NACA

RESEARCH MEMORANDUM

EFFECTS OF TWIST AND CAMBER, FENCES, AND HORIZONTAL-TAIL HEIGHT ON THE LOW-SPEED LONGITUDINAL STABILITY CHARACTERISTICS OF A WING-FUSELAGE COMBINATION WITH A 45° SWEPTBACK WING OF ASPECT RATIO 8 AT A REYNOLDS NUMBER OF 4.0×10^6

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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EFFECTS OF TWIST AND CAMBER, FENCES, AND HORIZONTAL-TAIL HEIGHT ON THE LOW-SPEED LONGITUDINAL STABILITY CHARACTERISTICS OF A WING-FUSELAGE COMBINATION WITH A 45° SWEPTBACK WING OF ASPECT RATIO 8 AT A REYNOLDS NUMBER OF 4.0×10^6

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SUMMARY

The separate and combined effects of twist and camber, fences, and horizontal-tail height on the static longitudinal stability of a 45° sweptback wing-fuselage combination of aspect ratio 8 were investigated at a Reynolds number of 4.0×10^6 and a Mach number of 0.19. Two wings were investigated: an untwisted wing which incorporated NACA 63A012 airfoil sections in the stream direction, and a twisted and cambered wing designed to provide an elliptical spanwise loading and uniform chordwise loading at a lift coefficient of 0.7 and a Mach number of 0.9. The twisted and cambered wing had a thickness of 12 percent chord in the stream direction and modified NACA 63-series airfoil sections. The vertical positions at which the horizontal tail was tested ranged from 14 percent wing semispan above to 15 percent wing semispan below the wing root chord extended. The effects of spanwise location of fences and of fence height ranging from 1.8 percent to 7.2 percent of the local wing chord were investigated.

Although the pitching-moment characteristics of a wing of this sweep and aspect ratio exhibit a large destabilizing change in aerodynamic center at a relatively low lift coefficient, the results of the tests indicate that substantial improvements in longitudinal stability can be obtained through the combined effects of twist and camber, a suitable arrangement of fences, and a properly located horizontal tail.

INTRODUCTION

As a part of a broad program to determine the aerodynamic characteristics of swept wings, an investigation has been conducted in the

Langley 19-foot pressure tunnel to study the effects of twist and camber on the low-speed longitudinal characteristics of a 45° sweptback wing of aspect ratio 8. Two wings, similar except for twist and camber, were tested. One wing had symmetrical airfoil sections streamwise and no twist, whereas the other wing had amounts of twist and camber to provide elliptical spanwise loading and uniform chordwise loading at a lift coefficient of 0.7 and a Mach number of 0.9. The results of force and pressure-distribution measurements for the wing-alone configuration are presented in references 1 to 4. The data indicate that the twist and camber improved the longitudinal stability characteristics of the wing up to a moderate lift coefficient, altered the stalling characteristics, and increased the maximum lift coefficient by 0.3.

Inasmuch as the changes in span loading and wing stalling characteristics effected by the twist and camber will alter the downwash field behind the wing, it is of interest to know whether the amounts of twist and camber dictated by high-speed loading considerations would aid in providing the airplane configuration with favorable longitudinal stability characteristics and thereby minimize the need of stall-control devices. Reference 5 indicates that in order to obtain favorable pitching-moment characteristics of the untwisted and uncambered wing in combination with a fuselage and horizontal tail, it was necessary that the tail be located in a favorable downwash field and that the wing be equipped with fences and leading-edge flaps.

In order to indicate the effects of twist and camber on the longitudinal stability characteristics of an airplane configuration, some of the more pertinent results obtained with the two wings in combination with a fuselage and a horizontal tail are presented herein. These results show the separate and combined effects of twist and camber, fences, and horizontal-tail height on the longitudinal stability characteristics of a 45° sweptback wing of aspect ratio 8 in combination with a fuselage. Some data obtained with the extended split flaps installed on the wing are also presented. The data presented herein were obtained at a Reynolds number of 4.0×10^6 and a Mach number of 0.19.

SYMBOLS

C_L lift coefficient, $\frac{\text{Lift}}{qS}$

$C_{L_{max}}$ maximum lift coefficient

C_m pitching-moment coefficient about $0.25\bar{c}$ of the flat wing and a point 9.34 percent $\bar{c}$ above $0.25\bar{c}$ of the twisted cambered wing, $\frac{\text{Moment}}{qS\bar{c}}$

τ horizontal-tail effectiveness parameter, $\left(\frac{dC_{m_t}}{d\alpha}\right)\left(\frac{1}{\frac{S_t}{S}\frac{l}{\bar{c}}C_{L_{\alpha_t}}}\right)$ (ref. 6)

$C_{L_{\alpha_t}}$ lift-curve slope of isolated horizontal tail, 0.055 per deg

q free-stream dynamic pressure, lb/sq ft

$\bar{c}$ mean aerodynamic chord, $\frac{2}{S}\int_0^{b/2} c^2 dy$, ft

S wing area, sq ft

S_t horizontal-tail area, sq ft

c local chord, ft

l horizontal-tail length; distance from $0.25\bar{c}$ of wing to $0.25\bar{c}$ of horizontal tail, ft

y lateral coordinate with respect to plane of symmetry, ft

b wing span, ft

α angle of attack of wing root chord, deg

i_t angle of incidence of horizontal tail measured with respect to wing-root chord, positive when trailing edge moves down, deg

i_w wing incidence angle referred to fuselage center line, deg

δ_f trailing-edge flap deflection, measured in a plane parallel with the plane of symmetry, deg

z_t vertical position of horizontal tail relative to wing-root-chord plane, positive up

$\frac{dC_{m_t}}{d\alpha}$ rate of change of pitching-moment coefficient due to horizontal tail with angle of attack

$\frac{dC_m}{d\alpha}$ rate of change of pitching-moment coefficient with angle of attack

$\frac{d\epsilon}{d\alpha}$ rate of change of downwash angle with angle of attack

$\frac{dC_m}{dC_L}$ rate of change of pitching-moment coefficient with lift coefficient

MODEL

Two wing-fuselage configurations, differing only in wing twist and camber, were tested with and without a horizontal tail. Each wing had sweepback of 45° along the quarter-chord line, an aspect ratio of 8, and taper ratio of 0.45. One wing had NACA 63_1A012 airfoil sections parallel with the plane of symmetry and was untwisted. For convenience, this wing is referred to herein as the "flat wing." The other wing had amounts of twist and camber calculated by method of reference 7 to provide an elliptical spanwise loading and a uniform chordwise loading at a lift coefficient of 0.7 and a Mach number of 0.9. The airfoil sections of the twisted and cambered wing parallel to the plane of symmetry were of the NACA 63_1A012 thickness distribution distributed about a slightly modified NACA $a = 1.0$ mean line having the desired design section lift coefficient. Equations which define the shape of the mean camber line are presented in reference 4. Dimensions and details of both models are given in figure 1. The spanwise variation of geometric twist and design section lift coefficient of the twisted and cambered wing are presented in figure 2.

The fences employed were constructed of $\frac{1}{16}$-inch sheet steel and were attached perpendicularly to the upper surface of the wing at the spanwise locations indicated in figure 1(b). The heights of the fences were varied from 0.072c to 0.018c.

The extended split flaps in the undeflected position had a chord equal to 20 percent of the local wing chord and were deflected 23.3° from the lower surface of the wing parallel to the plane of symmetry. The flaps extended outboard from the wing-fuselage junction to 0.50b/2.

The wing was attached to a fuselage of circular cross section and fineness ratio 10 in a position midway between the center line and upper surface of the fuselage (fig. 1(a)). Provisions were made so that the wing could be set at 0° or 4° incidence with respect to the fuselage center line.

The horizontal tail had 45° sweepback along the quarter-chord line, an aspect ratio of 4, a taper ratio of 0.45, and NACA 63A012 airfoil sections parallel to the plane of symmetry (fig. 1). The tail was attached to the fuselage by means of a steel strut.

TESTS AND CORRECTIONS

The tests were conducted in the Langley 19-foot pressure tunnel with the air compressed to approximately 33 pounds per square inch absolute. Figure 3 shows a rear view of the twisted and cambered model and the manner in which the models were mounted in the tunnel. Measurements of lift and pitching moment were made at a Reynolds number of 4.0×10^6 and a Mach number of 0.19 through an angle-of-attack range from -4° to 31°. The horizontal tail was tested at various vertical positions ranging from 0.14b/2 above to 0.15b/2 below the wing-root-chord plane. The fences used in most of the tests were of 0.072c height; however, in some cases the fence height was reduced to as low as 0.018c. The effects of small variation of spanwise location of some fences were also investigated.

The data presented have been corrected for air-stream misalinement, support tare and interference effects, and jet-boundary effects. The jet-boundary corrections were determined by the method of reference 8.

RESULTS AND DISCUSSION

The data showing the effects of the twist and camber on the longitudinal characteristics of the wing-fuselage configuration and on the span loading of the wing-alone configuration are presented in figures 4 and 5, respectively. The effect of horizontal-tail height on the longitudinal characteristics of the wing-fuselage configuration with and without twist and camber is presented in figures 6 and 7. The effects of upper-surface fences on the longitudinal characteristics of the wing-fuselage configuration in combination with a horizontal tail are shown by the data presented in figures 8 to 11. The results presented in figures 12 to 14 show the effects of extended trailing-edge flaps, fence location, and fence height on the longitudinal stability of the twisted and cambered wing in combination with a fuselage and a horizontal tail.

Wing-Fuselage Configuration

Flat wing.- The flat wing exhibited a large unstable variation of pitching-moment coefficient with lift coefficient through the lift-coefficient range which was accompanied by a gradual decrease in the lift-curve slope (fig. 4). Pressure-distribution data presented in reference 1 indicate that the unstable change in the stability characteristics and the decrease in the lift-curve slope results primarily from a loss of lift over the outboard sections of the wing due to trailing-edge separation.

Twisted and cambered wing.- The twist and camber altered the stall characteristics of the wing so that separation began at the midsemispan of the wing and spread outboard and forward. Thus, the loss of lift over the outboard sections was delayed (ref. 4) and as a result the longitudinal stability was improved up to a moderate lift coefficient (fig. 4). The variation of dC_m/dC_L of the twisted and cambered wing, contrary to that of the flat wing, is fairly constant up to a lift coefficient of 0.7. At a lift coefficient greater than 0.7 the twisted and cambered wing was severely unstable. The effect of the twist and camber on the span loading of the wing-alone configuration can be seen from the results presented in figure 5.

Wing-Fuselage Configuration With Horizontal Tail

Plain wing.- As shown by the pitching-moment characteristics of figure 6, a horizontal tail located at various vertical positions ranging from 15 percent semispan below to 14 percent semispan above the wing-root chord extended did not appreciably improve the stability in the high-lift range of either the flat or the twisted and cambered wing configurations. This result does not necessarily mean that the tail is ineffective in the high-lift range regardless of vertical position, but rather that the high degree of instability of the wing-fuselage configuration masks the stabilizing effect contributed by the horizontal tail. In order to show more clearly the stabilizing effect of the tail located at various vertical positions, variations of tail effectiveness parameter τ with angle of attack are presented in figure 7. The change of tail incidence noted herein have a negligible effect on the values of τ. It should be pointed out that, inasmuch as tail height is referred to the wing-root-chord plane of both the flat and the twisted and cambered wing configurations, the tail positions of the twisted and cambered configuration would be on a more comparable basis with those of the flat wing configuration if referred to the wing chord extended at a spanwise station corresponding to that of the mean aerodynamic chord of the tail. On that basis the values of the tail height of the twisted and cambered configuration would be approximately 0.03b/2 less than the values given.

References 6 and 9 indicated that the high values of $\frac{d\epsilon}{d\alpha}$ that exist immediately above the wake center, and the low values of $\frac{d\epsilon}{d\alpha}$ that exist immediately below the wake center are reflected in the tail effectiveness characteristics. The influence of tail height on the effectiveness of the tail in combination with the flat wing configuration agree with results of references 6 and 9 in that the tail was most effective through the moderate and high angle-of-attack range when located 0.06b/2 below the wing root chord extended; with the tail above the wing chord plane, the effectiveness was decreased, and the 0.14b/2 tail became ineffective at high angles of attack. For the twisted and cambered configuration the effect of tail height on tail effectiveness does not appear to agree with results of references 6 and 9 in that the tail was effective throughout the angle-of-attack range for positions ranging from 0.15b/2 below to 0.14b/2 above the wing-root chord extended. The increase in tail effectiveness with twist and camber is attributed partly to the effects of a vertical displacement of the wake associated with twist and partly to the change in the downwash characteristics due to the effect of the twist and camber on the span loading of the wing. Although the tail was effective throughout the angle-of-attack range for all vertical positions investigated, the effectiveness of the tail at $z_t = -0.06b/2$ was selected as optimum. At moderate angles of attack the tail at $z_t = 0.14b/2$ exhibited a slight decrease in effectiveness, which is associated with unfavorable downwash characteristics above the wake.

Effect of fences.- On the basis of references 2 and 4 a combination of fences located at 0.575b/2 and 0.80b/2 was selected as representative of an effective fence arrangement. The fences delayed flow separation which occurred along the trailing edge of the outboard sections of the flat wing (ref. 1) so that with the tail at $z_t = -0.06b/2$ the stability was considerably improved in the lift-coefficient range below approximately 1.0 (fig. 8(a)); however, at lift coefficients greater than 1.0 a large positive change in $\frac{dC_m}{dC_L}$ (fig. 8(c)) occurred with or without fences. Fences also improved the pitching-moment characteristics of the twisted and cambered wing for this tail location (fig. 8(d)), so that the large positive value of $\frac{dC_m}{dC_L}$ (0.47) which occurred over the lift-coefficient range from 0.85 to 1.05 was reduced to -0.08 by the addition of fences. Even with the fences, however, the change of static margin through the lift range as indicated by $\Delta\frac{dC_m}{dC_L}$ (approx. 0.12) may be considered as undesirable. It is of interest to note that the effectiveness of the tail at $z_t = -0.06b/2$ was not appreciably affected by fences (fig. 9).

In order to emphasize the effect of tail location on the stability, data obtained with the tail located 0.06b/2 below and 0.14b/2 above the wing root chord plane of the twisted and cambered wing are presented in figure 10. Due to the lower relative effectiveness of the tail at $z_t = 0.14b/2$ (fig. 11) the change of static margin in the lift range up to almost $C_{L_{max}}$ as indicated by $\frac{dC_m}{dC_L}$ (fig. 10(b)) was approximately twice that indicated with the tail at $z_t = -0.06b/2$.

Effects of fences and flaps.- The results presented in figure 12(a) and 12(b) indicate that the longitudinal stability characteristics of the twisted and cambered configuration with fences were better with trailing-edge flaps off than with the trailing-edge flaps deflected. With the trailing-edge flaps deflected, the change of static margin $\left(\Delta \frac{dC_m}{dC_L} = 0.22\right)$ through the lift range was approximately twice that indicated for the configuration with flaps off $\left(\Delta \frac{dC_m}{dC_L} = 0.12\right)$. In the case of the wing alone (ref. 4), flaps had but small effect on the stability characteristics of the configuration with either fences on or fences off. Hence the effect of flaps in decreasing the stability characteristics of the model airplane configuration is attributed to the influence of the flaps in depressing the wake and thereby reducing the effectiveness of the tail at $z_t = -0.06b/2$.

Location and height of fences.- The effects on the longitudinal stability characteristics of the twisted and cambered configuration with trailing-edge flaps deflected, resulting either from small variations in the spanwise location of the inboard fence or from decreasing the height of the fences, are presented in figures 13 and 14. Comparison of these data with data obtained with the twisted and cambered configuration without fences and flaps (fig. 6) indicates that large improvements in stability were provided with fences irrespective of either 0.05b/2 changes of inboard fence location or a decrease of fence height from 0.072c to 0.018c. Although the effects of these changes are somewhat obscured by the instability present with the extended trailing-edge flaps installed, the curves of $\frac{dC_m}{dC_L}$ (figs. 13 and 14) indicate that either a 0.05b/2 spanwise change from the 0.575b/2 location of the fence or a decrease of fence height from 0.072c to 0.018c had an adverse effect on the stability in the lift-coefficient range beyond approximately 0.9. The change of static margin of the configuration with the tail located at $z_t = -0.06b/2$, flaps deflected, and fences located at 0.575b/2 and 0.80b/2 was approximately 0.22; whereas, with either a 0.05b/2 spanwise change of location or a decrease in height from 0.072c to 0.036c of the inboard fence, the change of static margin through the lift range was increased approximately 0.04. When the height of the fences located at 0.575b/2 and 0.80b/2 was reduced to 0.018c the change of static margin through the lift range was increased approximately 0.07.

CONCLUDING REMARKS

The results of tests to determine the separate and combined effects of twist and camber, fences, and horizontal-tail height, on the static longitudinal stability of a 45° sweptback wing-fuselage combination of aspect ratio 8 indicate that:

1. A substantial improvement in the longitudinal stability characteristics of a complete airplane configuration having a wing of the plan form investigated can be obtained by the combined effects of twist and camber, a suitable arrangement of fences, and a properly located horizontal tail.

2. The change of static margin through the lift range of the twisted and cambered wing-fuselage configuration with fences located at 0.575b/2 and 0.80b/2 and a horizontal tail located 0.06b/2 below the wing root chord plane was approximately 0.12 with trailing-edge flaps off and approximately twice as much with trailing-edge flaps on. The effect of flaps in decreasing the stability is attributed to the influence of flaps in depressing the wake thereby resulting in a reduction in the effectiveness of the -0.06b/2 tail.

3. Either a 0.05b/2 spanwise change from the 0.575b/2 location or a decrease in height from 0.072c to 0.036c of the inboard fence, produced an increase of approximately 0.04 in the change of the value of static margin through the lift range of the configuration with flaps deflected.

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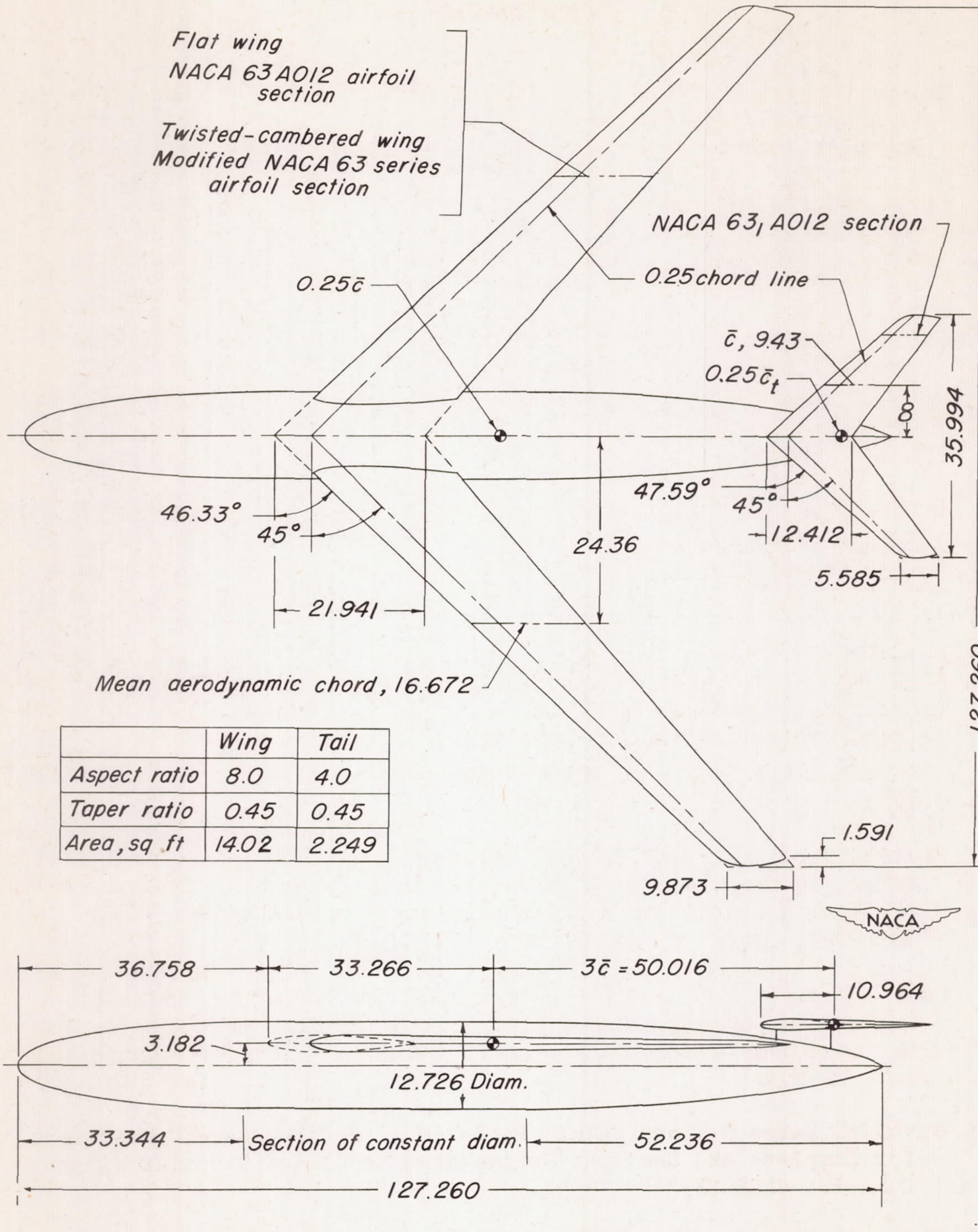
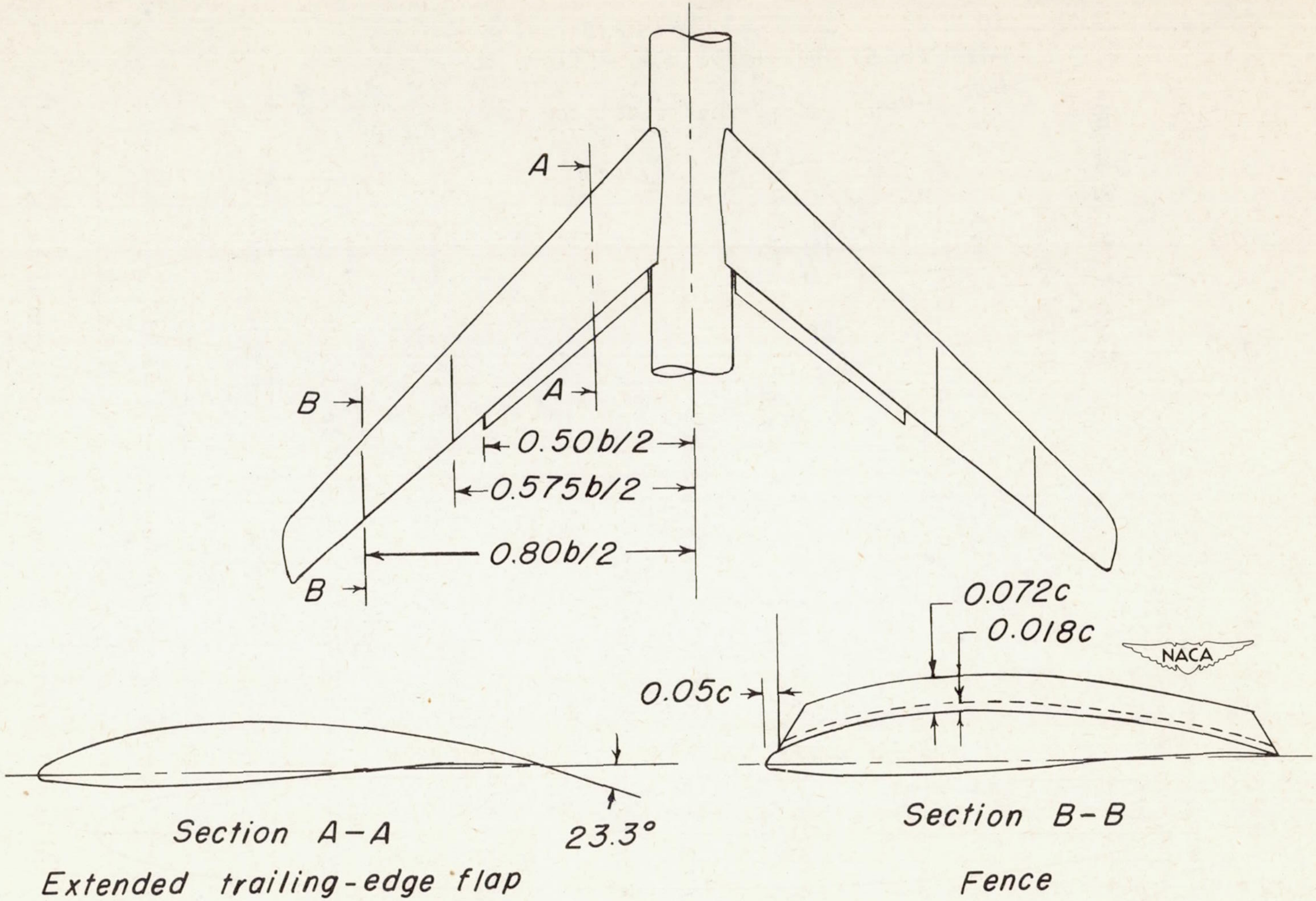


	Wing	Tail
Aspect ratio	8.0	4.0
Taper ratio	0.45	0.45
Area, sq ft	14.02	2.249

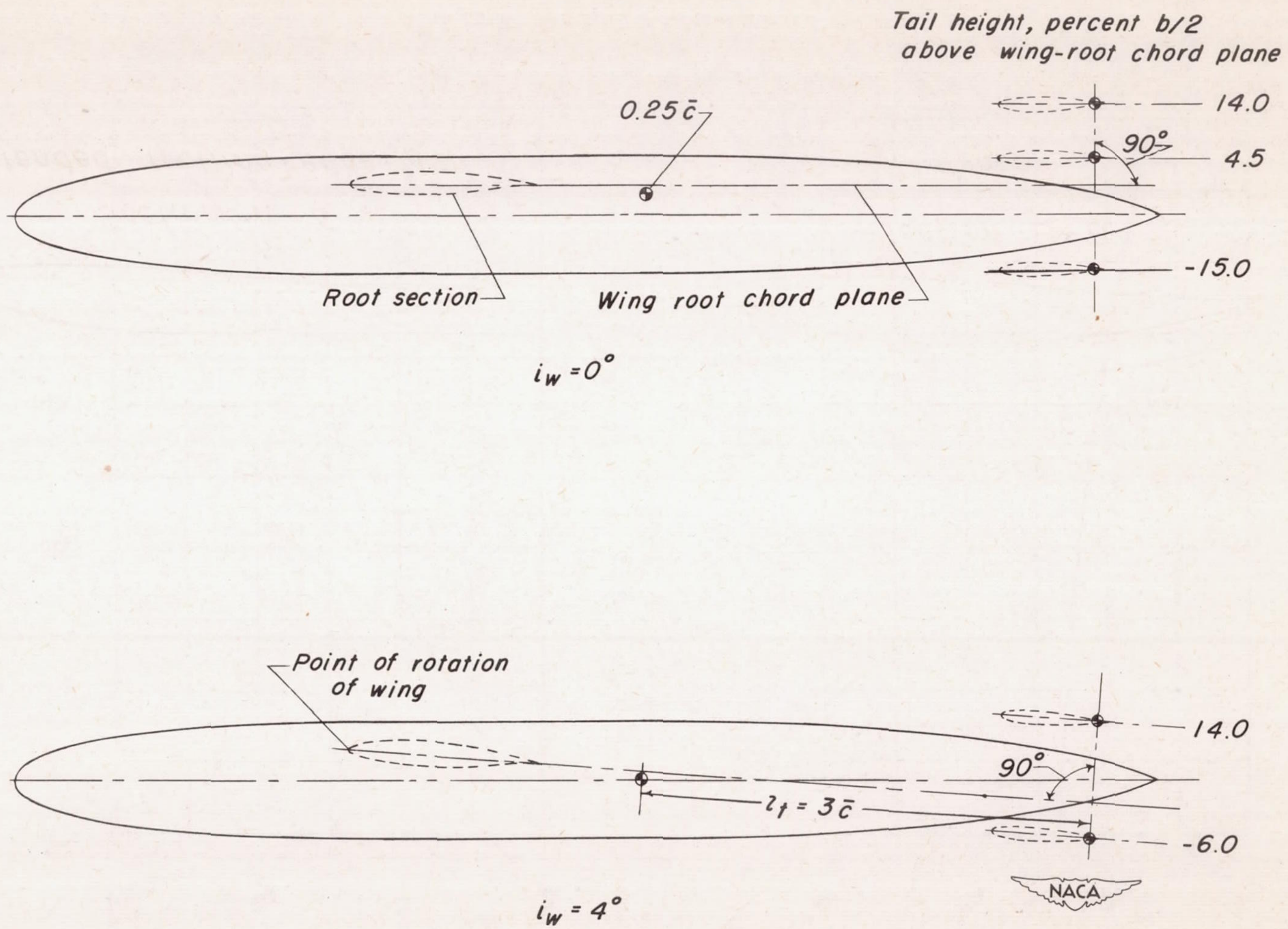
(a) Geometry of wing, fuselage, and horizontal tail.

Figure 1.- Model details. (All dimensions in inches except where noted.)



(b) Details of fences and flaps.

Figure 1.- Continued.



(c) Horizontal tail location.

Figure 1.- Concluded.

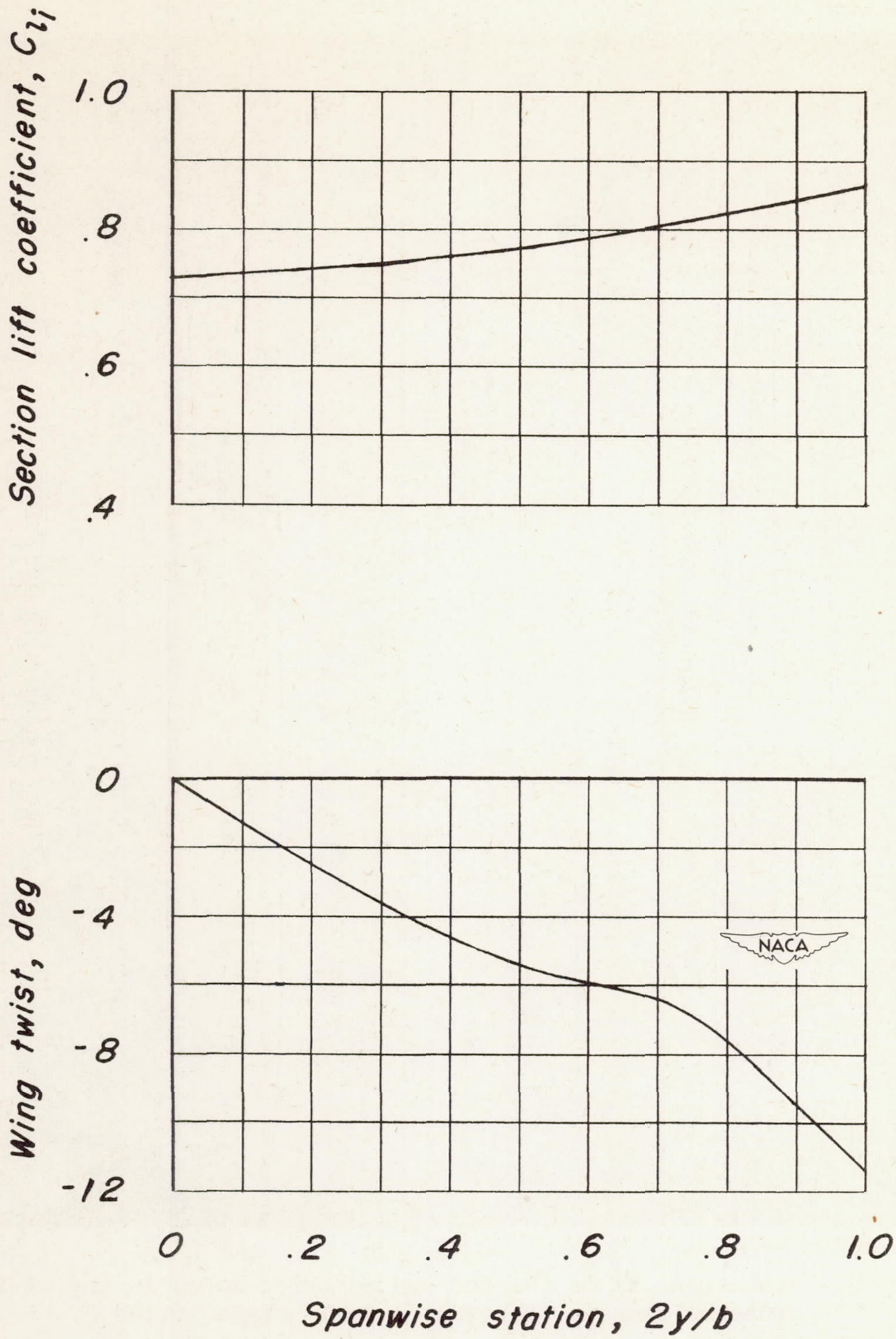


Figure 2.- Spanwise variation of wing twist and distribution of section lift coefficient of the twisted and cambered wing.

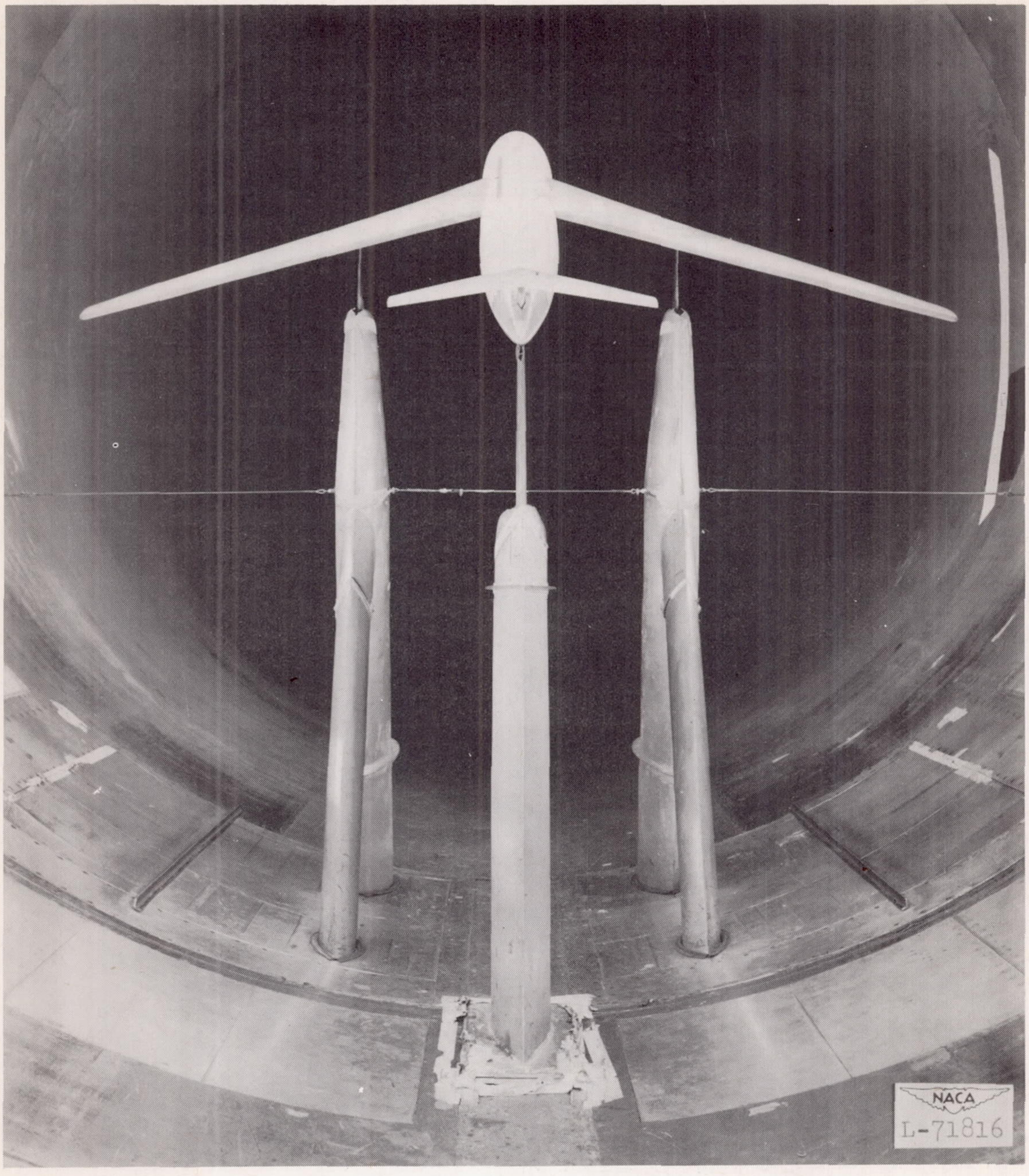


Figure 3.- Rear view of the twisted and cambered model in the 19-foot pressure tunnel. Horizontal-tail height, 0.14b/2.

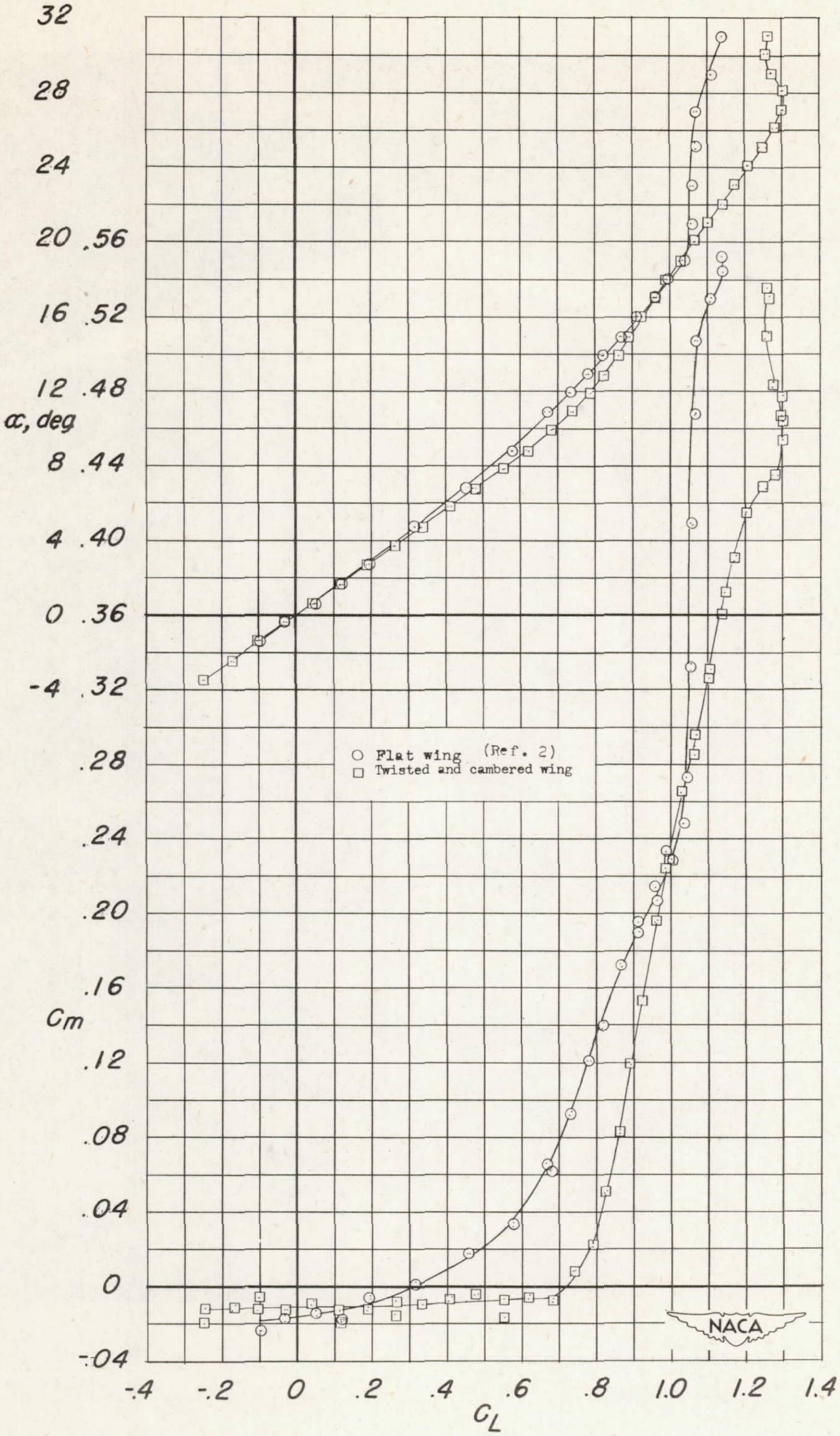


Figure 4.- Lift and pitching-moment characteristics of a swept-wing—fuselage configuration with and without twist and camber. $i_w = 0^{\circ}$.

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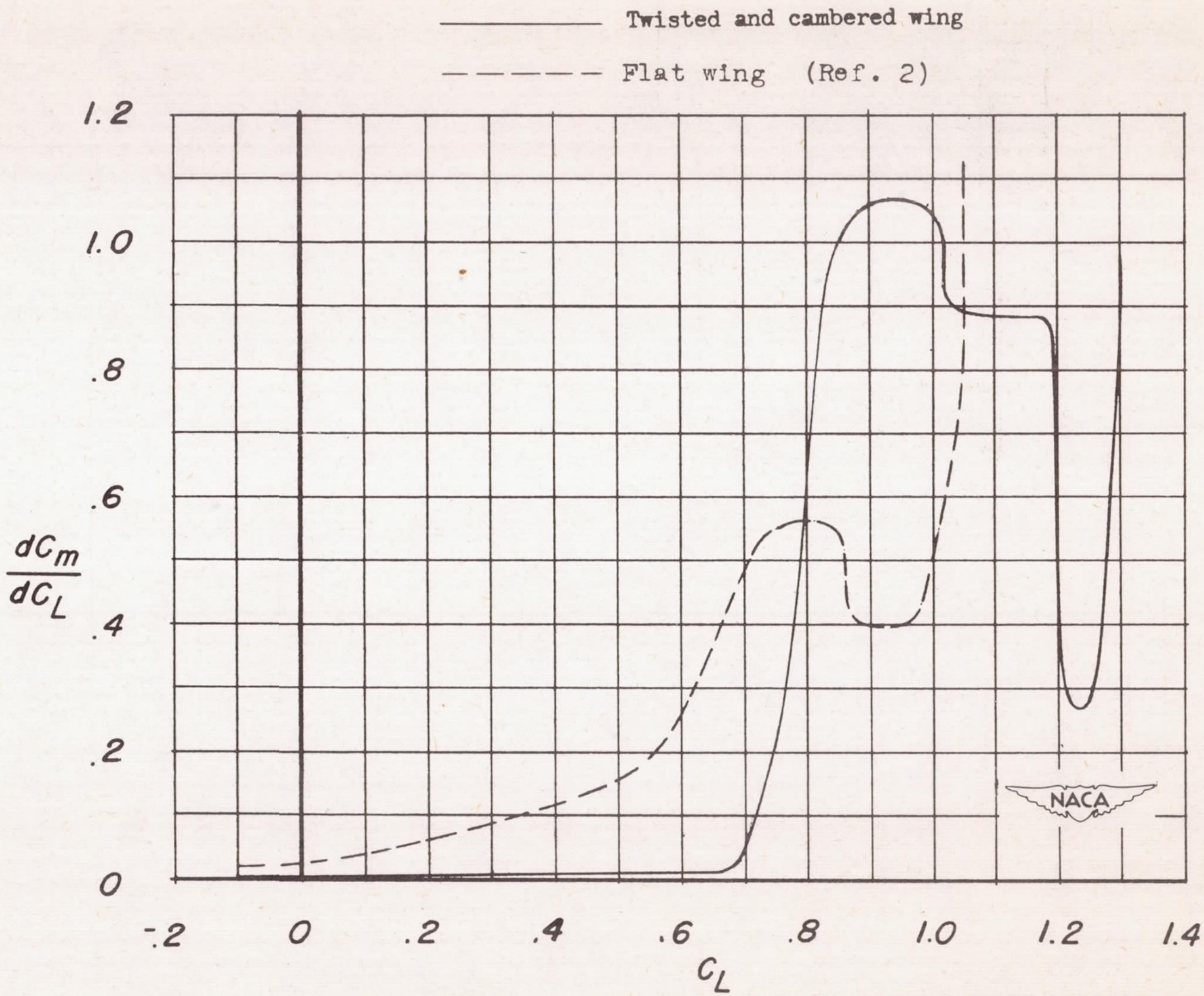

Figure 4.- Concluded.

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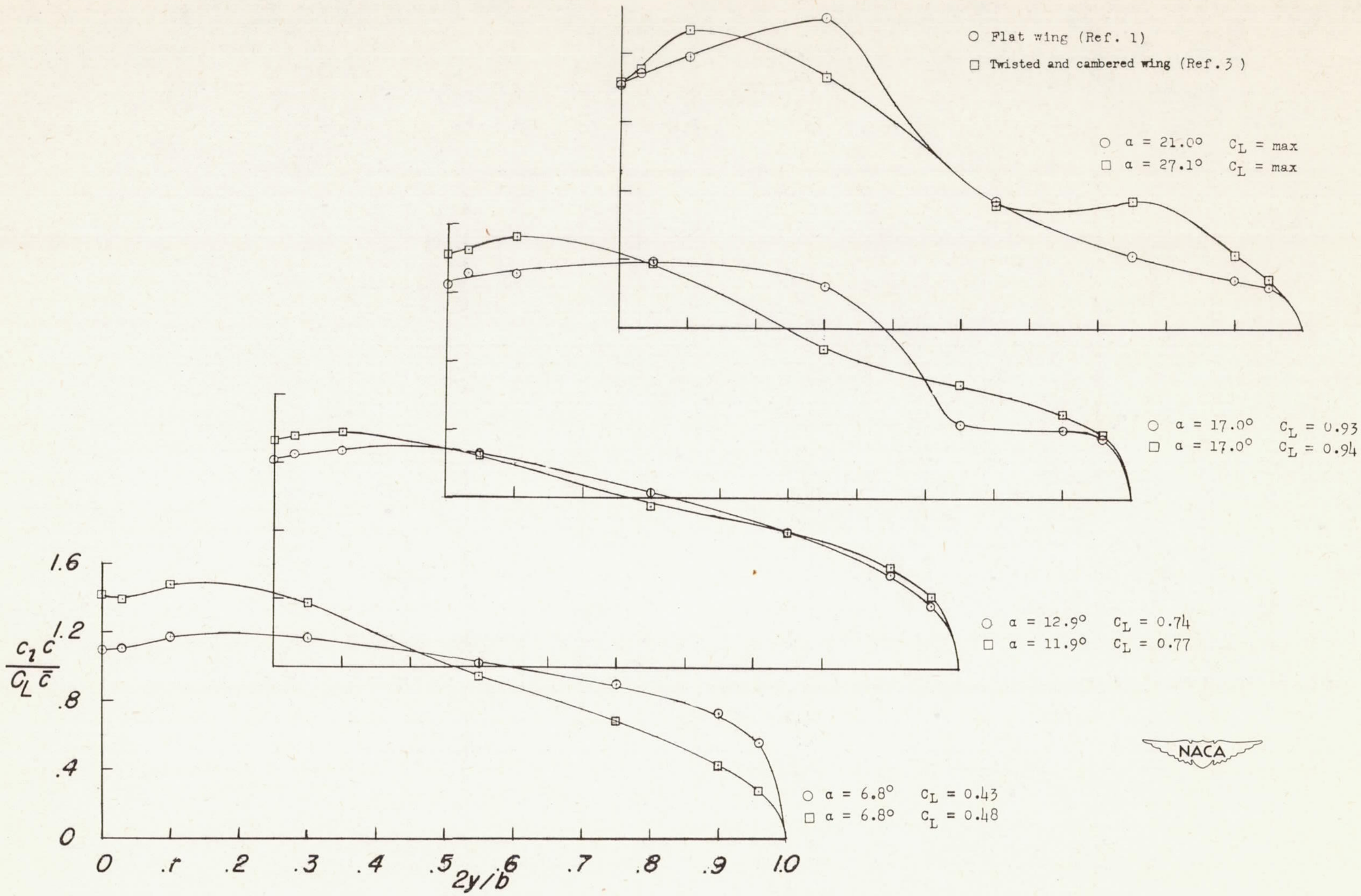

Figure 5.- Effect of twist and camber on the spanwise loading characteristics of a 45° sweptback wing of aspect ratio 8.

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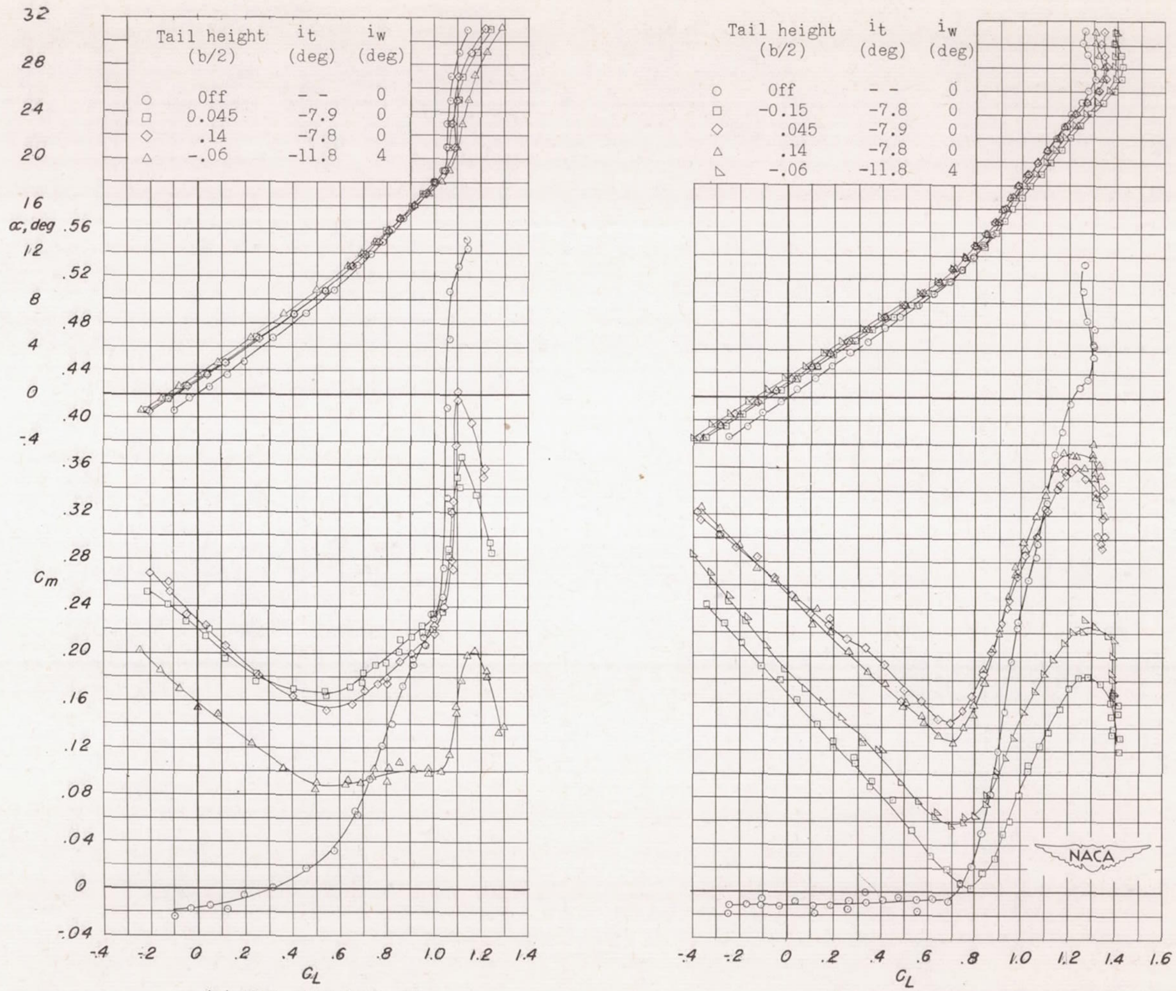

(a) Flat wing (ref. 5).

(b) Twisted and cambered wing.

Figure 6.- Effect of a horizontal tail located at various vertical positions on the lift and pitching-moment characteristics of swept-wing—fuselage configuration.

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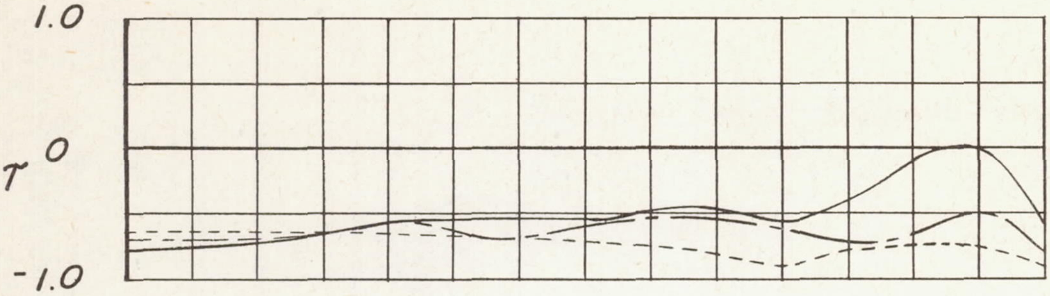
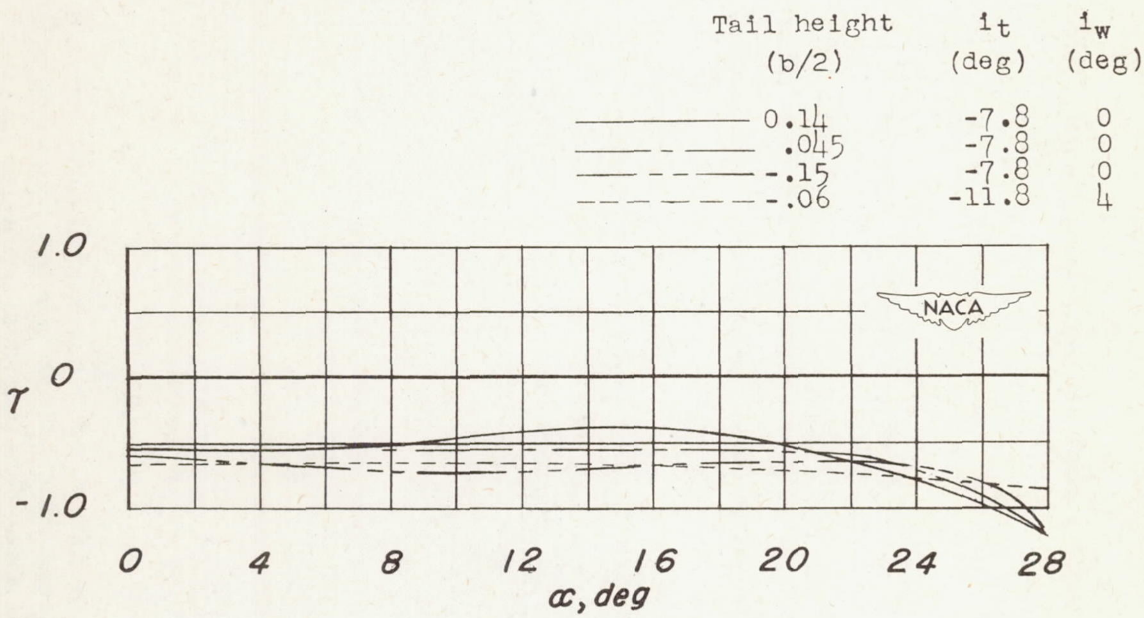
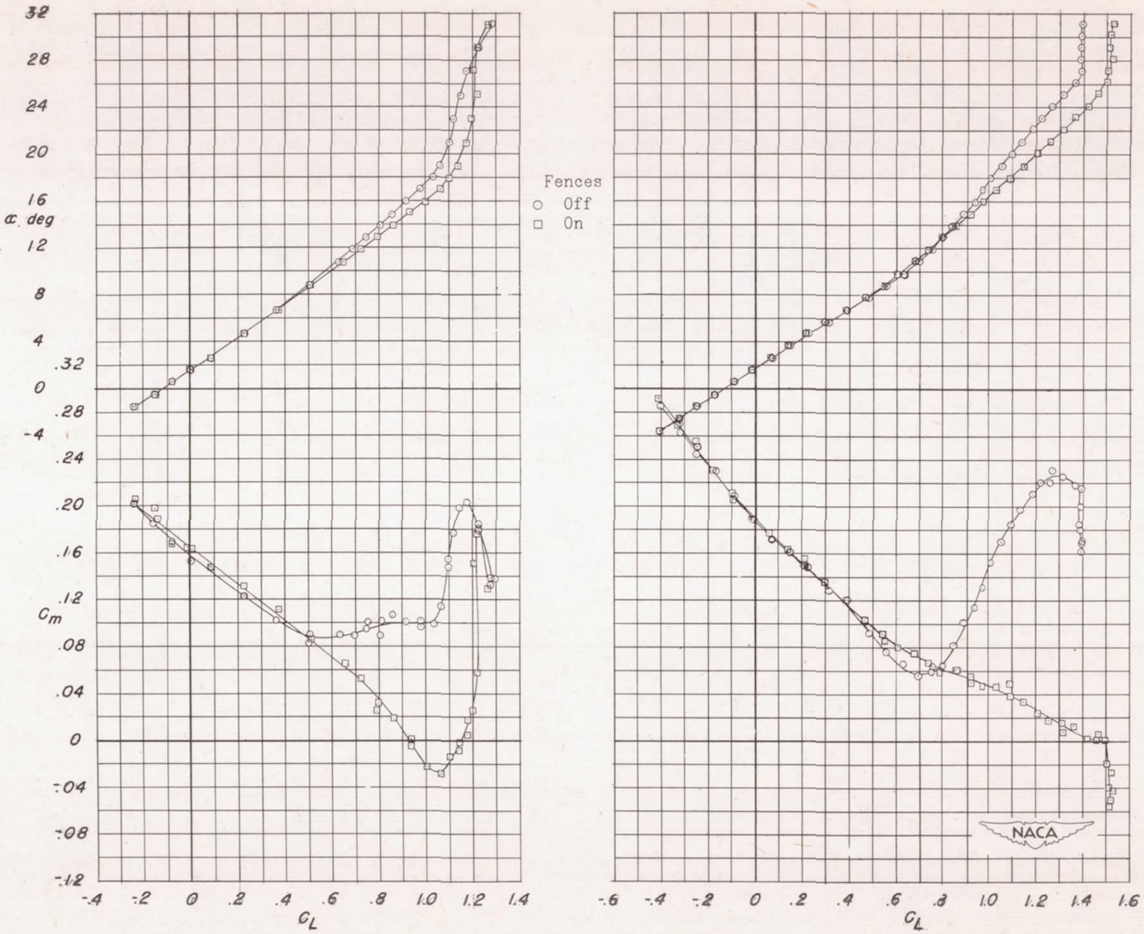


(a) Flat wing (ref. 5).



(b) Twisted and cambered wing.

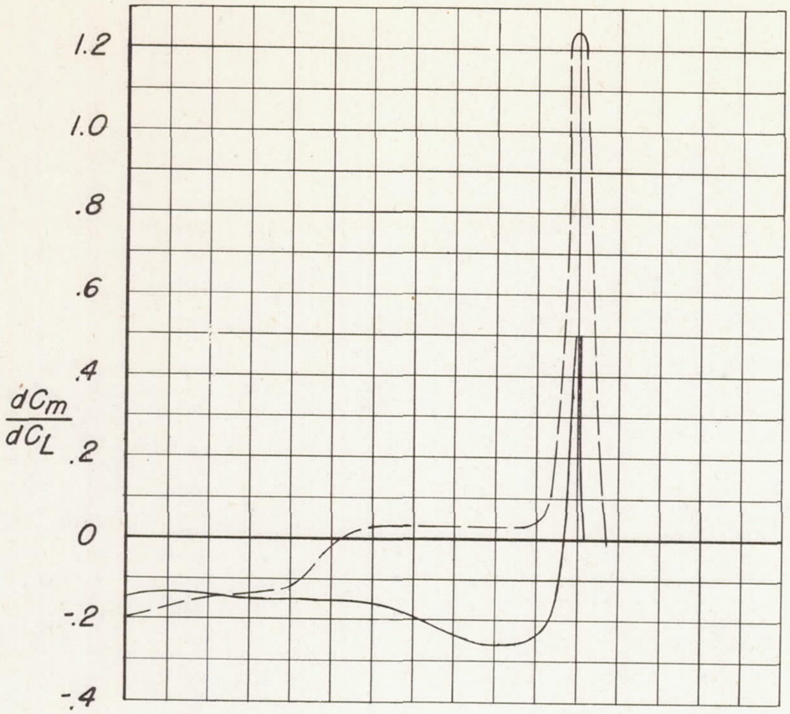
Figure 7.- Variation of tail effectiveness τ with angle of attack of wing-fuselage configuration with fences and flaps off.



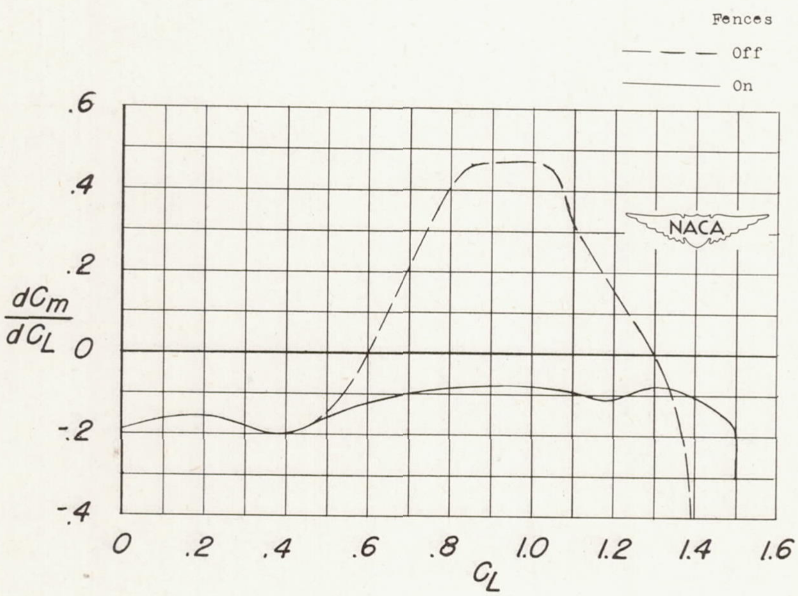
(a) Flat wing (ref. 5).

(b) Twisted and cambered wing.

Figure 8.- Effects of fences located at 0.575b/2 and 0.80b/2 on the lift and pitching-moment characteristics of a swept-wing—fuselage configuration. Flaps off; tail height, -0.06b/2; i_t = -11.8°; i_W = 4°.

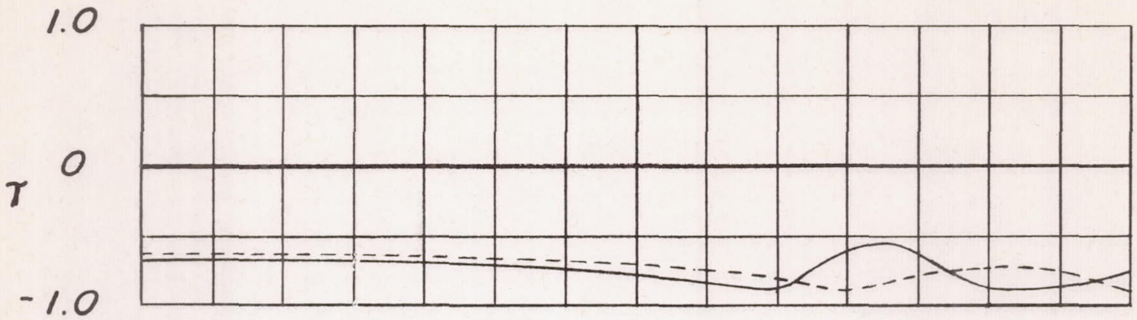


(c) Flat wing.

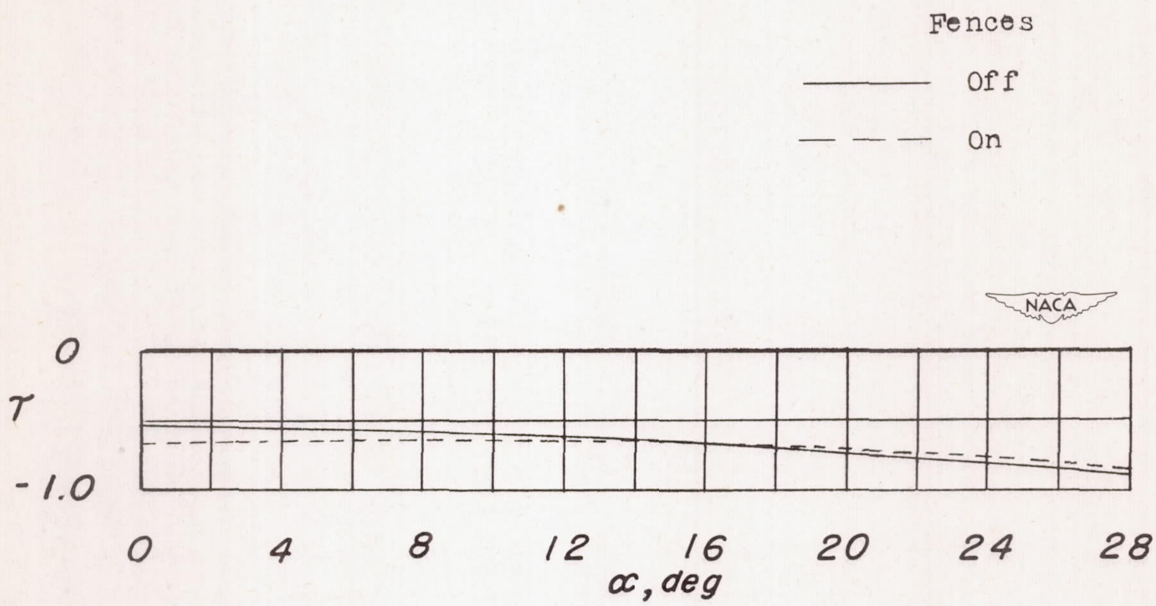


(d) Twisted and cambered wing.

Figure 8.- Concluded.

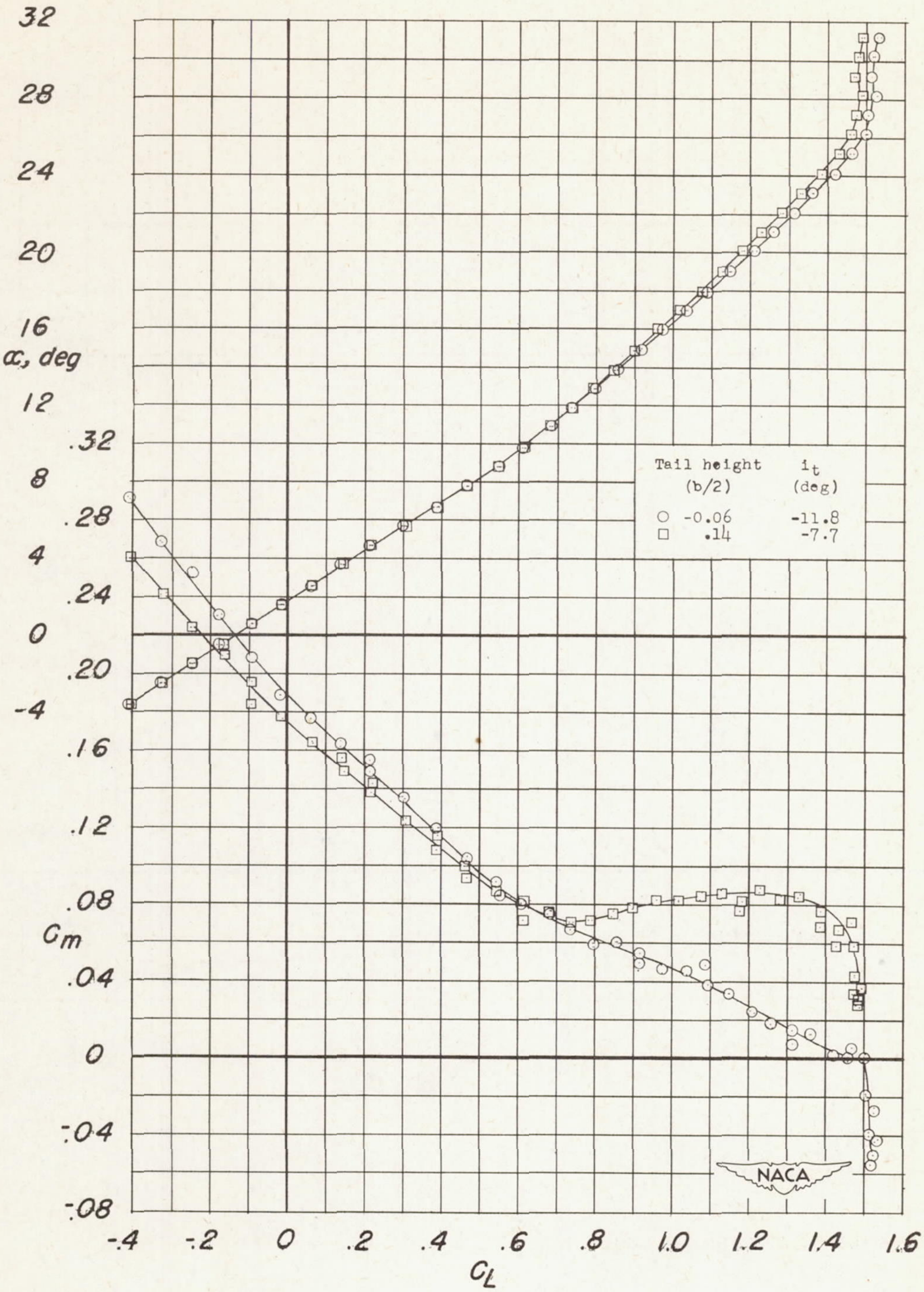


(a) Flat wing (ref. 5).



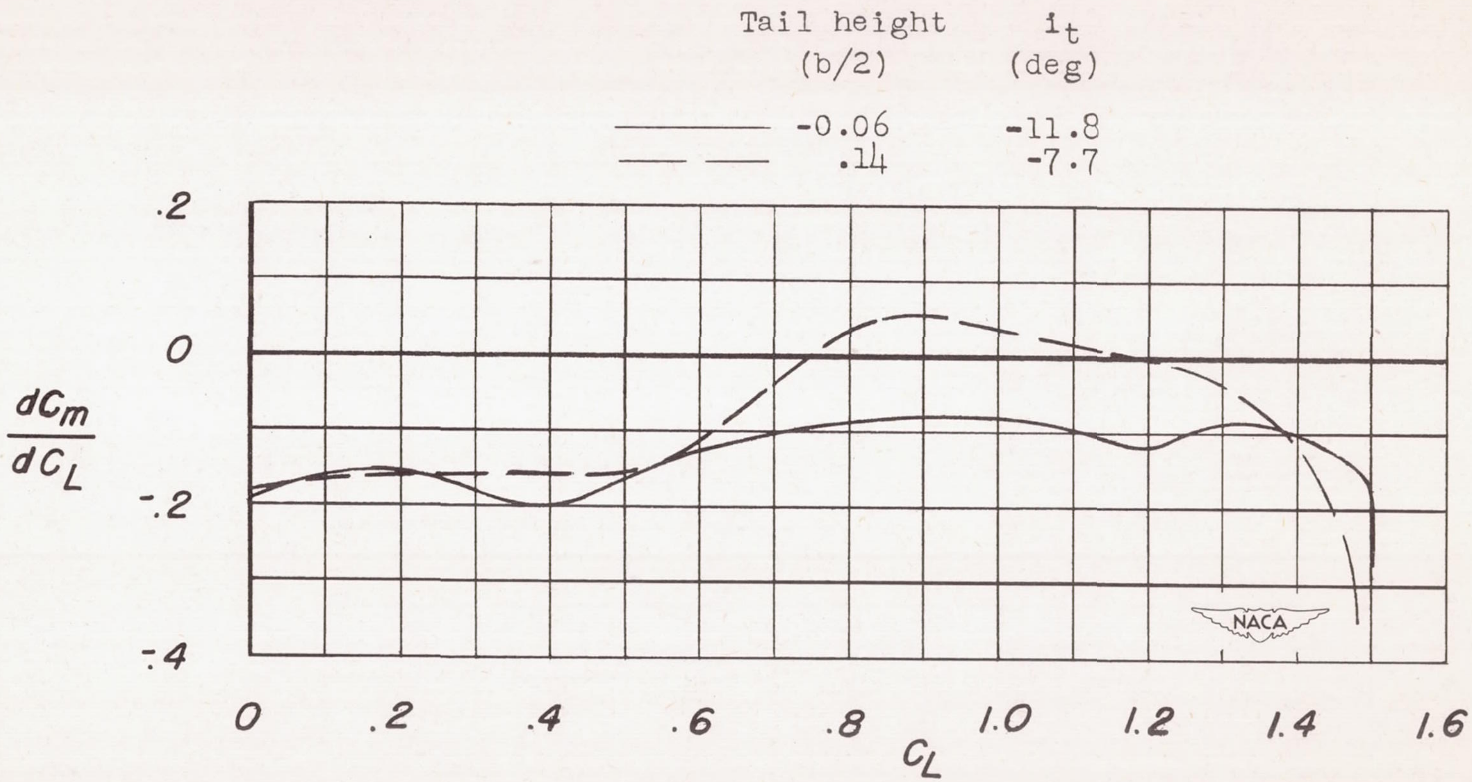
(b) Twisted and cambered wing.

Figure 9.- Effect of fences located at 0.575b/2 and 0.80b/2 on the tail effectiveness parameter τ. Tail height, -0.06b/2; flaps off; $i_t = -11.8^{\circ}$; $i_w = 4^{\circ}$.



(a) α, C_m against C_L.

Figure 10.- Effects of tail height on the lift and pitching-moment characteristics of a twisted and cambered, swept-wing—fuselage configuration with fences located at 0.575b/2 and 0.80b/2. $i_w = 4^{\circ}$.



(b) dC_m/dC_L against C_L.

Figure 10.- Concluded.

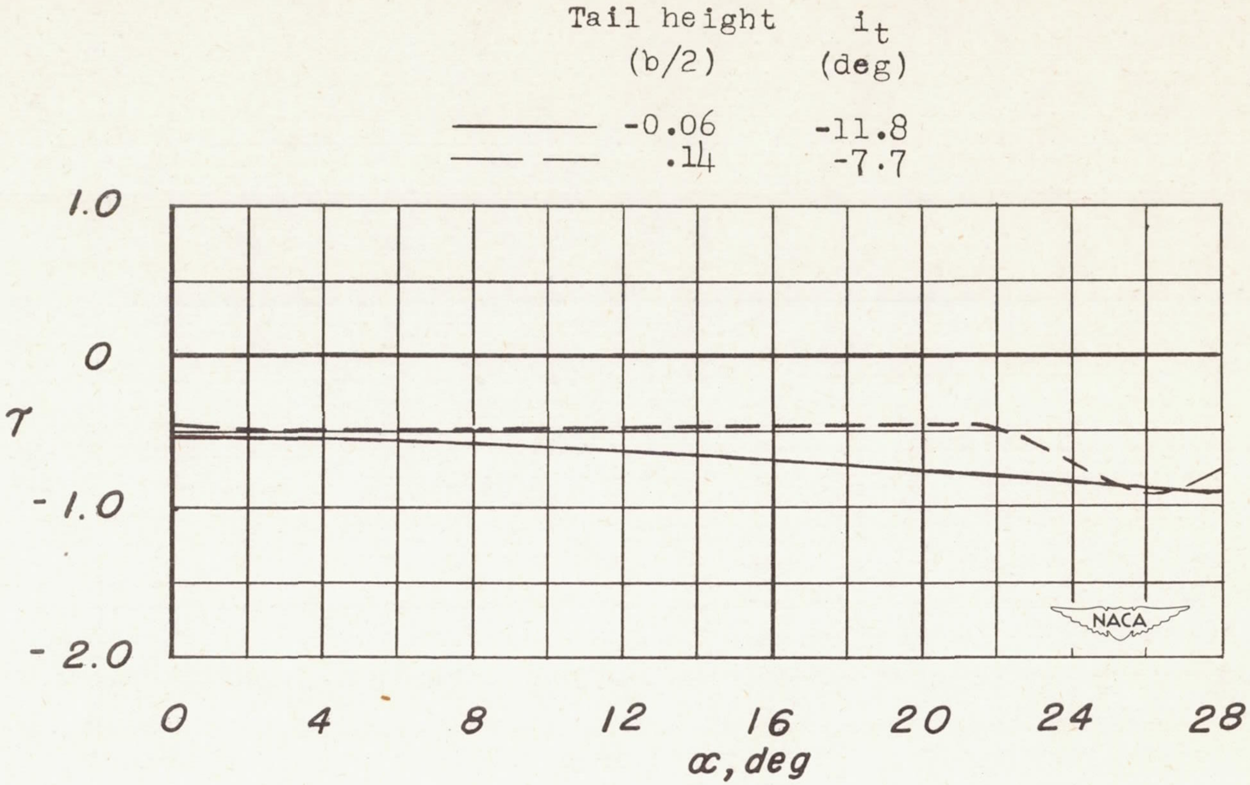
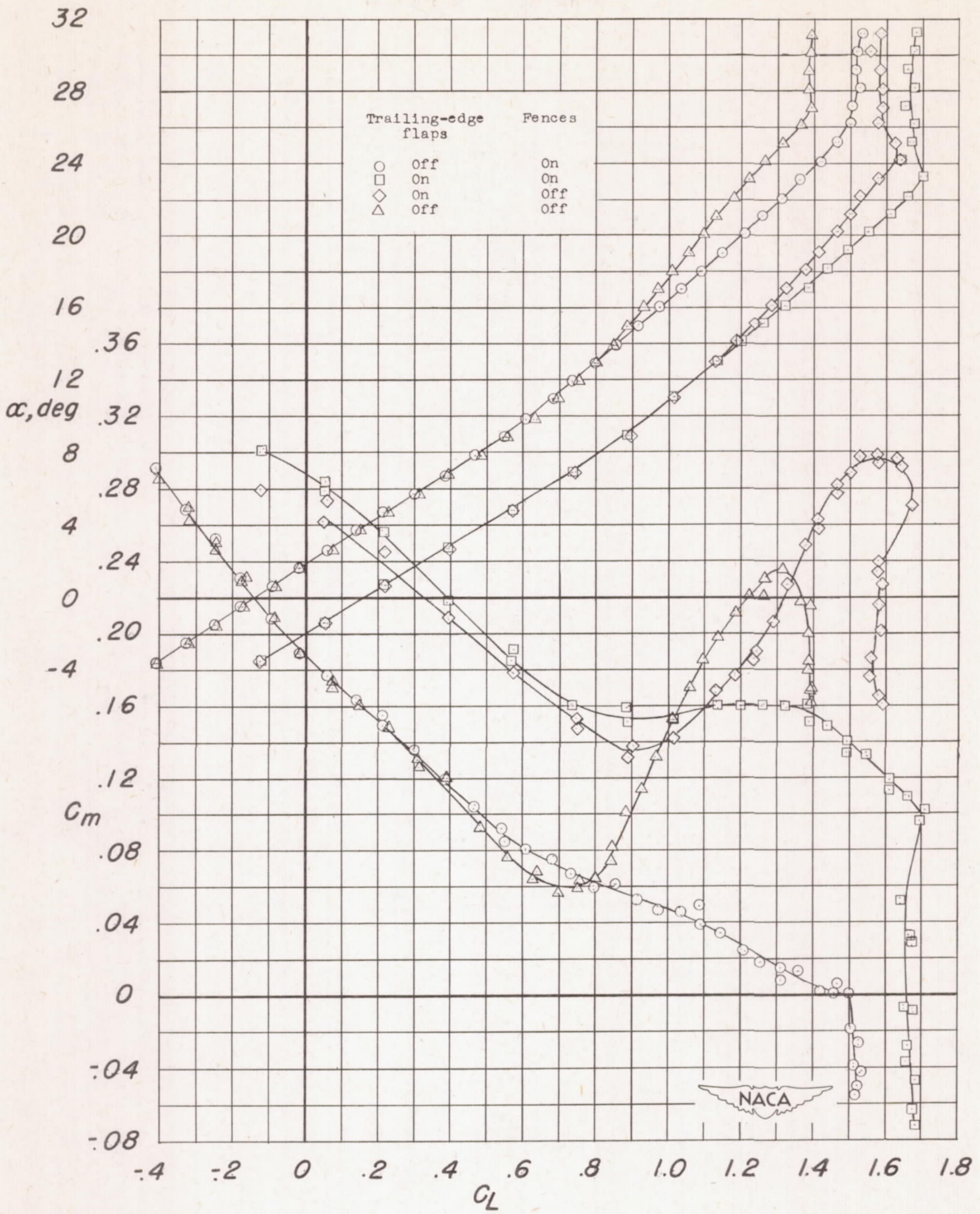
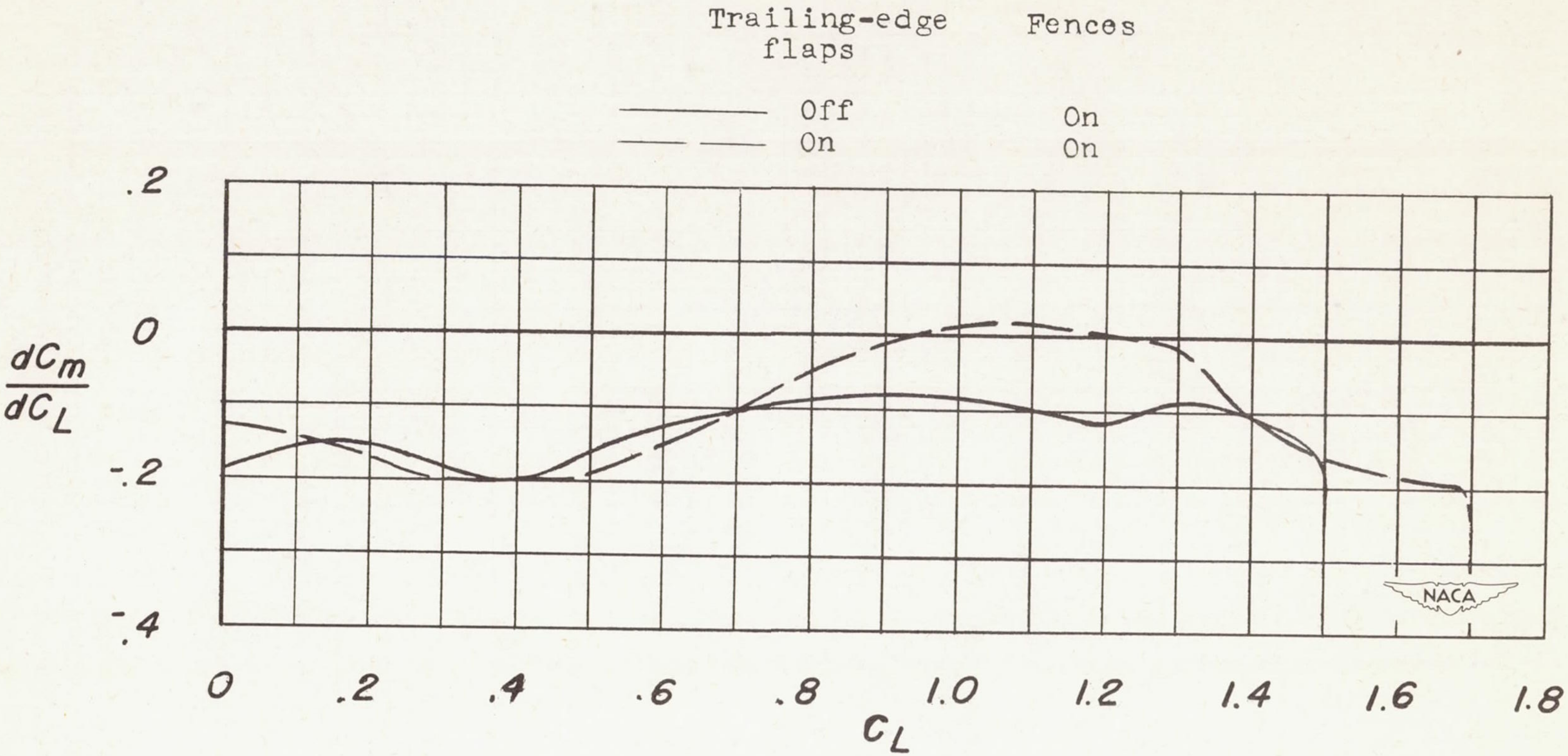


Figure 11.- Effect of tail height on the variation of tail effectiveness parameter τ with angle of attack of a twisted and cambered wing-fuselage configuration with fences located at 0.575b/2 and 0.80b/2. Flaps off; $i_w = 4^{\circ}$.



(a) α, C_m against C_L.

Figure 12.- The separate and combined effects of fences (located at 0.575b/2 and 0.80b/2) and trailing-edge flaps on the lift and pitching-moment characteristics of a twisted and cambered, swept-wing—fuselage configuration with a horizontal tail. Tail height, -0.06b/2; $i_t = -11.8^{\circ}$; $i_w = 4^{\circ}$.



(b) dC_m/dC_L against C_L.

Figure 12.- Concluded.

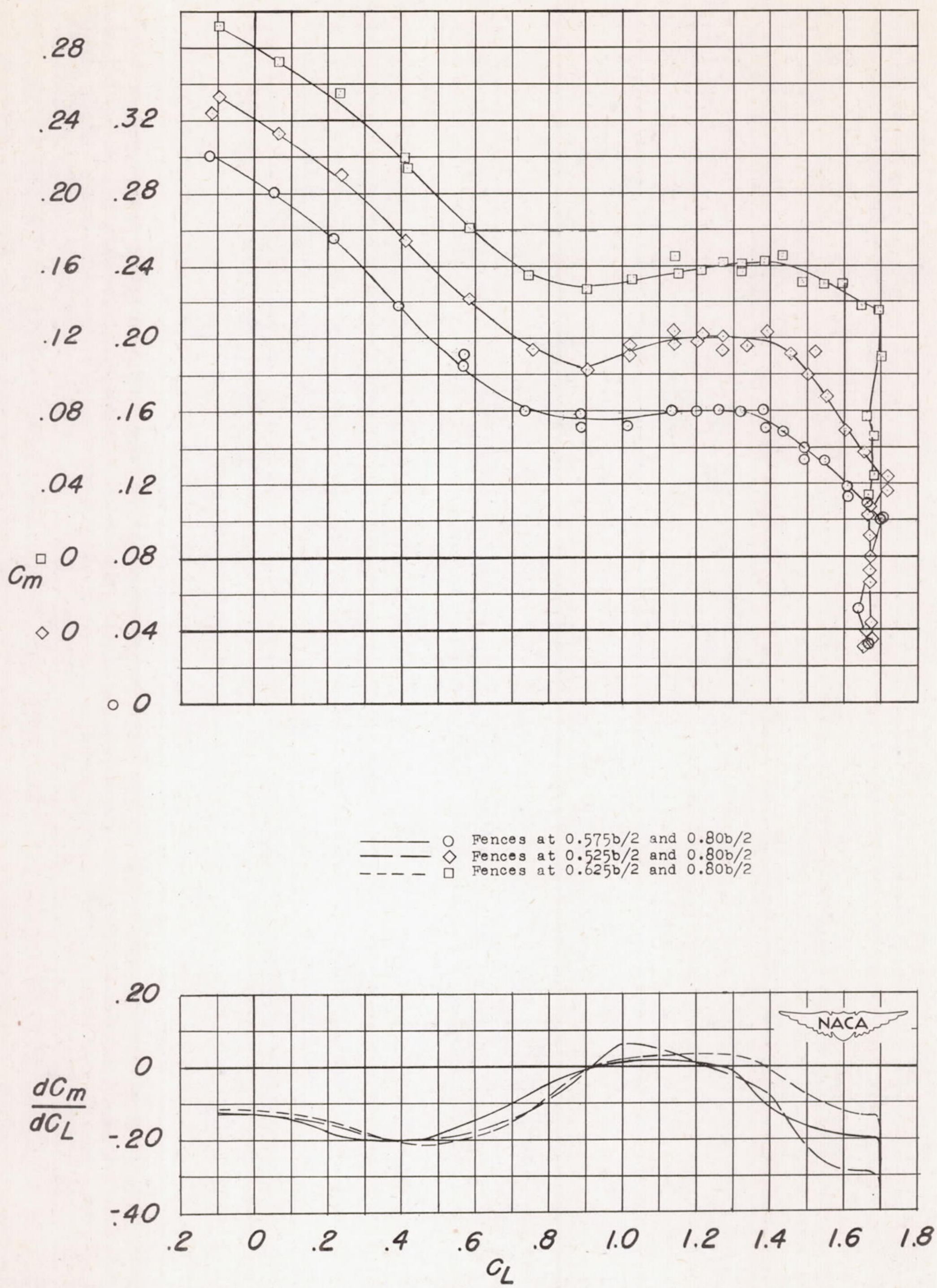


Figure 13.- Effects of small changes in spanwise location of the inboard fence on the pitching-moment characteristics of a twisted and cambered, swept-wing—fuselage configuration with a horizontal tail. Tail height, -0.06b/2; $\delta_f = 23^\circ$; $i_t = -11.8^\circ$; $i_w = 4^\circ$.

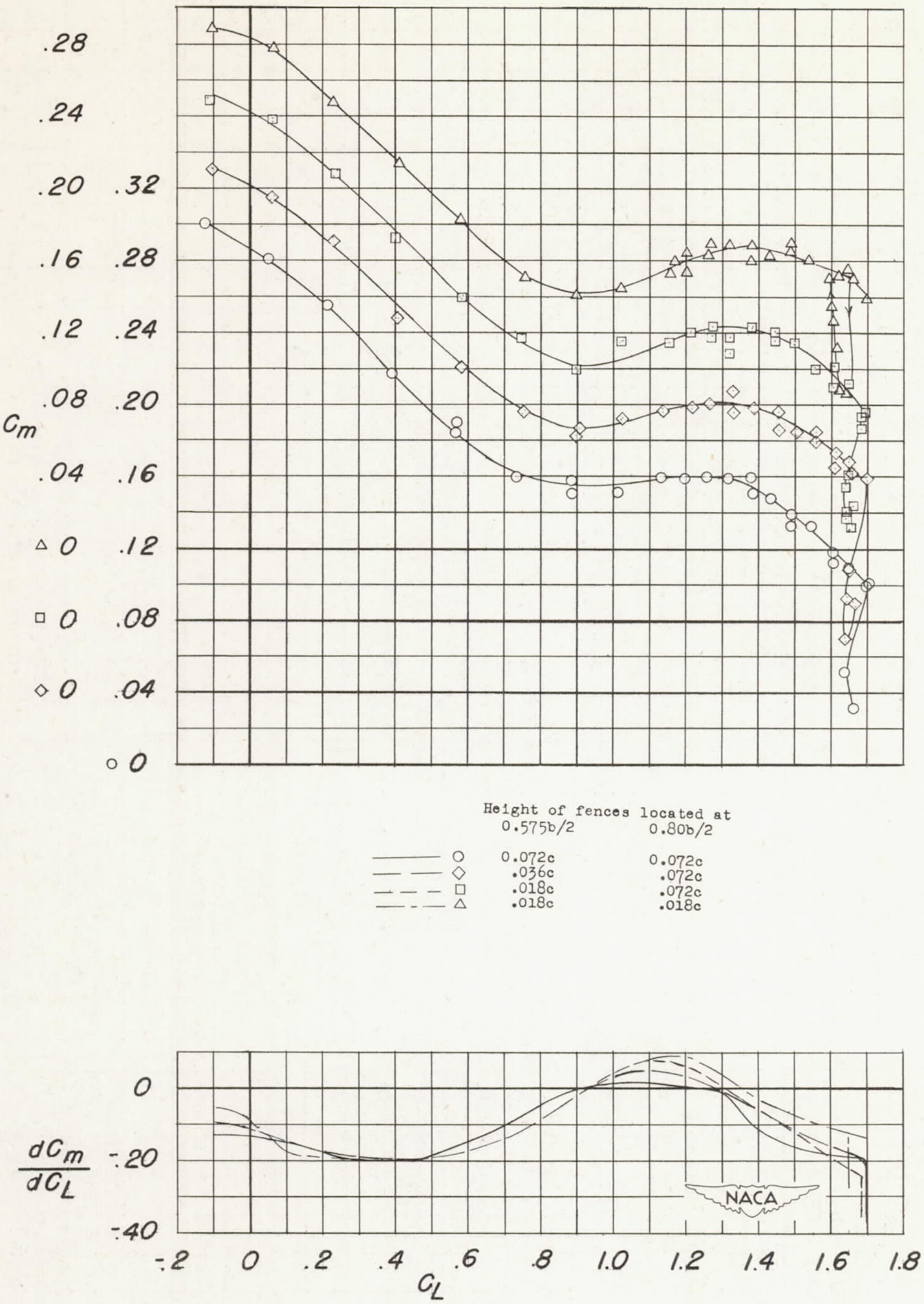


Figure 14.- Effects of a decrease in fence height on the pitching-moment coefficient of a twisted and cambered swept-wing—fuselage configuration with a horizontal tail. Tail height, -0.06b/2; $\delta_f = 23^\circ$; $i_t = -11.8^\circ$; $i_w = 4^\circ$.

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