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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 2169

WIND-TUNNEL INVESTIGATION AT LOW SPEED OF A 45° SWEPTBACK UNTAPERED SEMISPAN WING OF ASPECT RATIO 1.59 EQUIPPED WITH VARIOUS 25-PERCENT-CHORD PLAIN FLAPS

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SUMMARY

A wind-tunnel investigation was made at low speed to determine the aerodynamic characteristics of a 45° sweptback untapered semispan wing of NACA 64A010 airfoil section normal to the leading edge and aspect ratio of 1.59 equipped with 25-percent-chord plain unsealed flaps having various spans and spanwise locations. Lift, drag, pitching-moment, and flap hinge-moment data were obtained for the wing with the various flaps deflected up to 60°. A comparison is made with data obtained on the present wing at 0° of sweep with an aspect ratio of 3.13.

In general, changes in angle of attack, flap deflection, flap span, and spanwise location produced trends in lift, drag, pitching moment, and flap hinge moment that were similar to but of different magnitudes from those for unswept wings. Existing empirical and theoretical methods for predicting the lift effectiveness of flaps of various spans gave very good agreement with the experimental results.

Because of the increase in the drag coefficients and the associated decrease in the lift-drag ratio with increasing flap deflection, an advantage may be gained by limiting the flap deflection to moderate angles (about 30°), even though the lift coefficients increase slightly with further increases in flap deflection. Flap deflections greater than 30° may be desirable, however, when steeper glide-path angles are required.

INTRODUCTION

The National Advisory Committee for Aeronautics is making an extensive investigation of the lift and control effectiveness of various flaps and control surfaces on wings having plan forms suitable for transonic and supersonic airplanes. The objective is to obtain flap and aileron design criterions similar to those available for unswept wings of larger aspect ratios (references 1 to 6). As part of this broad study, the lift and lateral control characteristics of an untapered low-aspect-ratio semi-span wing having various amounts of sweep and equipped with 25-percent-chord plain unsealed flaps or ailerons of various spans and spanwise locations are being investigated at low speed in the Langley 300 MPH 7- by 10-foot tunnel.

This paper presents the results of the investigation of the 45° sweptback-wing configuration having an aspect ratio of 1.59 and utilizing the 25-percent-chord control surfaces as lift flaps. The results of a similar investigation of the unswept-wing configuration of aspect ratio 3.13 were presented in reference 7. Lift, drag, pitching-moment, and flap hinge-moment data were obtained through a large angle-of-attack range for various flap deflections up to 60°.

SYMBOLS

The forces and moments measured on the wing are presented about the wind axes which, for the conditions of these tests (zero yaw), correspond to the stability axes. The pitching-moment data are measured about the origin of axes as shown in figure 1 which corresponds to the 25-percent-chord station of the mean aerodynamic chord. The lift, drag, and pitching-moment data presented herein represent the aerodynamic effects of deflection of the flaps in the same direction on both semispans of the complete wing.

C_L	lift coefficient (L/qS)
ΔC_L	increment of lift coefficient
C_D	drag coefficient (D/qS)
C_m	pitching-moment coefficient $(M/qS\bar{c})$
ΔC_m	increment of pitching-moment coefficient
C_h	flap hinge-moment coefficient $(H/2qM_1)$
L	twice lift of semispan model, pounds
D	twice drag of semispan model, pounds
M	twice pitching moment of semispan model measured about $0.25\bar{c}$, foot-pounds

H	flap hinge moment, measured about flap hinge axis, foot-pounds
M_1	area moment of flap rearward of and about hinge axis, feet^3 (see table I)
q	free-stream dynamic pressure, pounds per square foot $\left(\frac{1}{2}\rho V^2\right)$
S	twice area of semispan wing model (19.32 sq ft)
b	twice span of semispan wing model (5.55 ft)
$\bar{c}$	wing mean aerodynamic chord (3.52 ft)
c	local chord
y	lateral distance from plane of symmetry, measured perpendicular to plane of symmetry, feet
b_f	span of flap, measured perpendicular to plane of symmetry, feet
V	free-stream velocity, feet per second
ρ	mass density of air, slugs per cubic feet
α	angle of attack of wing measured at plane of symmetry, degrees
δ_f	flap deflection relative to wing chord plane, measured perpendicular to flap hinge axis (positive when trailing edge is down), degrees
α_δ	flap effectiveness parameter; that is, effective change in angle of attack caused by unit angular change in flap deflection

Subscripts:

f_i	inboard end of flap
f_o	outboard end of flap
max	maximum

MODEL AND APPARATUS

The semispan-wing model used in the investigation was constructed of laminated mahogany over a solid-steel spar. The plan-form dimensions are shown in figure 1. The wing sections normal to the leading edge were NACA 64A010 and the model had an aspect ratio of 1.59 (based on full-span dimensions), a taper ratio of 1.0, and 45° of sweepback. The wing model had neither twist nor dihedral. The model was the same as that used in the investigation reported in reference 7, modified by rotating the 50-percent-chord line about the root station and rotating the wing-tip chord about its 50-percent-chord station so as to be parallel to the air stream.

A cross section of the wing showing the details of the 25-percent-chord unsealed plain flaps is shown in figure 1. The flaps were constructed of mahogany with steel spars and had joints at three spanwise stations so that various spans of flaps at various spanwise locations could be investigated (fig. 1 and table I). The chordwise gaps between flap segments were sealed when two or more flap segments were tested in combination. A motor-driven flap-actuating mechanism which was remotely controlled was used to obtain the various flap deflections used in the investigation, and these deflections were constantly indicated on a meter by the use of a calibrated potentiometer which was mounted on the hinge axis near the root chord of the model. The flap hinge moments were measured by a calibrated electrical resistance type of strain gage.

The Langley 300 MPH 7- by 10-foot tunnel is a closed-throat single-return tunnel. The semispan-wing model was mounted vertically in the tunnel with the root chord adjacent to the ceiling of the tunnel, which served as a reflected plane (fig. 2). The model was mounted on the six-component balance system so that all forces and moments acting on the model could be measured. A small clearance was maintained between the model and the tunnel ceiling so that no part of the model came into contact with the tunnel structure. A $\frac{1}{16}$-inch-thick metal end plate was attached to the root of the model to deflect the air flowing into the test section through the clearance hole in order to minimize the effect of this spanwise air flow on the flow over the model.

TESTS

All the tests were performed at an average dynamic pressure of approximately 100 pounds per square foot, which corresponds to a Mach number of 0.27 and a Reynolds number of about 6.3×10^6 based on the wing mean aerodynamic chord of 3.52 feet. Measurements have indicated that the tunnel turbulence factor is very close to unity.

Tests of the wing were made with the inboard half-span and the full-span flaps at seven deflections between 0° and 60° and with the partial-span flaps at the outboard and midspan locations at a flap deflection of 30° for an angle-of-attack range of from -4° to about the wing stall angle.

CORRECTIONS

Jet-boundary corrections, determined by the method presented in reference 8, have been applied to the angle-of-attack and drag-coefficient values. Blockage corrections, to account for the constriction effects of the model and its wake, have also been applied to the test data (reference 9). No corrections have been applied to the data to account for the very small amount of wing twist produced by flap deflection or for the effect of air-flow leakage around the end plate at the root of the model.

RESULTS AND DISCUSSION

The static aerodynamic characteristics of the wing in pitch for the various deflections of the inboard half-span $\left(b_f = 0.477\frac{b}{2}\right)$ and the full-span $\left(b_f = 0.875\frac{b}{2}\right)$ flaps are presented in figures 3 and 4, respectively. Corresponding data for the wing equipped with outboard flaps $\left(y_{f_o} = 0.955\frac{b}{2}\right)$ having various spans and for the wing equipped with approximately half-span flaps at three spanwise locations are presented in figures 5 and 6, respectively, for a flap deflection of 30°. The incremental values of lift and pitching-moment coefficients resulting from flap deflection of the inboard half-span and the full-span flaps are shown in figures 7 and 8, respectively. The effects of flap span (expressed as percent of full-span flap area) and spanwise location on the incremental lift coefficient caused by 30° of flap deflection at 0° angle of attack are presented in figure 9. The variation of the pitching-moment coefficients with flap span and spanwise location for the wing with the flaps deflected 30° at three values of α is presented in figure 10.

Lift characteristics.- For the angle-of-attack range covered in the investigation, increasing either the flap span or the flap deflection up to about 40° resulted in an increase in the lift coefficient (figs. 3 to 6). From the variation of the increment of lift coefficient produced by flap deflection at $C_{L_{max}}$ with flap deflection (fig. 7), deflections greater than about 40° result in losses in $\Delta C_{L_{max}}$ and only slight gains are shown for deflections greater than 30°. The variations of ΔC_L and $\Delta C_{L_{max}}$ with flap deflection (fig. 7) are similar to, but of considerably smaller magnitude, than those exhibited by the wing at 0° of sweepback and aspect ratio of 3.13 as reported in reference 7 and show the expected effects of increasing the sweep and decreasing the aspect ratio. The experimental values of ΔC_L for a flap deflection of 30°

at $\alpha = 0^{\circ}$ are compared with the empirically and theoretically determined lift effectiveness in figure 9; this comparison shows that the decreases in ΔC_L are of the right magnitude. Method I of reference 10 was used for the wing equipped with outboard flaps and an application of the Weissinger method was used for the wing equipped with inboard flaps. The value of the flap effectiveness parameter α_{δ} used in these estimations was 0.54 and was obtained from section data of an unsealed flap type of control on an NACA 64A010 section (reference 11), corrected for flap chord by the method of reference 10. In presenting the data the parameter flap area was used instead of flap span since theory assumes that flaps are cut parallel to free stream. For flaps cut normal to the hinge axis, the span of the flap at the hinge axis does not give a true representation of flap size and it appears that the ratio of flap area to the area of the full-span flap should be used in all cases. The agreement of the estimated and theoretical values of ΔC_L with the experimental data for a flap deflection of 30° at 0° angle of attack is very good and indicates that low-aspect-ratio swept wings have variations of effectiveness with flap span similar to wings of less sweep and/or higher aspect ratio.

Drag characteristics.- Analysis of the lift and drag data of figures 3 and 4 indicates that, for lift coefficients greater than about 0.6 for the wing with the inboard-span flaps deflected and for lift coefficients greater than about 0.8 for the wing with the full-span flaps deflected, a flap deflection of 30° provides the optimum value of lift-drag ratio L/D. Further increases in flap deflection generally result in a decrease in the L/D values; therefore, because of the increase in the drag coefficients with increasing flap deflections, an advantage may be gained by limiting the flap deflection to moderate angles (about 30°), even though the lift coefficients increase slightly with further increases in flap deflection. Other advantages gained by limiting the flap deflection to moderate angles are the lower hinge moments and the smaller longitudinal-trim changes resulting from flap deflection, especially for the wing equipped with the full-span flaps. When high drag coefficients are desirable to increase the glide-path angle, flap deflections of greater than 30° may be used.

At the higher lift coefficients, the drag coefficients generally decreased as the flap span was increased (figs. 3 to 5). The drag coefficients also decreased as the half-span flaps were moved to a more inboard location (fig. 6). These effects of angle of attack, flap deflection, flap span, and spanwise flap location were generally the same as for the model at 0° of sweep (reference 7).

Pitching-moment characteristics.- For all flap configurations and flap deflections, the wing had an unstable variation of pitching-moment coefficient with lift coefficient at low values of C_L, the aerodynamic center being located at about $0.18\bar{c}$ (figs. 3 to 6). This longitudinal instability decreased and the variation of C_m with C_L became stable as the lift coefficient was increased.

Flap deflection produced negative increments of pitching-moment coefficient ΔC_m that were linear with flap deflection for deflections of less than about 20° (fig. 8). Flap deflections greater than 20° generally gave progressively smaller increases in ΔC_m with increasing flap deflection (figs. 3, 4, and 8). Similar effects due to flap deflection were noted for the unswept wing (reference 7), although for the unswept configuration the C_m increments were less affected by angle-of-attack variations than those for the swept configuration.

The variations of the pitching-moment coefficient with flap span and spanwise location (fig. 10) were similar to those for sweptback wings of higher aspect ratios. The method of reference 10 did not satisfactorily predict the magnitudes of these variations for the low-aspect-ratio wing of the present investigation.

Hinge-moment characteristics.- The flap hinge-moment data of figures 3 to 6 show, as would normally be expected, that the values of flap hinge-moment coefficient generally became more negative as either the flap deflection or the angle of attack was increased except for the higher flap deflections where the values of C_h became less negative with increasing angle of attack. (See figs. 3 and 4.) Although the effects of flap span were slight and, in some cases, inconsistent, the hinge-moment coefficients of the outboard flaps generally became less negative as the flap span was increased (fig. 5). A similar decrease in magnitude of C_h due to spanwise location of the half-span flaps was noted when the flap was moved inboard from the wing tip (fig. 6).

These effects of flap deflection, flap span, and spanwise location on the hinge-moment characteristics are similar to those for the model at 0° of sweep (reference 7), though generally of smaller magnitude.

CONCLUSIONS

A wind-tunnel investigation was made at low speed to determine the aerodynamic characteristics of a 45° sweptback untapered semispan wing of aspect ratio 1.59 equipped with 25-percent-chord unsealed plain flaps having various spans and spanwise locations. The results of the investigation led to the following conclusions:

1. Changes in angle of attack, flap deflection, flap span, and spanwise flap location generally produced trends in lift, drag, pitching moment, and flap hinge moment that were similar to but of different magnitude from those for unswept wings.

2. Existing empirical and theoretical methods for predicting the lift effectiveness of flaps of various spans gave very good agreement with the experimental results.

3. Because of the increase in the drag coefficients and the associated decrease in the values of the lift-drag ratio with increasing flap deflection, an advantage may be gained by limiting the flap deflection to moderate angles (about 30°), even though slight increases in lift coefficient result from further increases in flap deflection. Flap deflections greater than 30° may be desirable, however, when steeper glide-path angles are required.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Air Force Base, Va., May 12, 1950

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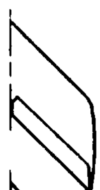
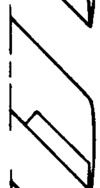
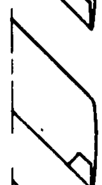
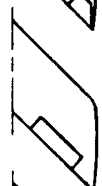
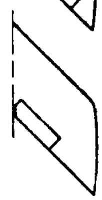
TABLE I

DIMENSIONAL CHARACTERISTICS OF THE VARIOUS 0.25c FLAPS TESTED ON THE 45° SWEPTBACK WING HAVING AN ASPECT RATIO OF 1.59

Configuration	Flap span, $\frac{b_f}{b/2}$	Flap spanwise location		M_1 (ft^3)
		$\frac{y_{f_i}}{b/2}$	$\frac{y_{f_o}}{b/2}$	
	0.875	0.080	0.955	0.7216
	.637	.318	.955	.5686
	.398	.557	.955	.3855
	.160	.795	.955	.2024
	.477	.318	.795	.3662
	.477	.080	.557	.3361

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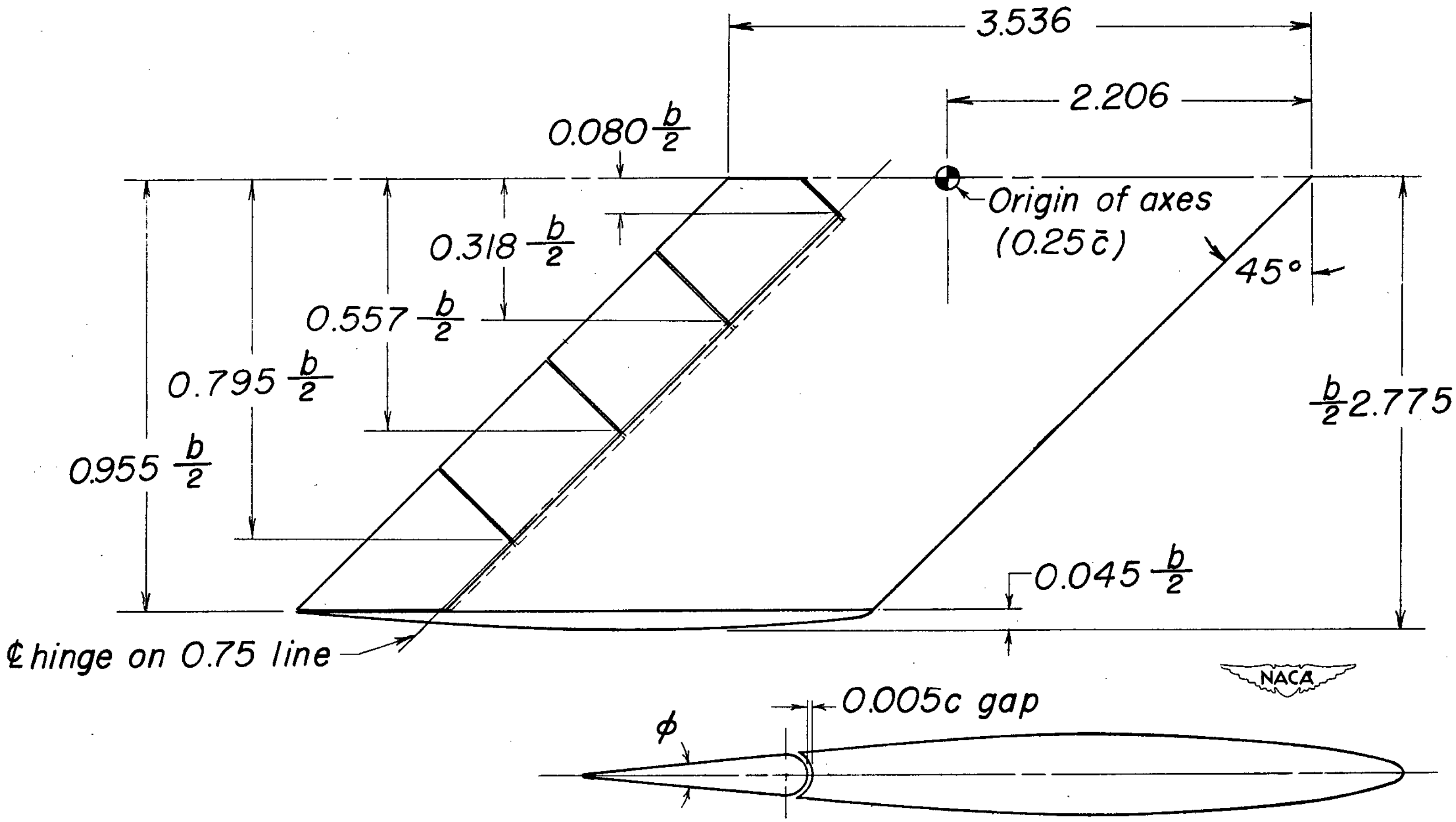


Figure 1.- Drawing of the 45° sweptback-semispan-wing model having an aspect ratio of 1.59. NACA 64A010 airfoil section normal to leading edge. Trailing-edge angle ϕ measured perpendicular to hinge axis is 12.0° and measured parallel to free stream is 8.5°. (All dimensions are in feet.)

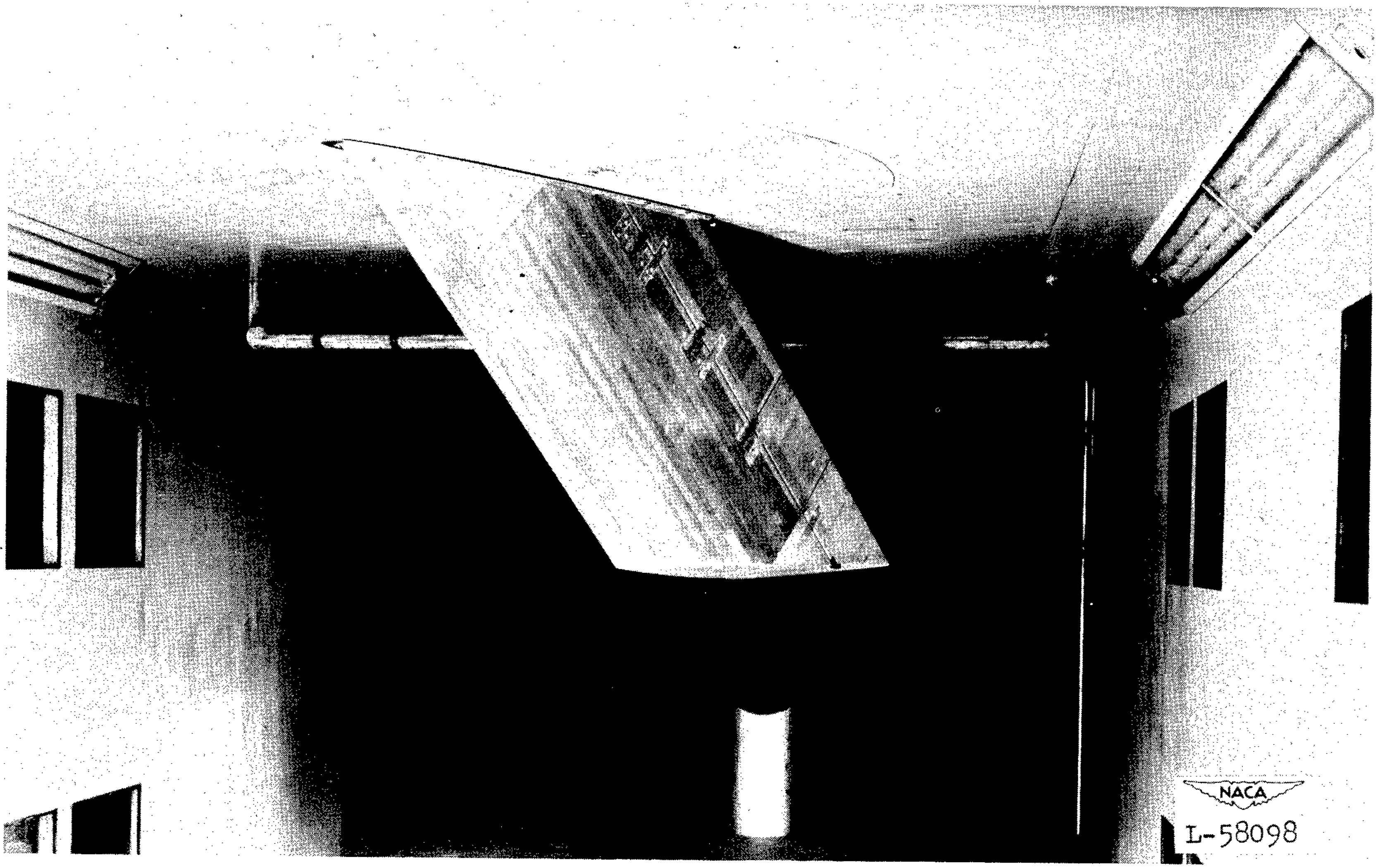


Figure 2.- The 45° sweptback-semispan-wing model having an aspect ratio of 1.59 mounted in the Langley 300 MPH 7- by 10-foot tunnel.

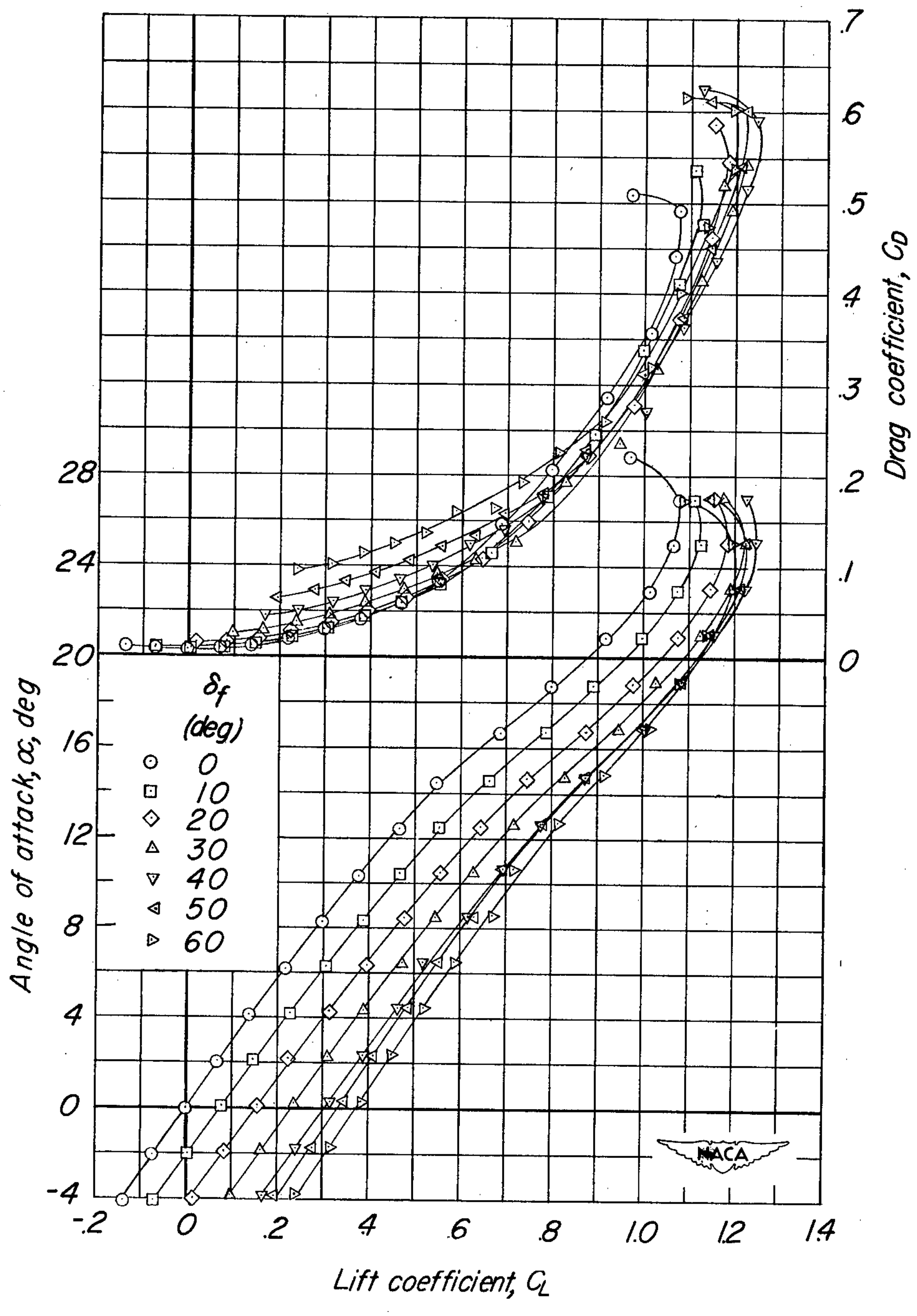


Figure 3.- Effect of flap deflection on the aerodynamic characteristics in pitch of the 45° sweptback wing having an aspect ratio of 1.59 and equipped with inboard half-span flaps $\left(b_f = 0.477\frac{b}{2}\right)$. $y_{f_i} = 0.080\frac{b}{2}$; $y_{f_o} = 0.557\frac{b}{2}$.

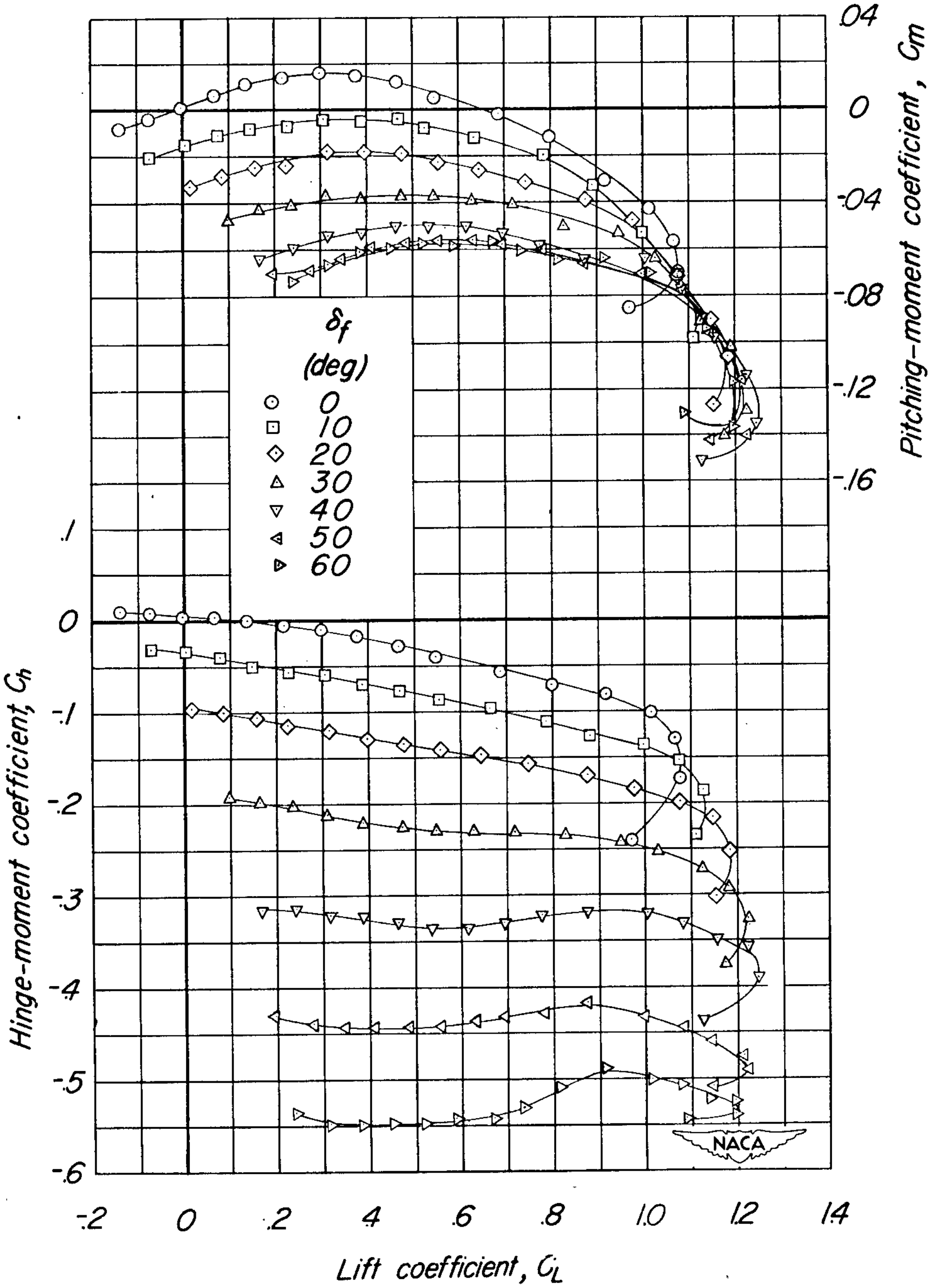


Figure 3.- Concluded.

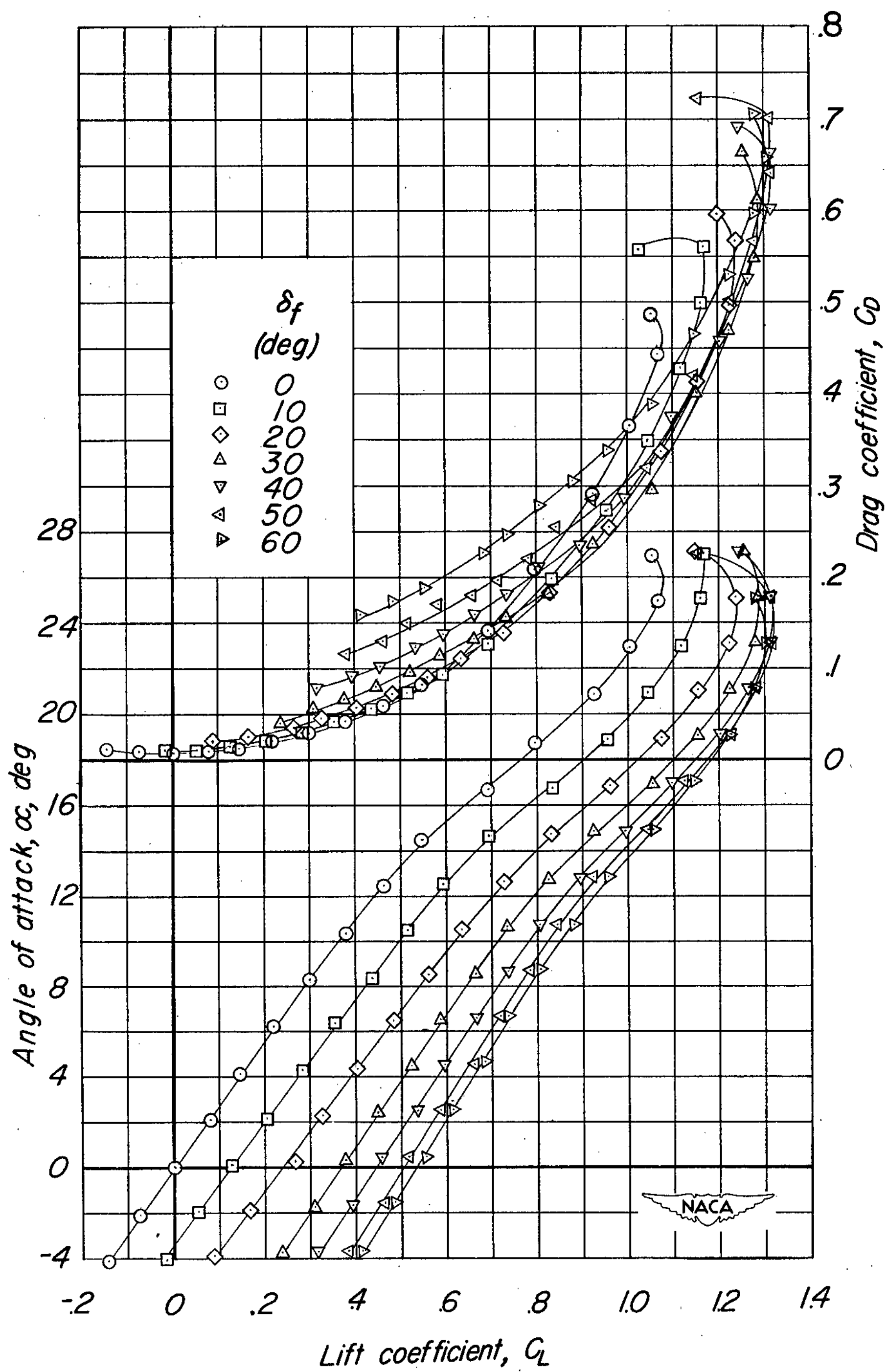
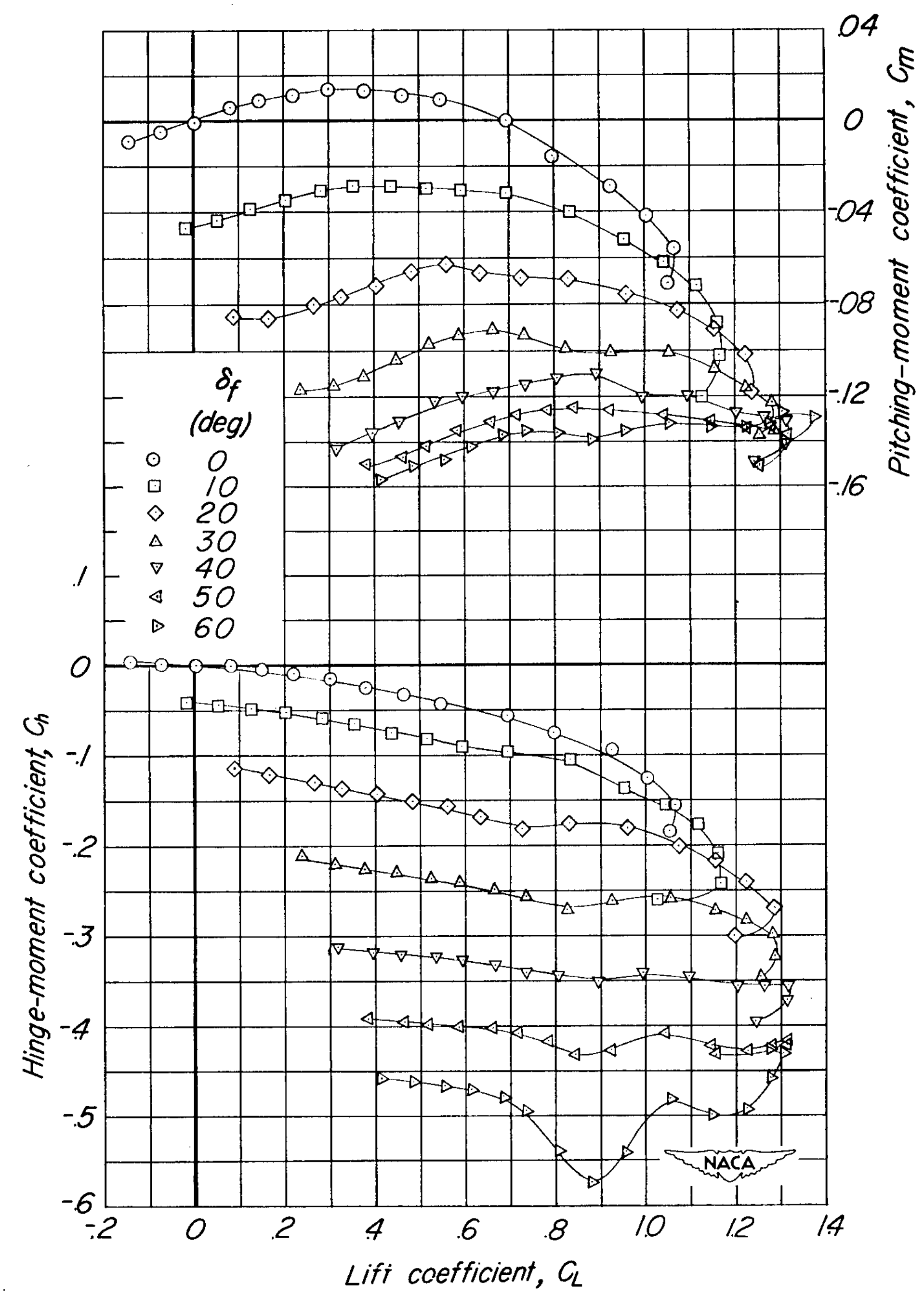


Figure 4.- Effect of flap deflection on the aerodynamic characteristics in pitch of the 45° sweptback wing having an aspect ratio of 1.59 and equipped with full-span flaps $\left(b_f = 0.875\frac{b}{2}\right)$. $y_{f_i} = 0.080\frac{b}{2}$; $y_{f_o} = 0.955\frac{b}{2}$.



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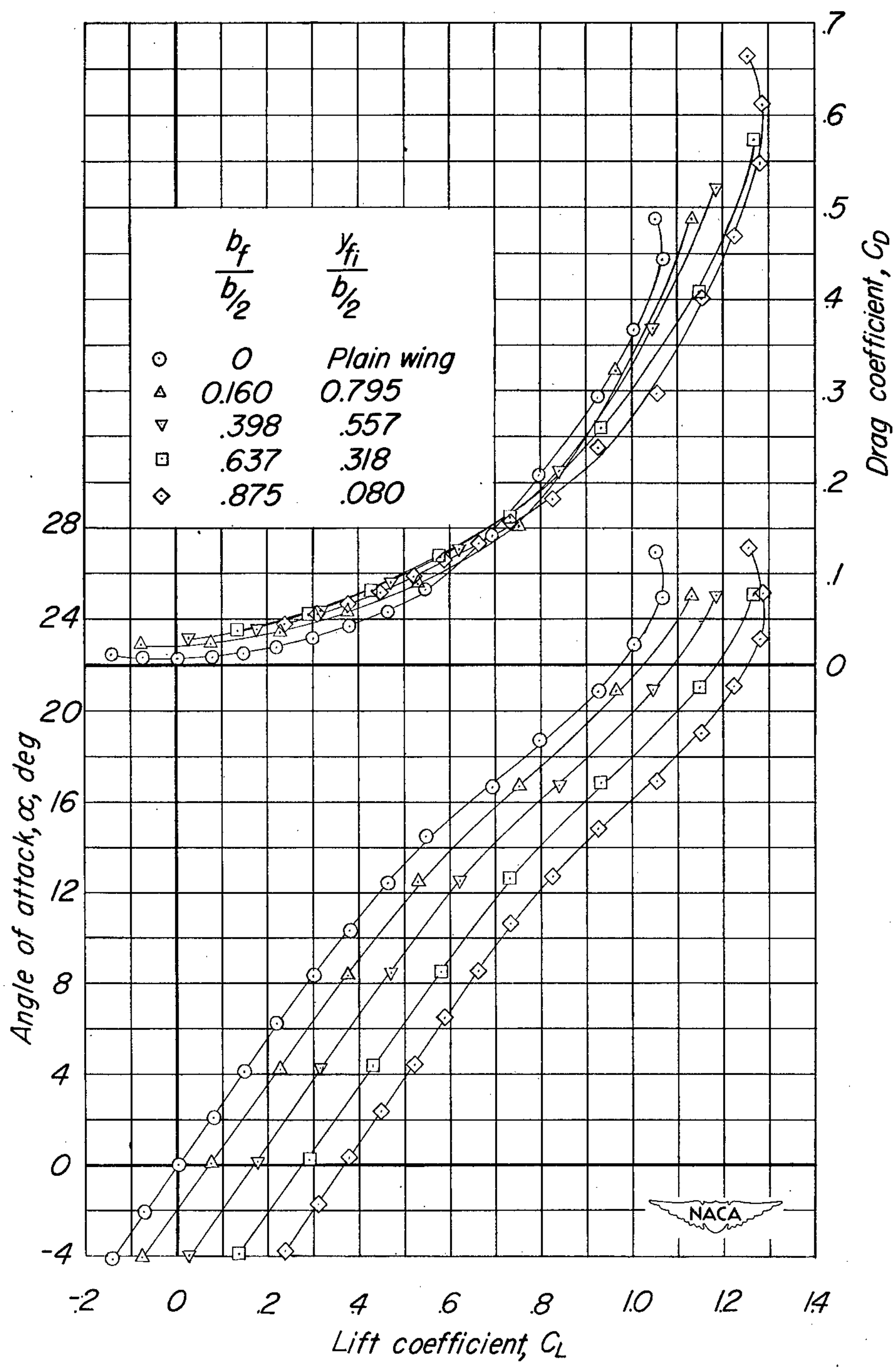

Figure 5.- Effect of the flap span on the aerodynamic characteristics in pitch of the 45° sweptback wing having an aspect ratio of 1.59 and equipped with outboard flaps $\left(y_{f_o} = 0.955\frac{b}{2}\right)$. $\delta_f = 30°$.

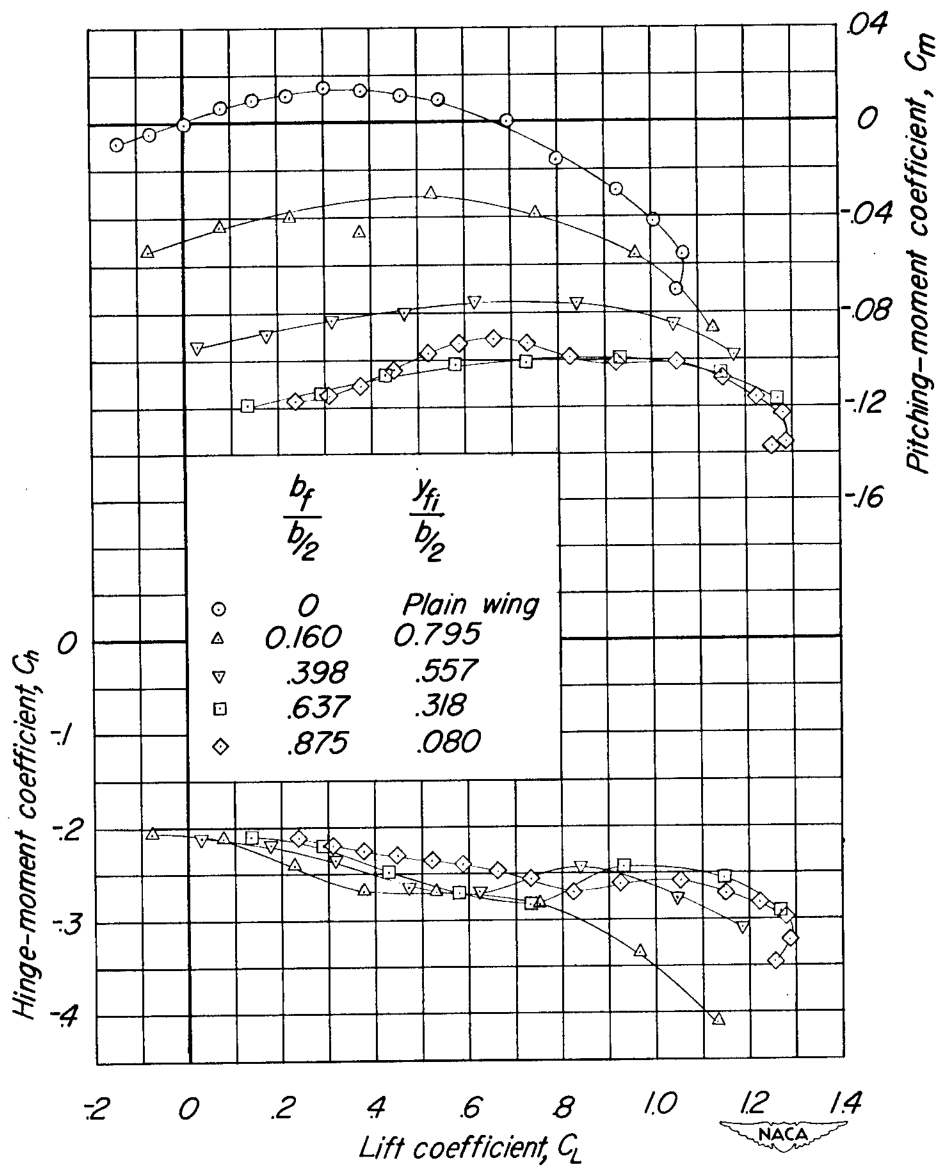

Figure 5.- Concluded.

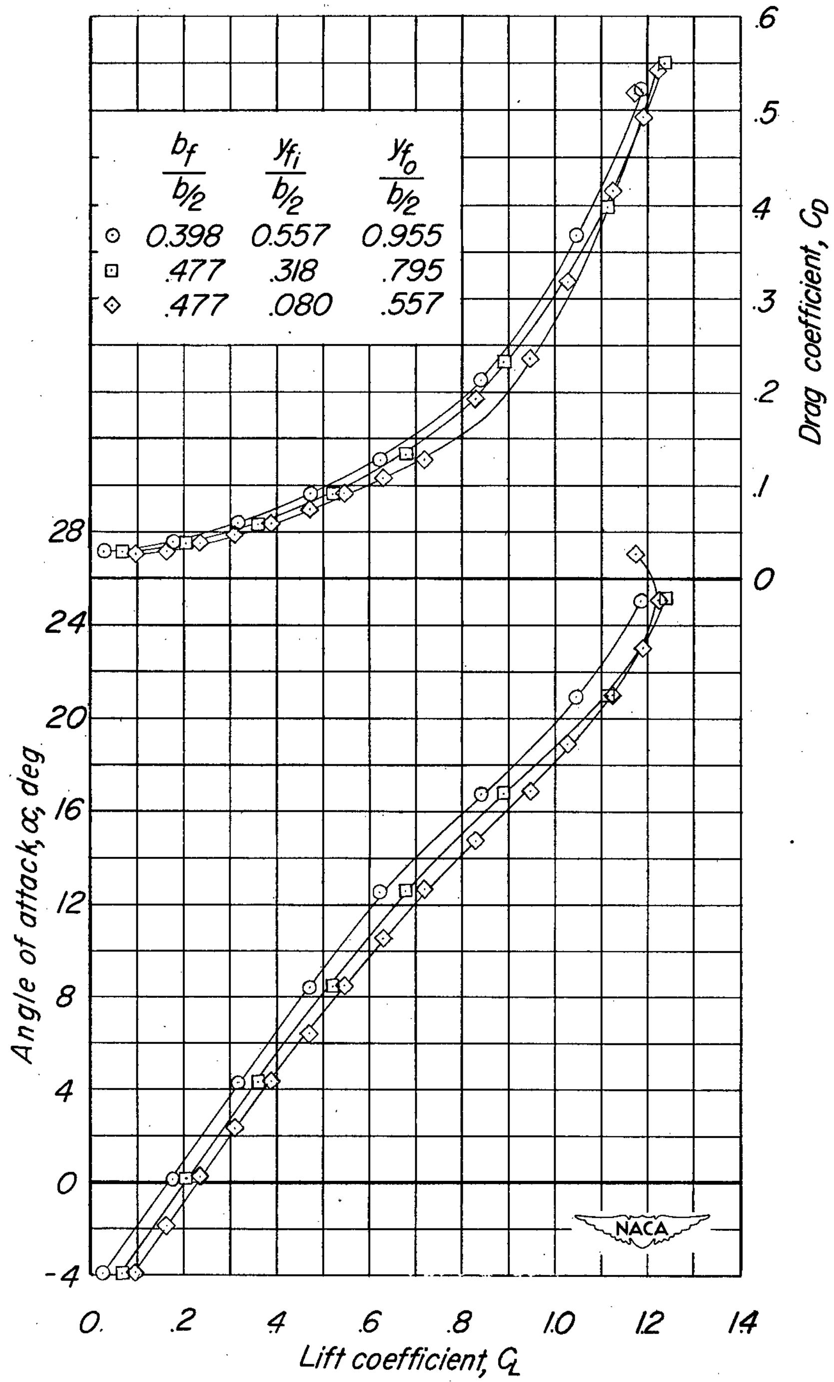

Figure 6.- Effect of spanwise flap location on the aerodynamic characteristics in pitch of the 45° sweptback wing having an aspect ratio of 1.59 and equipped with approximately half-span flaps. $\delta_f = 30°$.

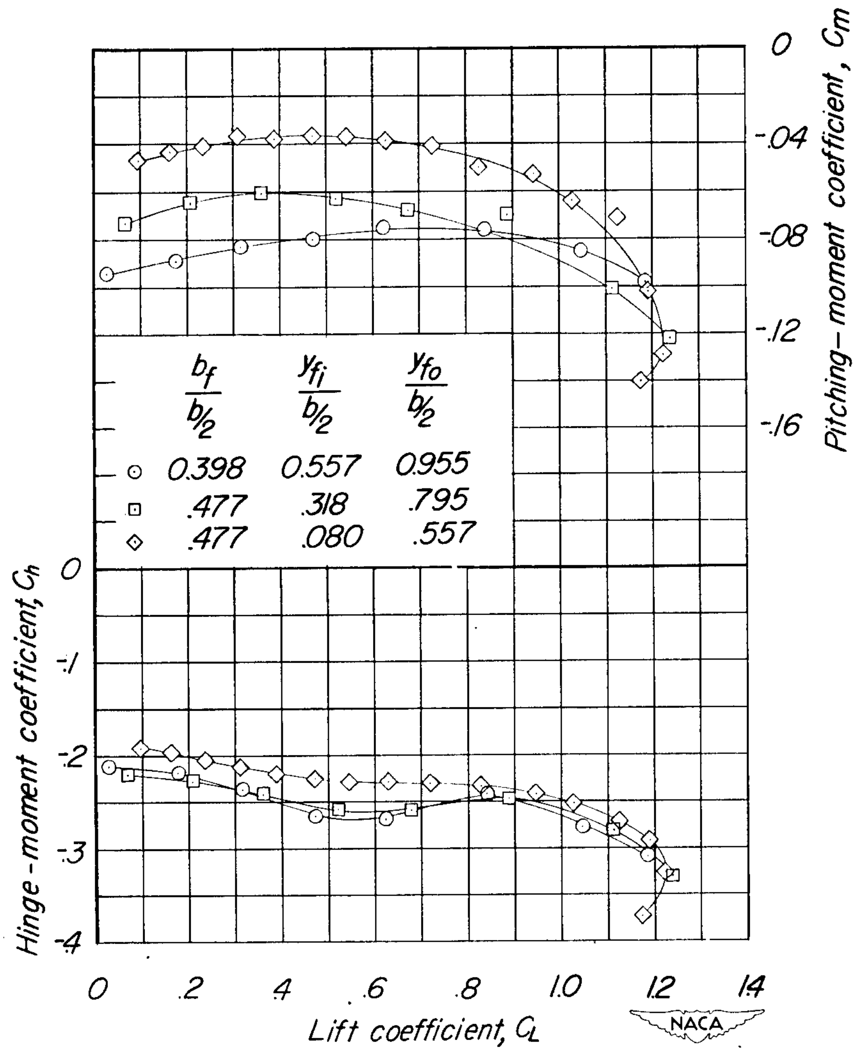

Figure 6.- Concluded.

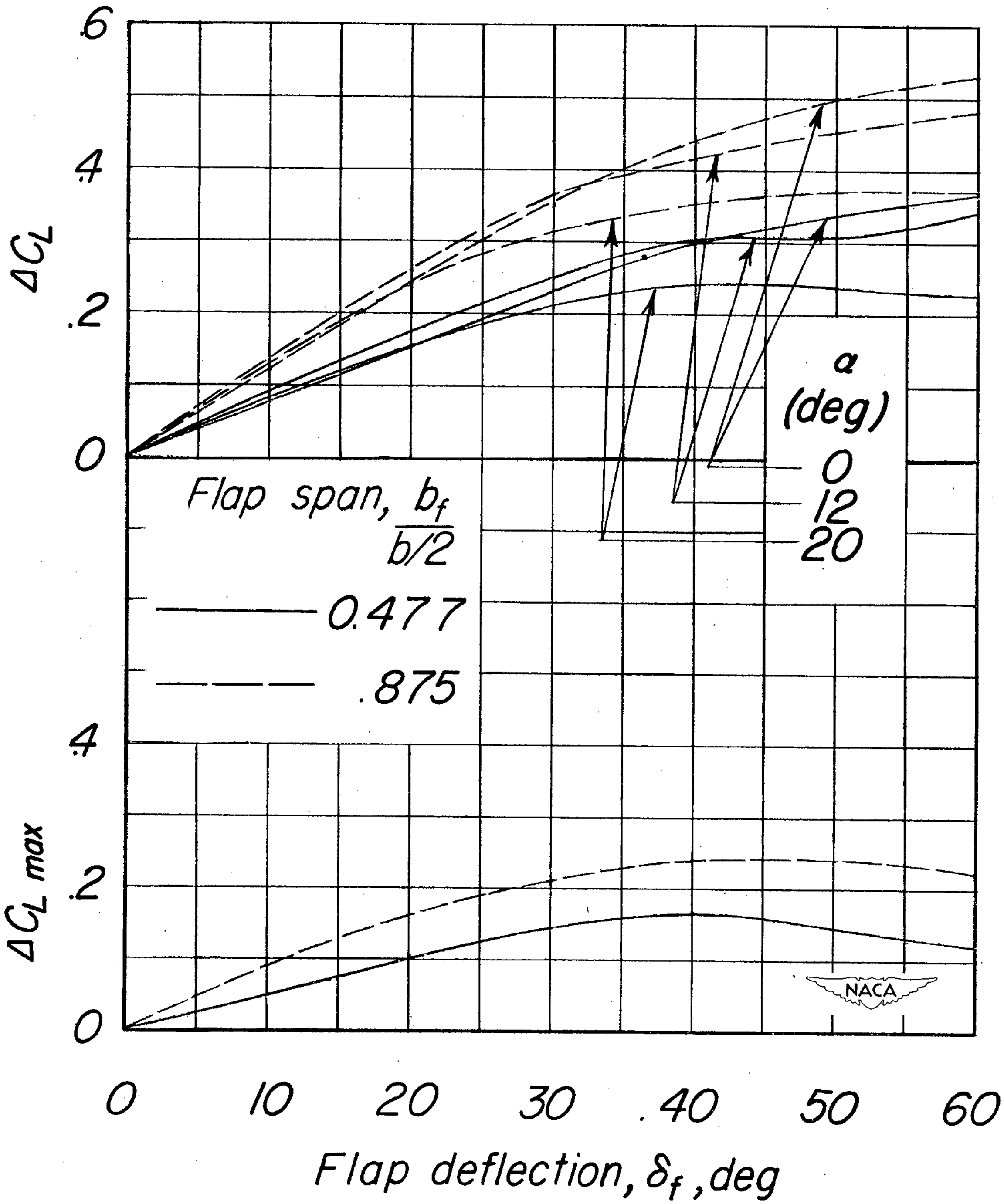

Figure 7.- Variation of the incremental lift coefficient with flap deflection for the 45° sweptback wing having an aspect ratio of 1.59 and equipped with inboard half-span $\left(b_f = 0.477\frac{b}{2};\ y_{f_o} = 0.557\frac{b}{2}\right)$ and full-span $\left(b_f = 0.875\frac{b}{2};\ y_{f_o} = 0.955\frac{b}{2}\right)$ flaps. $y_{f_i} = 0.080\frac{b}{2}$.

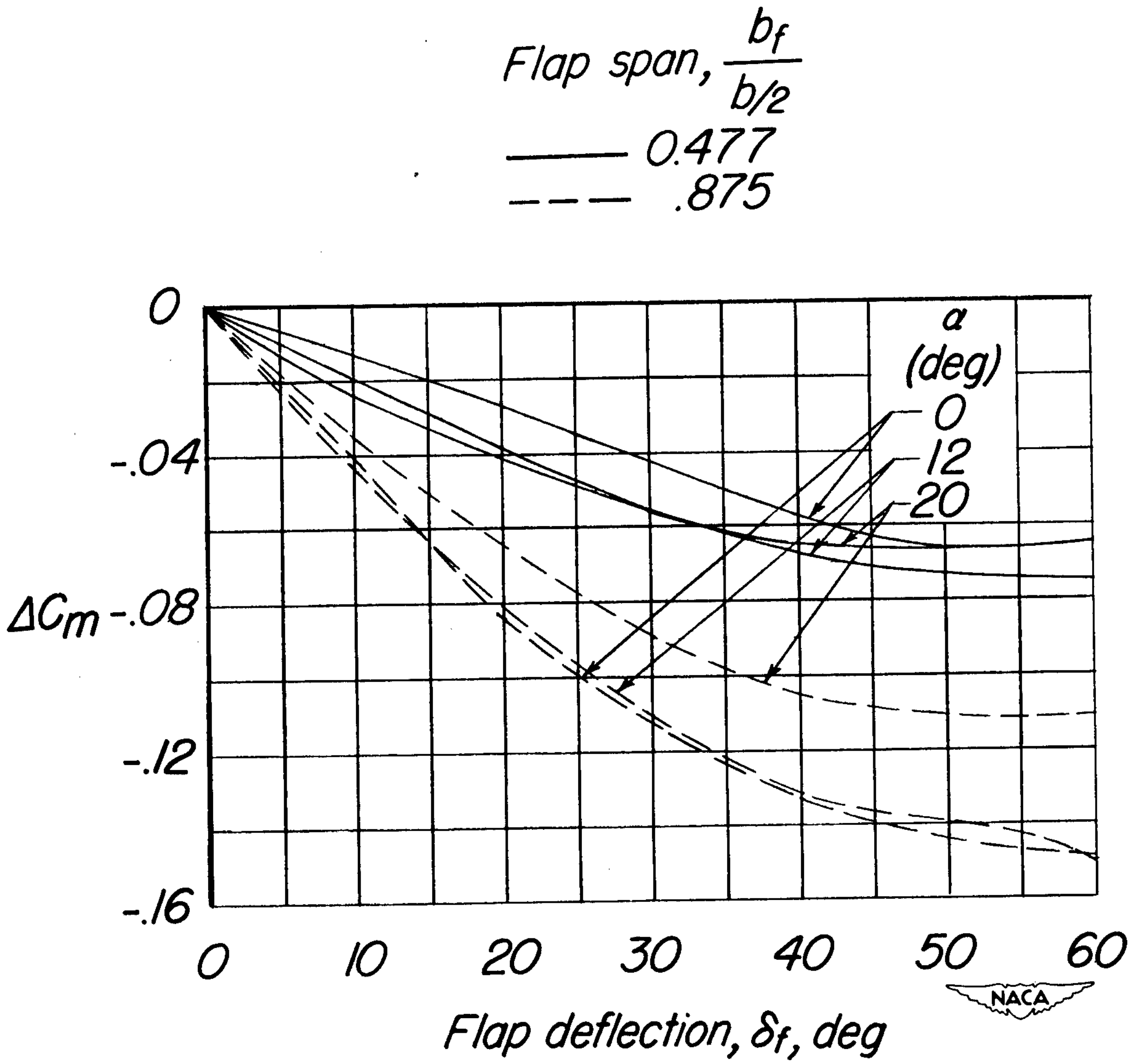

Figure 8.- Variation of the incremental pitching-moment coefficient with flap deflection for the 45° sweptback wing having an aspect ratio of 1.59 and equipped with inboard half-span $\left(b_f = 0.477\frac{b}{2};\ y_{f_o} = 0.557\frac{b}{2}\right)$ and full-span $\left(b_f = 0.875\frac{b}{2};\ y_{f_o} = 0.955\frac{b}{2}\right)$ flaps. $y_{f_i} = 0.080\frac{b}{2}$.

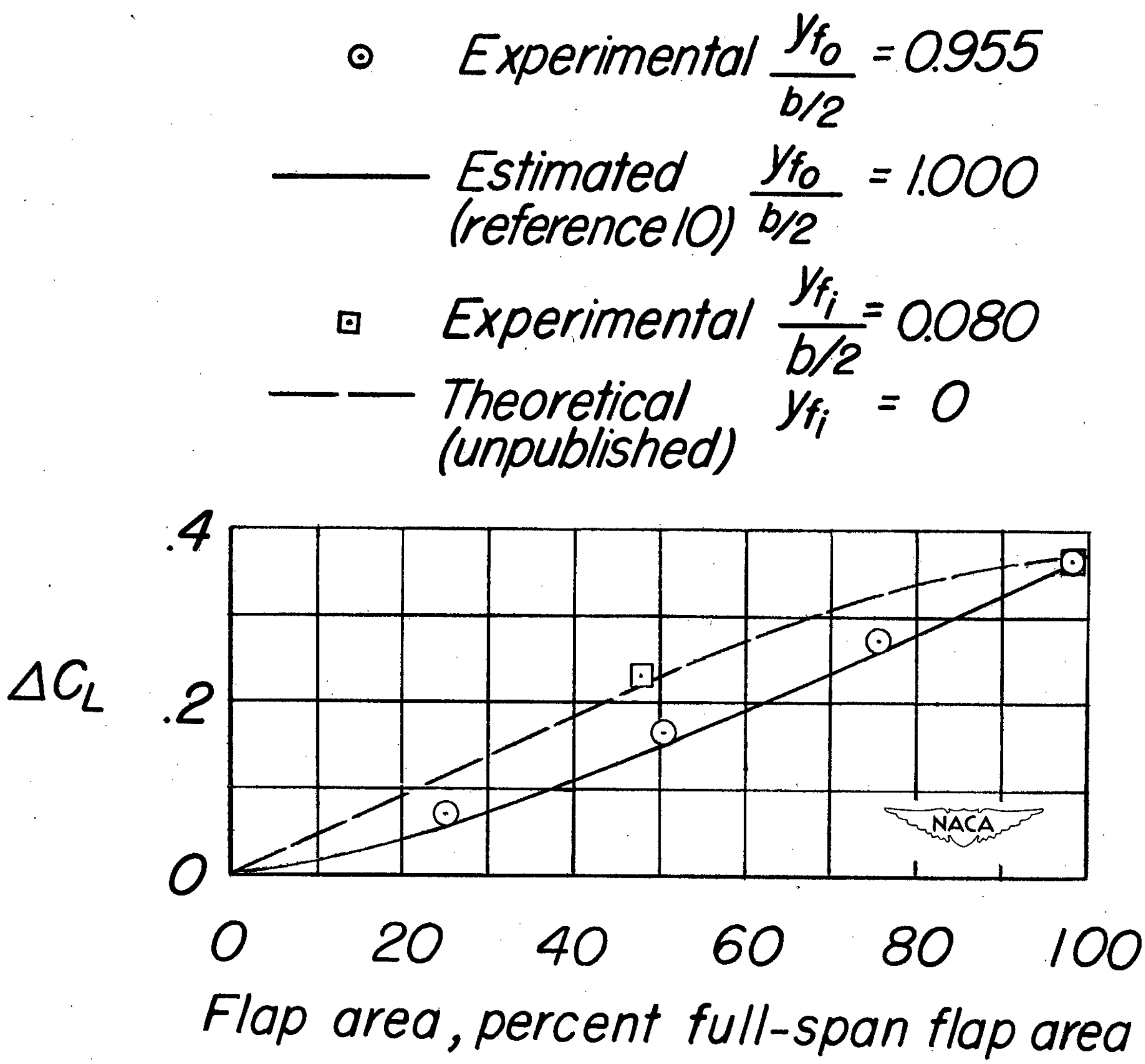

Figure 9.- Effect of flap span (expressed as percent of full-span flap area) and spanwise location on the incremental lift coefficient produced by a flap deflection of 30° of the 45° sweptback wing having an aspect ratio of 1.59. $\alpha = 0°$.

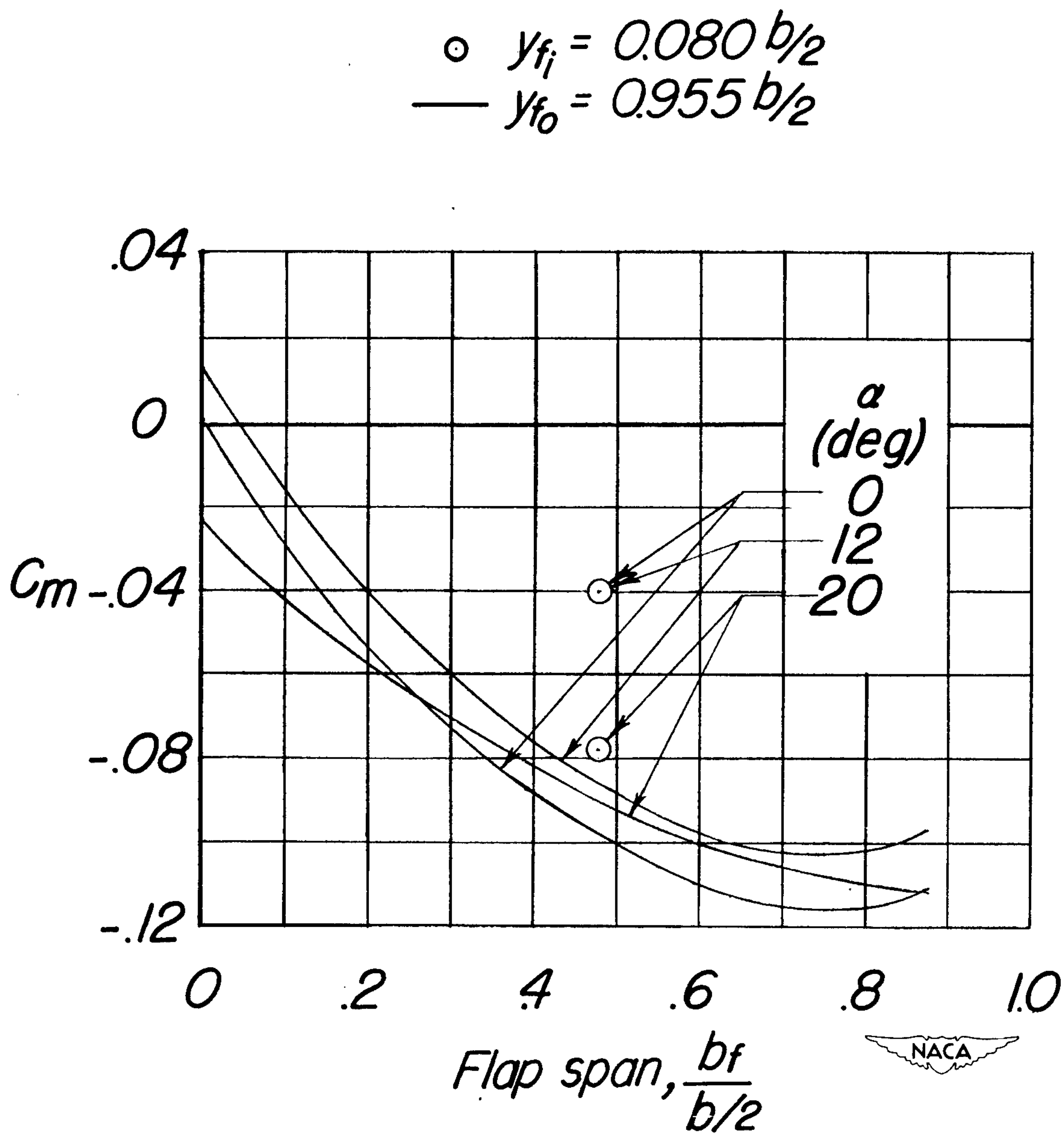

Figure 10.- Effect of flap span and spanwise location on the pitching-moment coefficient of the 45° sweptback wing having an aspect ratio of 1.59. $\delta_f = 30^\circ$.