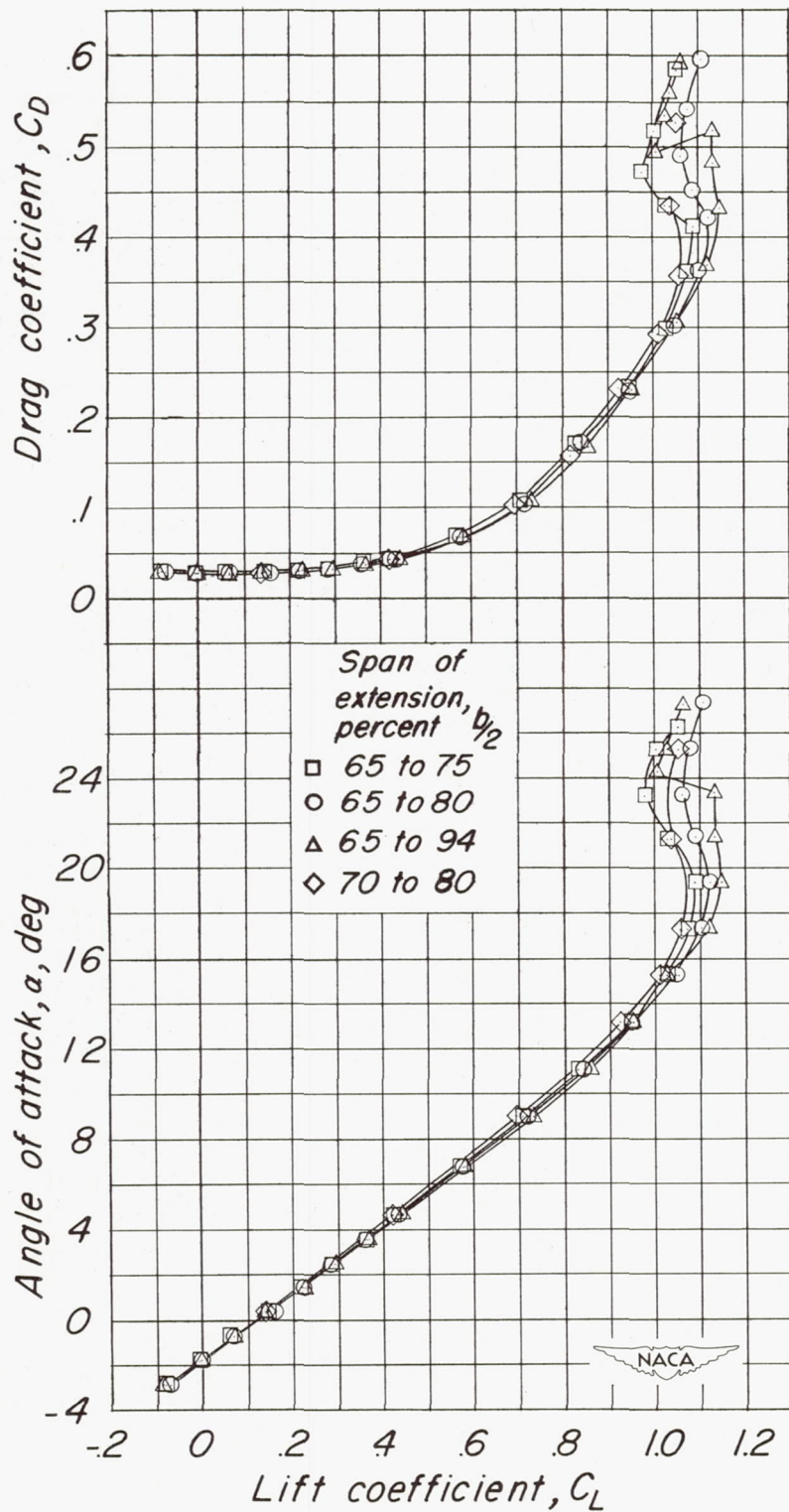


Figure 22.- Effect of spanwise extent of $0.10c$ leading-edge chord-extensions. $\delta_f = \delta_s = i_t = 0^\circ$.

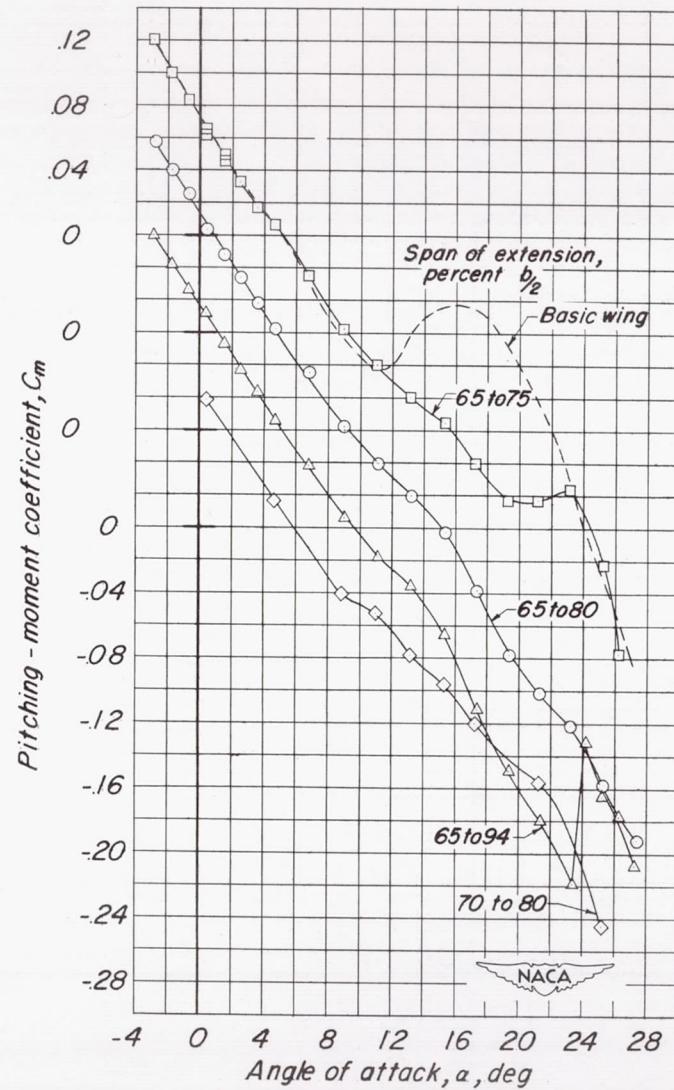
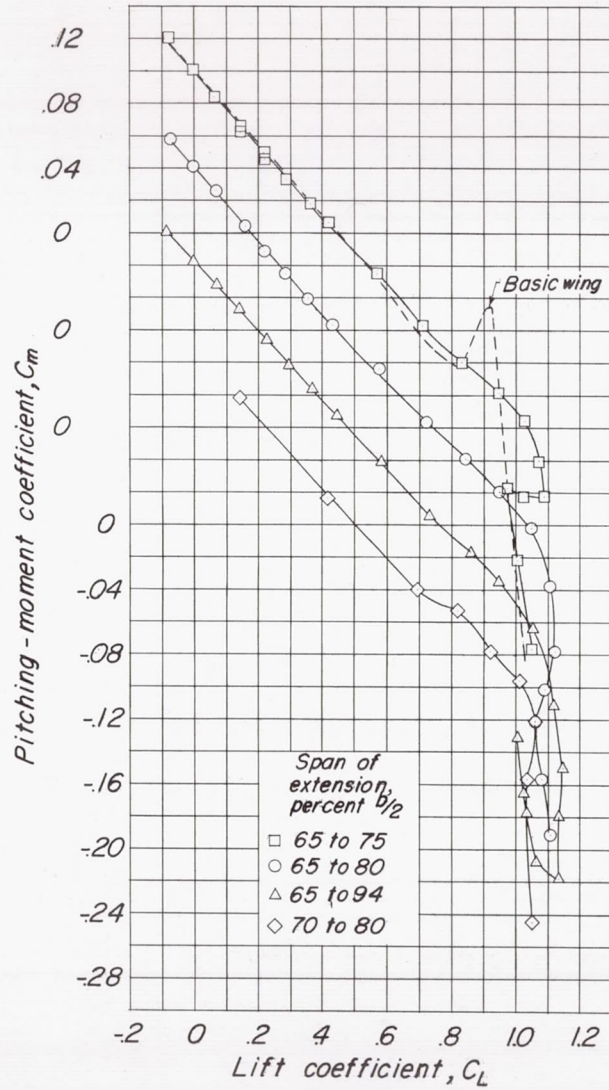


Figure 22.- Concluded.

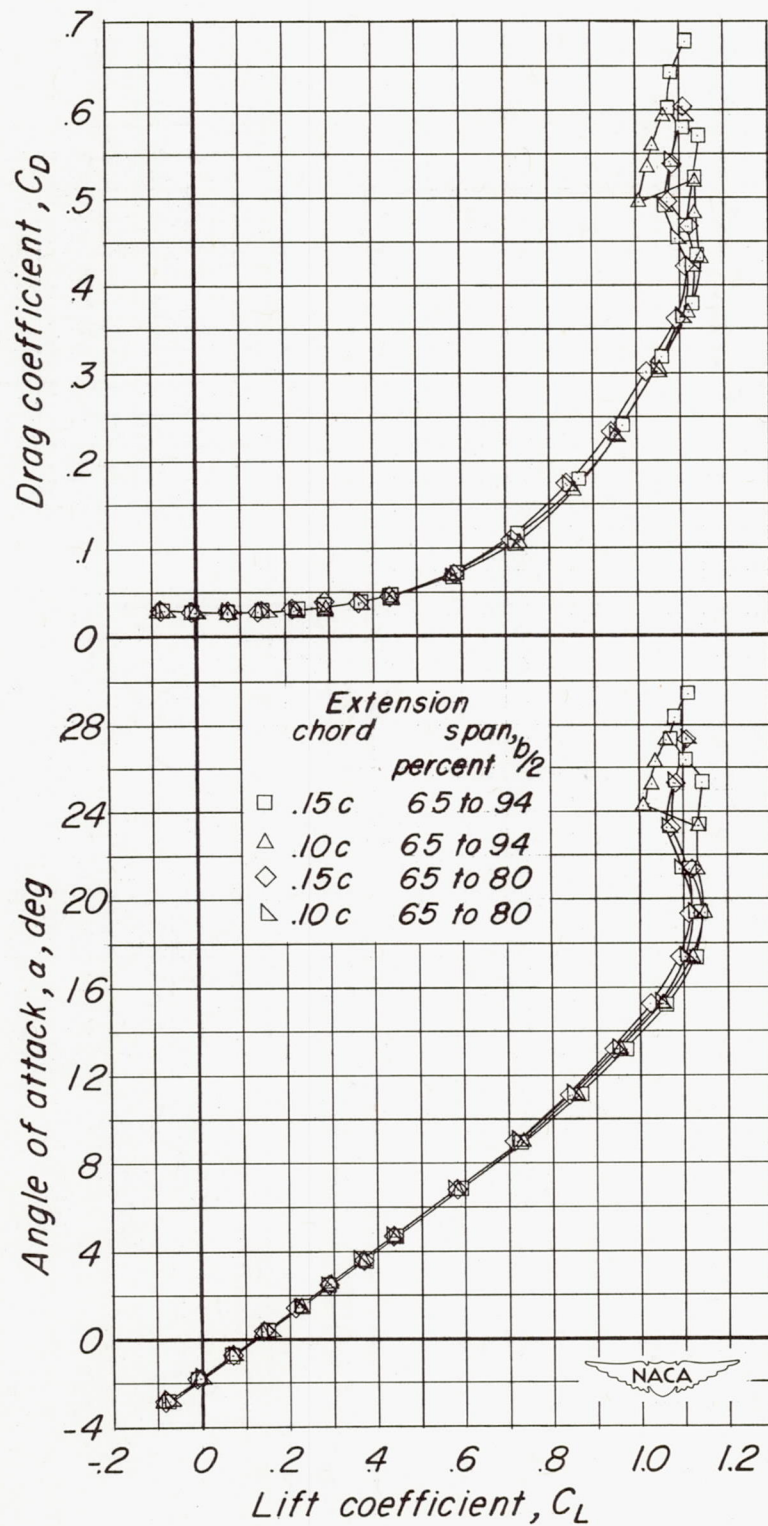


Figure 23.- Effect of chordwise extent of leading-edge chord-extensions.
 $\delta_f = \delta_s = i_t = 0^\circ$.

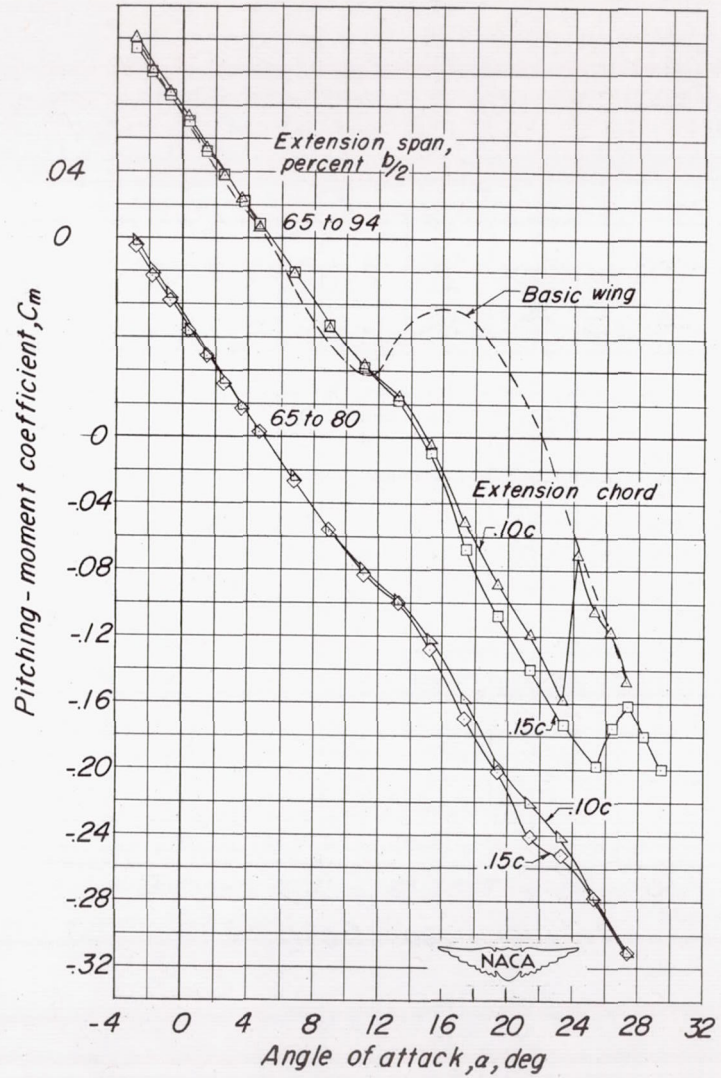
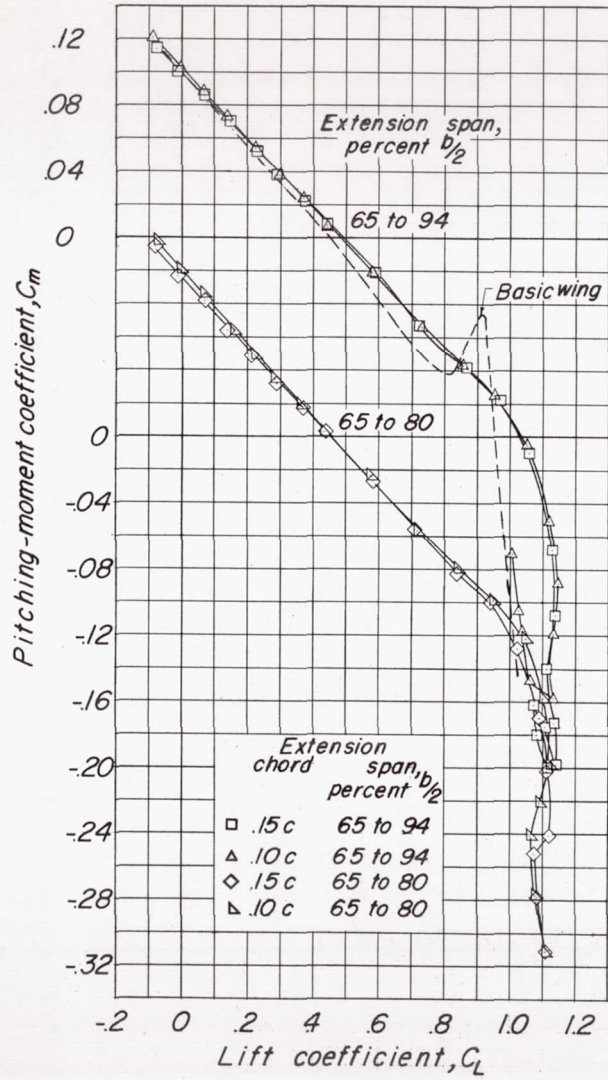


Figure 23.- Concluded.

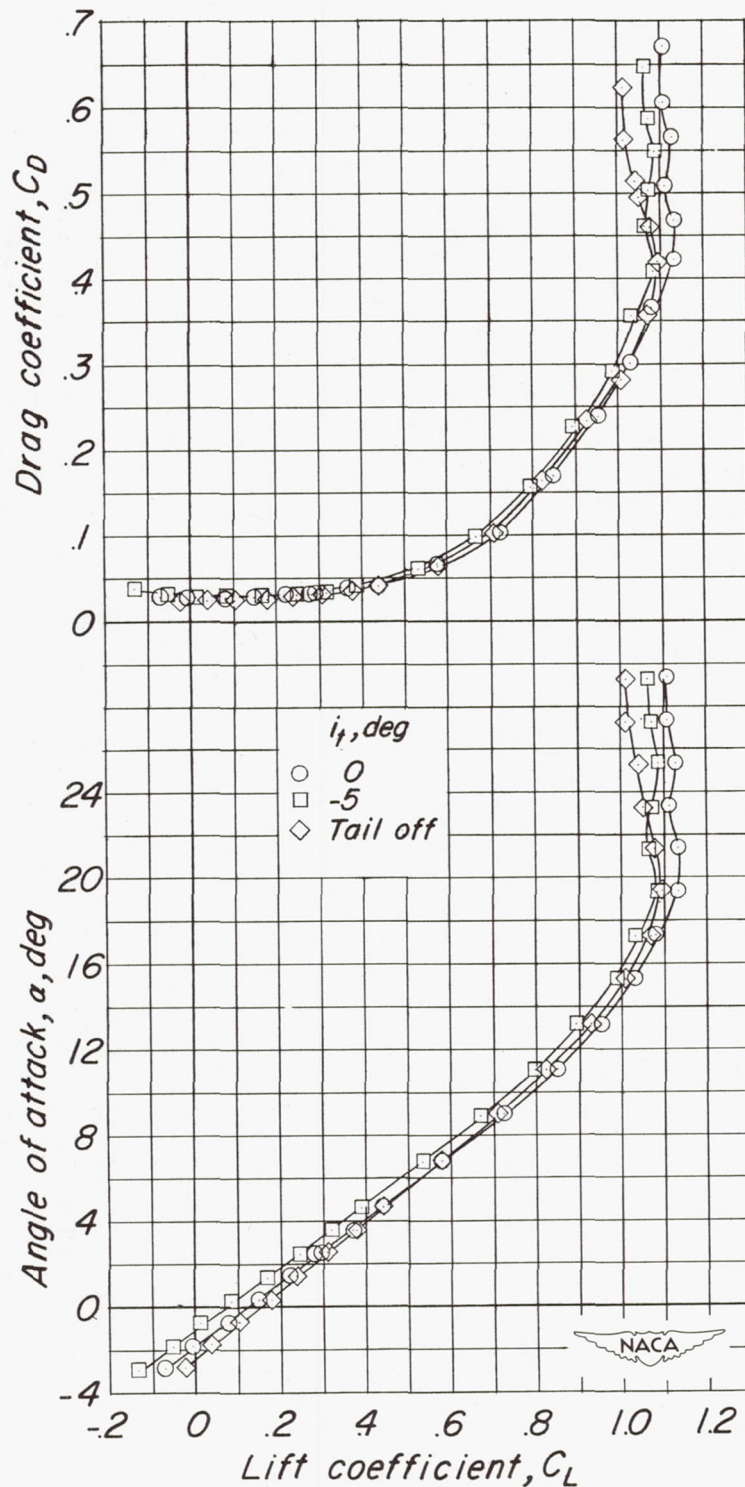


Figure 24.- Effect of stabilizer deflection on the aerodynamic characteristics of the model with a 0.10c leading-edge chord-extension from 70 to 94 percent semispan. $\delta_F = \delta_S = 0^\circ$.

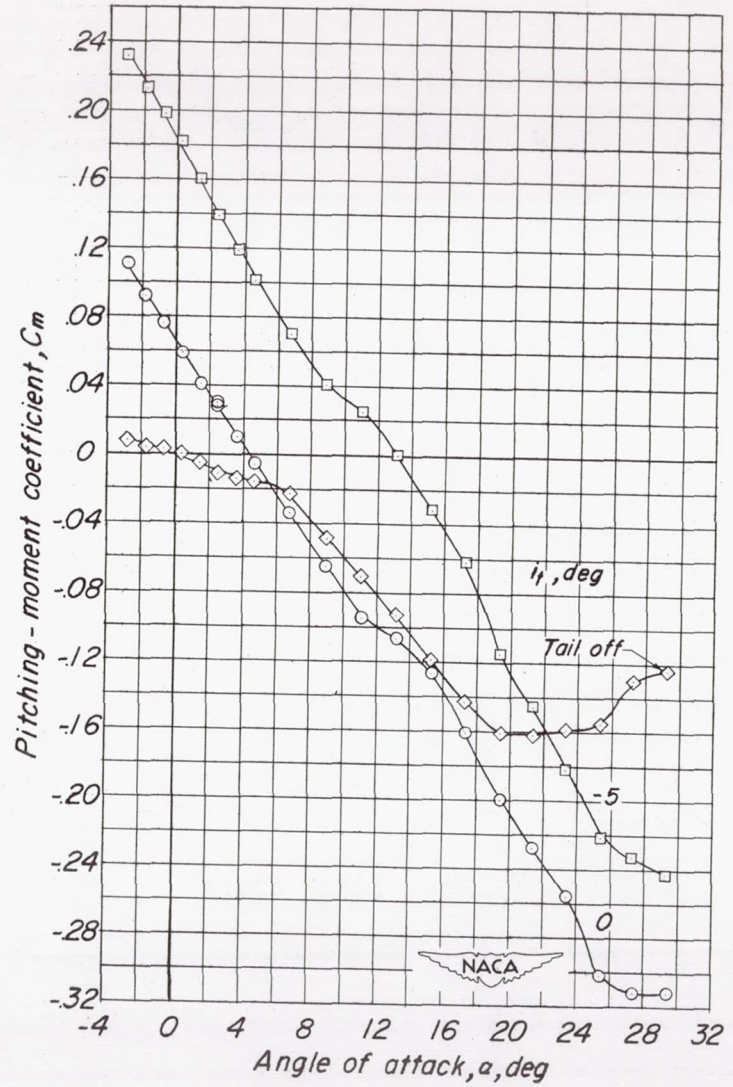
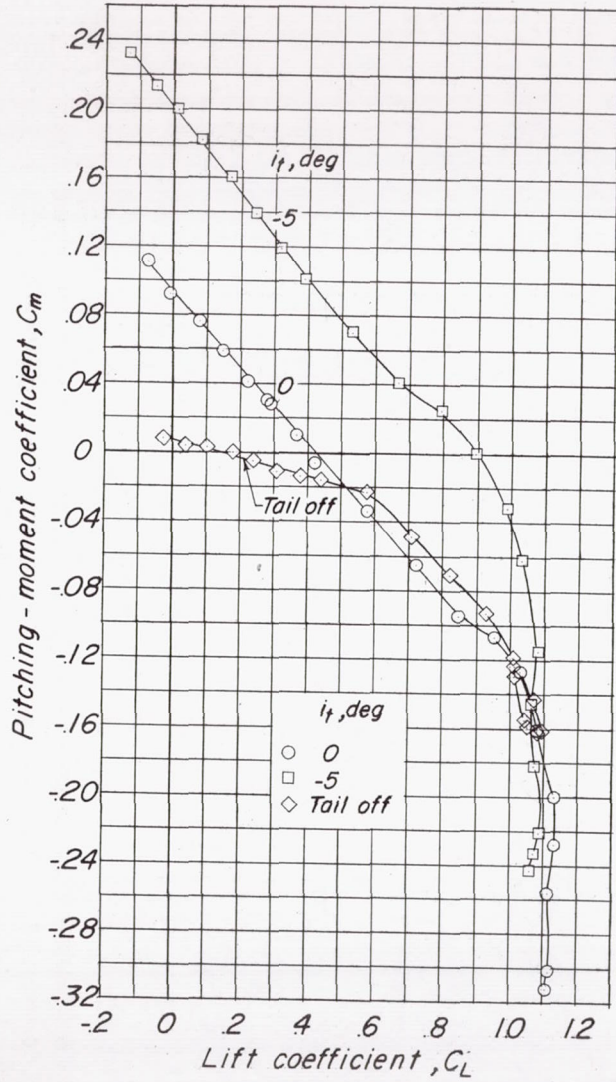


Figure 24.- Concluded.

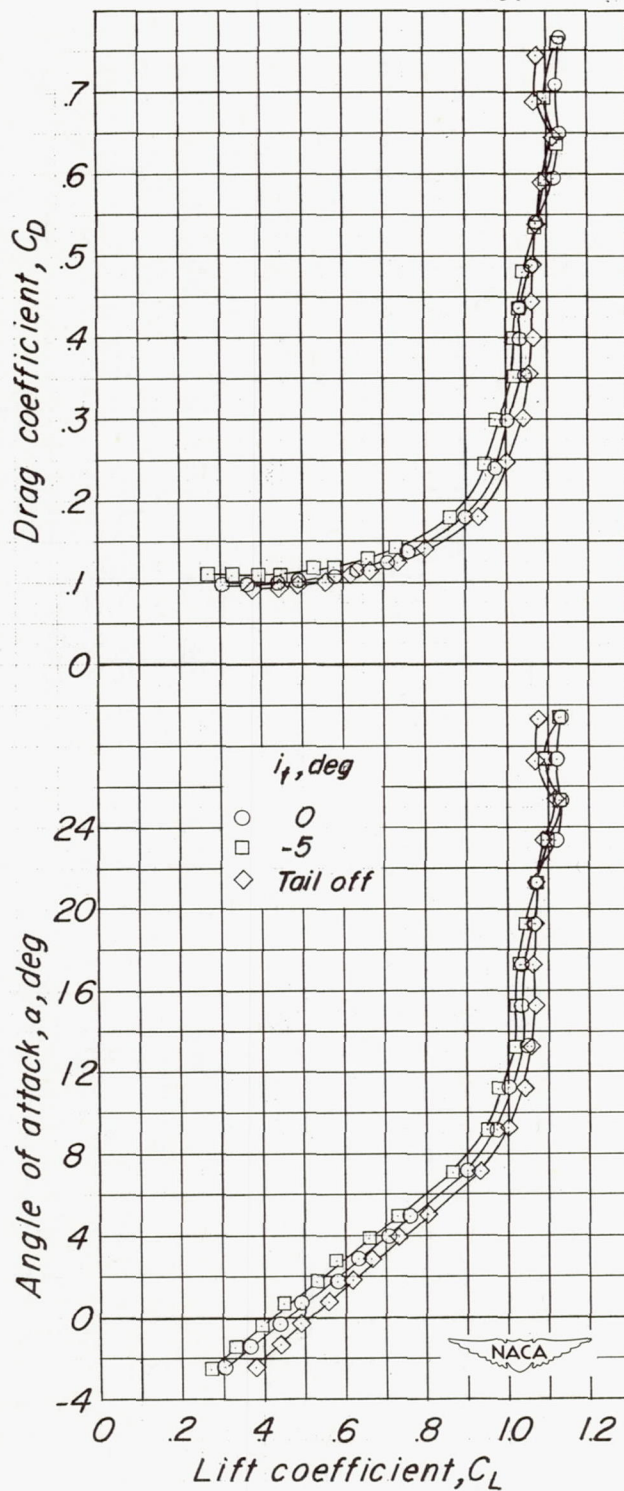


Figure 25.- Effect of stabilizer deflection on the aerodynamic characteristics of the model with a 0.10c leading-edge chord-extension from 70 to 94 percent semispan. $\delta_f = 40^\circ$; $\delta_s = 0^\circ$.

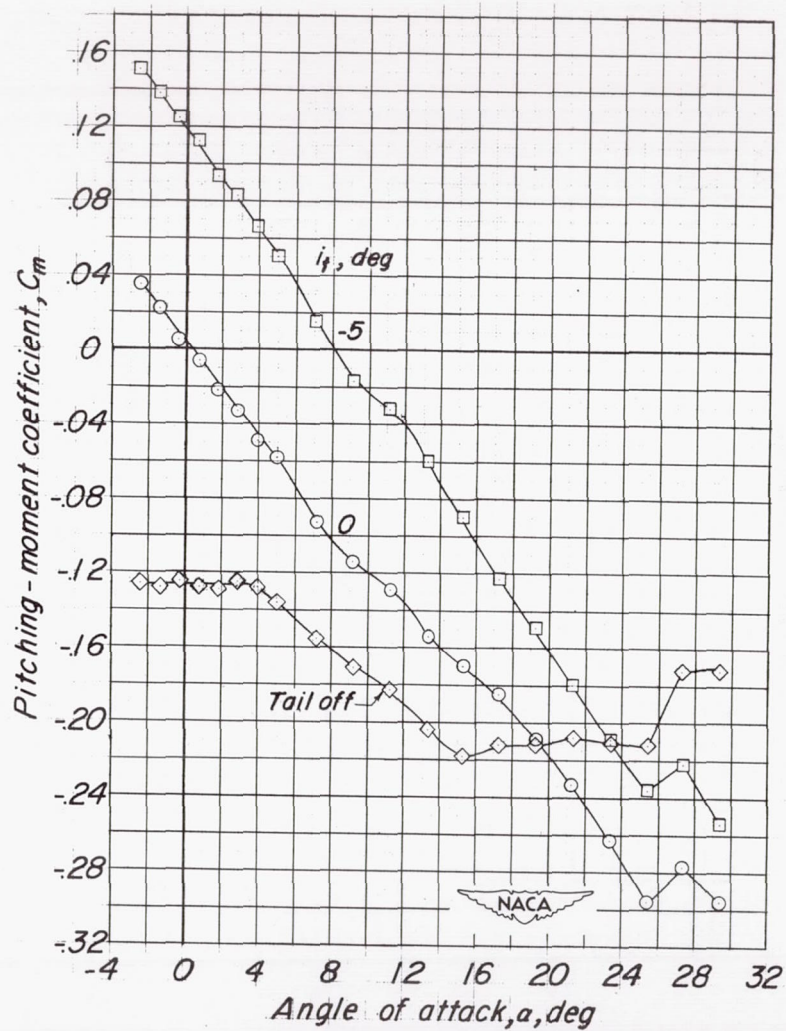
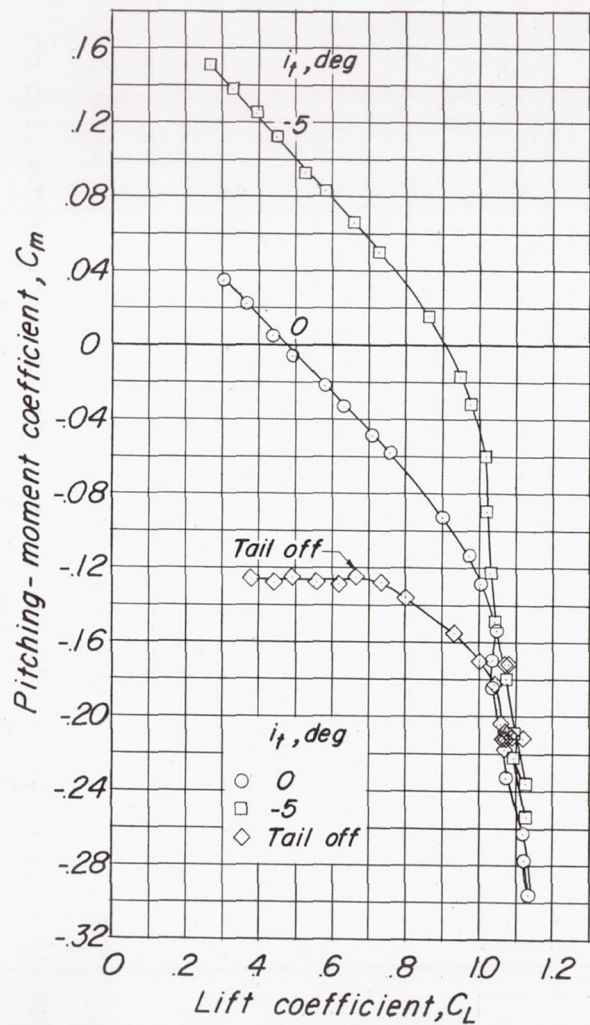
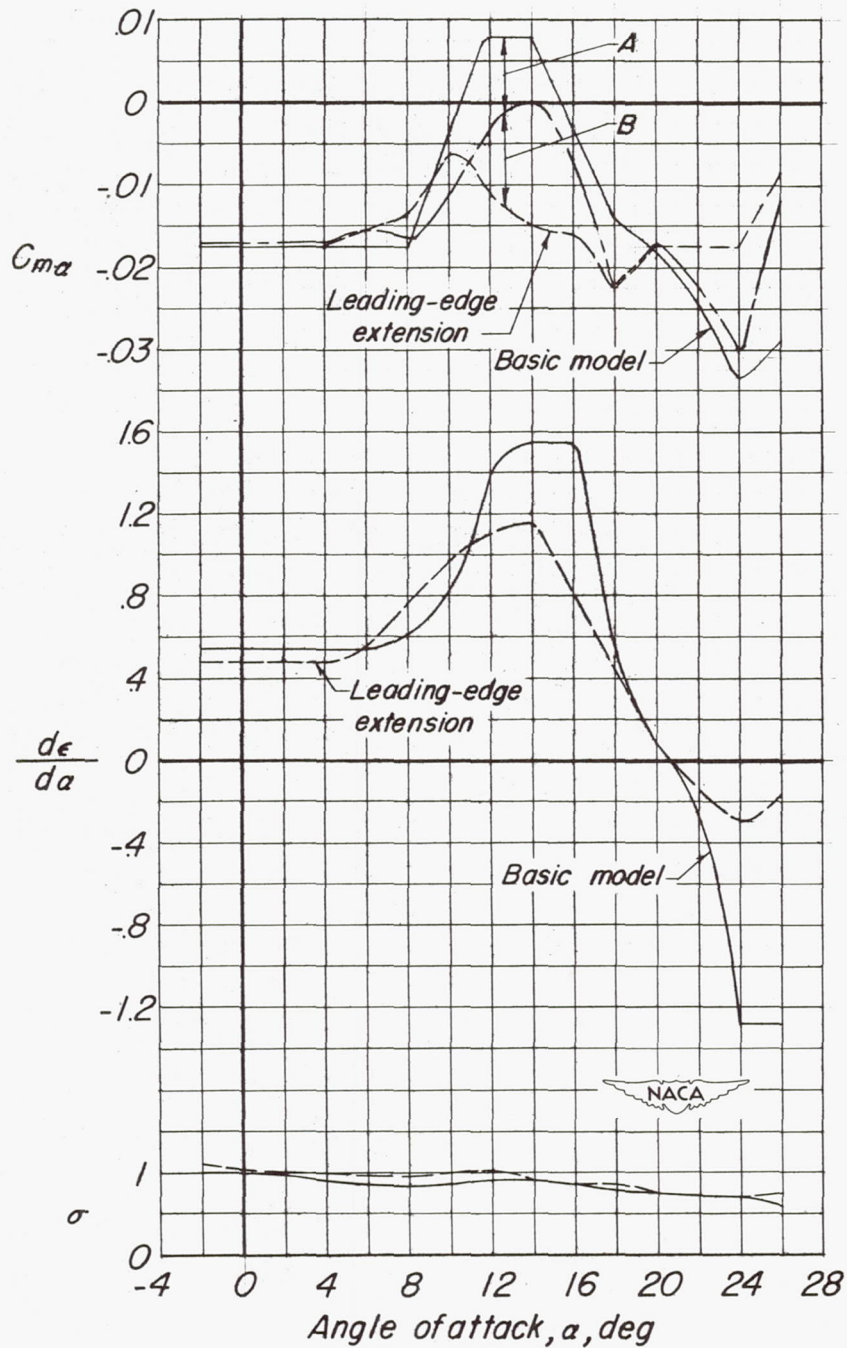


Figure 25.- Concluded.

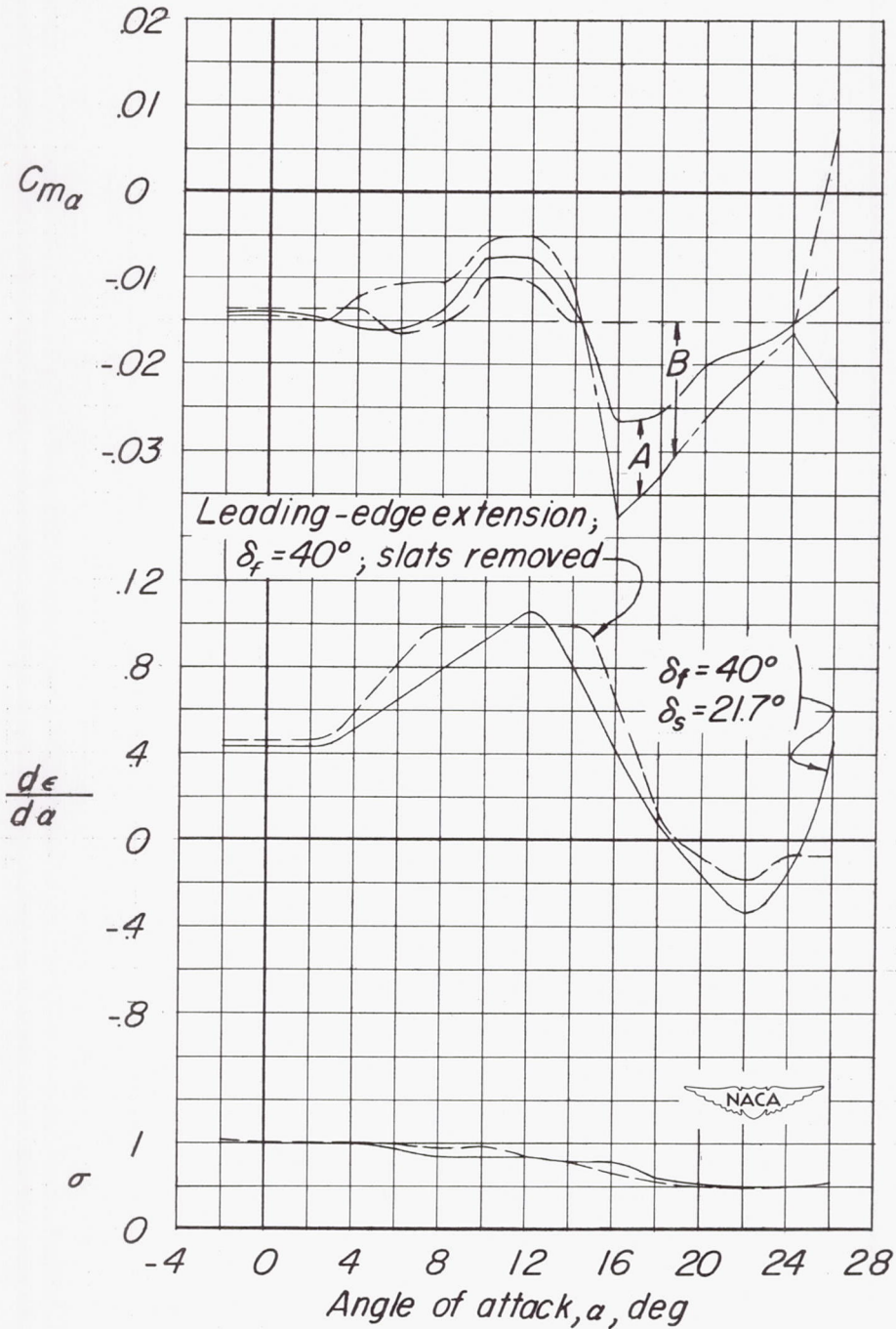
A - Effect of extension on wing-fuselage contribution
 B - Effect of extension on tail contribution



(a) $\delta_F = \delta_S = 0^\circ$.

Figure 26.- Analysis of effect of leading-edge chord-extension on longitudinal stability characteristics.

A-Effect of extension on wing-fuselage contribution
 B-Effect of extension on tail contribution



(b) $\delta_f = 40^\circ$.

Figure 26.- Concluded.

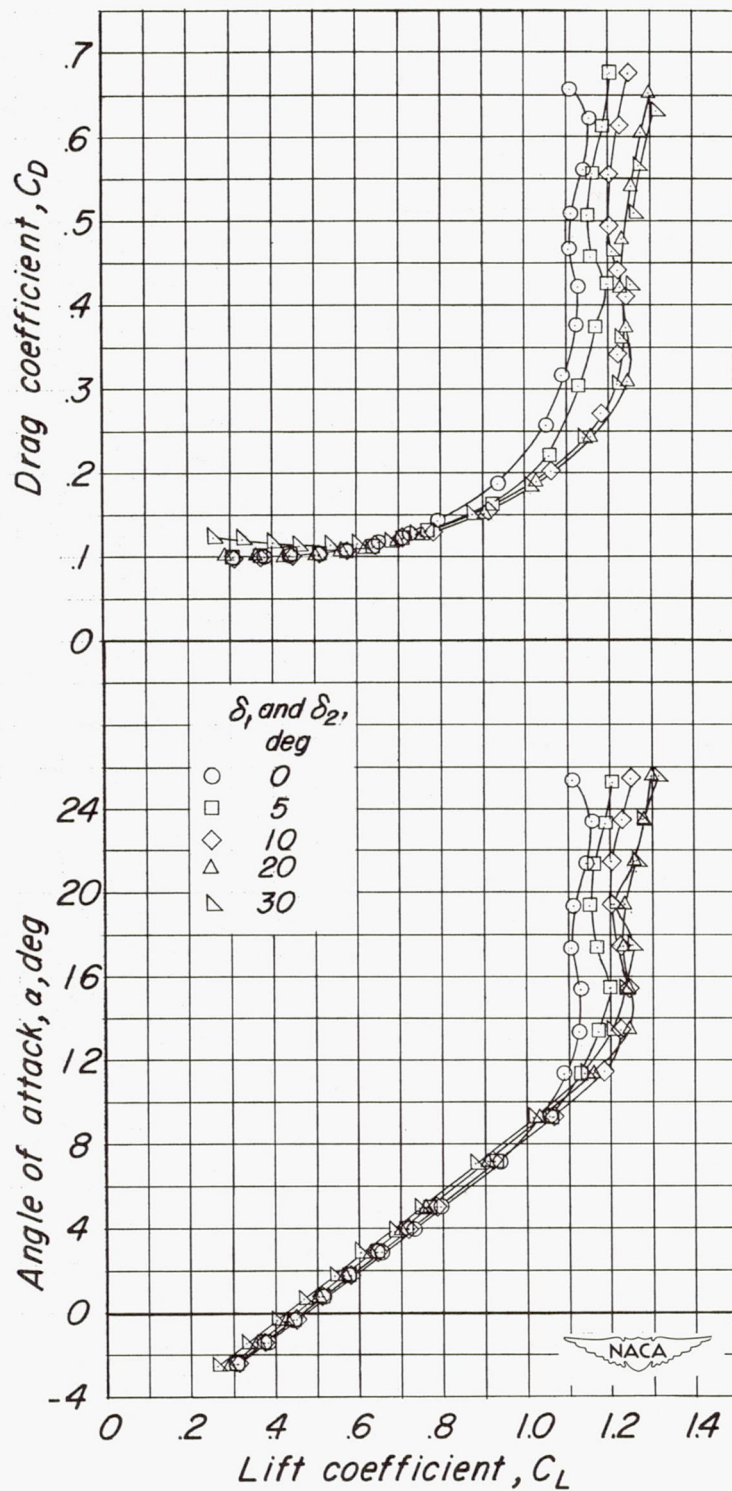


Figure 27.- Effect of leading-edge droop angle with 0.10c leading-edge chord-extension from 65 to 94 percent semispan. $\delta_f = 40^\circ$; $i_t = 0^\circ$; slats removed.

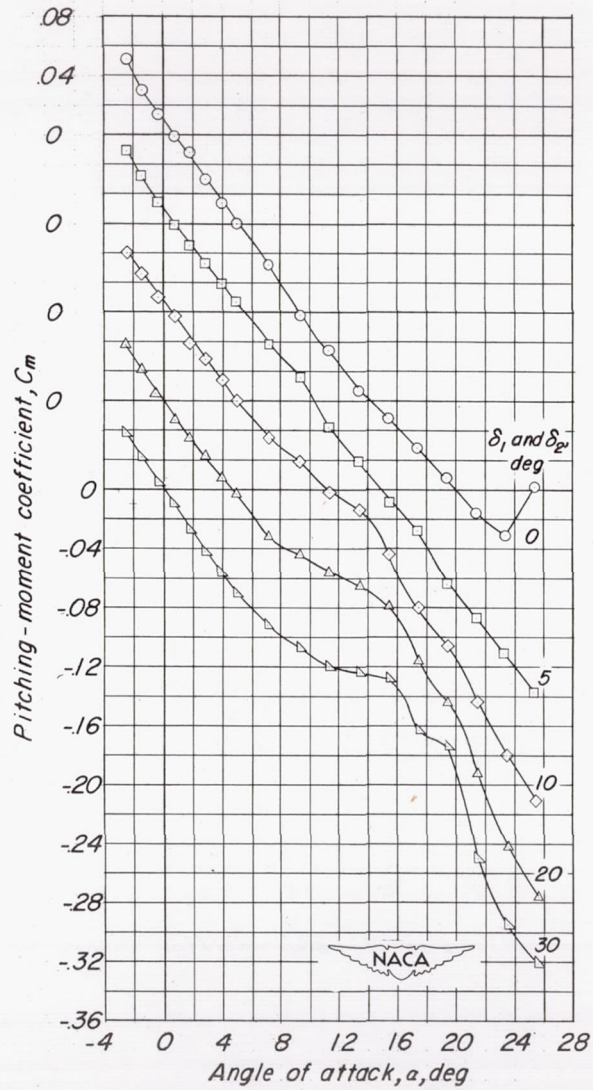
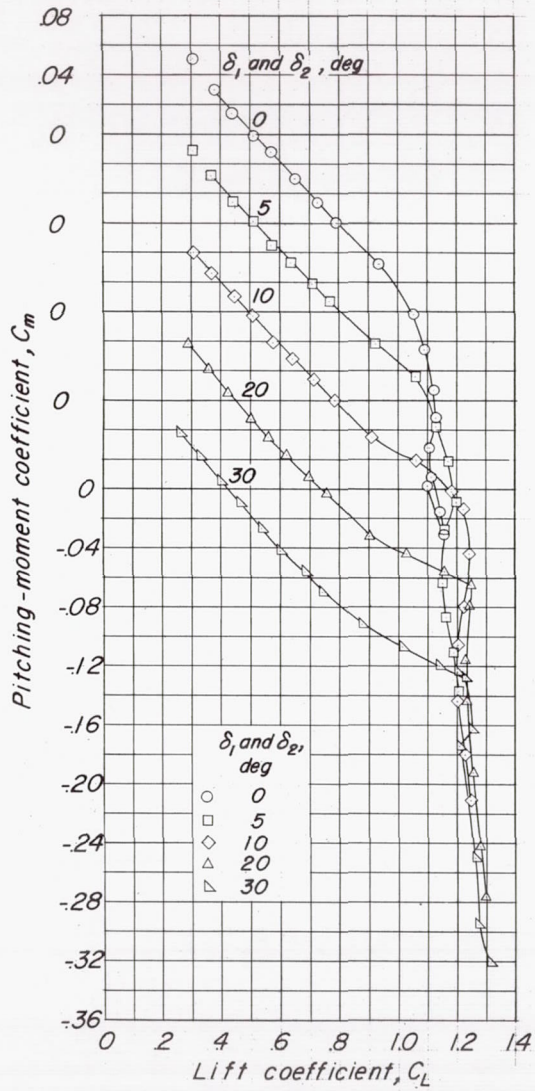


Figure 27.- Concluded.

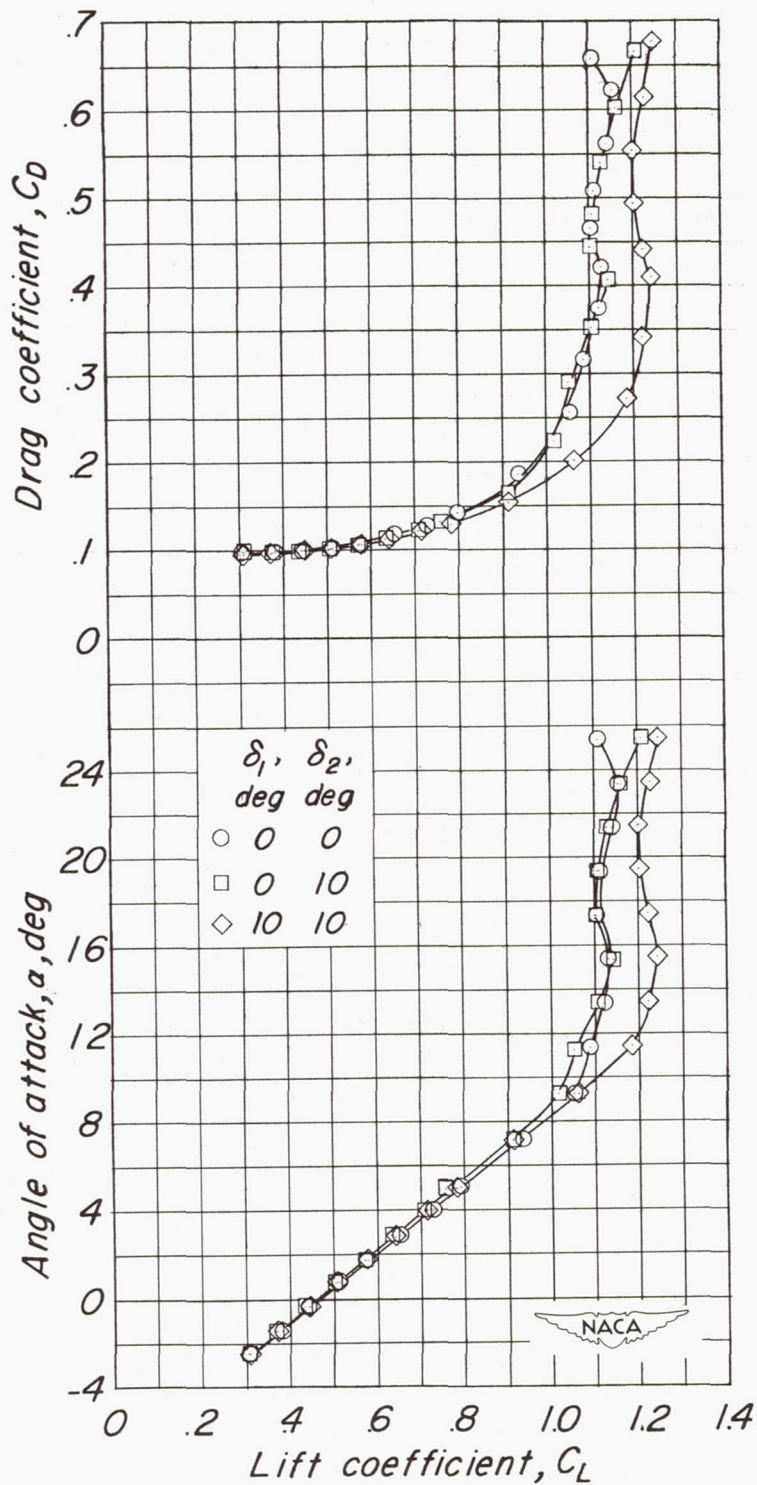


Figure 28.- Effect of spanwise extent of leading-edge droop with 0.10c leading-edge chord-extension from 65 to 94 percent semispan. $\delta_F = 40^\circ$; $i_t = 0^\circ$; slats removed.

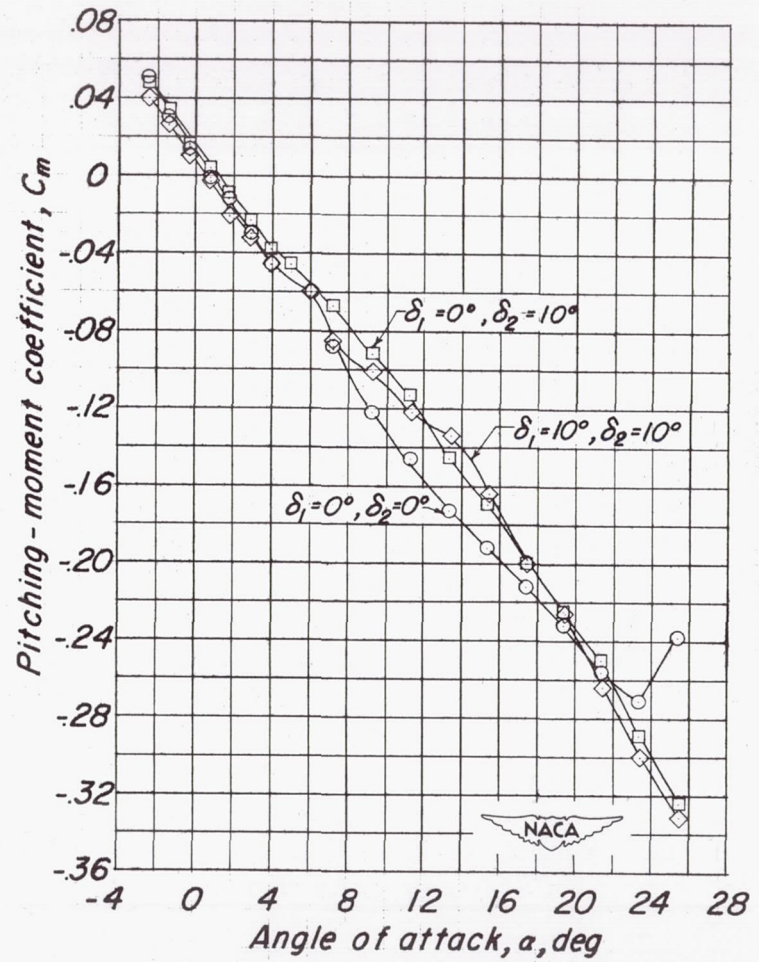
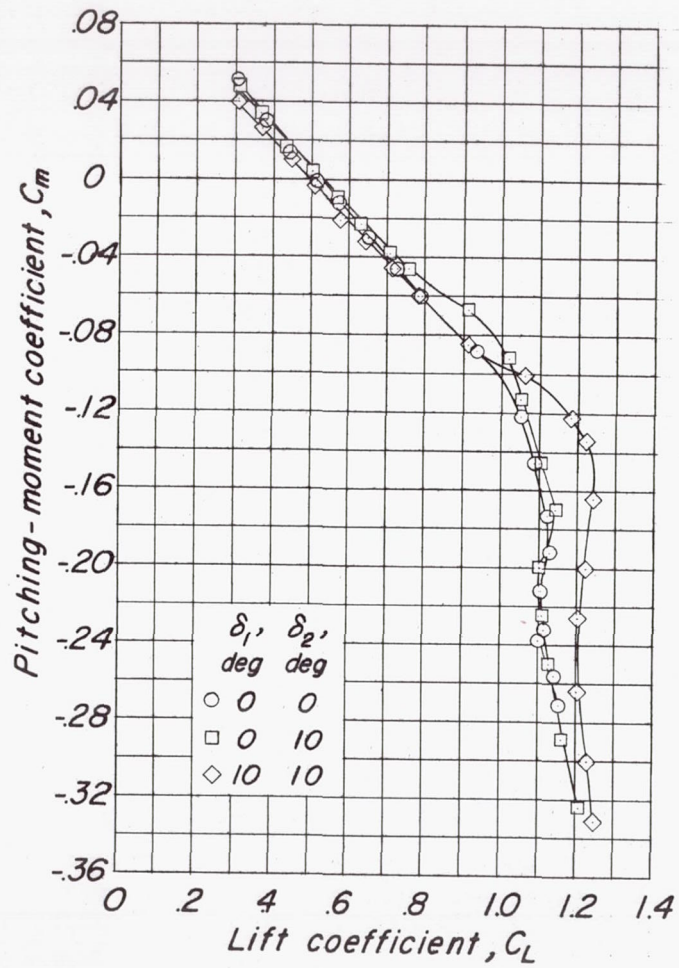


Figure 28.- Concluded.

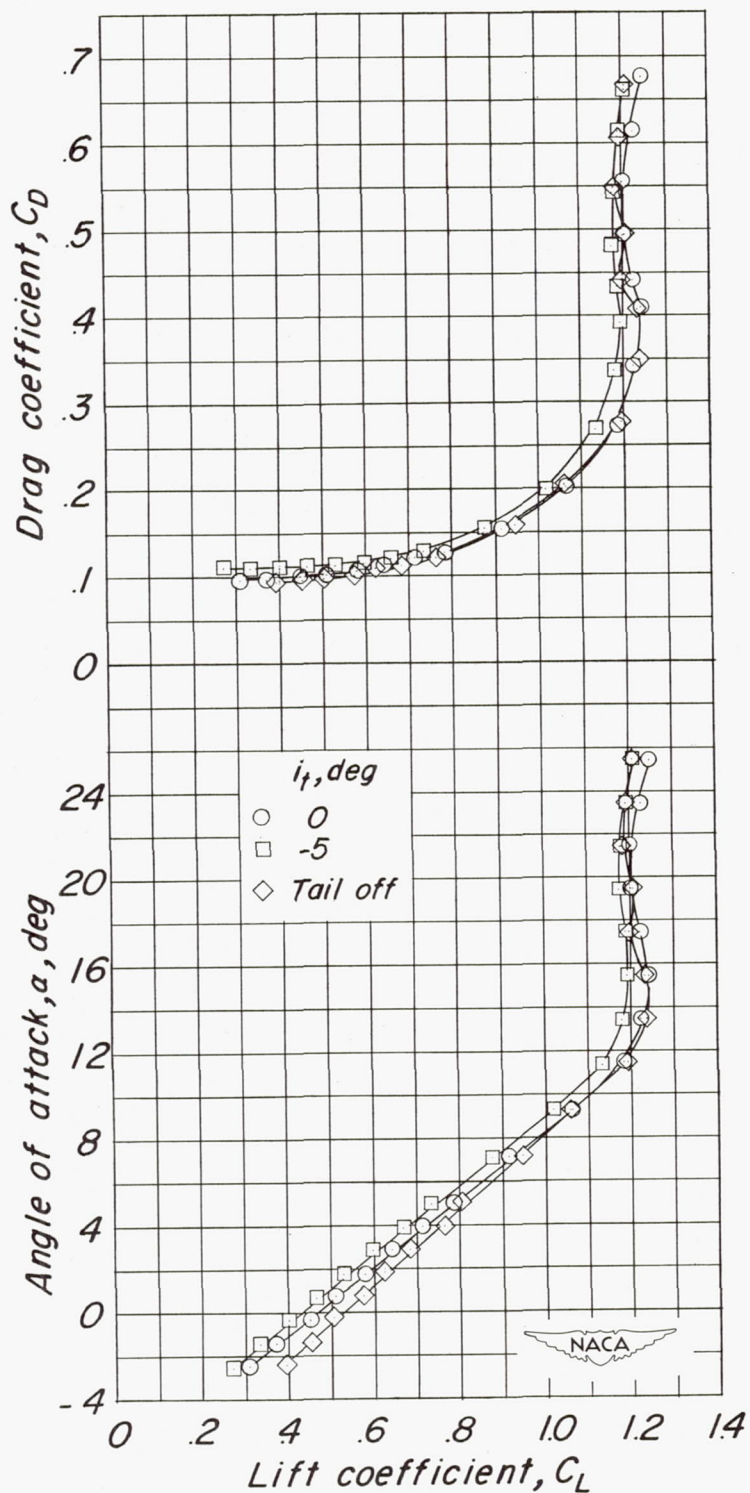


Figure 29.- Effect of stabilizer deflection on the aerodynamic characteristics of the model with drooped 0.10c leading-edge chord-extension from 65 to 94 percent semispan. $\delta_1 = 10^\circ$; $\delta_2 = 10^\circ$; $\delta_f = 40^\circ$; slats removed.

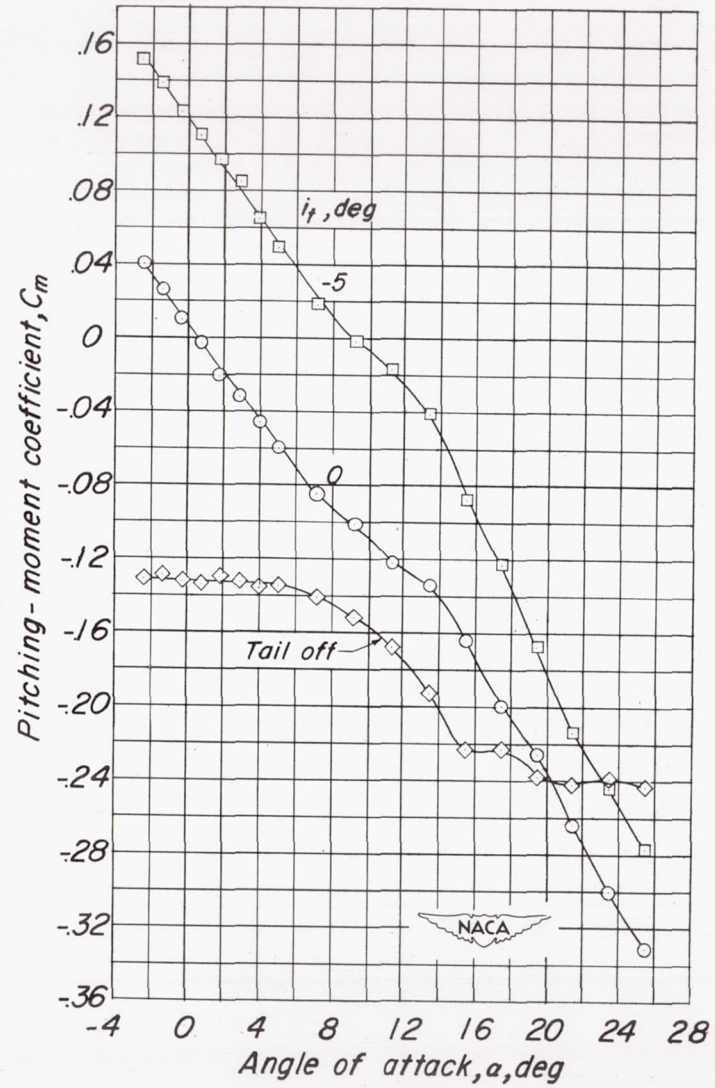
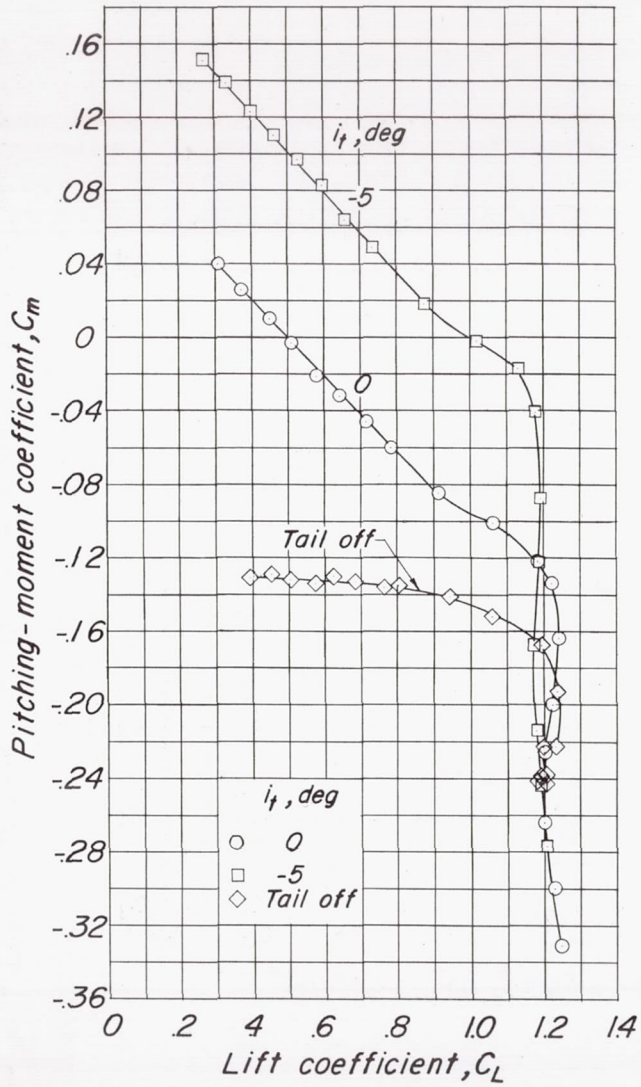


Figure 29.- Concluded.

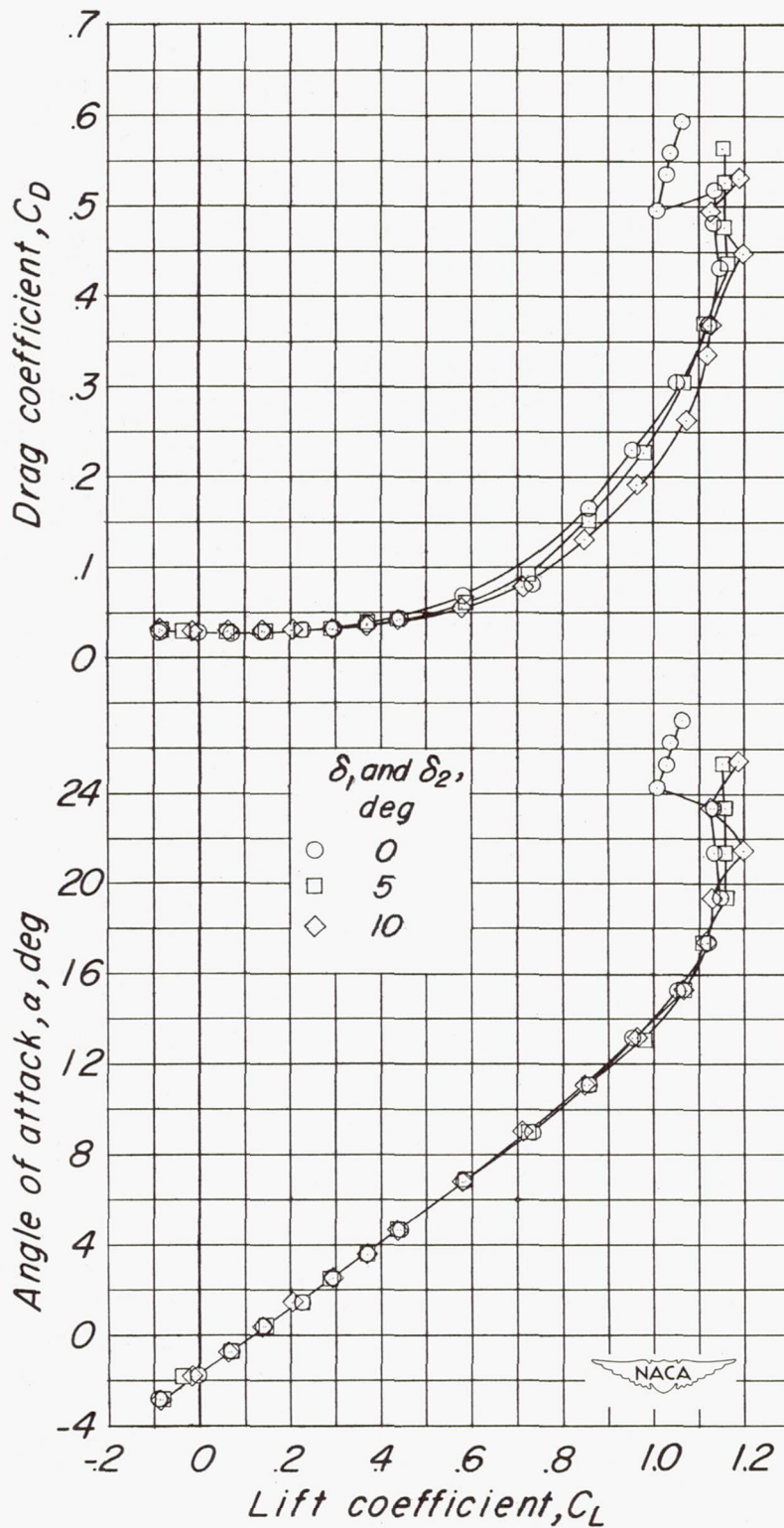


Figure 30.- Effect of leading-edge droop angle with 0.10c leading-edge chord-extension from 65 to 94 percent semispan. $\delta_f = 0^\circ$.

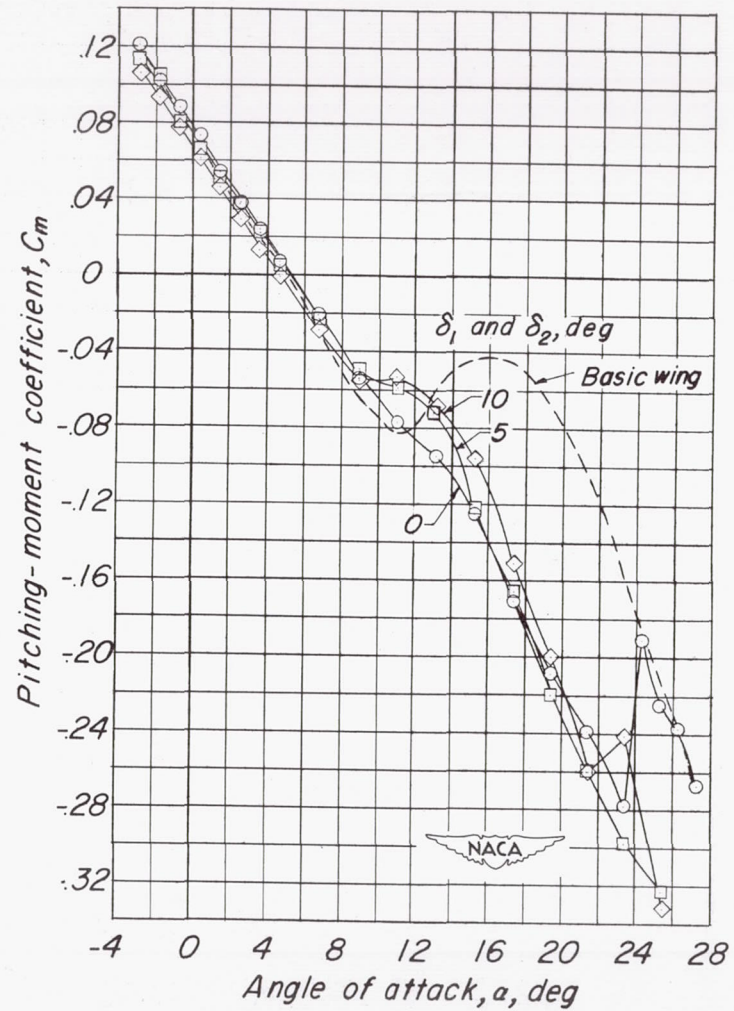
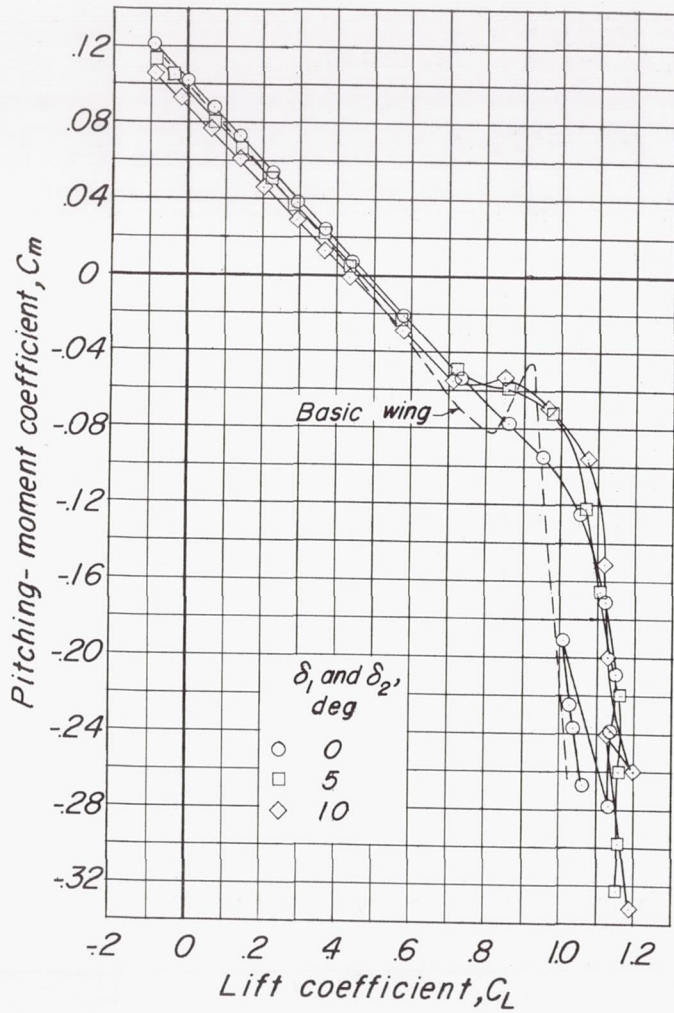


Figure 30.- Concluded.

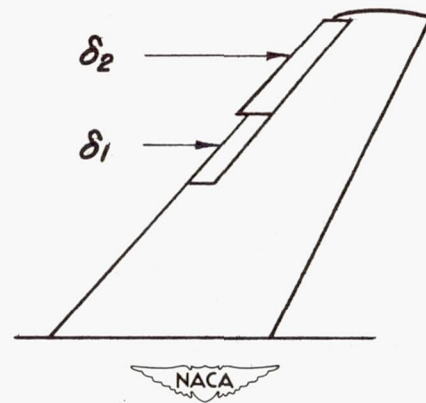
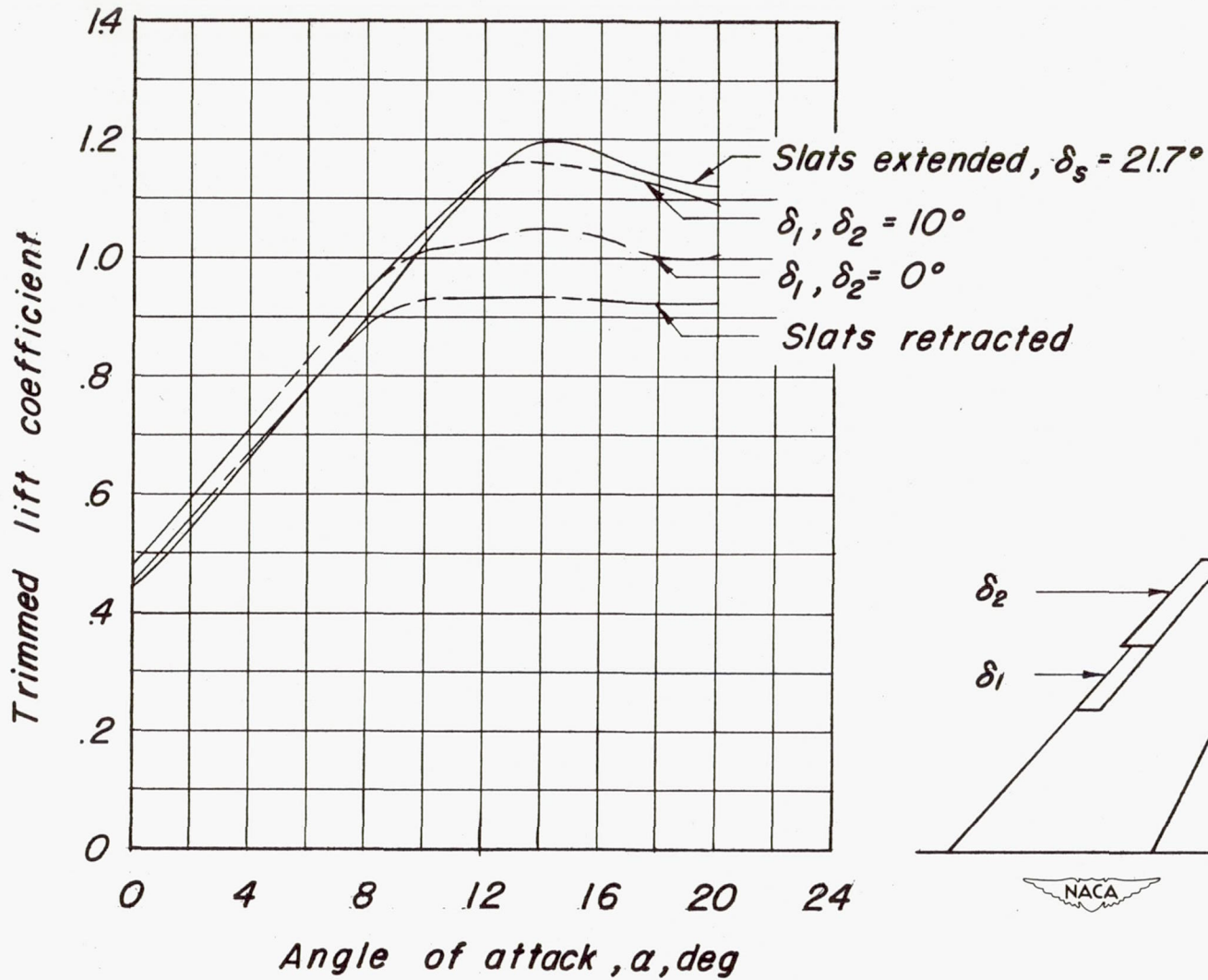


Figure 31.- Summary of effects of leading-edge chord-extensions on trimmed lift characteristics. $\delta_f = 40^\circ$.

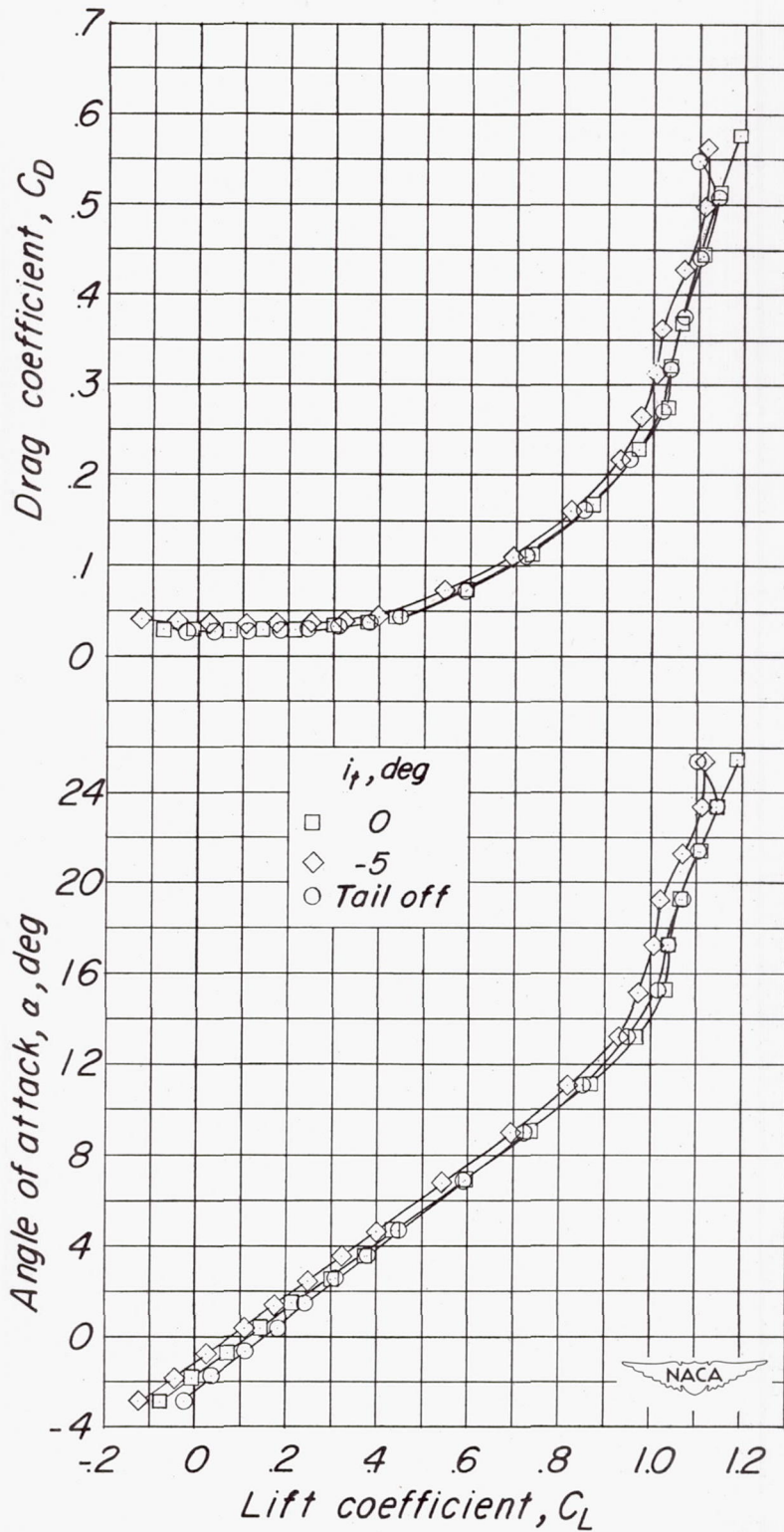


Figure 32.- Effect of stabilizer deflection on the aerodynamic characteristics of the model with the large inlet. $\delta_f = \delta_s = 0^\circ$.

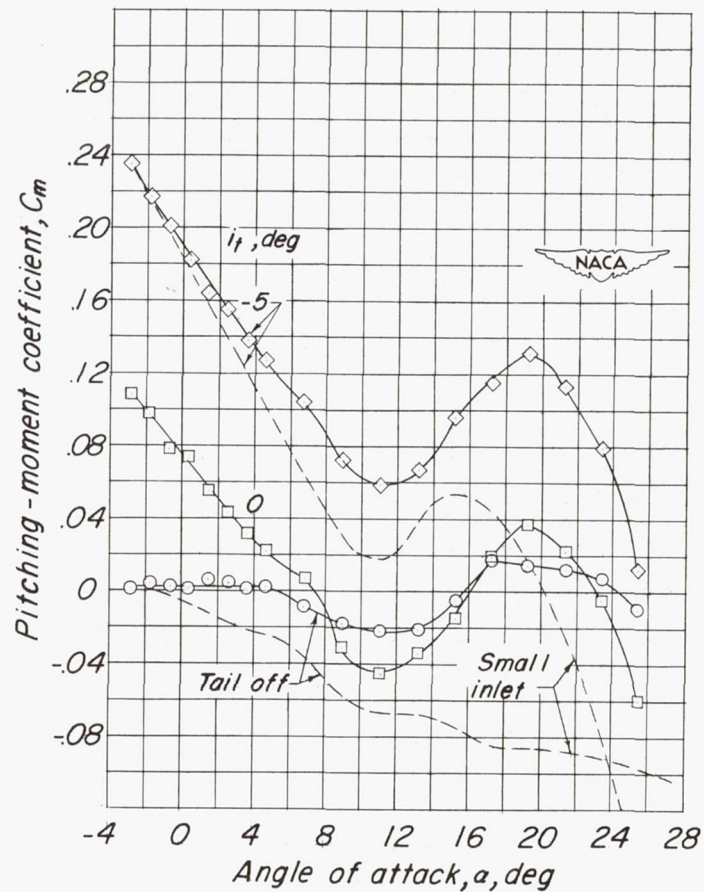
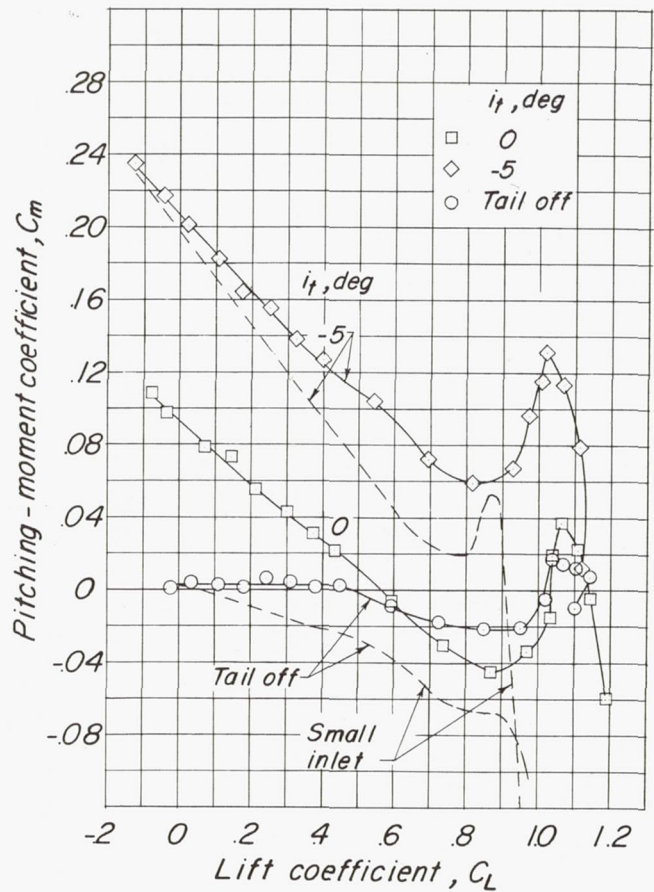


Figure 32.- Concluded.

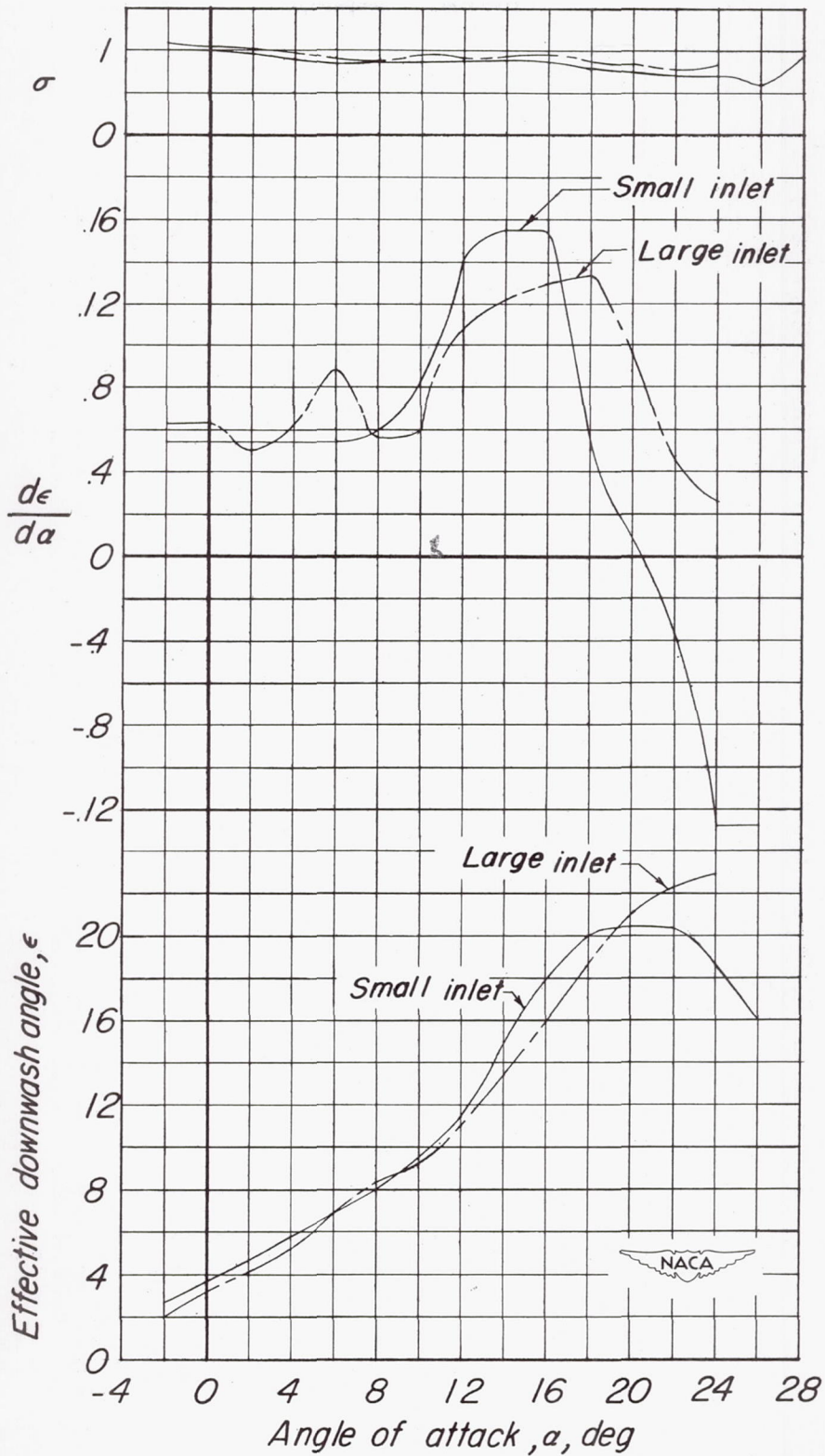


Figure 33.- Effect of inlet size on the effective downwash and tail effectiveness parameter. $\delta_f = \delta_s = 0^\circ$.

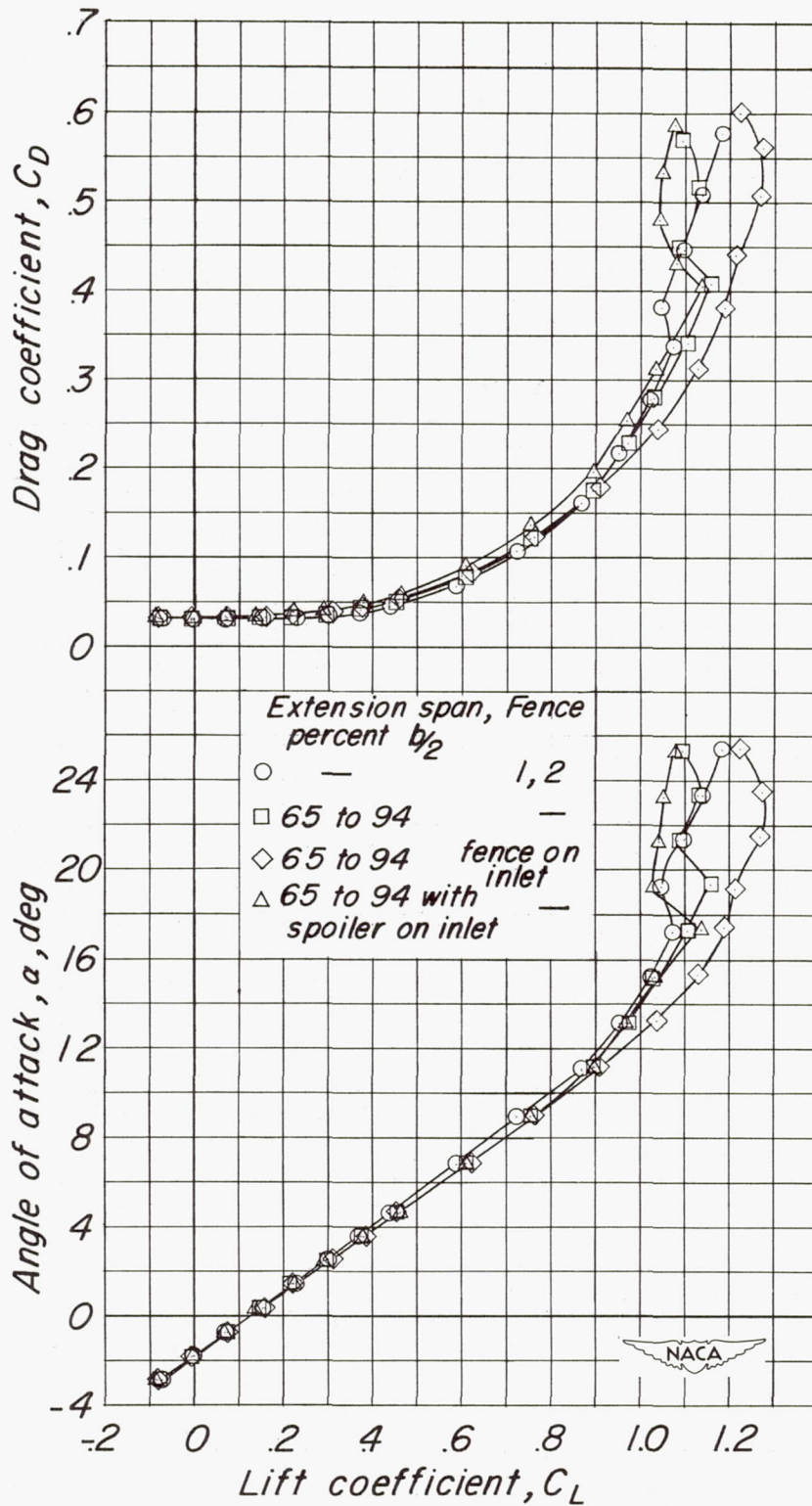


Figure 34.- Effect of fences and chord-extensions on characteristics of the model with the large inlet. $\delta_f = \delta_s = 0^\circ$.

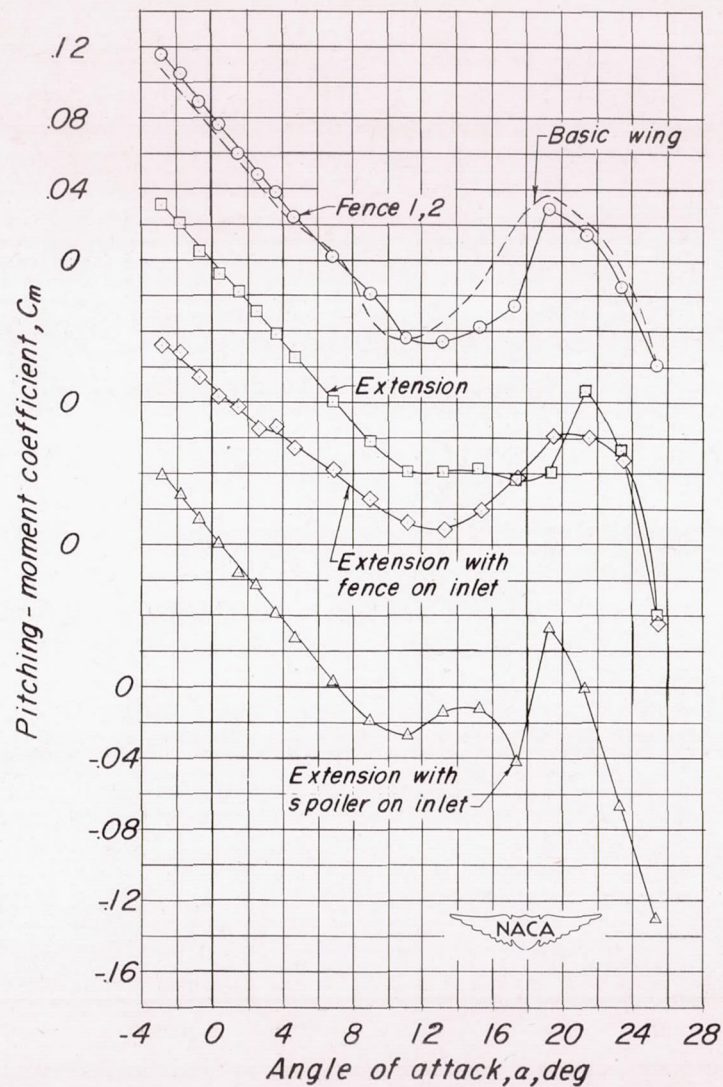
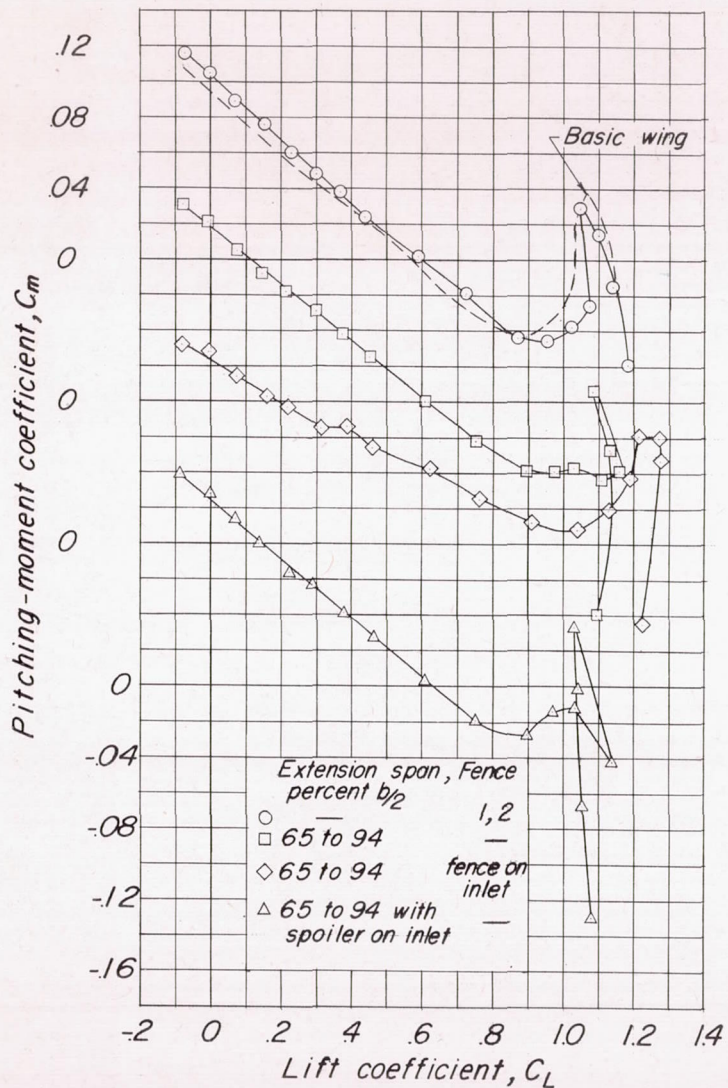


Figure 34.- Concluded.

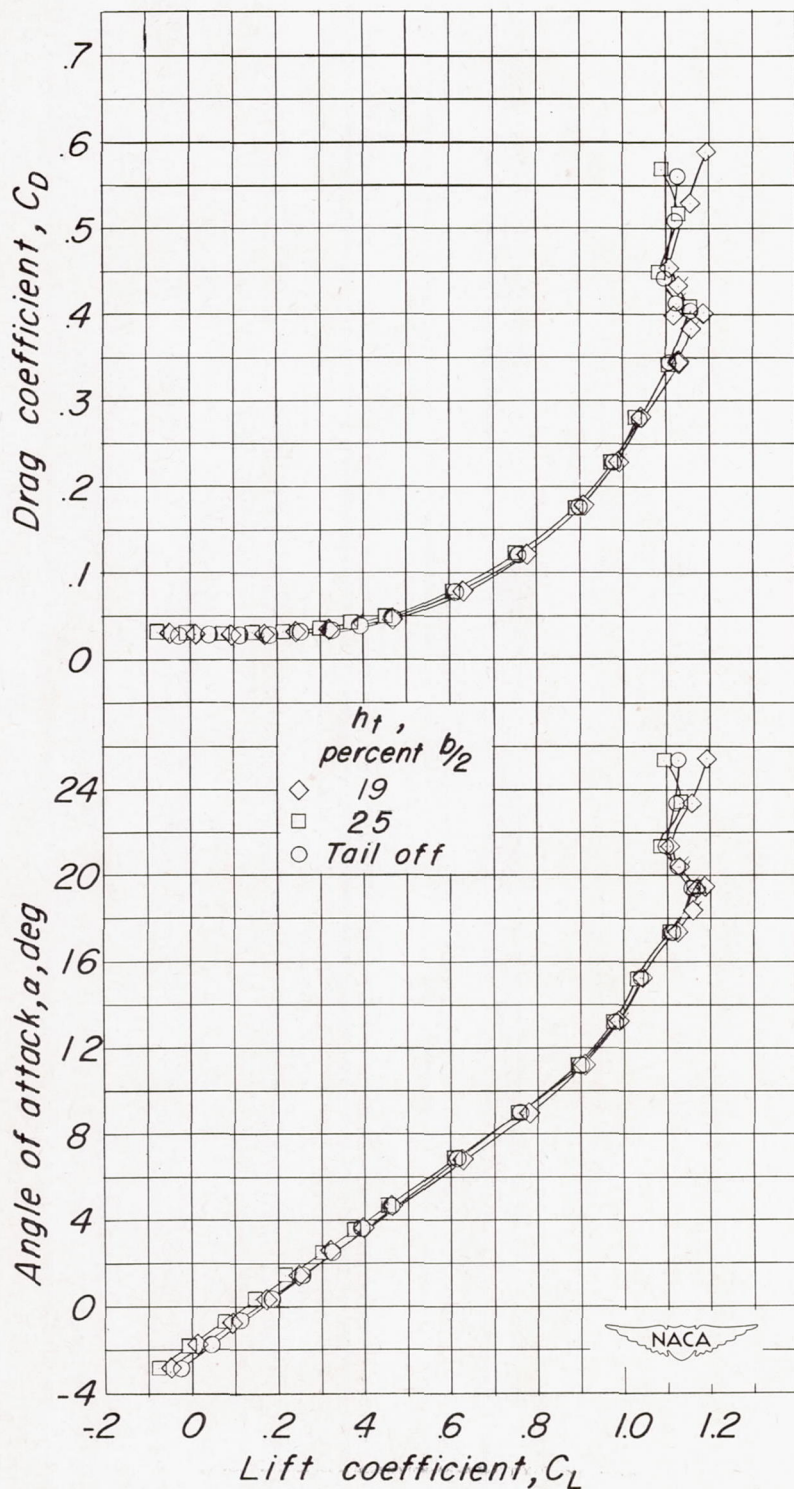


Figure 35.- Effect of lowering the horizontal tail on characteristics of the model with the large inlet. Leading-edge chord-extensions from 65 to 94 percent semispan. $\delta_f = \delta_s = 0^\circ$.

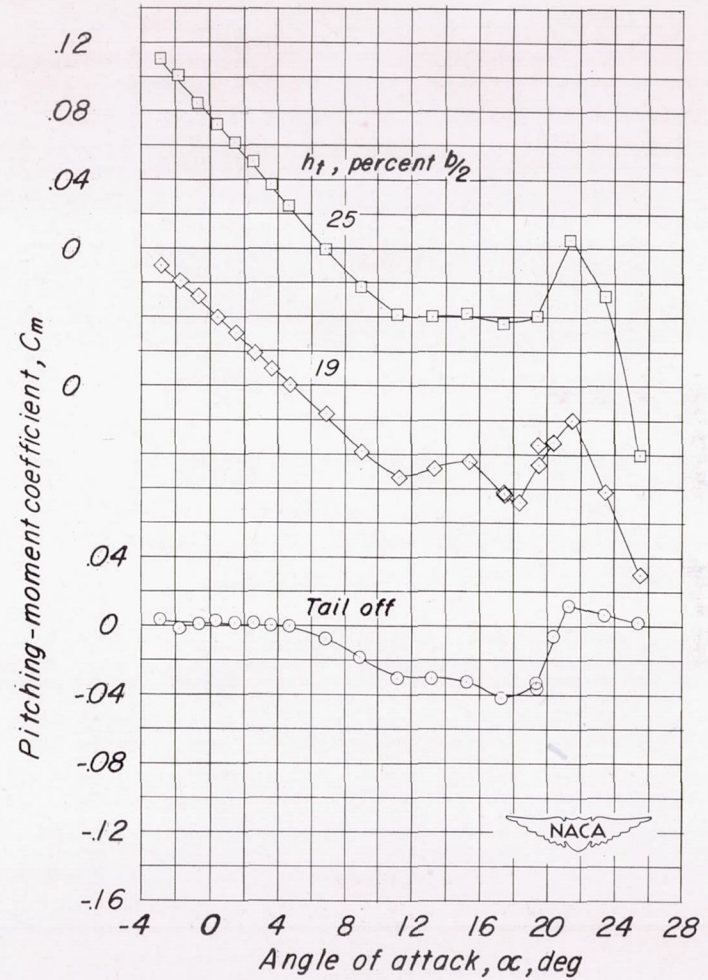
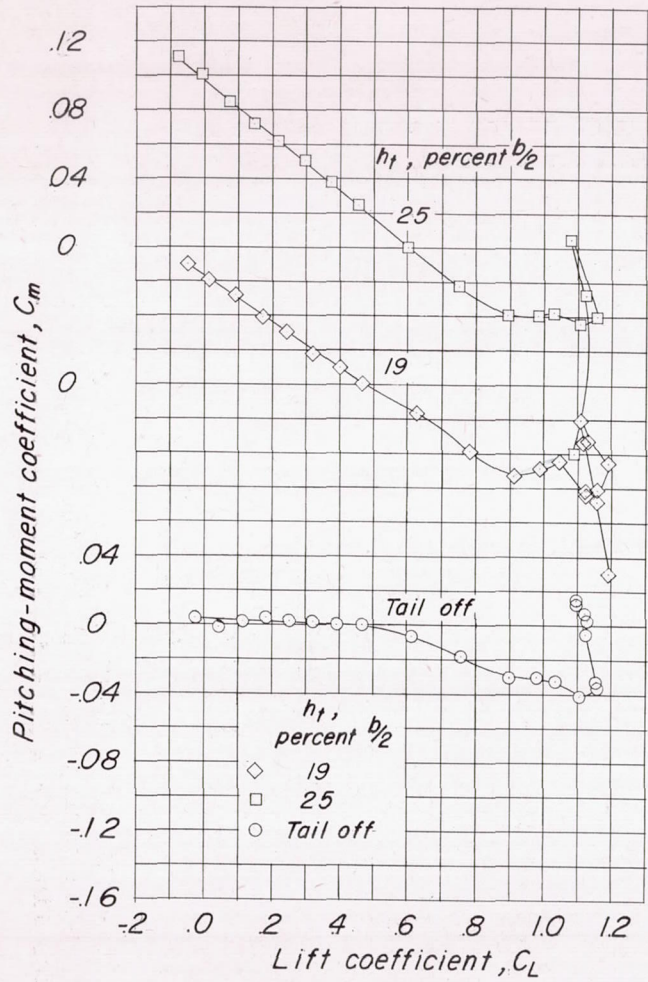


Figure 35.- Concluded.

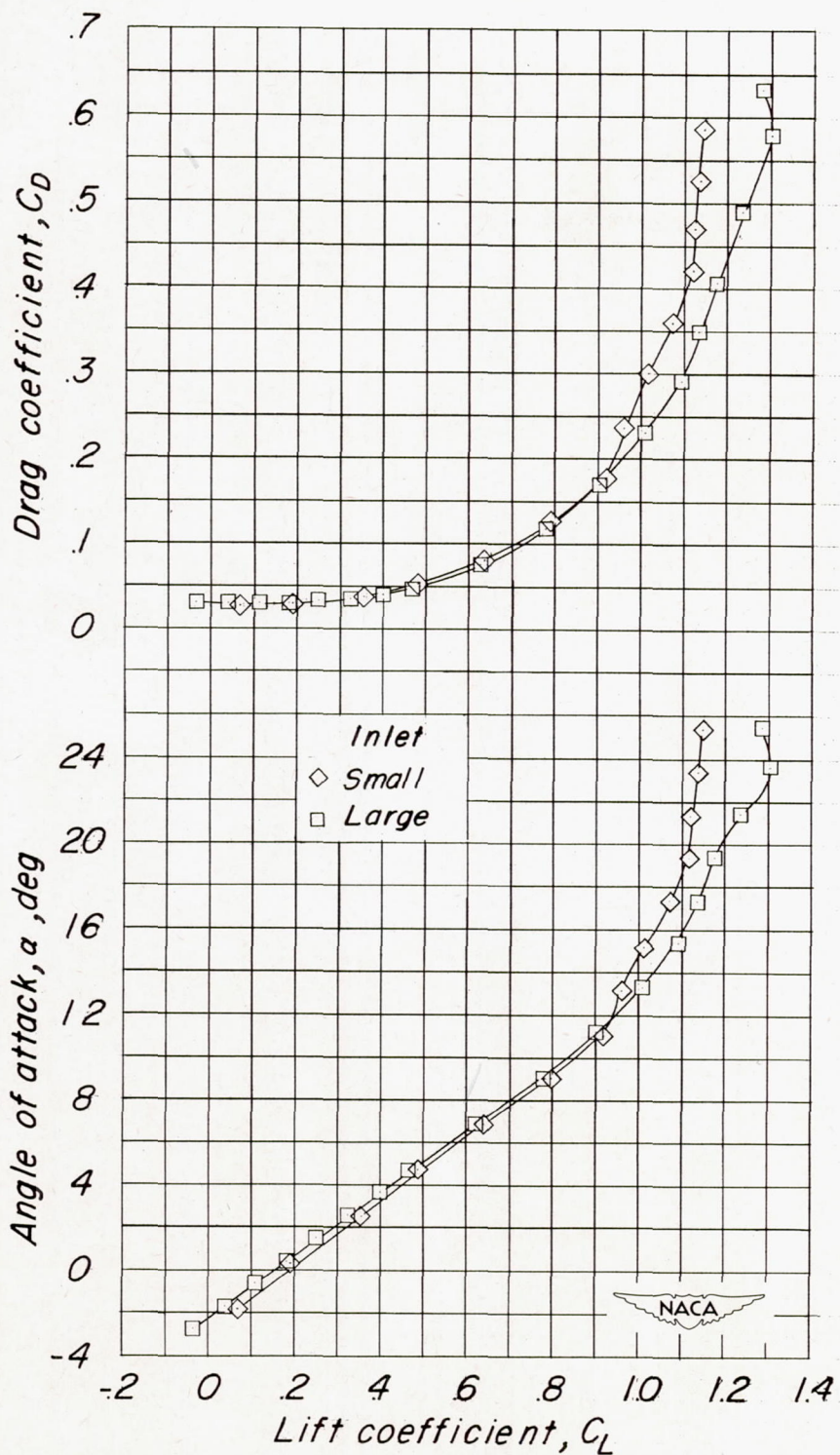


Figure 36.- Effect of inlet size on aerodynamic characteristics of the model with horizontal tail located 7 percent semispan below fuselage center line. $\delta_f = \delta_s = i_t = 0^\circ$.

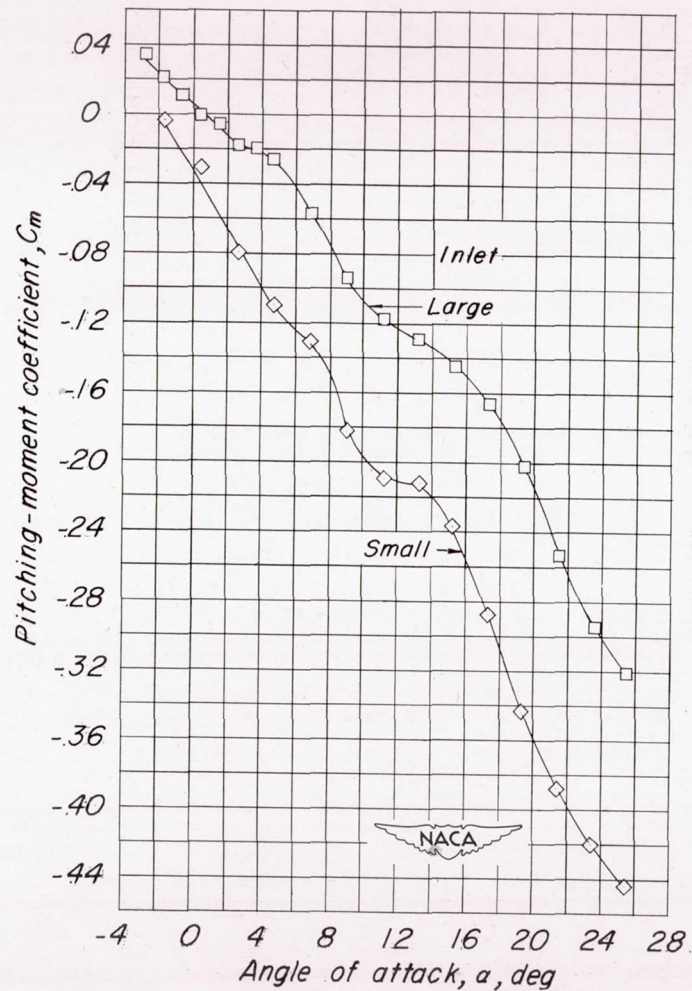
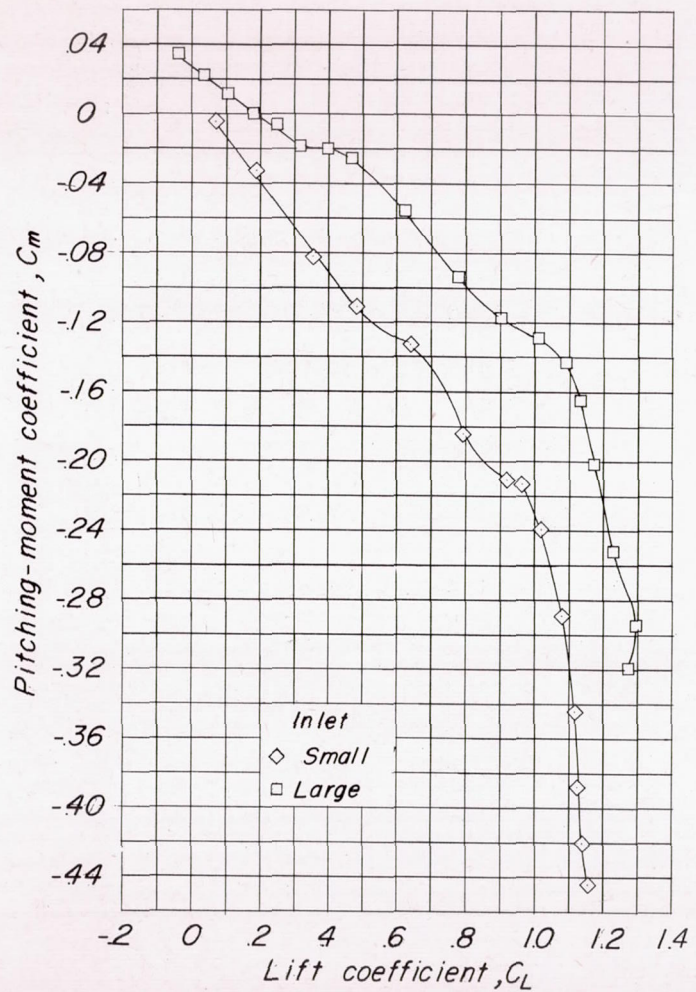
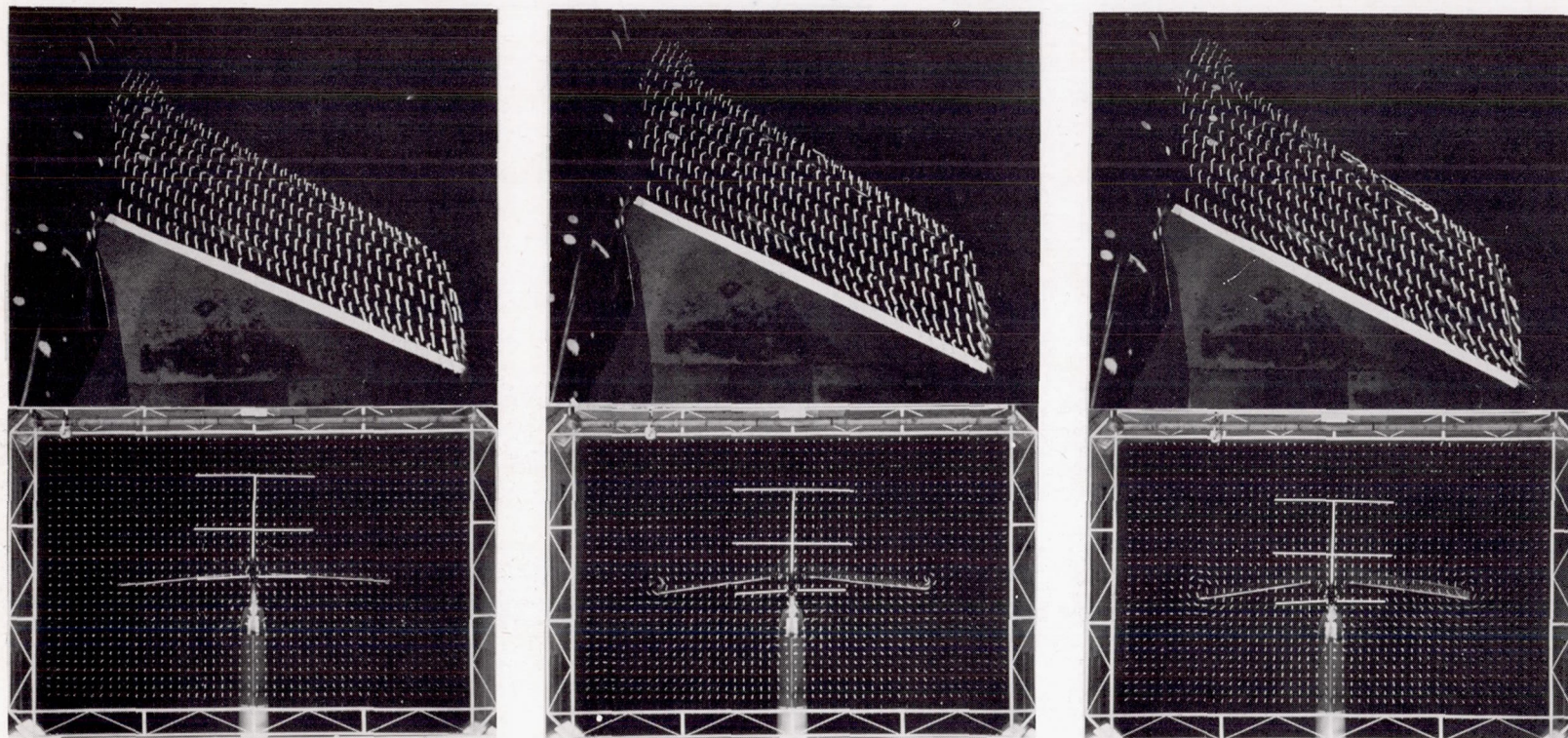


Figure 36.- Concluded.



$\alpha = 0.3^\circ; C_L = 0.19$

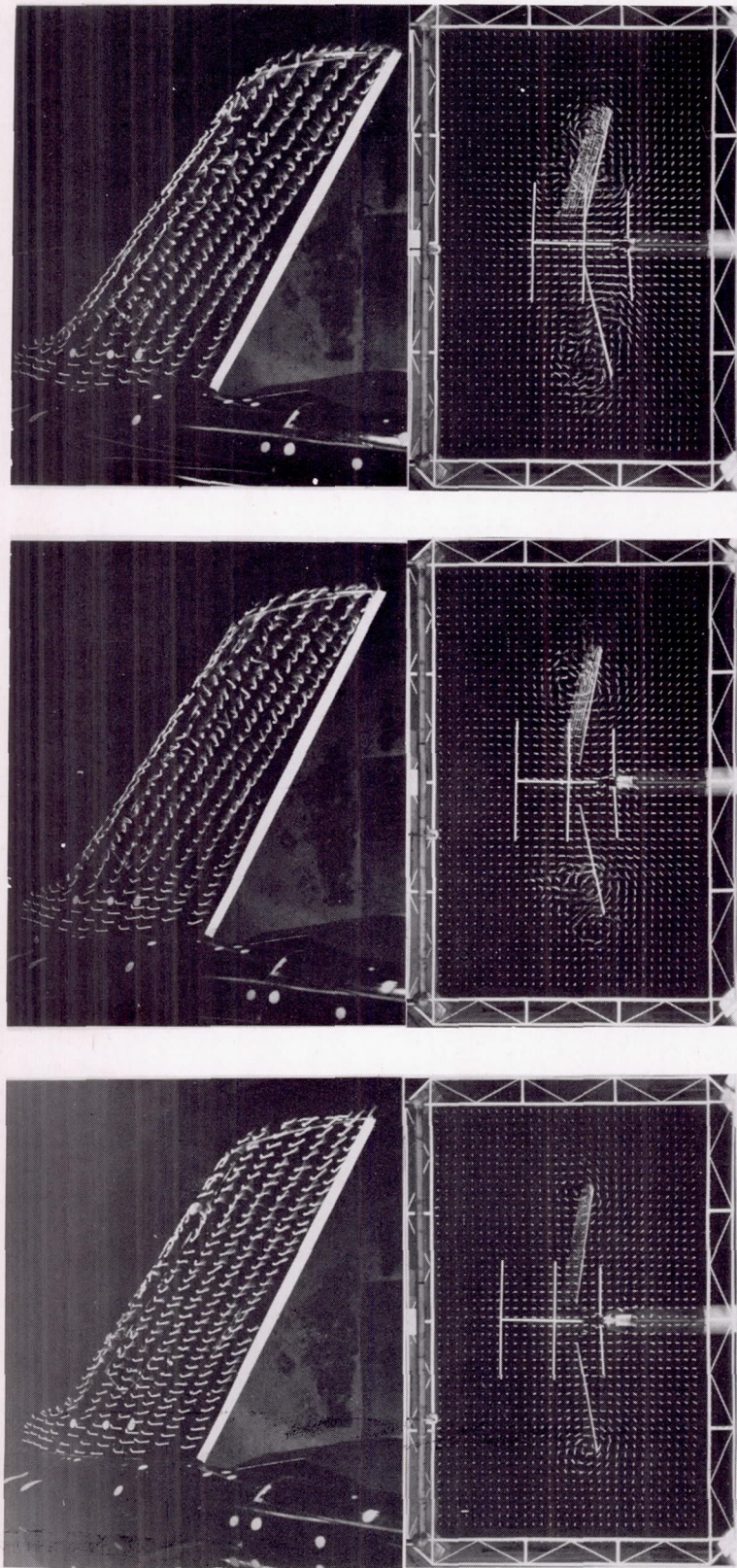
$\alpha = 4.6^\circ; C_L = 0.44$

$\alpha = 68^\circ; C_L = 0.57$

Figure 37.- Tuft-grid and surface-tuft photographs for basic model configuration. $\delta_f = \delta_s = 0^\circ$.



L-77949



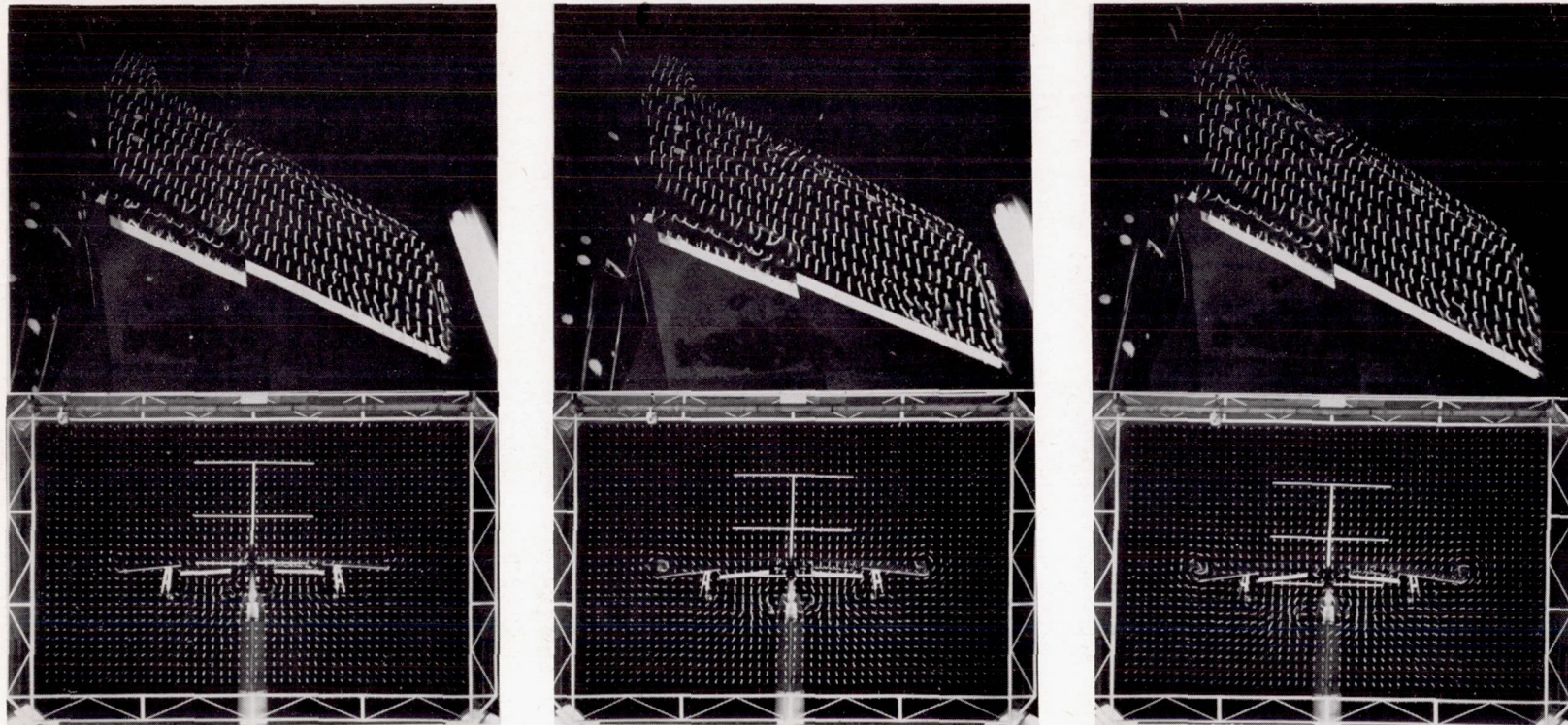
L-77950

$\alpha = 17.1^\circ; C_L = 0.94$

$\alpha = 13.1^\circ; C_L = 0.92$

$\alpha = 8.9^\circ; C_L = 0.72$

Figure 37.- Concluded.

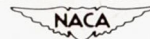


$\alpha = 0.6^\circ; C_L = 0.53$

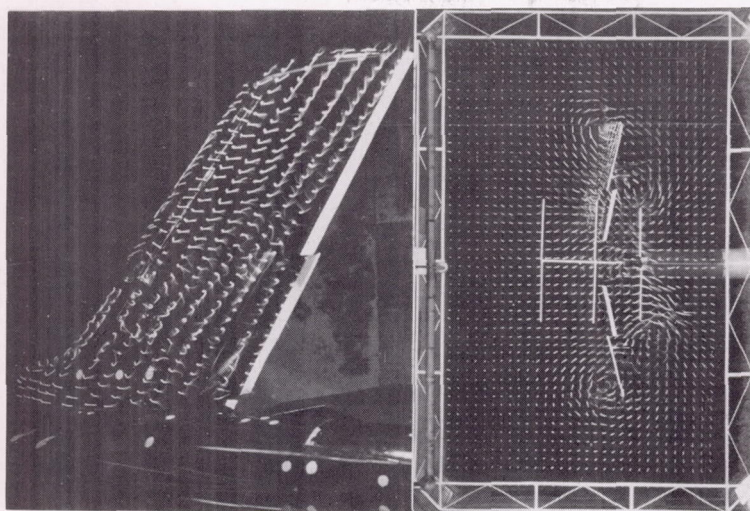
$\alpha = 4.9^\circ; C_L = 0.77$

$\alpha = 7.1^\circ; C_L = 0.91$

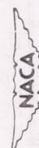
Figure 38.- Tuft-grid and surface-tuft photographs for basic model configuration. $\delta_F = 40^\circ$; $\delta_S = 21.7^\circ$.



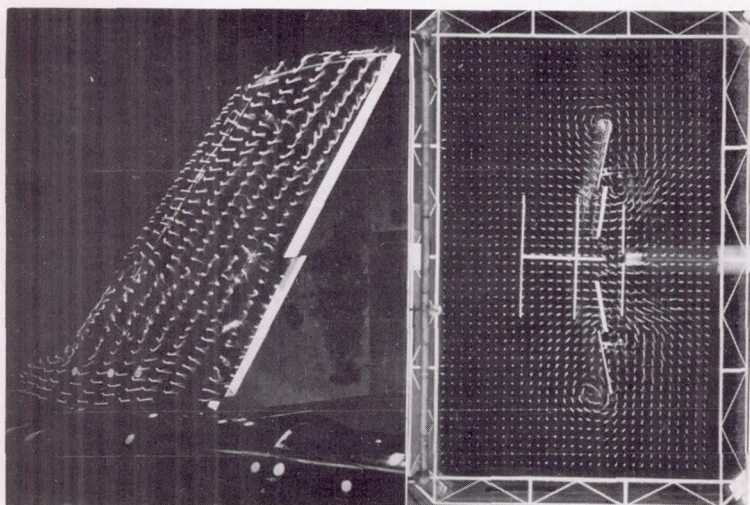
L-77951



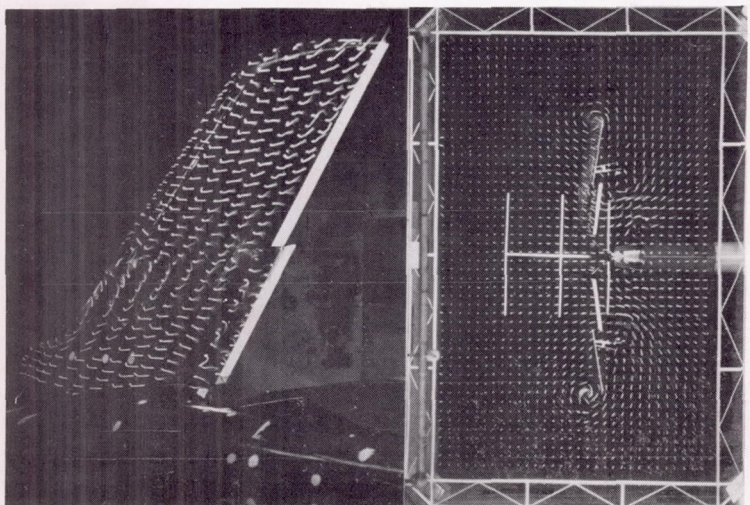
$\alpha = 17.4^\circ ; C_L = 1.24$



L-77952

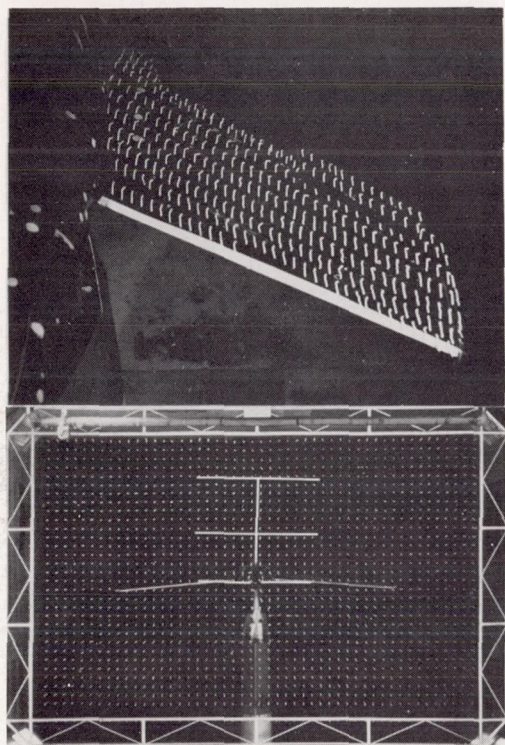


$\alpha = 13.4^\circ ; C_L = 1.26$

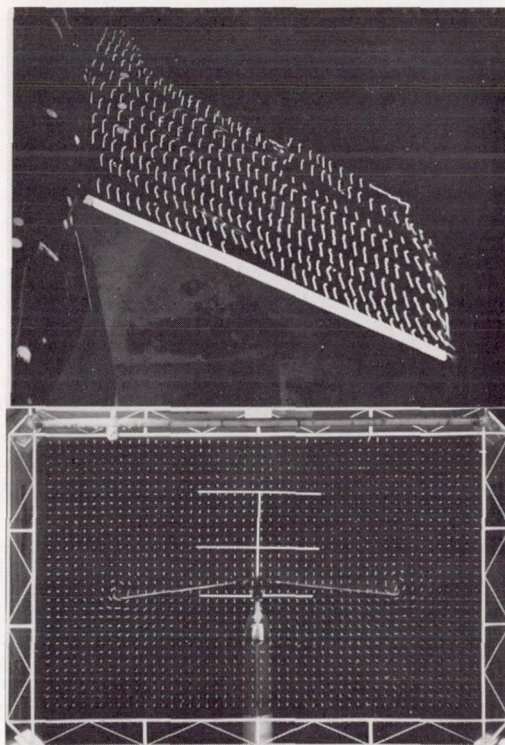


$\alpha = 9.2^\circ ; C_L = 1.04$

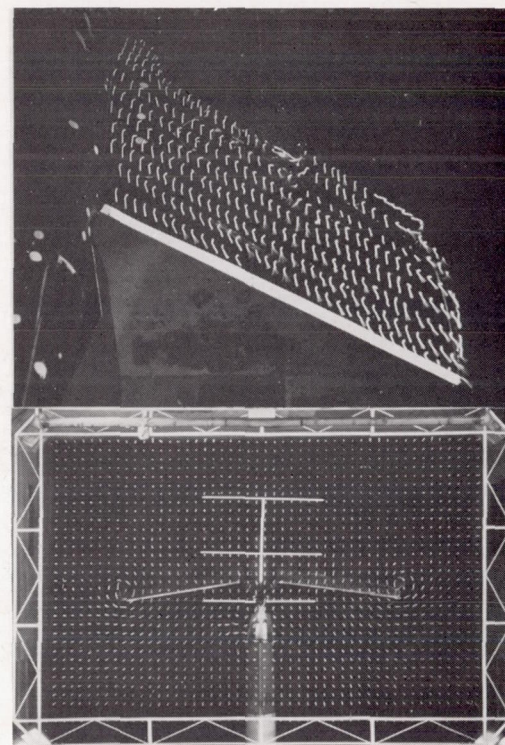
Figure 38.- Concluded.



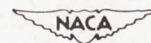
$\alpha = 0.3^\circ$, $C_L = 0.18$



$\alpha = 4.6^\circ$, $C_L = 0.44$

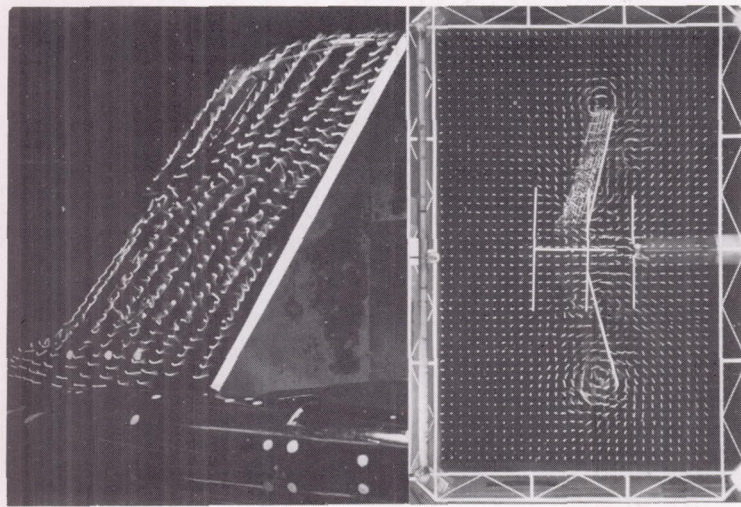


$\alpha = 68^\circ$, $C_L = 0.58$



L-77953

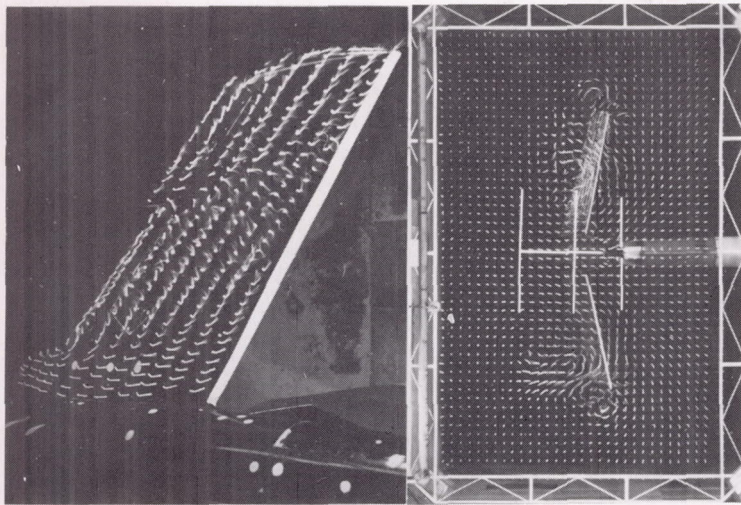
Figure 39.- Tuft-grid and surface-tuft photographs of model with leading-edge chord-extension from 65 to 94 percent semispan. $\delta_f = \delta_s = 0^\circ$.



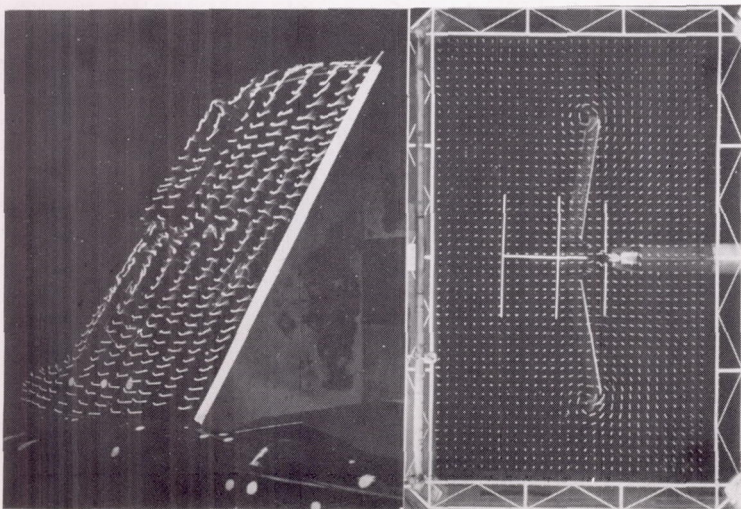
$\alpha = 17.2^\circ ; C_L = 1.10$



L-77954

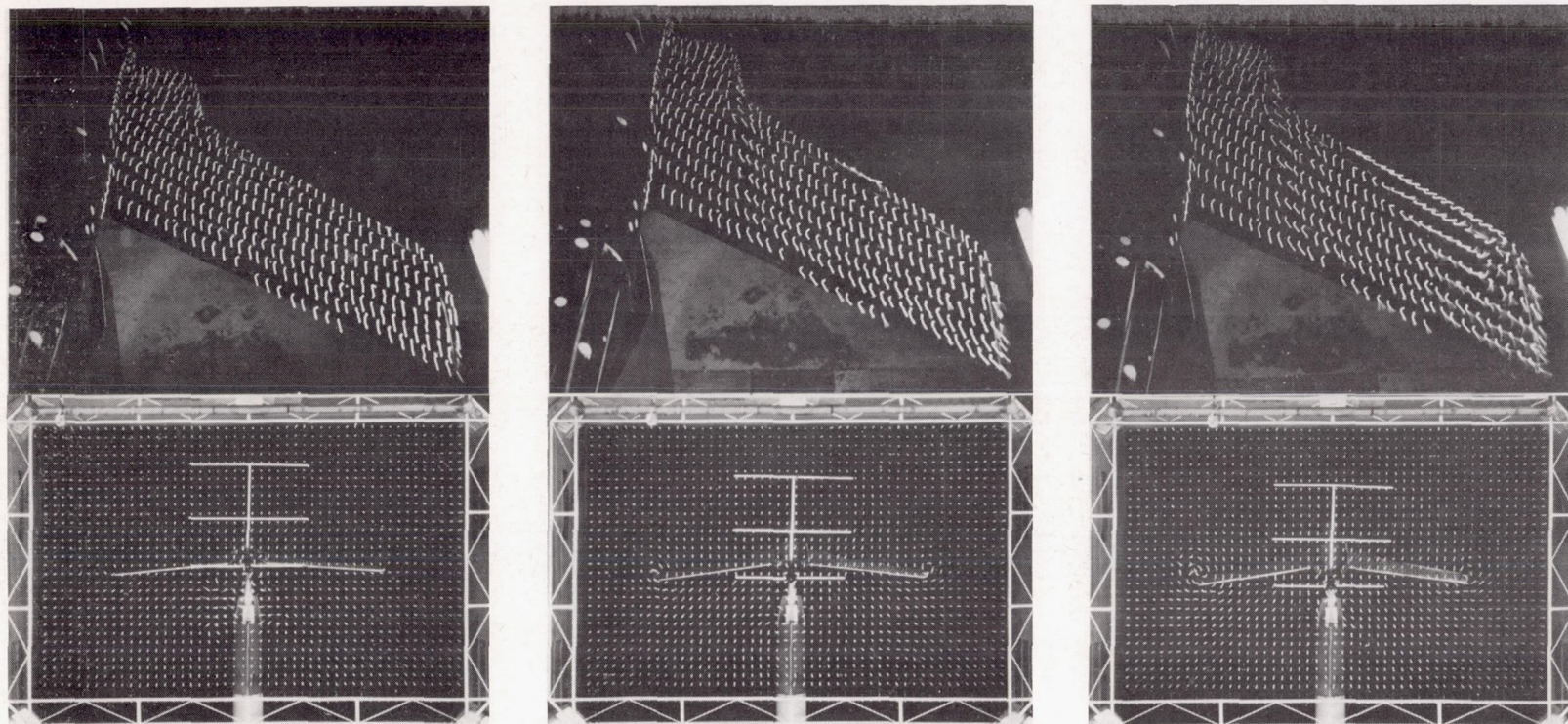


$\alpha = 13.1^\circ ; C_L = 0.93$



$\alpha = 8.9^\circ ; C_L = 0.72$

Figure 39.- Concluded.

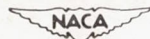


$\alpha = 0.4^\circ; C_L = 0.18$

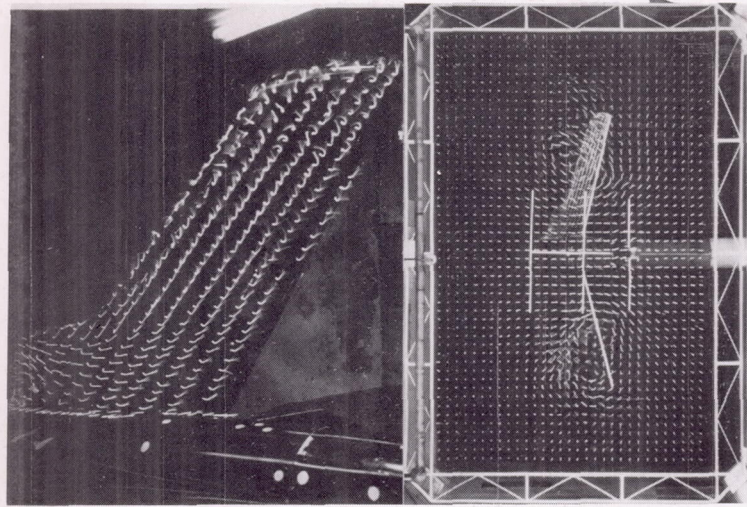
$\alpha = 4.6^\circ; C_L = 0.45$

$\alpha = 6.8^\circ; C_L = 0.59$

Figure 40.- Tuft-grid and surface-tuft photographs of model with large inlet. $\delta_f = \delta_s = 0^\circ$.



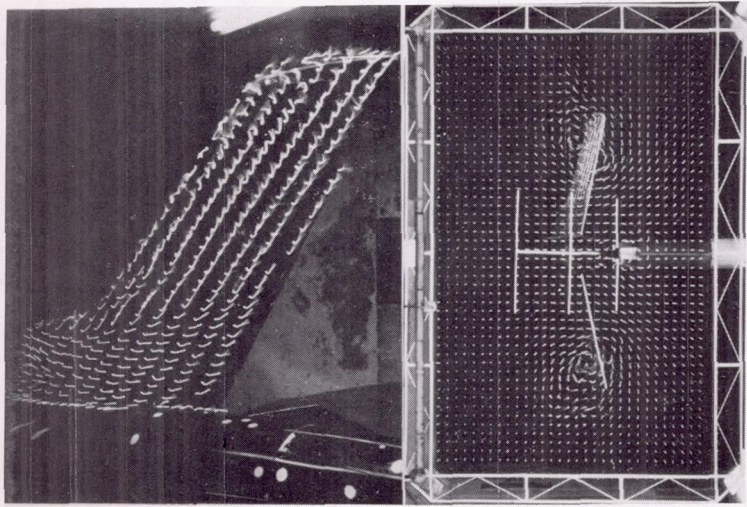
L-77955



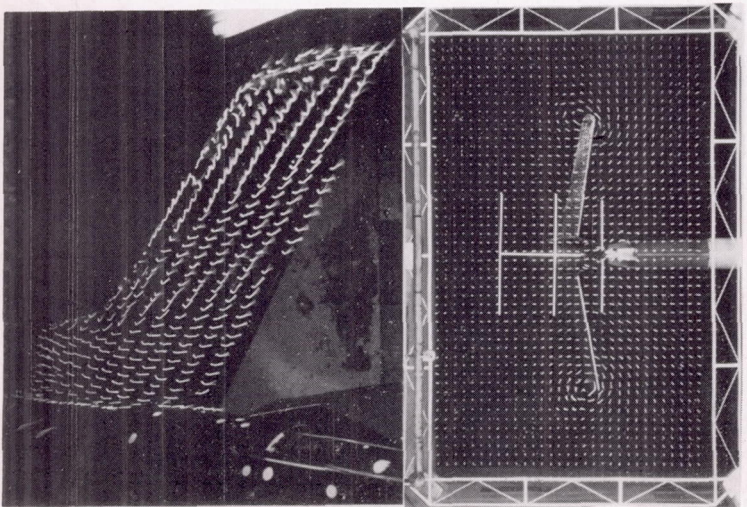
$\alpha = 17.2^\circ; C_L = 1.04$



L-77956

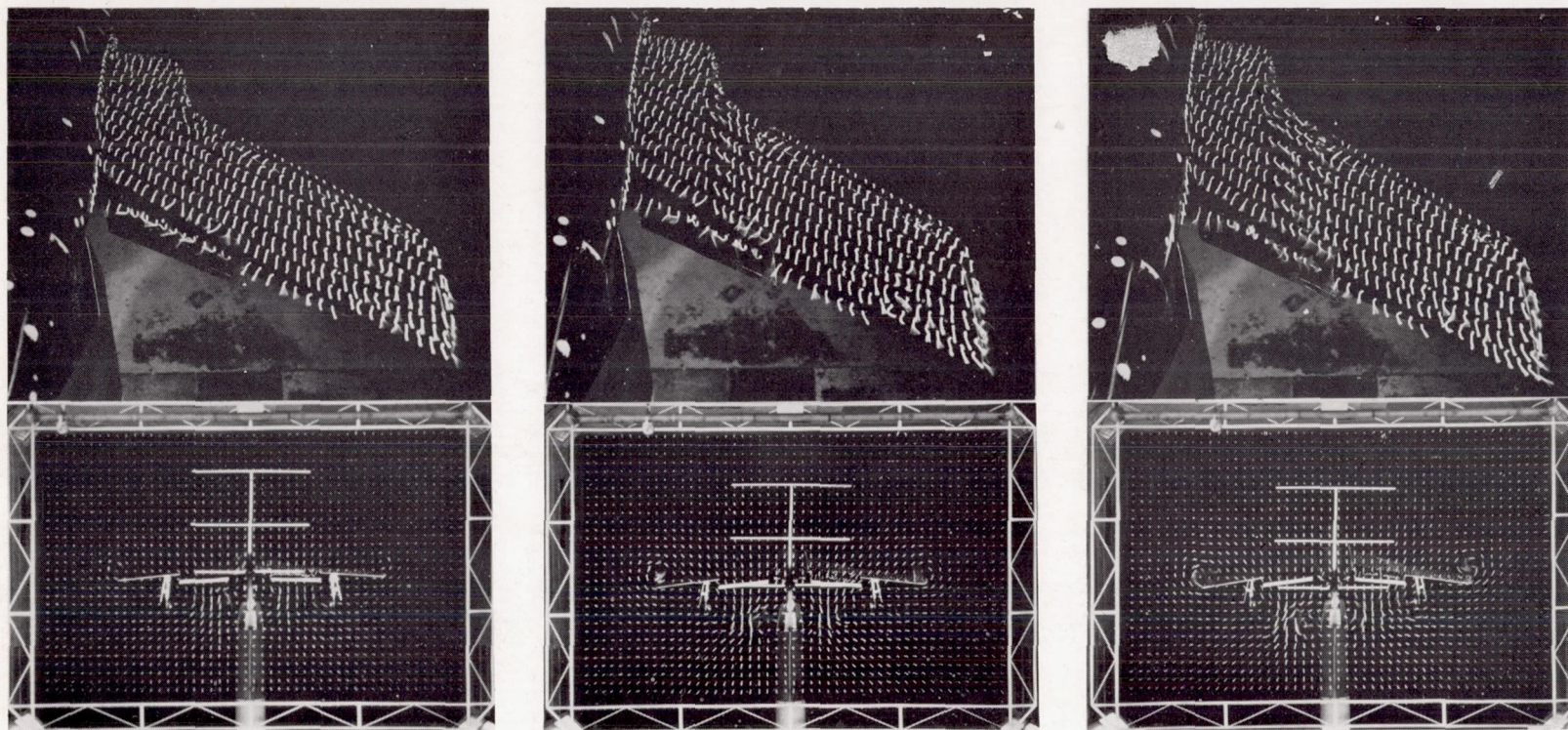


$\alpha = 13.2^\circ; C_L = 0.95$



$\alpha = 9.0^\circ; C_L = 0.73$

Figure 40.- Concluded.



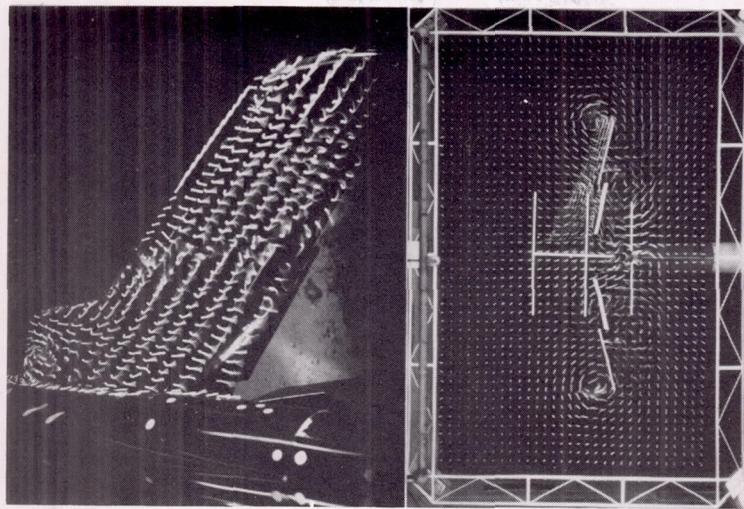
$\alpha = 0.7^\circ$; $C_L = 0.54$

$\alpha = 5.0^\circ$; $C_L = 0.82$

$\alpha = 7.2^\circ$; $C_L = 0.97$

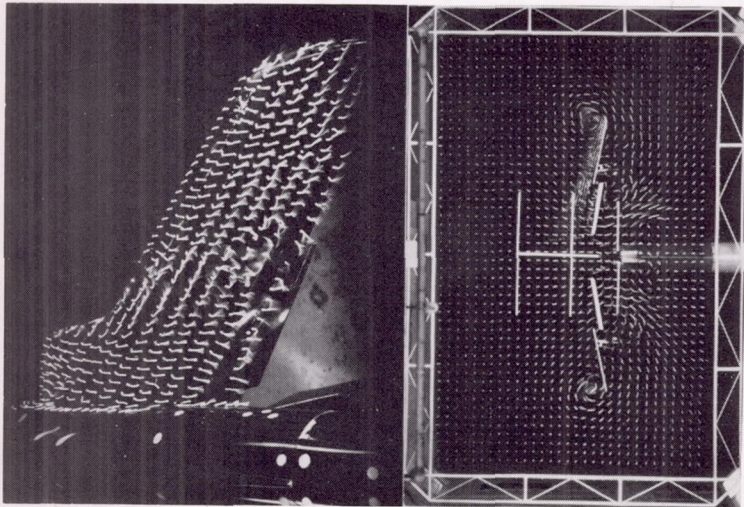
Figure 41.- Tuft-grid and surface-tuft photographs of model with large inlet. $\delta_f = 40^\circ$; $\delta_s = 21.7^\circ$.

NACA
L-77957

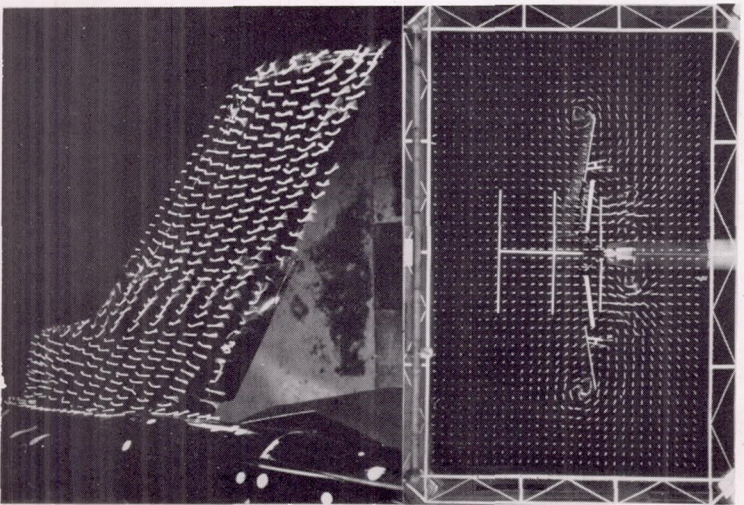


$\alpha = 17.5^\circ; C_L = 1.29$

NACA
L-77958

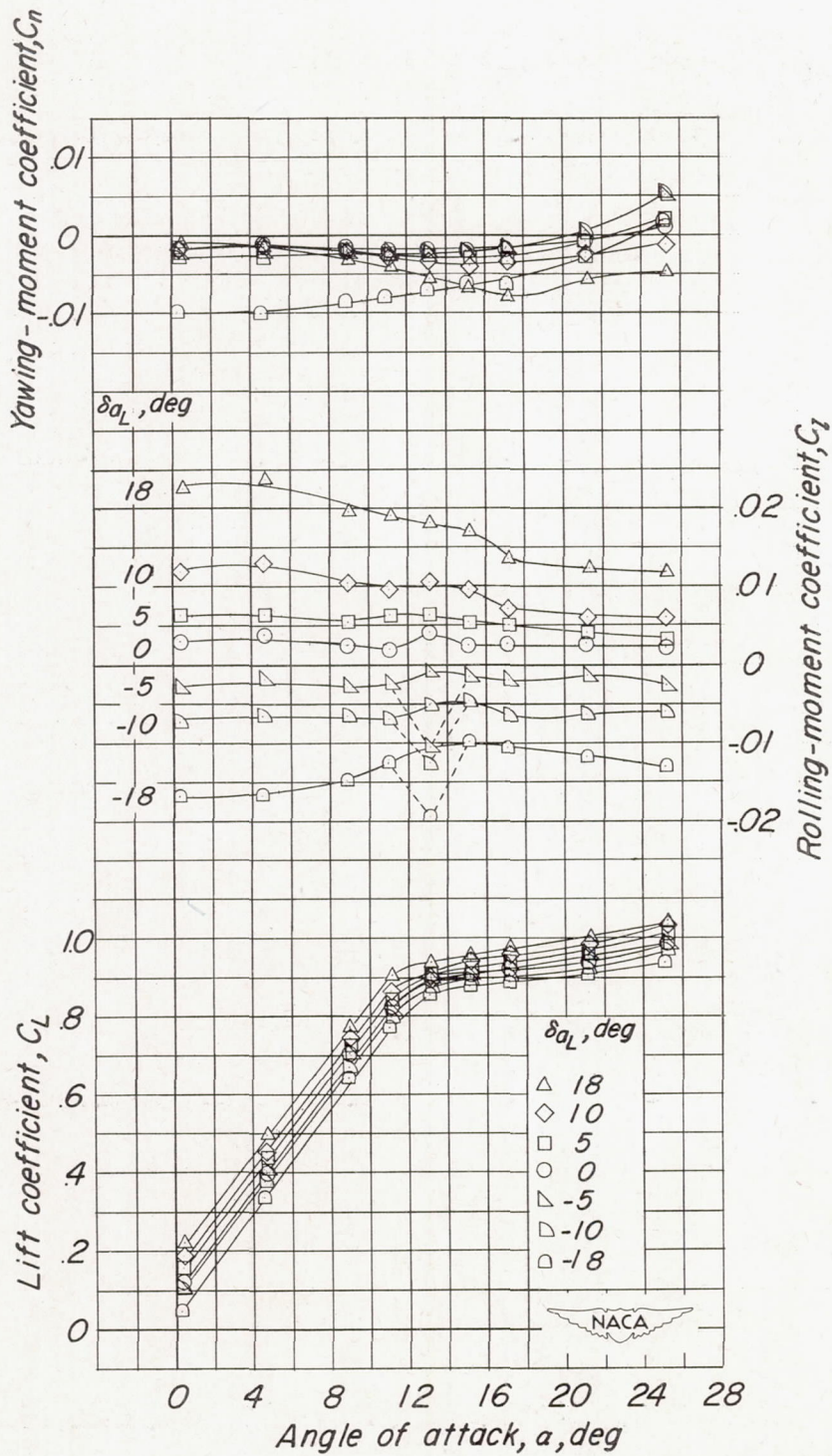


$\alpha = 13.3^\circ; C_L = 1.20$



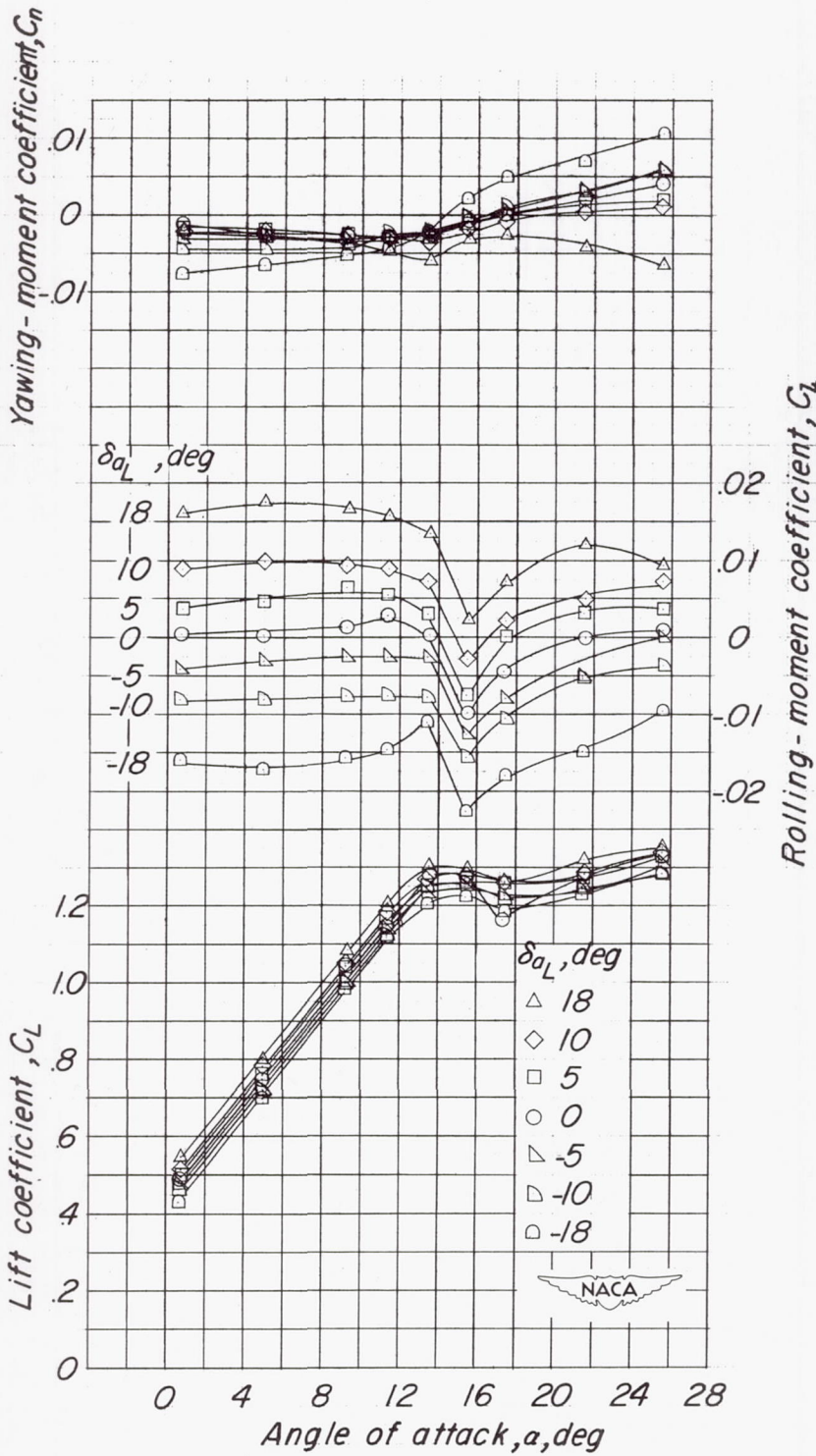
$\alpha = 9.2^\circ; C_L = 1.08$

Figure 41.- Concluded.



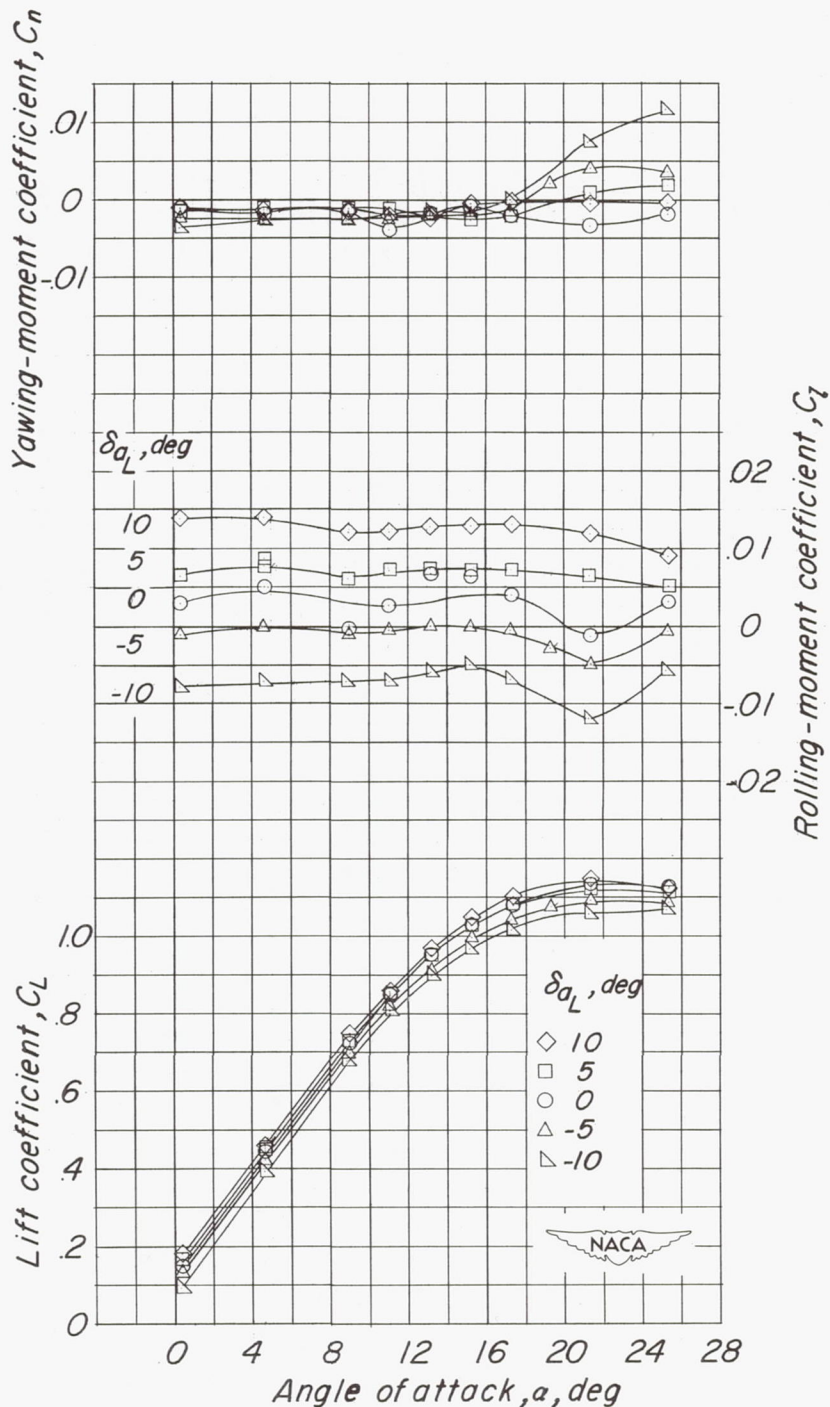
(a) $\delta_F = \delta_S = 0^\circ$.

Figure 42.- Effect of left-aileron deflection on the aerodynamic characteristics of the basic model. $i_t = 0^\circ$.



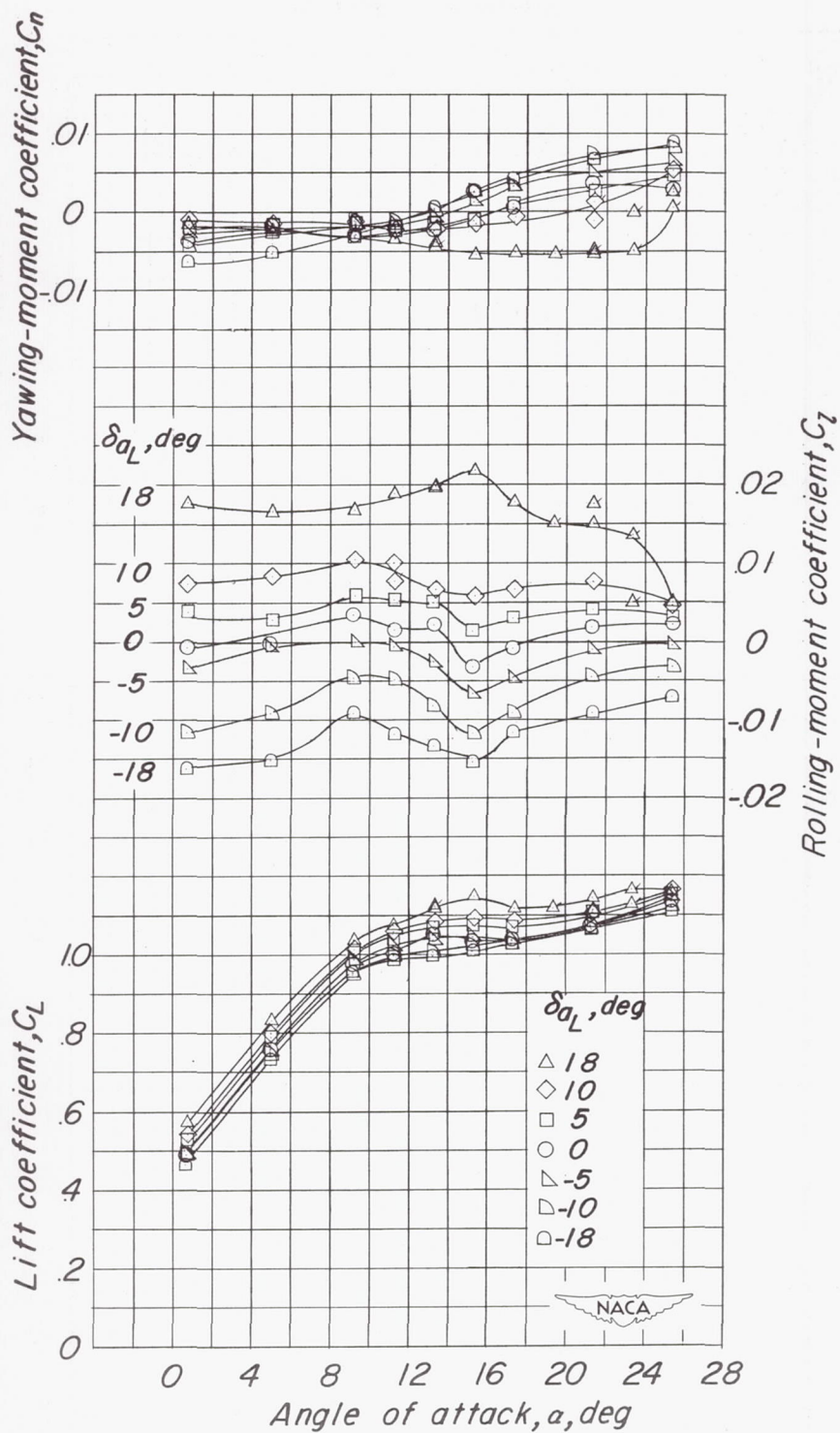
(b) $\delta_f = 40^\circ$; $\delta_s = 21.7^\circ$.

Figure 42.- Concluded.



(a) $\delta_F = \delta_S = 0^\circ$.

Figure 43.- Effect of left-aileron deflection on the aerodynamic characteristics of the model with a 0.10c leading-edge chord-extension from 70 to 94 percent semispan. $i_t = 0^\circ$.



(b) $\delta_f = 40^\circ$.

Figure 43.- Concluded.

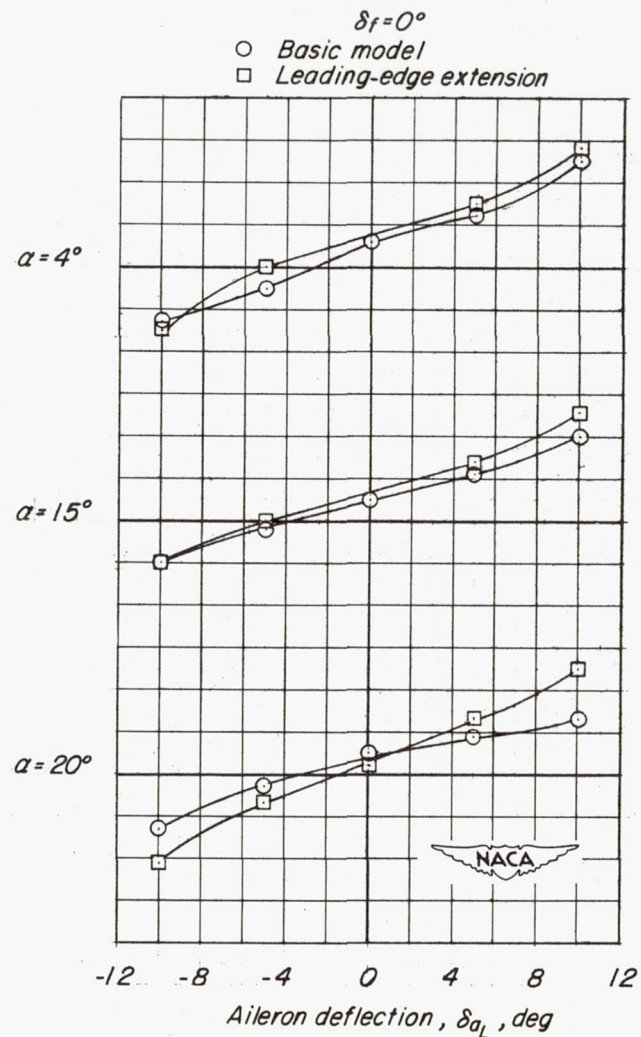
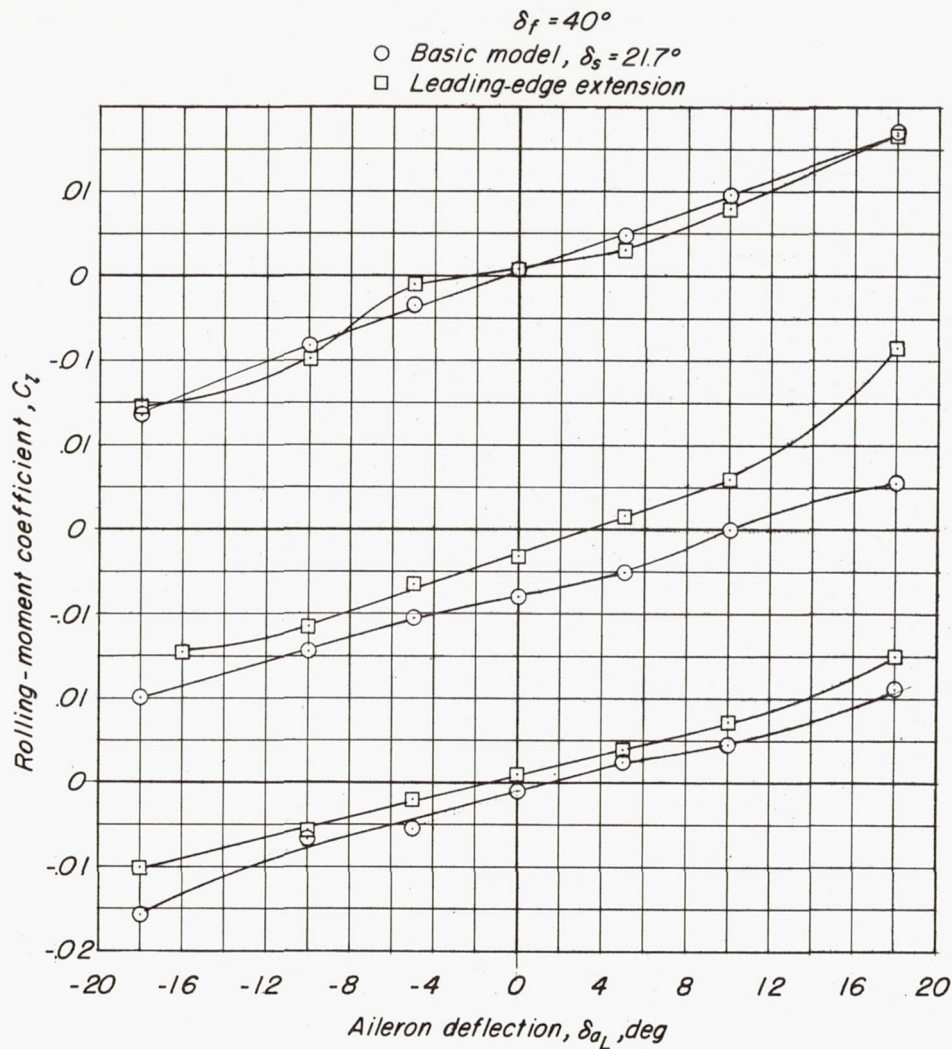
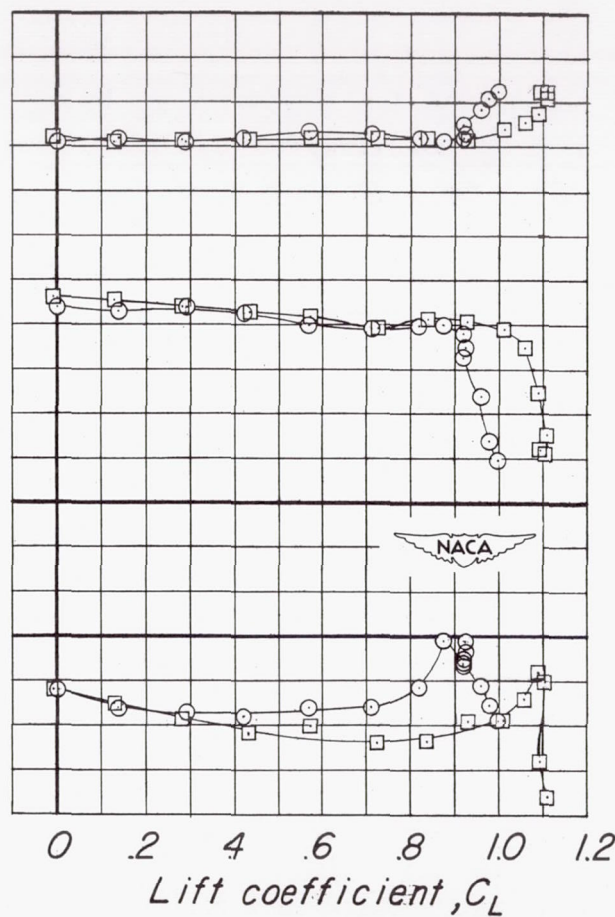
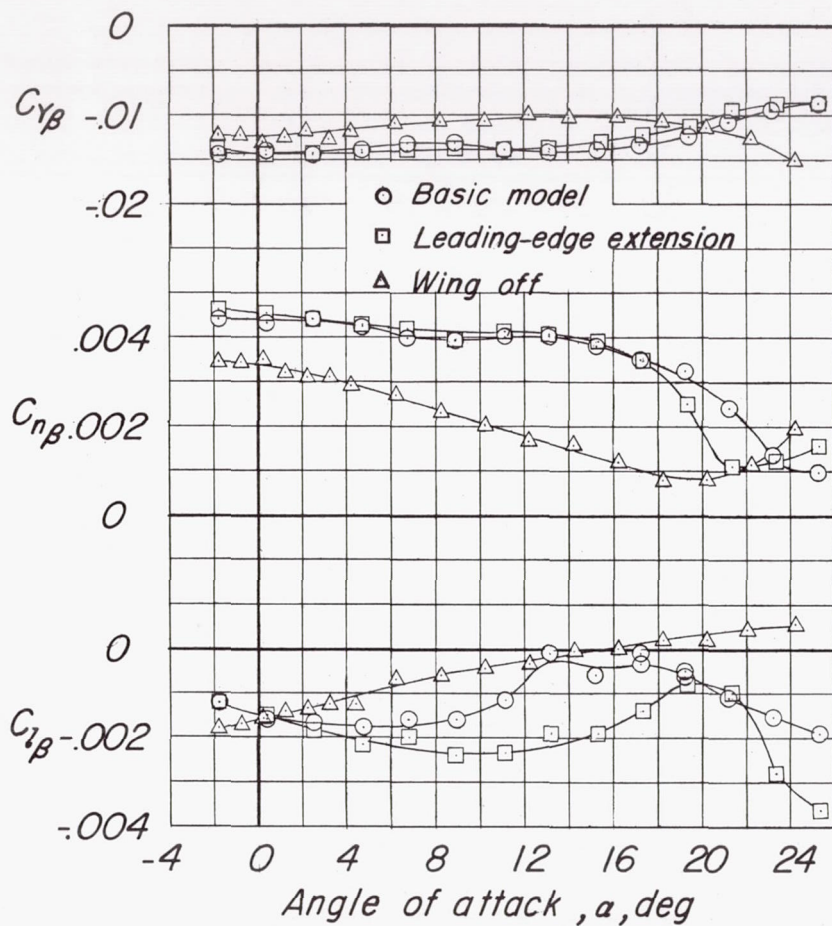
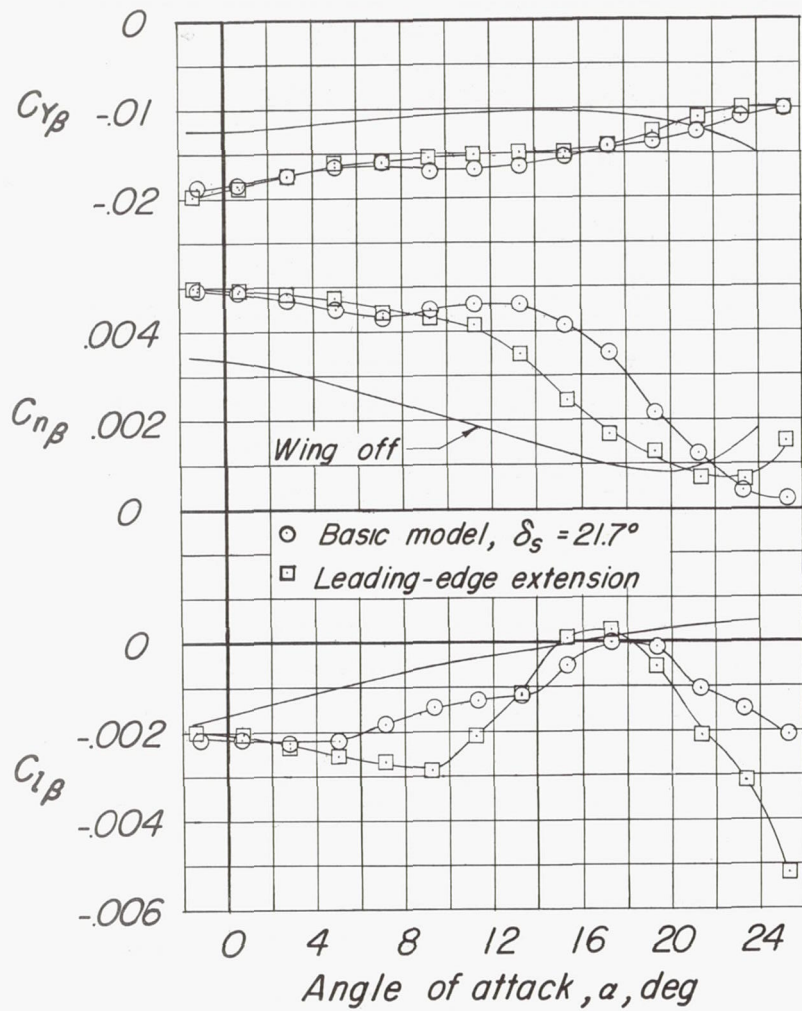


Figure 44.- Comparison of aileron effectiveness with and without a 0.10c leading-edge chord-extension from 70 to 94 percent semispan.



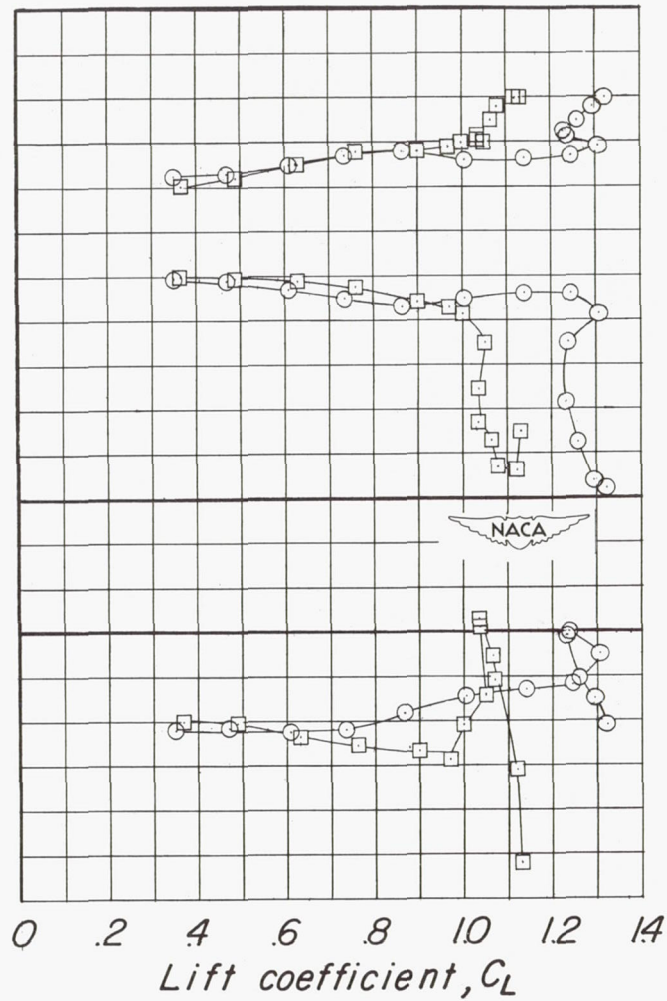
(a) $\delta_f = \delta_s = \delta_1 = \delta_2 = 0^\circ$.

Figure 45.- Effect of leading-edge chord-extension on the lateral-stability derivatives. 0.10 chord-extension from 70 to 94 percent semispan.



(b) $\delta_f = 40^\circ$.

Figure 45.- Concluded.



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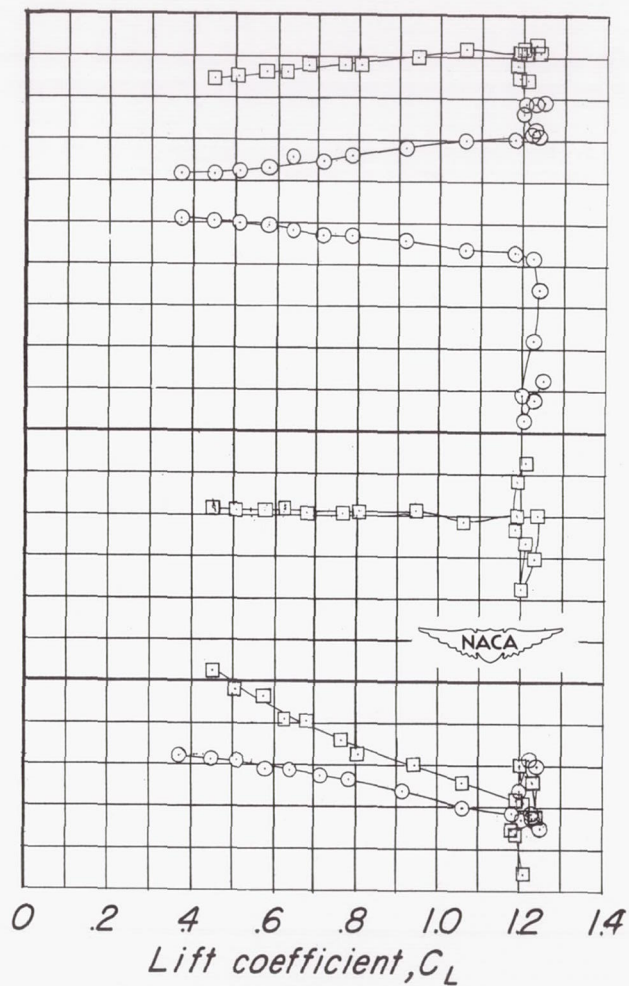
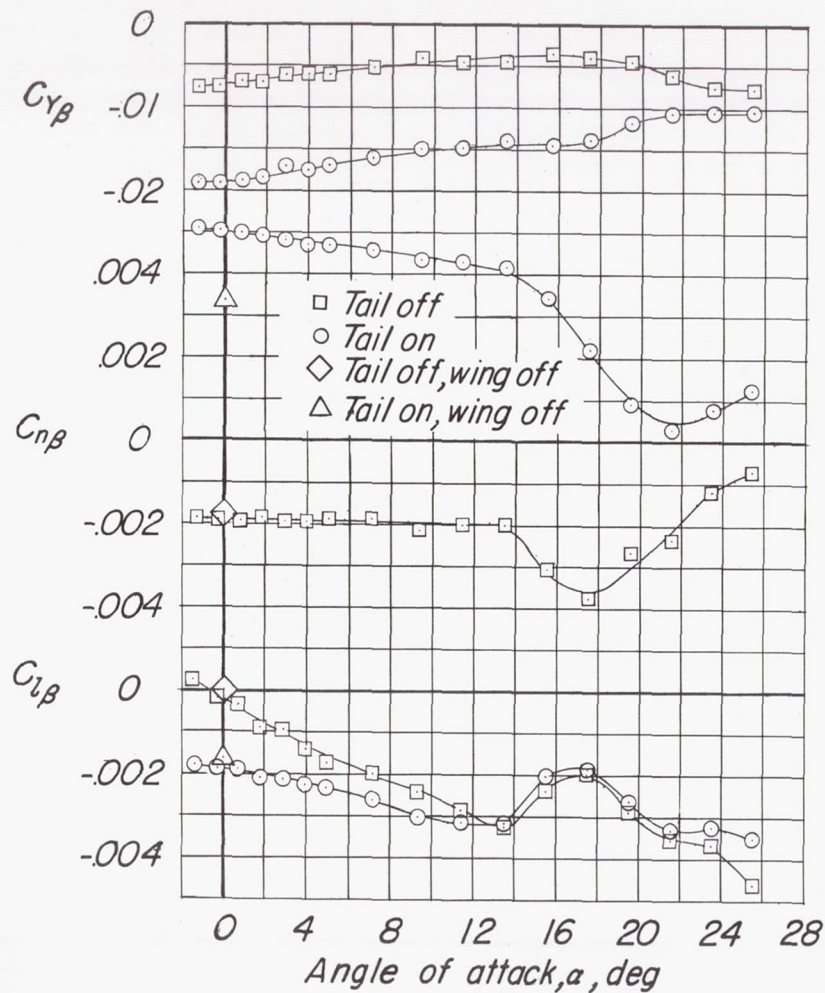
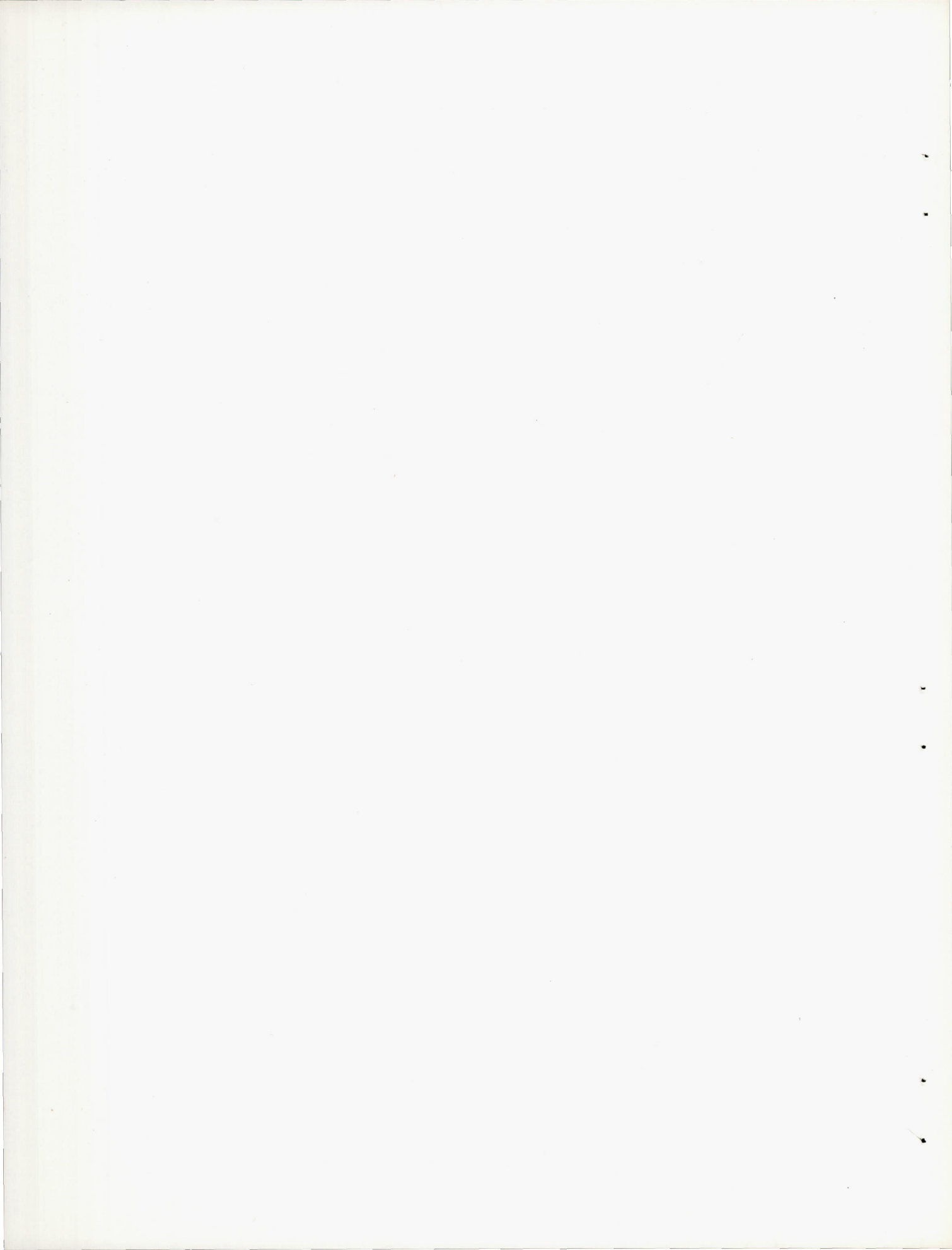
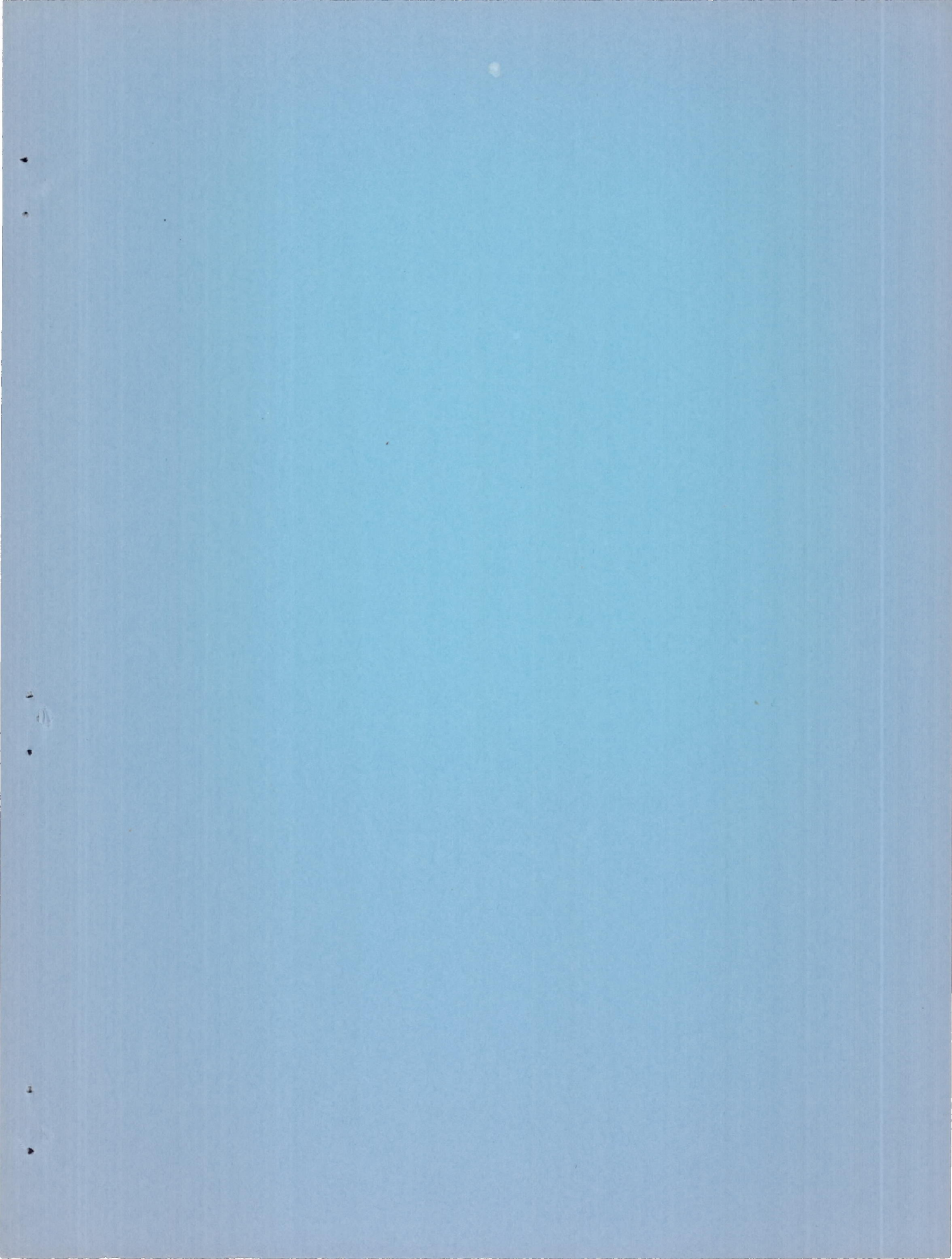


Figure 46.- Lateral-stability derivatives with drooped chord-extension.
 0.10 chord-extension from 65 to 94 percent semispan. $\delta_f = 40^\circ$;
 $\delta_1 = \delta_2 = 10^\circ$.

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