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RESEARCH MEMORANDUM

A WIND-TUNNEL INVESTIGATION AT LOW SPEED OF VARIOUS LATERAL CONTROLS ON A 45° SWEPT-BACK WING

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

A wind-tunnel investigation was conducted at low speed of chord-extension controls, conventional ailerons, and spoilers on a 45° swept-back wing of aspect ratio 4.5 and of taper ratio 0.5. Measurements were made of the lift, drag, pitching moments, rolling moments, and the rates of roll produced by the various controls. The effect on the pitching-moment characteristics of "fences" on the upper surface of the airfoil parallel to the air stream was also determined.

The results indicate that the conventional ailerons were more effective in producing rolling moments than either the chord-extension controls or the spoilers. Maximum effectiveness of the spoilers was obtained with the spoilers perpendicular to the air stream.

The fences parallel to the air stream extended the linear variation of pitching-moment coefficient with lift coefficient from a lift coefficient of 0.45 to 0.80, but did not affect the longitudinal instability at higher lift coefficients.

INTRODUCTION

One of the major problems involved in the use of swept wings is the provision of adequate lateral control, especially at high lift coefficients. The experimental data of reference 1 indicate that the effectiveness of conventional ailerons in producing rolling moments is considerably reduced by incorporating sweepback in the wing plan form. Therefore, the effectiveness of a different type of lateral-control device, consisting of the rearward extension of the wing chord, was investigated on a 45° swept-back semispan wing. Spoilers were also tested on the same wing to determine the effect of spoiler location relative to the air stream on their effectiveness for providing rolling moments.

As simple sweep theory indicates that the damping in roll is reduced by sweep and, since it was believed that the chord-extension controls would increase this damping, comparative measurements were made of the rates of roll produced by these controls and by conventional ailerons on a full-span model of the same plan form as the semispan wing. In order to obtain a more comprehensive comparison of the effectiveness of the controls, the rolling moments were also measured at various angles of yaw.

In an attempt to control the outboard spanwise flow in the boundary layer and thereby delay separation at the wing tip, the effect of fences alined in the free-stream direction on the upper surface of the semispan model was determined.

SYMBOLS, COEFFICIENTS, AND CORRECTIONS

The data are presented in the form of standard NACA coefficients and symbols. All forces and moments are presented about the stability axes with their origin on the root chord at the same fore and aft location as a point at 25 percent of the mean aerodynamic chord of the plain wing.

C_L lift coefficient $\left(\frac{\text{twice lift of semispan model}}{qS}\right)$

C_D drag coefficient $\left(\frac{\text{twice drag of semispan model}}{qS}\right)$

ΔC_D increment of drag coefficient caused by the extension of the controls

C_l rolling-moment coefficient $\left(\frac{\text{rolling moment}}{qSb}\right)$

C_m pitching-moment coefficient $\left(\frac{\text{twice pitching moment of semispan model}}{qS\bar{c}}\right)$

$\frac{pb}{2V}$ helix angle of roll, radians

α angle of attack of the wing chord line, degrees

ψ angle of yaw, degrees

q free-stream dynamic pressure $\left(\frac{1}{2}\rho V^2\right)$, pounds per square foot

S full-span wing area, square feet

b full wing span, feet

p rate of roll, radians per second

V airspeed, feet per second

ρ air density, slugs per cubic foot

c wing chord, feet

$\bar{c}$ wing mean aerodynamic chord, feet

A aspect ratio $\left(\frac{b^2}{S}\right)$

R_{eff} effective Reynolds number $\left(\frac{V\bar{c}}{\text{kinematic viscosity}}\right) \times (\text{turbulence factor})$

where the following turbulence factors, as determined from sphere tests, were used:
(a) 2.34 – turbulence net in[1]
(b) 1.0 – turbulence net out

δ conventional aileron deflection measured in a plane perpendicular to the hinge line, degrees

Subscripts

L left aileron

R right aileron

u uncorrected values

The data obtained from tests of the semispan model were corrected for the effects of the tunnel walls by the method of reference 2, which does not consider corrections for a swept-back wing. In order to facilitate the reduction of the data, the corrections were assumed to be identical to those for a model of unswept plan form of the same aspect ratio, span, and taper ratio. The corrections applied to the data obtained from tests of the semispan model are as follows:

[1]In order to increase the effective Reynolds number for the full-span model, a turbulence net was installed in the wind tunnel.

$\Delta\alpha_1$ (jet-boundary correction) = 0.652 C_{L_u}

$\Delta\alpha_2$ (streamline-curvature correction) = 0.0646 C_{L_u}

$\Delta C_D = 0.0133\ C_{L_u}{}^2$

$\Delta C_m = 0.00188\ C_{L_u}$

$\Delta C_L = -0.004\ C_{L_u}$

A previous check of the corrections for a similar model of a swept-back wing indicated sweepback to have a negligible effect on the magnitude of the corrections.

The drag coefficients presented for the semispan model are not the absolute values as the drag of the reflection turntable is included. However, the incremental drag coefficients caused by the controls are believed to be approximately correct.

The rolling moments produced by the chord-extension controls on the semispan model were not corrected for reflected load effects, as it was desired to obtain only the comparative effectiveness of the various controls.

No corrections have been applied to the data obtained from tests of the full-span model because of the small size of the model relative to the size of the test section of the wind tunnel.

MODELS AND APPARATUS

A semispan model and a full-span model were used for the investigation in the Ames 7- by 10-foot wind tunnel. The wing panels of the full-span model were three-eights of the scale of the semispan model. Both models had NACA 64A210 (a=0.8) airfoil sections[2] parallel to the plane of symmetry, the 25-percent chord line swept back 45°, an aspect ratio of 4.5, and a taper ratio of 0.5. A summary of the geometric characteristics of the models is presented in table I.

The semispan model was mounted on a turntable that was flush with the tunnel floor which simulated the plane of symmetry (fig. 1). The forces and moments acting on the model were measured by the normal six-component wind-tunnel balance system.

The full-span model was mounted on a sting support as shown in figure 2. Rolling-moments of the full-span model were measured,

[2]The symbol A represents an airfoil section with straight sides near the trailing edge.

exclusive of the forces on the support, by means of a cantilever electrical strain gage. No allowance was made for interference effects of the sting on the model. The model was allowed to rotate unrestrained about an axis parallel to the air stream. In this manner rates of roll produced by the various controls were determined by timing a given number of complete revolutions of the model. In order to obtain steady rates of roll, the model was statically balanced about the axis of rotation at each angle of attack by the addition of lead weights at the nose of the model. The angle of attack of the model was changed by rotation about a lateral axis located at 19.8 percent of the mean aerodynamic chord.

The dimensional data for the chord-extension controls tested on the semispan model are presented in table II and figure 3. These controls (made of 0.091-inch sheet steel) were attached to the upper surface of the wing which was recessed to provide a smooth contour. The controls projected along the airfoil mean camber line, giving an angle of 2°55' between the wing chord plane and the controls. Controls A and B were assumed to be extended by rotation about a point on the wing trailing edge (fig. 3). No consideration was given to the fact that control A could not be retracted within the wing plan form as it was desired to determine the maximum effectiveness obtainable with such a control. Control B was similar to control A except that control B could be retracted within the wing plan form. Control C was merely a constant-chord extension and control D was similar to control A except that control D covered the entire wing span.

Spoilers were tested on the upper surface of the semispan model in the positions shown in figure 4. The spoilers (made of 0.051-inch aluminum alloy) were mounted perpendicular to the wing chord plane and extended 1 inch above the wing surface. Four fences (1 inch high) alined parallel to the plane of symmetry were also tested on the upper surface of the semispan model (also shown in fig. 4).

A chord-extension control (control A_1) similar to control A was tested on the full-span model. Instead of extending the control along the airfoil mean camber line as on the semispan model, it was extended tangent to the airfoil upper surface. This resulted in an angle of 9°18' between the control and the wing chord plane. A plain, unsealed aileron of 20-percent chord and 50-percent span was also investigated on the full-span model (fig. 2).

RESULTS AND DISCUSSION

Chord-Extension Controls on the Semispan Model

The results obtained from the tests of the chord-extension controls on the semispan model are presented in figures 5 and 6. As shown by these data, the chord-extension controls are characterized at low angles of attack by low rolling effectiveness which is considerably improved as the angle of attack is increased. The maximum lift increments and the lift-curve slope increase caused by these controls are approximately proportional to the increase in wing area as illustrated by the following table which compares the percentage increase in maximum lift coefficient and the percentage increase in lift-curve slope with the percentage increase in area:

Control	Increase in area (%)	Increase in maximum lift coefficient (%)	Increase in lift-curve slope (%)
A (16°)	12.3	12.7	9
B	10.4	10.4	7
C	7.7	8.2	7
D	24.5	30.9	20

As would be expected, the chord-extension controls caused an increase in the longitudinal stability of the model.

A Chord-Extension Control and a Conventional Aileron on the Full-Span Model

In order to obtain a comparison of the performance of the chord-extension control with that of a conventional aileron, tests were conducted upon the full-span model with a conventional aileron of 20-percent chord and 50-percent span and with a chord-extension control of 50-percent semispan similar to control A extended 16°. Measurements were made of the rolling moments at various angles of yaw throughout the angle-of-attack range and the rates of roll with the model rotating unrestrained. It was found that at small angles of attack control A, as tested on the full-span model, was incapable of producing steady rates of roll with the model unrestrained. Therefore, the control was extended tangent to the upper surface of the airfoil (referred to as control A_1), thereby increasing the control deflection relative to the wing chord plane from 2°55' to 9°18'. All the results presented for the chord-extension control on the full-span model are for a deflection of 9°18'.

The rolling-moment coefficients and the wing-tip helix angles measured with the chord-extension control A_1 and with the conventional ailerons on the full-span model are presented in figure 7. As shown by these data, the ailerons were considerably more effective than the chord-extension controls. Also the effectiveness of the chord-extension control was seriously reduced as the angle of yaw was increased. The wing-tip helix angles which the conventional ailerons are capable of producing were also estimated from the measured rolling-moment coefficients, using the damping in roll of reference 3 reduced by the cosine of the sweepback angle. The results, shown in figure 7, indicate that simple sweep theory gives a good first approximation of the damping in roll at small angles of attack, but at higher angles of attack where the wing tip was stalled the consequent reduction in the damping in roll should be considered.

By means of a turbulence net and by varying the dynamic pressure from 5 to 50 pounds per square foot, the Reynolds number of the full-span model was varied from 0.27×10^6 to 2.08×10^6. The effect of this variation of Reynolds number on the wing-tip helix angles produced by control A_1 is shown in figure 8.

Spoilers on the Semispan Model

The data from the tests of the spoilers of 50-percent span on the semispan model are presented in figure 9. As shown by these data, the largest rolling-moment coefficients were measured for the spoiler perpendicular to the air stream. However, at high angles of attack, there was either a complete reversal in spoiler effectivness or the effectiveness was seriously reduced, depending on the spoiler location. The spoilers were considerably more effective at low angles of attack, but were less effective at high angles of attack than the chord-extension controls. The conventional ailerons tested on the full-span model were more effective than any of the other controls tested.

Fences on the Semispan Model

During the course of the investigation fences were tested on the upper surface of the semispan model in an effort to extend the linearity of the pitching-moment characteristics to higher lift coefficients. As shown by the data in figure 10, the fences did extend the linear variation of pitching-moment coefficient with lift coefficient from a lift coefficient of 0.45 to 0.80. However, the longitudinal stability at higher lift coefficients was not improved.

CONCLUSIONS

The results of the wind-tunnel investigation of several lateral-control devices and fences on a 45° swept-back wing of aspect ratio 4.5 and of taper ratio 0.5 indicate:

1. The conventional ailerons were more effective in producing rolling moments than either the chord-extension controls or the spoilers throughout the useful angle-of-attack range.

2. The maximum effectiveness of the spoilers in producing rolling moments was obtained with the spoilers perpendicular to the air stream.

3. Simple sweep theory provided a good first approximation of the damping in roll at small angles of attack, but was unsatisfactory for predicting the damping in roll at higher angles of attack when the wing was partially stalled.

4. The fences parallel to the air stream increased the maximum lift coefficient for a linear variation of pitching-moment coefficient with lift coefficient from 0.45 to 0.80, but caused no improvement in the longitudinal stability at higher lift coefficients.

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REFERENCES

1. Letko, William, and Goodman, Alex: Preliminary Wind-Tunnel Investigation at Low Speed of Stability and Control Characteristics of Swept-Back Wings. NACA TN No. 1046, 1946.

2. Swanson, Robert S., and Toll, Thomas A.: Jet-Boundary Corrections for Reflection-Plane Models in Rectangular Wind Tunnels. NACA ARR No. 3E22, 1943.

3. Swanson, Robert S., and Priddy, E. LaVerne: Lifting-Surface-Theory Values of the Damping in Roll and the Parameter Used in Estimating Aileron Stick Forces. NACA ARR No. L5F23, 1945.

TABLE I.– GEOMETRY OF MODELS

Dimension	Semispan wing	Full–span wing
Aspect ratio	4.5	4.5
Taper ratio	.5	.5
Sweepback of 0.25–chord line, degrees	45	45
Airfoil section	NACA 64A210 (a=0.8)	NACA 64A210 (a=0.8)
Span, feet	4	3
Area, square feet	7.097	1.996
Mean aerodynamic chord, feet	1.844	.692
Root chord, feet	2.371	.889
Tip chord, feet	1.185	.444

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TABLE II.- DIMENSIONAL DATA FOR CHORD-EXTENSION CONTROLS ON THE SEMISPAN MODEL

Control	Control span / Wing semispan	Angle between wing trailing edge and control trailing edge in plan view (deg)	Area (sq ft)
A	0.50	16	0.87
A	.50	11	.598
A	.50	6	.326
B	.44	16	.74
C	.50	0 (constant-chord control)	.55
D	1.00	8	1.74

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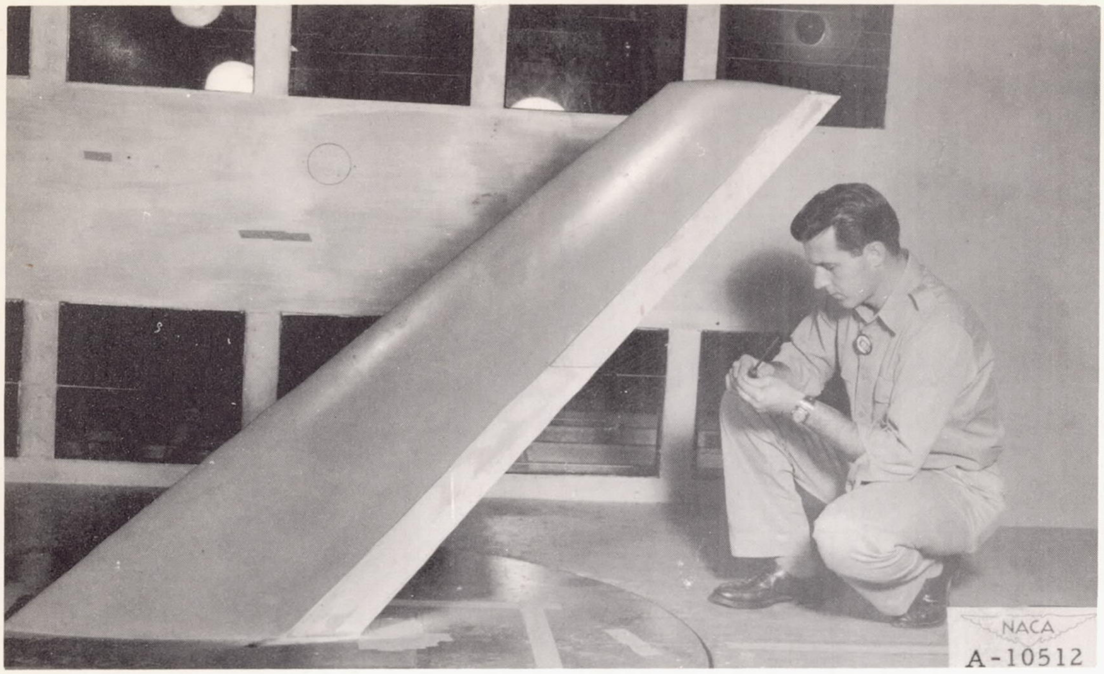
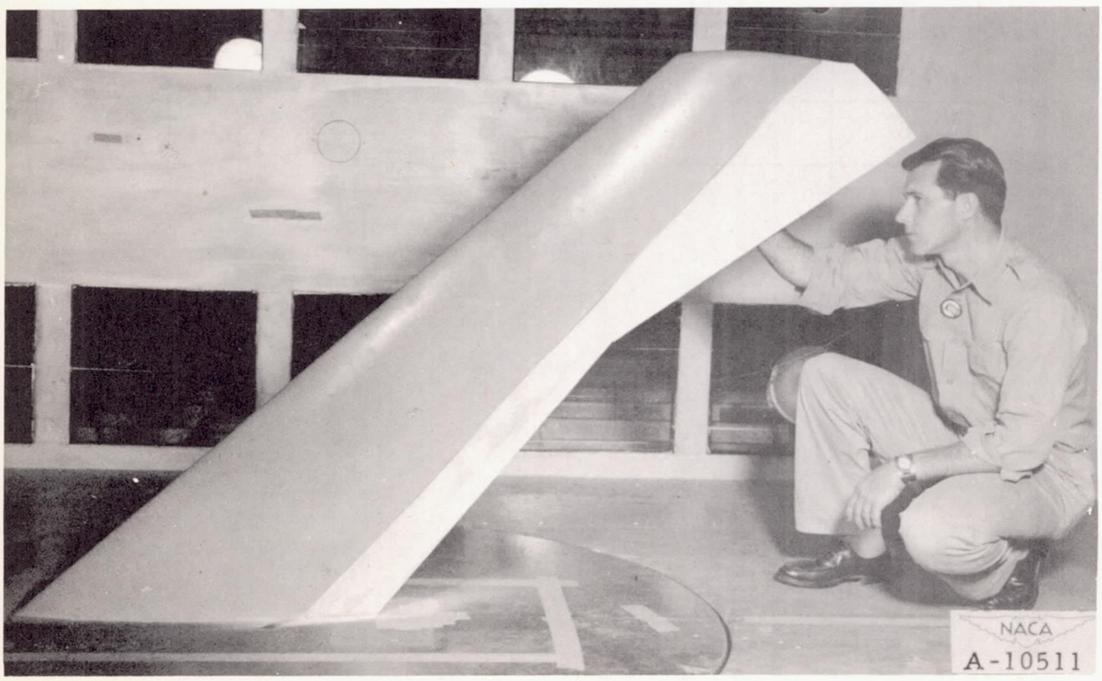
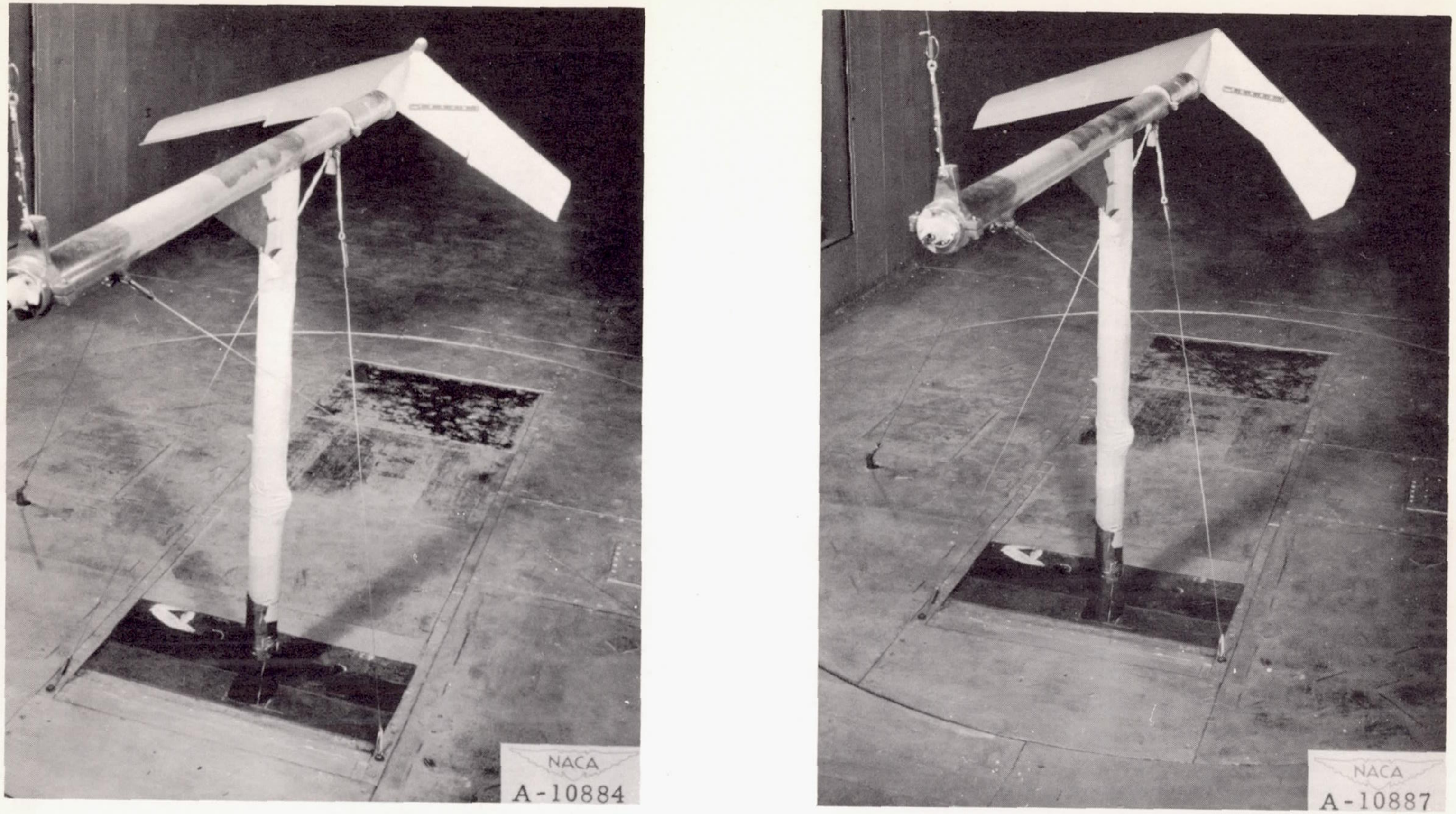


(a) Plain wing



(b) Control A extended

Figure 1.- Semispan model mounted in the Ames 7- by 10-foot wind tunnel.



(a) Conventional ailerons deflected

(b) Control A_1 extended

Figure 2.– Full-span model mounted on the sting in the Ames 7– by 10–foot wind tunnel.

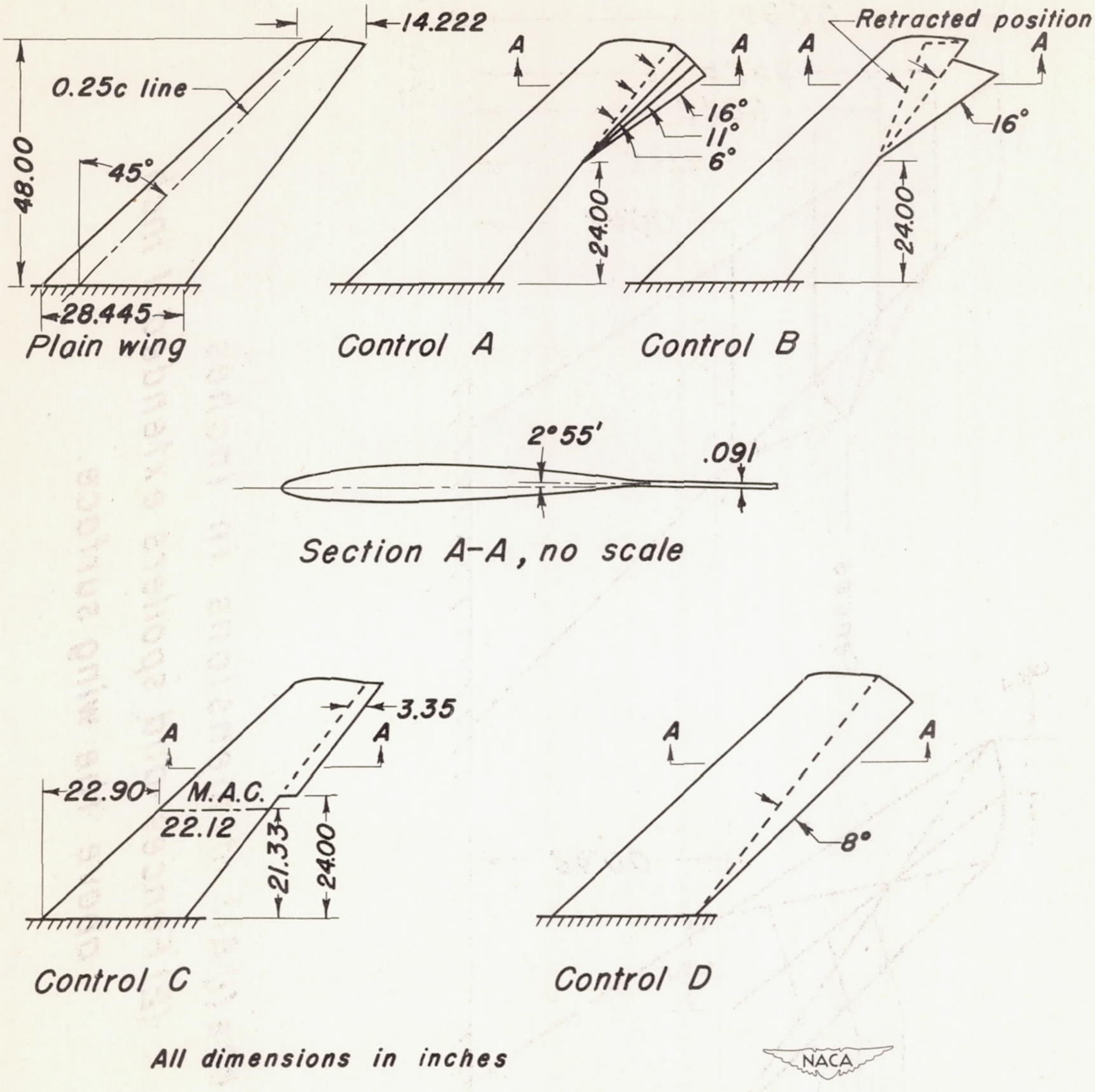
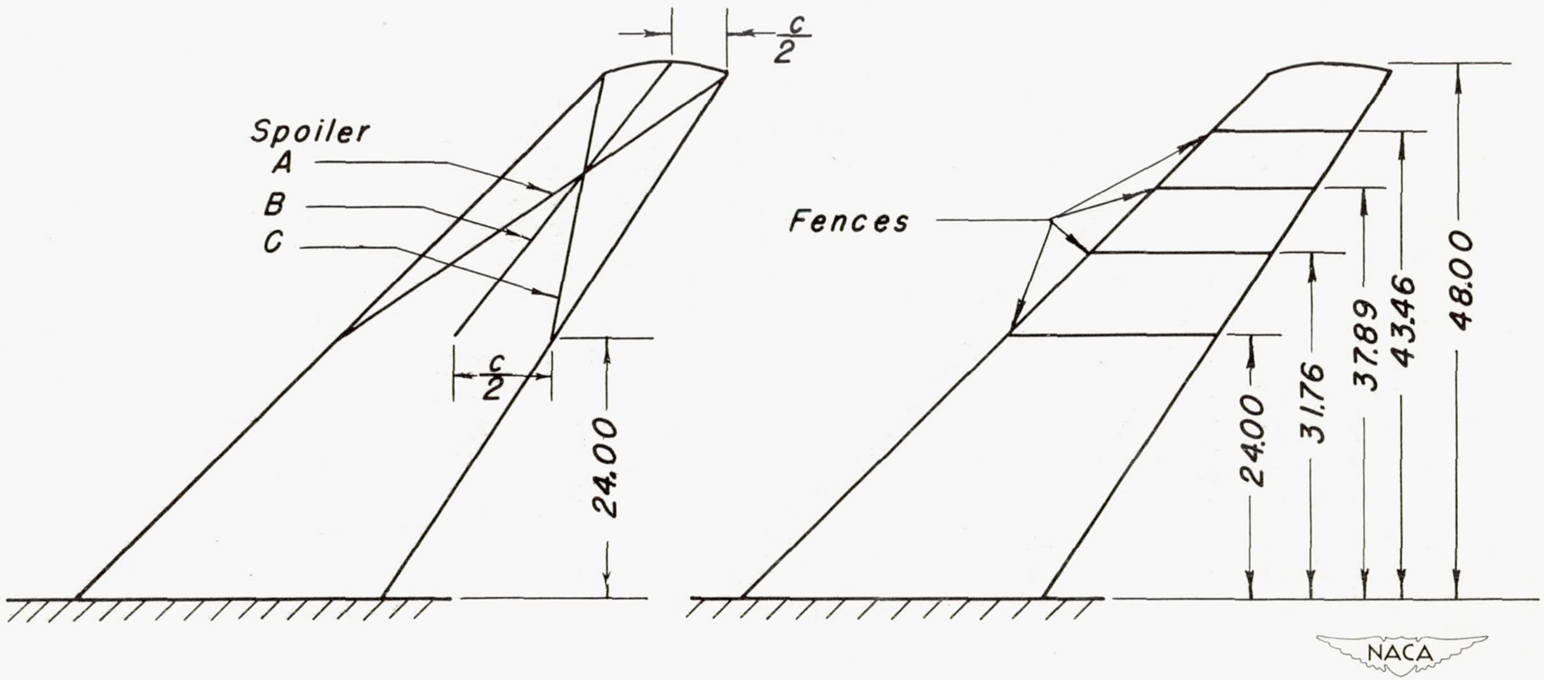


Figure 3.- Chord-extension controls tested on semispan model.



Note (1) All dimensions in inches

(2) Fences and spoilers extended 1 inch above the wing surface.

Figure 4.- Spoilers and fences tested on the semispan model.

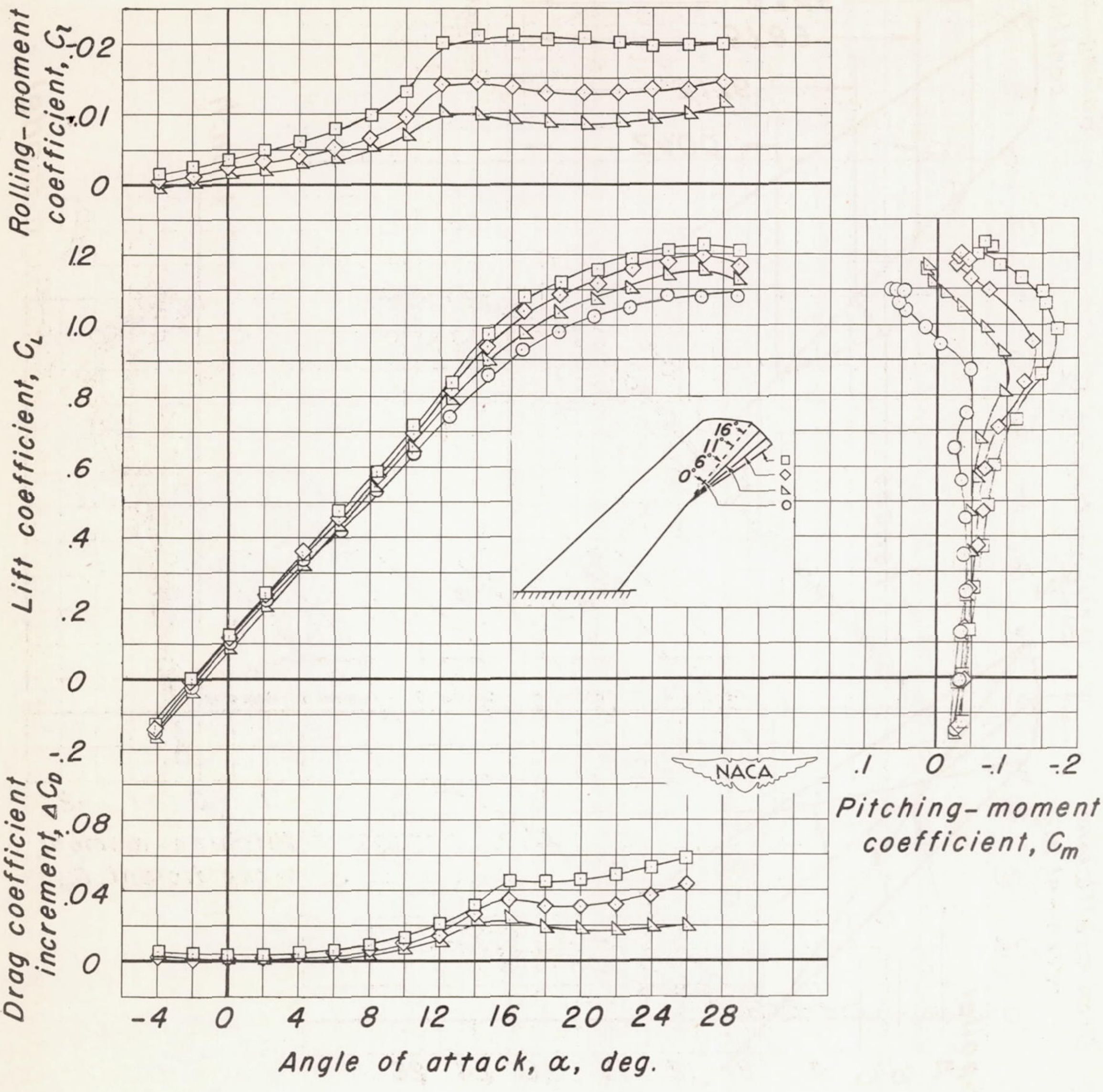


Figure 5.- Effect of chord-extension control A on aerodynamic characteristics of the semispan model. $R_{eff} = 1.88 \times 10^6$.

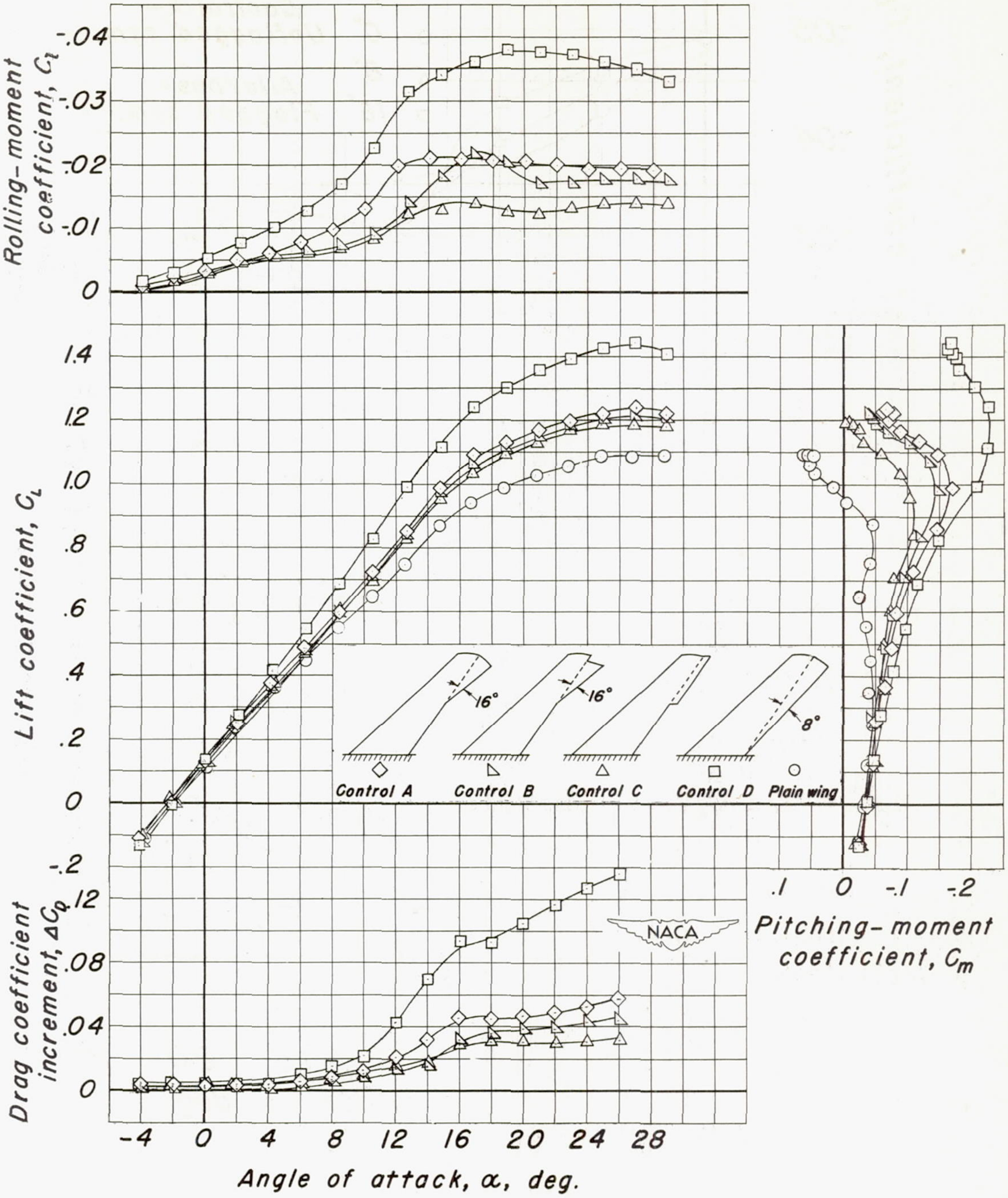


Figure 6.- Effect of chord-extension controls on aerodynamic characteristics of the semispan model. $R_{eff} = 1.88 \times 10^6$.

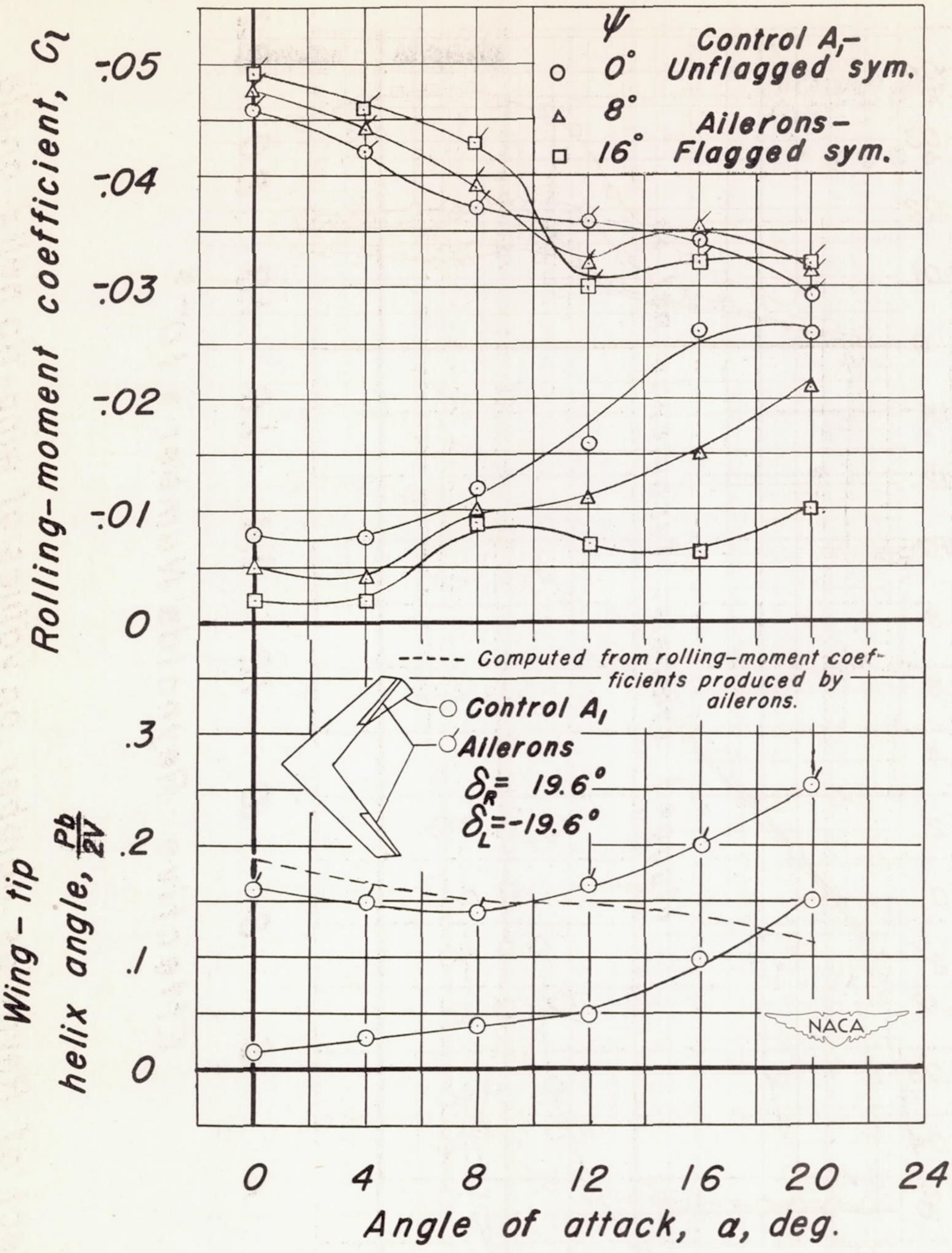


Figure 7.- Comparison of rolling-moment coefficients and wing-tip helix angles produced by chord-extension control A_1 and conventional ailerons on the full-span model. $R_{eff} = 1.88 \times 10^6$.

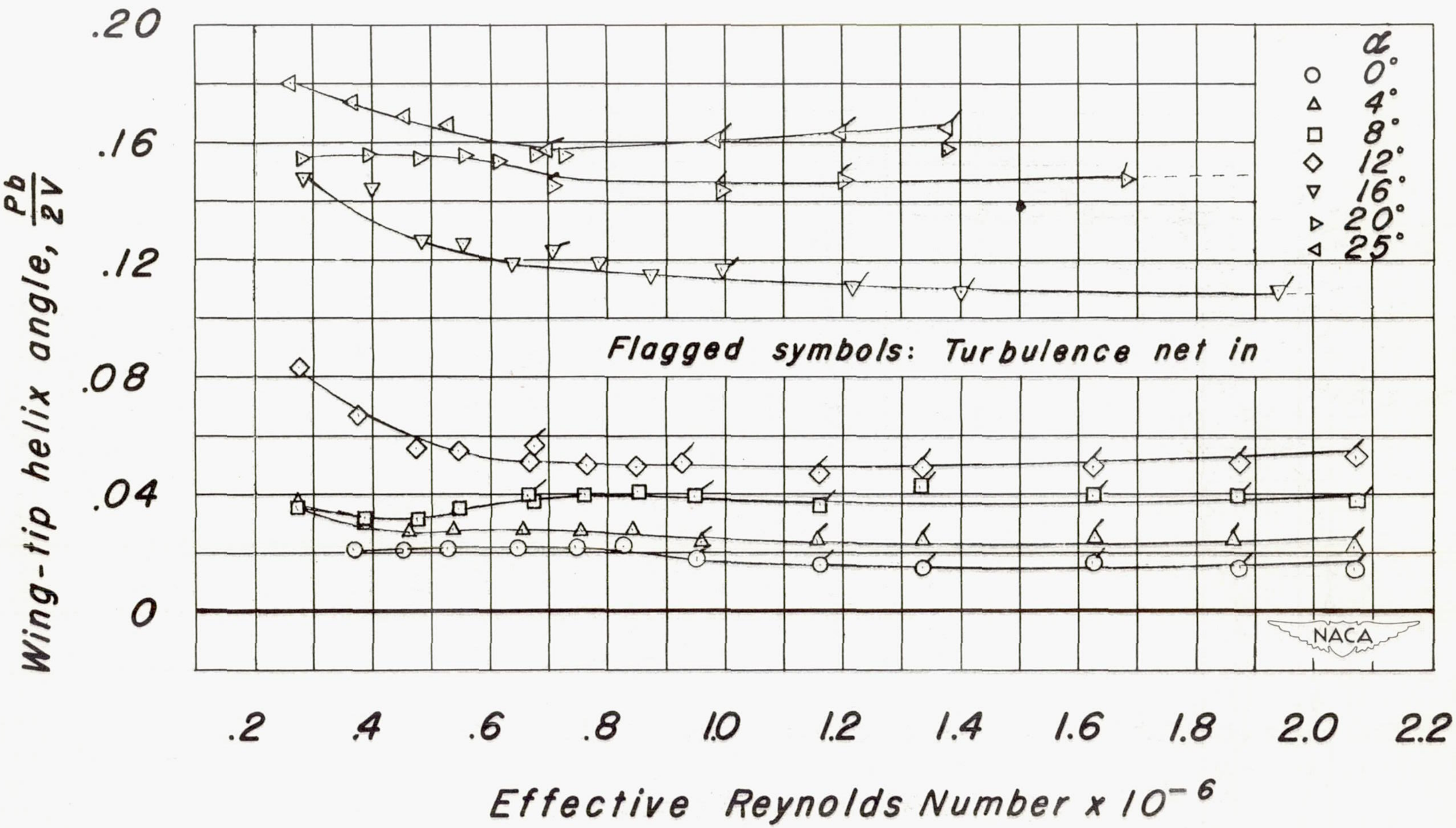


Figure 8.- Effect of Reynolds number on values of wing-tip helix angle produced by chord-extension control A_1 on the full-span model.

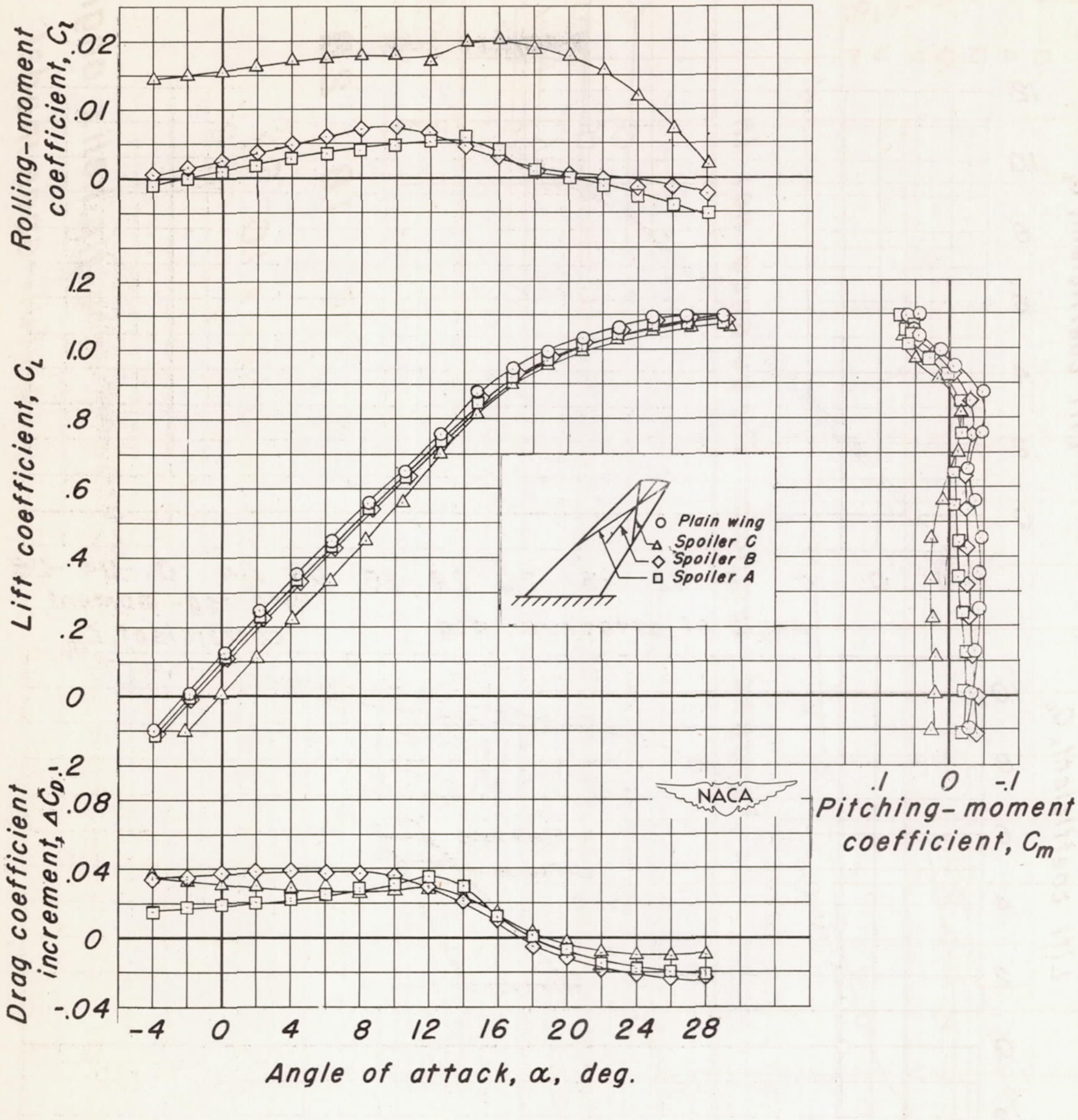


Figure 9.- Effect of spoilers on the aerodynamic characteristics of the semispan model. $R_{eff} = 1.88 \times 10^6$.

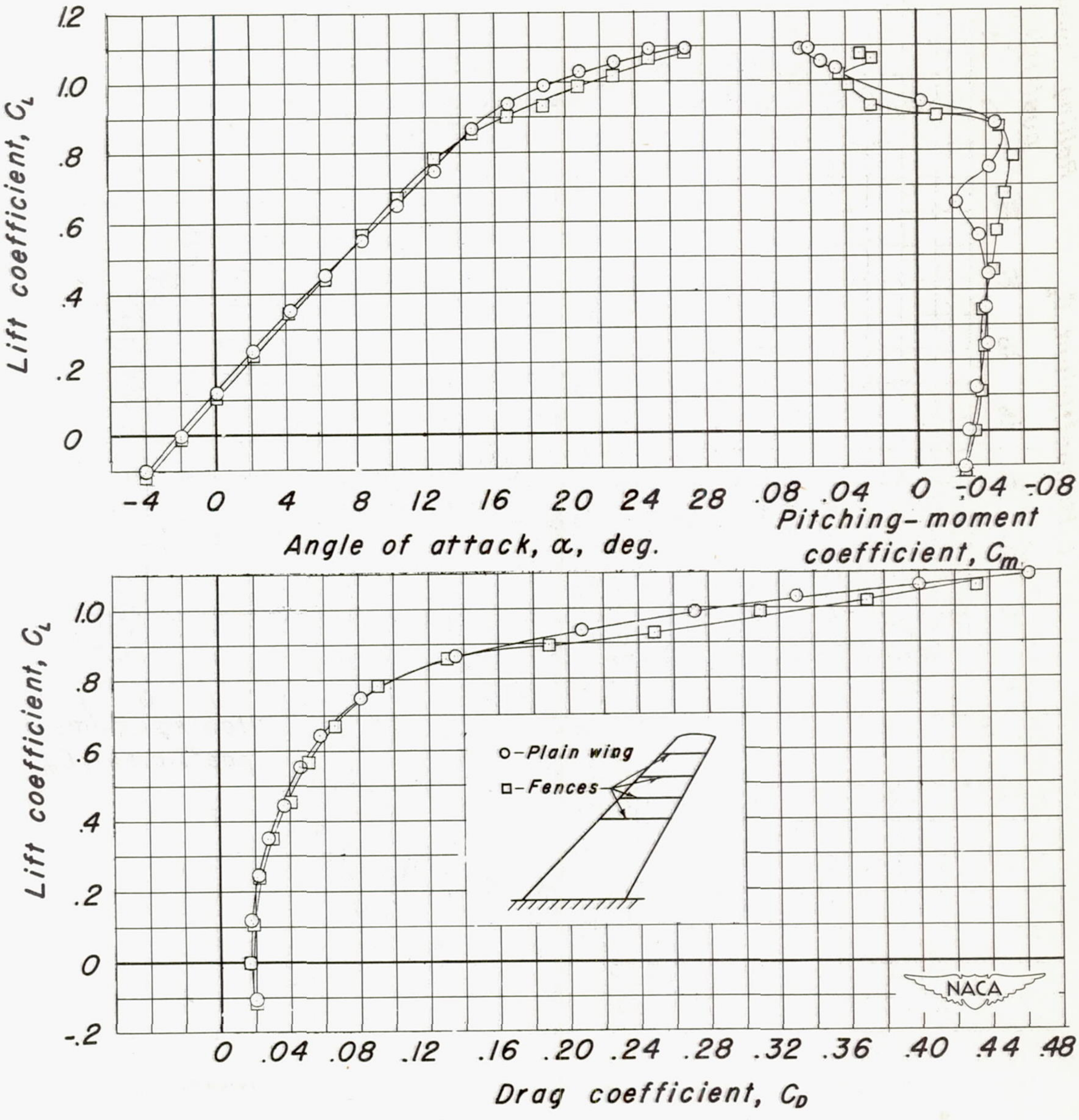


Figure 10.- Effect of upper-surface fences on the aerodynamic characteristics of the semispan model. $R_{eff} = 1.88 \times 10^6$.