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STATIC STABILITY CHARACTERISTICS OF A 0.16-SCALE MODEL OF A JET-LIFT V/STOL RESEARCH AIRPLANE IN CRUISE

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SUMMARY

A 0.16-scale model of a jet-lift research airplane was investigated in the 17-foot (5.18-meter) test section of the Langley 300-MPH 7- by 10-foot tunnel. The basic configuration is shown to possess unstable longitudinal characteristics and insufficient control capability over most of the poststall angle-of-attack range. The data indicate that the stability contribution from auxiliary horizontal-tail surfaces (strakes) used in conjunction with the basic high horizontal tail permits the airplane to be trimmed with conventional elevator control. An alternate tail configuration at a lower height, however, is shown to offer more significant improvement to the basic longitudinal stability. The lateral-directional characteristics of the model are not appreciably affected by the addition of the auxiliary tail surfaces, but the alternate tail arrangement results in reduced dihedral effect. The effects of cruise power on the static stability of the basic and modified configurations are small.

INTRODUCTION

The National Aeronautics and Space Administration is actively engaged in the study of vertical and short take-off and landing (V/STOL) airplanes. One configuration currently under investigation uses vertically mounted jet engines for take-off and landing and horizontally mounted engines for high-speed cruise. Transition into forward flight from the vertical mode is accomplished by accelerating the airplane with the cruise engines until the wing lift is sufficient to support the airplane. When this condition is reached, the lift engines are shut down. During low-speed transition flight jet-reaction controls are used, and in cruise flight aerodynamic control surfaces are used.

Data from a recent wind-tunnel investigation of a 0.16-scale model of this airplane (ref. 1) reveal static longitudinal-stability characteristics important to potential users of the present airplane and also to designers of similar configurations in the future. The data indicate that the basic airplane becomes highly unstable longitudinally immediately after stall. This pitch-up characteristic is not uncommon for airplanes having the horizontal stabilizer mounted high on the vertical fin, particularly at high angles of attack when the tail is blanketed by the wake of the engine nacelles. (See ref. 2.) In low-speed transition flight the jet-reaction controls are sufficient to overcome this instability, but in cruise the aerodynamic surfaces do not provide sufficient control. The present investigation was conducted, therefore, in an attempt to improve the stability characteristics of the airplane in the cruise condition.

The longitudinal-stability characteristics of the basic model in the cruise configuration and the effects of adding auxiliary horizontal-tail surfaces are presented. In addition, the results obtained with an alternate tail configuration are given. Also included are the effects of these modifications on the lateral-directional characteristics and the effects of power on the basic and modified airplane characteristics.

SYMBOLS

The data are referred to the stability system of axes. Moments are referred to a point 0.1 wing mean aerodynamic chord aft of the wing leading edge and 0.088 wing mean aerodynamic chord above the wing chord plane. (See fig. 1.) Units for the physical quantities used herein are presented in both U.S. Customary Units and the International System of Units. Factors relating these two systems of units may be found in reference 3.

b — wing span, feet (meters)

$\bar{c}$ — wing mean aerodynamic chord, feet (meters)

C_D — drag coefficient, $\frac{\text{Drag}}{qS}$

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

C_l — rolling-moment coefficient, $\frac{\text{Rolling moment}}{qSb}$

C_m — pitching-moment coefficient, $\frac{\text{Pitching moment}}{qS\bar{c}}$

C_n — yawing-moment coefficient, $\frac{\text{Yawing moment}}{qSb}$

C_T — thrust coefficient, $\frac{\text{Thrust}}{qS}$

C_Y — side-force coefficient, $\frac{\text{Side force}}{qS}$

q — dynamic pressure, pounds force/foot^2 (newtons/meter^2)

S wing planform area, feet^2 (meters^2)

α angle of attack, degrees

β angle of sideslip, degrees

δ_e elevator deflection, positive when trailing edge is down, degrees

Model components:

B fuselage body

T_1 basic high horizontal tail

T_2 auxiliary horizontal tail (strakes)

T_3 low horizontal tail

W wing

MODEL AND TESTS

Model

The model was a 0.16-scale representation of a jet-propelled V/STOL research airplane which employs four direct-lift engines and two lift-cruise engines. Sketches and geometric characteristics of the model are given in figure 1. Photographs of the model mounted in the 17-foot (5.18-meter) test section of the Langley 300-MPH 7- by 10-foot tunnel are given in figure 2. A detailed description of the model is given in reference 1.

The basic high horizontal tail T_1 (fig. 1) incorporated a full-span elevator which was adjustable in 10° increments from -30° to 30°. The auxiliary horizontal-tail surfaces (also called "strakes") T_2 used in conjunction with the basic tail are shown in figure 3. They were fixed to the fuselage at an incidence angle of 3.2° with respect to the fuselage horizontal reference plane. The low horizontal tail T_3 which was investigated as an alternate for the basic tail is shown in figure 4. The low tail was set at 0° with respect to the fuselage horizontal reference plane and at an anhedral angle of 25° in an attempt to minimize the impingement of the cruise engine exhaust. The volume coefficients for both the basic high tail and the alternate low tail were equal. Boundary-layer transition was fixed at 0.10 local chord on the wing, on the horizontal and vertical tails, and on the strakes with strips of No. 70 carborundum grit. Model power was provided by two cold-air ejectors mounted in nacelles alongside the fuselage. Ejectors of the type used on this model are described in reference 4.

Tests

Most of the data included herein were obtained in the 17-foot (5.18-meter) test section of the Langley 300-MPH 7- by 10-foot tunnel. Where sufficient data were not available from the Langley tunnel, the unpublished results of tests conducted in the University of Maryland Low Speed wind tunnel under U.S. Air Force contract are presented. In each tunnel six components of forces and moments were measured through a range of angles of attack and sideslip. The tests with which the present investigation is concerned were conducted with the model in the normal cruise configuration. The wing flaps were set at 0°, the jet-exit doors on the fuselage underside were closed, and the landing gear was removed. Most of the data were obtained at a dynamic pressure of 11 lbf/ft^2 (526.68 $newtons/meter^2$) and a Reynolds number based on $\bar{c}$ of 0.43×10^6. Some of the data in the University of Maryland tunnel were obtained at a dynamic pressure of 60 lbf/ft^2 (2872.80 $newtons/meter^2$) and a Reynolds number based on $\bar{c}$ of 1.01×10^6. The large difference in Reynolds numbers, however, does not affect the primary conclusions obtained from this investigation. Most of the power-on data were obtained at a thrust coefficient of about 0.38. However, the only available power-on data for the basic high-tail configuration (WBT_1) were obtained at a thrust coefficient of about 2.6.

PRESENTATION OF RESULTS

The results from this investigation are presented as follows:

	Figure
Longitudinal characteristics:	
Basic high-tail configuration (WBT_1):	
$C_T = 0$	5(a)
$C_T = 2.60$	5(b)
High-tail configuration with strakes (WBT_1T_2):	
$C_T = 0$	6(a)
$C_T = 0.38$	6(b)
Low-tail configuration (WBT_3):	
$C_T = 0$	7(a)
$C_T = 0.38$	7(b)
Lateral-directional characteristics:	
Comparison of basic and modified configurations in sideslip:	
$C_T = 0$	8(a)
$C_T = 0.38$	8(b)

DISCUSSION OF RESULTS

Basic Configuration

The problem encountered with the basic model $\left(WBT_1\right)$, which is typical of high-tail configurations, is illustrated in figure 5(a) where the power-off longitudinal characteristics and the control effect of maximum elevator deflection are given. Beyond the angle of attack for primary stall, the pitching-moment variation changes rapidly and becomes highly unstable up to an angle of attack of about 28^o. Above this angle of attack, the model regains longitudinal stability and trims at an angle in excess of 44^o; this condition is often called the "deep-stall" trim condition. Maximum elevator deflection is incapable in providing trim from $\alpha \approx 22^o$ up to the deep-stall trim point. Although the wing-body (tail-off) pitching-moment variation becomes increasingly stable beyond an angle of attack of about 16^o, the high rate of change of downwash at the tail with angle of attack causes the unstable characteristic of the complete configuration to persist up to the higher angles. In addition, the reduction in elevator effectiveness shown at the higher angles of attack indicates a considerable loss in dynamic pressure at the tail. The high rate of change of downwash and loss in dynamic pressure are the result of the blanketing of the horizontal tail by the wake from the large engine nacelles and the wing. Although recovery of positive stability is effected when the tail emerges from the disturbed flow region (at $\alpha \approx 30^o$), the elevator effectiveness continues to decrease up to the maximum angle of attack of the investigation.

Modified Configurations

Several methods were considered in attempts to make the basic airplane controllable, even if not statically stable, throughout the angle-of-attack range. Because the full-scale airplane was in the advanced stages of fabrication when the present data were obtained, solutions short of major tail redesign were naturally considered first.

Horizontal strakes.- Numerous potential solutions with the model in the power-off condition were investigated by the contractor in the University of Maryland wind tunnel. The results indicated that the auxiliary horizontal-tail surfaces or strakes used in combination with the basic tail (fig. 3) could provide a simple modification which would result in acceptable control characteristics.

The modified configuration $\left(WBT_1T_2\right)$ was then investigated at the Langley Research Center in both the powered and unpowered conditions primarily to assess the effects of power. The data of figure 6 indicate that the strakes have only a slight effect prior to stall. In the region where the basic configuration $\left(WBT_1\right)$ stalls and subsequently becomes unstable, however, it is shown that the strakes begin to provide a stable contribution to the wing-body combination. Consequently, the poststall stability of the modified configuration

$\left(WBT_1T_2\right)$ is such that the remaining out-of-trim moments are within the control capability of the elevator. Similar improvements were obtained with a low auxiliary horizontal tail in the investigation reported in reference 2.

As a consequence of the foregoing results, strakes have been installed on the full-scale airplane, and the resulting configuration is an improvement over the basic one which had only the high tail. It should be pointed out, however, that even with the strakes installed, only a small margin of control is available at the higher angles of attack because of the reduced dynamic pressure at the tail.

Low horizontal tail.- Although it may not be structurally or economically feasible to replace the high tail with a low horizontal tail on the full-scale airplane, the airplane characteristics with a low tail were of sufficient interest to warrant further wind-tunnel investigation. The information obtained thereby could be of value in the design of future airplanes of similar configuration or advanced versions of the current airplane, particularly when similar tail and nacelle arrangements are used.

The longitudinal characteristics of the model with the low horizontal tail installed $\left(\text{configuration } WBT_3\right)$ (fig. 7) indicate that the stability before stall is either about neutral or slightly negative (depending upon the center of gravity and power setting chosen). Immediately after stall, however, the pitching-moment variation becomes stable and remains so throughout the angle-of-attack range. Although the prestall stability could be improved by increased tail volume or incidence and result in favorable characteristics for the low-tail configuration $\left(WBT_3\right)$ throughout the angle-of-attack range in cruise, the possible penalties which may be incurred by reduced tail height in hover and low-speed transition must also be considered. (See ref. 5.)

Effect of Tail Modifications in Sideslip

To assess the effects of the previously discussed modifications on the lateral-directional stability of the model, the variation of lateral-directional characteristics with sideslip angle at $\alpha = 0^{\circ}$ is compared in figure 8 for the basic configuration $\left(WBT_1\right)$, the configuration with strakes $\left(WBT_1T_2\right)$, and the low-tail configuration $\left(WBT_3\right)$, both with and without power. The addition of the strakes to the basic airplane had only a small effect on the lateral-directional characteristics. With the low-tail configuration, however, the stable dihedral effect shown for both the basic configuration and the configuration with strakes was considerably reduced as a result of the anhedral angle of the low tail. This tail anhedral angle may also account for the increased directional stability exhibited by the low-tail configuration at the higher sideslip angles.

Effects of Cruise Power

The effects of cruise engine power can be assessed by comparing the (a) parts of figures 5 to 8 with their respective (b) parts. In general, the effect of cruise engine power on stability is small. The data in figure 5(b) were obtained at a thrust coefficient which was actually much greater than the cruise thrust coefficient at which the remaining data were obtained. The primary effect of this excess power, however, was a change in trim; only a small change in stability is evident.

The trend of power effects appears to be that the application of power slightly increases the poststall stability of the basic configuration (WBT_1) and of the configuration with strakes (WBT_1T_2) and decreases the prestall stability of the low-tail configuration (WBT_3).

SUMMARY OF RESULTS

A wind-tunnel investigation of the static stability characteristics of a model of a jet-lift research airplane in the cruise configuration indicated unfavorable longitudinal and control characteristics for the basic model over most of the angle-of-attack range. Two different modifications were investigated in attempts to improve these unfavorable characteristics. The results are summarized as follows:

Auxiliary horizontal surfaces (strakes) mounted below the horizontal tail provided sufficient improvement to the stability of the basic model to permit controllability throughout the angle-of-attack range. The effects of the strakes in sideslip were small.

An alternate horizontal-tail configuration at a lower tail height was also investigated. The low tail provided a greater improvement in longitudinal stability than that provided by the strakes. The particular low-tail configuration used, however, caused a reduction in the effective dihedral of the basic model.

The effects of cruise power on the stability characteristics of the basic and modified configurations were small.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., May 8, 1969,
721-01-00-39-23.

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1. Winston, Matthew M.: Wind-Tunnel Data From a 0.16-Scale V/STOL Model With Direct-Lift and Lift-Cruise Jets. NASA TM X-1758, 1969.
2. Ray, Edward J.; and Taylor, Robert T.: Effect of Configuration Variables on the Subsonic Longitudinal Stability Characteristics of a High-Tail Transport Configuration. NASA TM X-1165, 1965.
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GEOMETRIC CHARACTERISTICS

	Wing	Horizontal tail	Vertical tail
Area	2.67 ft^2 (.25 m^2)	.68 ft^2 (.06 m^2)	.70 ft^2 (.07 m^2)
Span	48.00 (121.92)	20.48 (52.02)	11.68 (29.67)
Root chord	11.52 (29.26)	6.80 (17.27)	11.44 (29.06)
Tip chord	4.48 (11.38)	2.72 (6.91)	5.90 (14.99)
Mean aerodynamic chord	8.52 (21.64)	5.05 (12.83)	8.96 (22.76)
Aspect ratio	5.90	4.30	1.35
Taper ratio	.39	.40	.52
Sweep (.25 chord line)	4.18°	12.37°	32.13°
Airfoil section		NACA 0010 (modified)	NACA 64A012
Root	NACA 64A012		
Tip	NACA 64A212		
Tail length		30.82 (78.28)	25.10 (63.75)

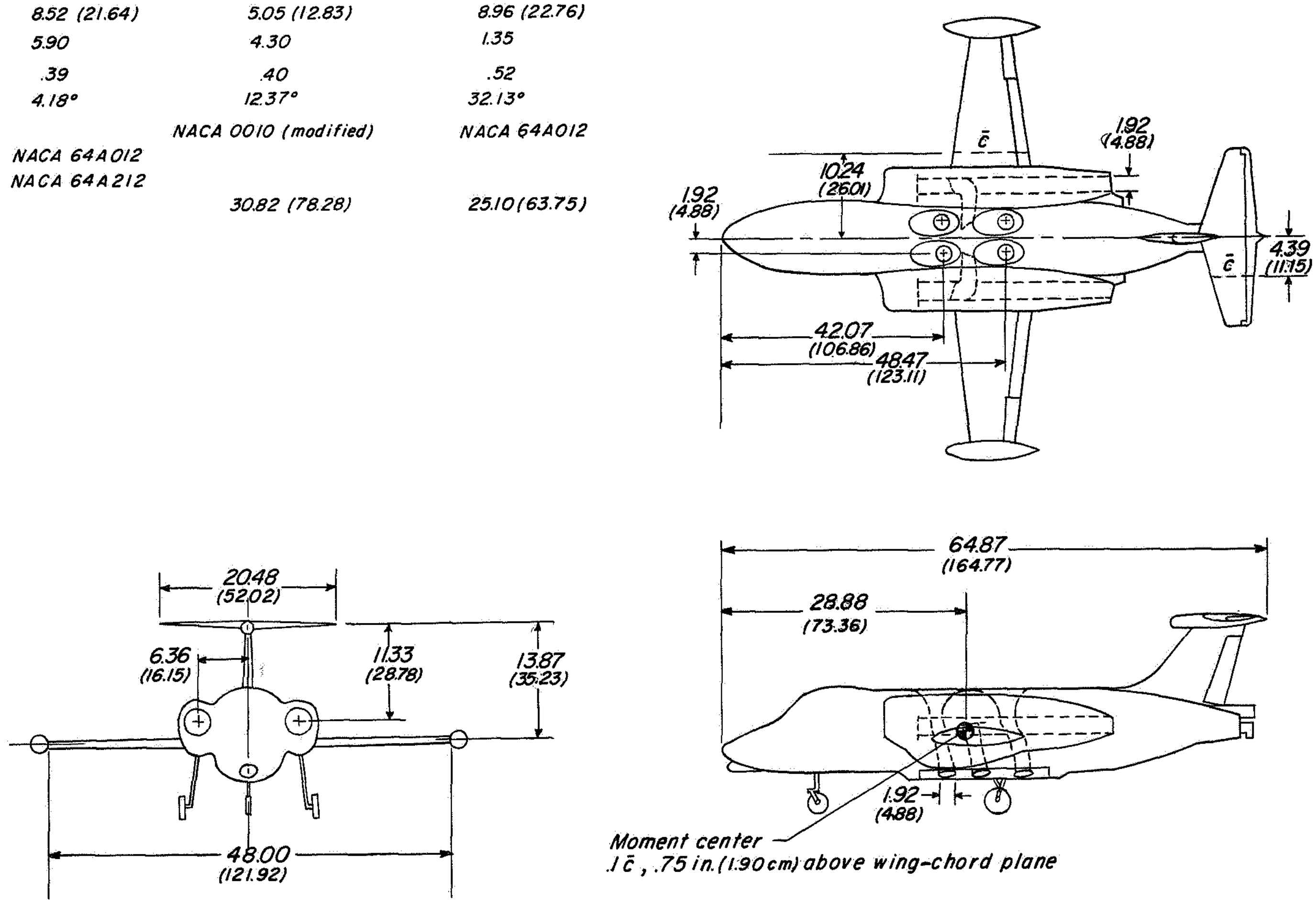
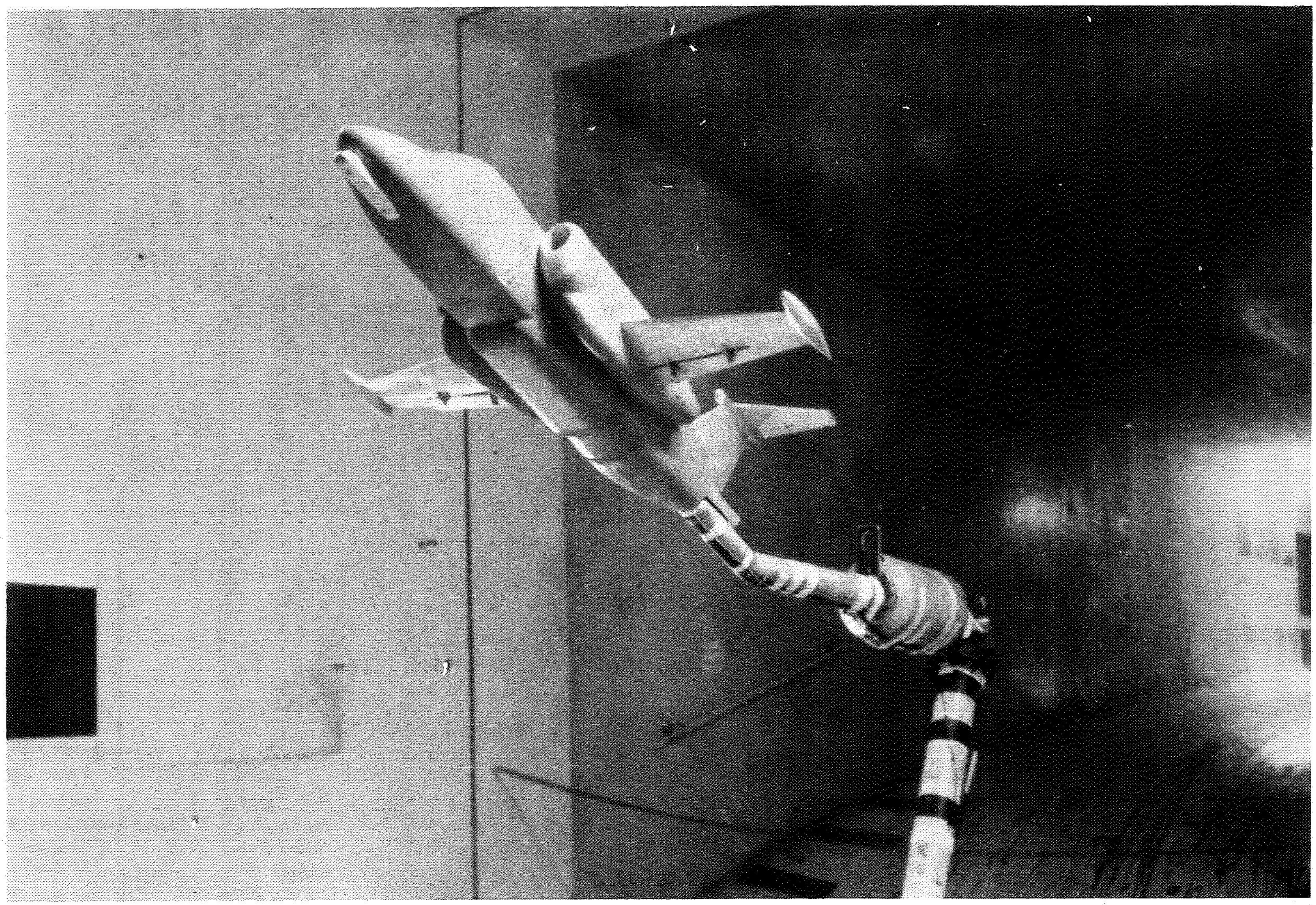
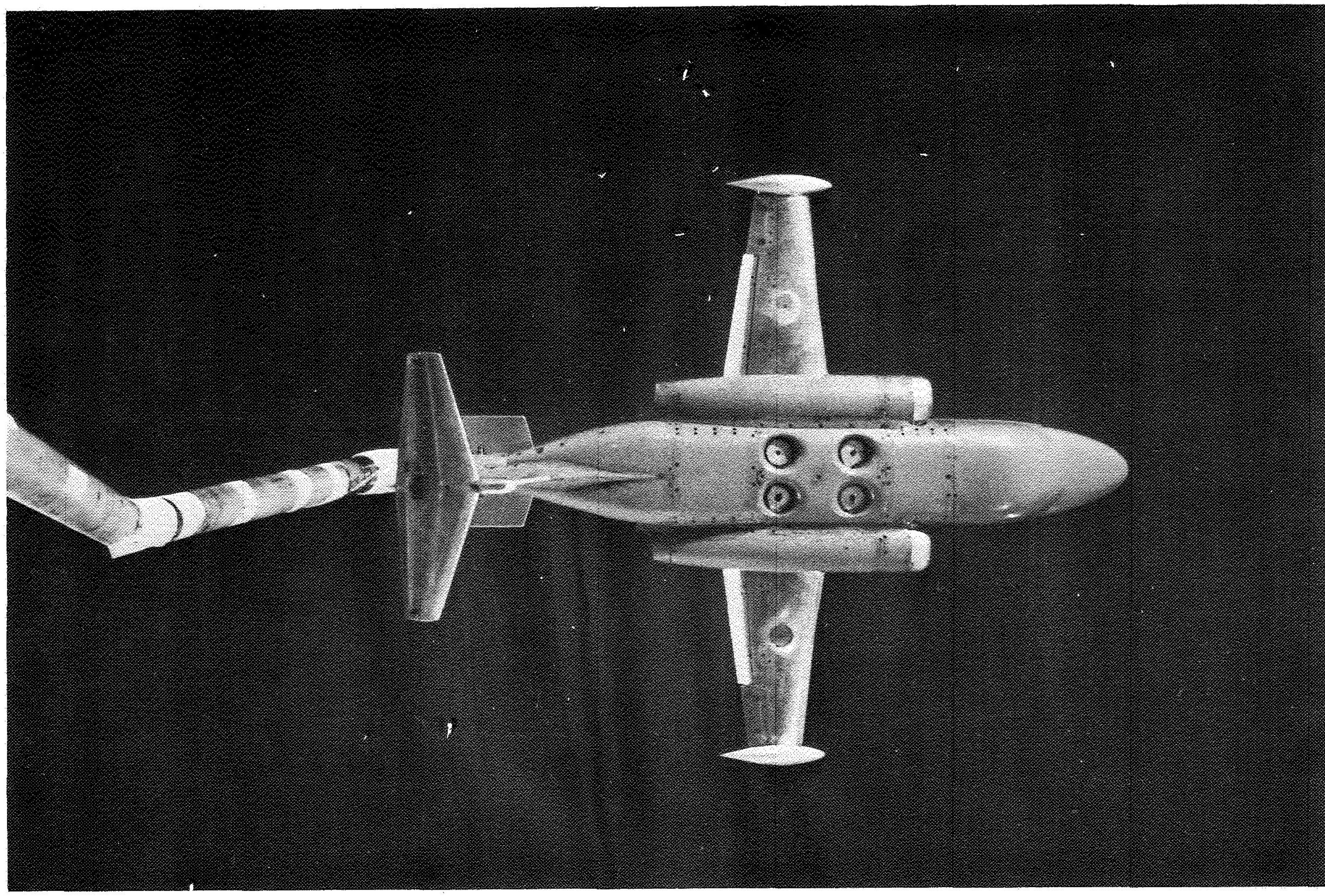


Figure 1.- Principal dimensions and geometric characteristics of the basic model. All dimensions are in inches (centimeters) unless otherwise specified.



(a) Basic high-horizontal-tail configuration (WBT_1). L-69-1376

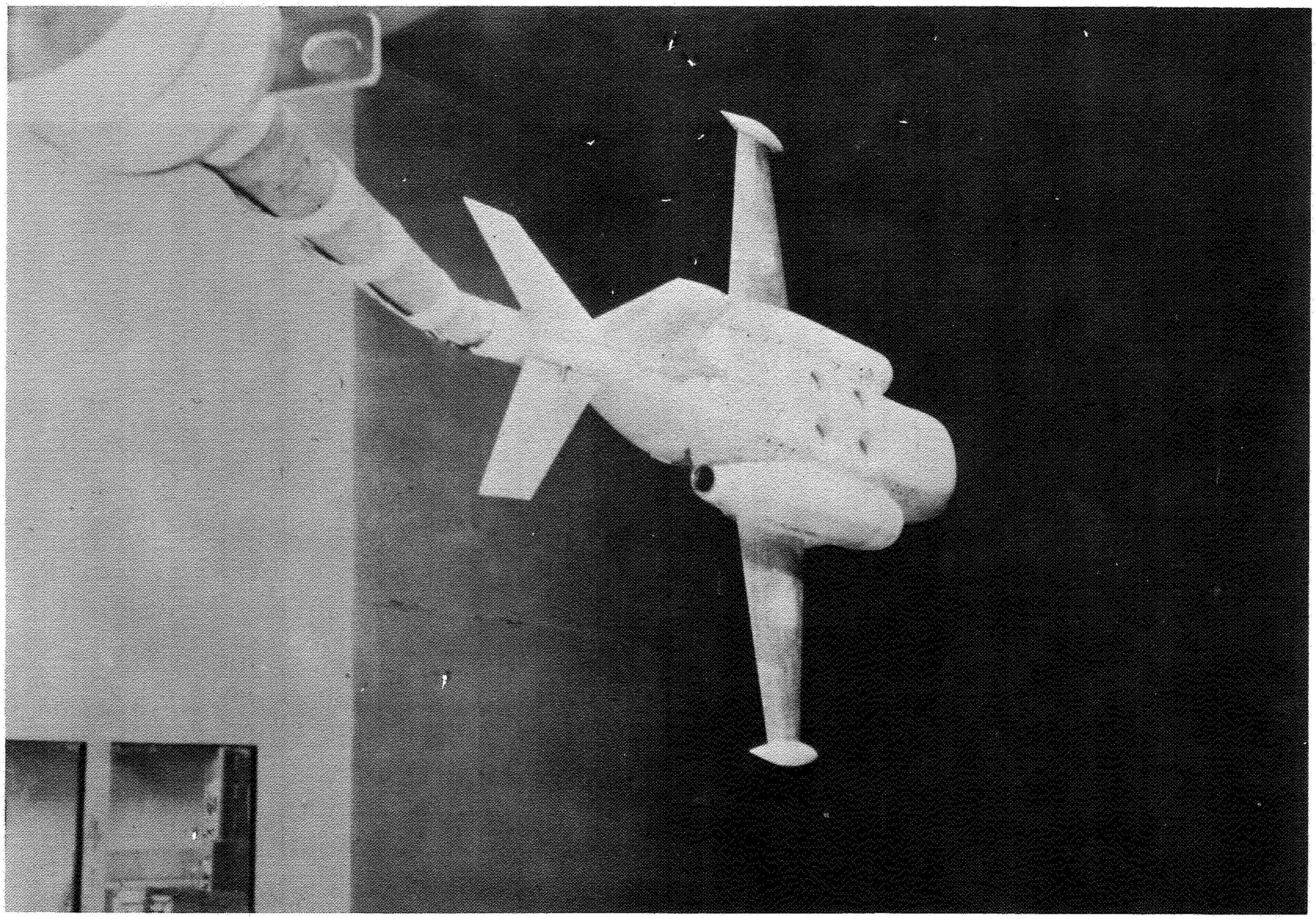
Figure 2.- Photographs of the model in the Langley 300-MPH 7- by 10-foot tunnel.



L-69-1377

(b) Basic configuration with strakes (WBT_1T_2).

Figure 2.- Continued.



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(c) Low-tail configuration (WBT_3).

Figure 2.- Concluded.

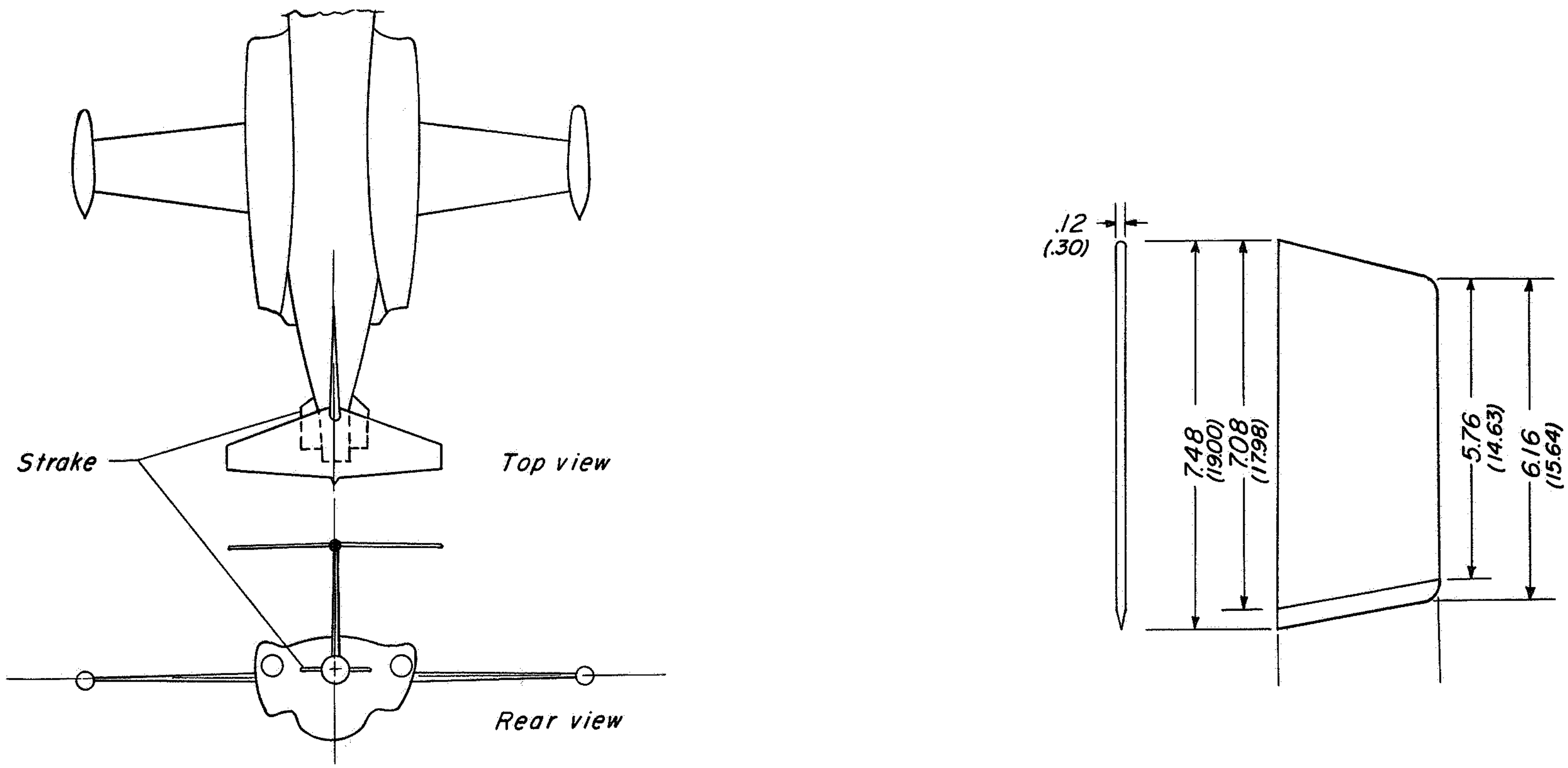


Figure 3.- Strake dimensions and installation. Dimensions are in inches (centimeters).

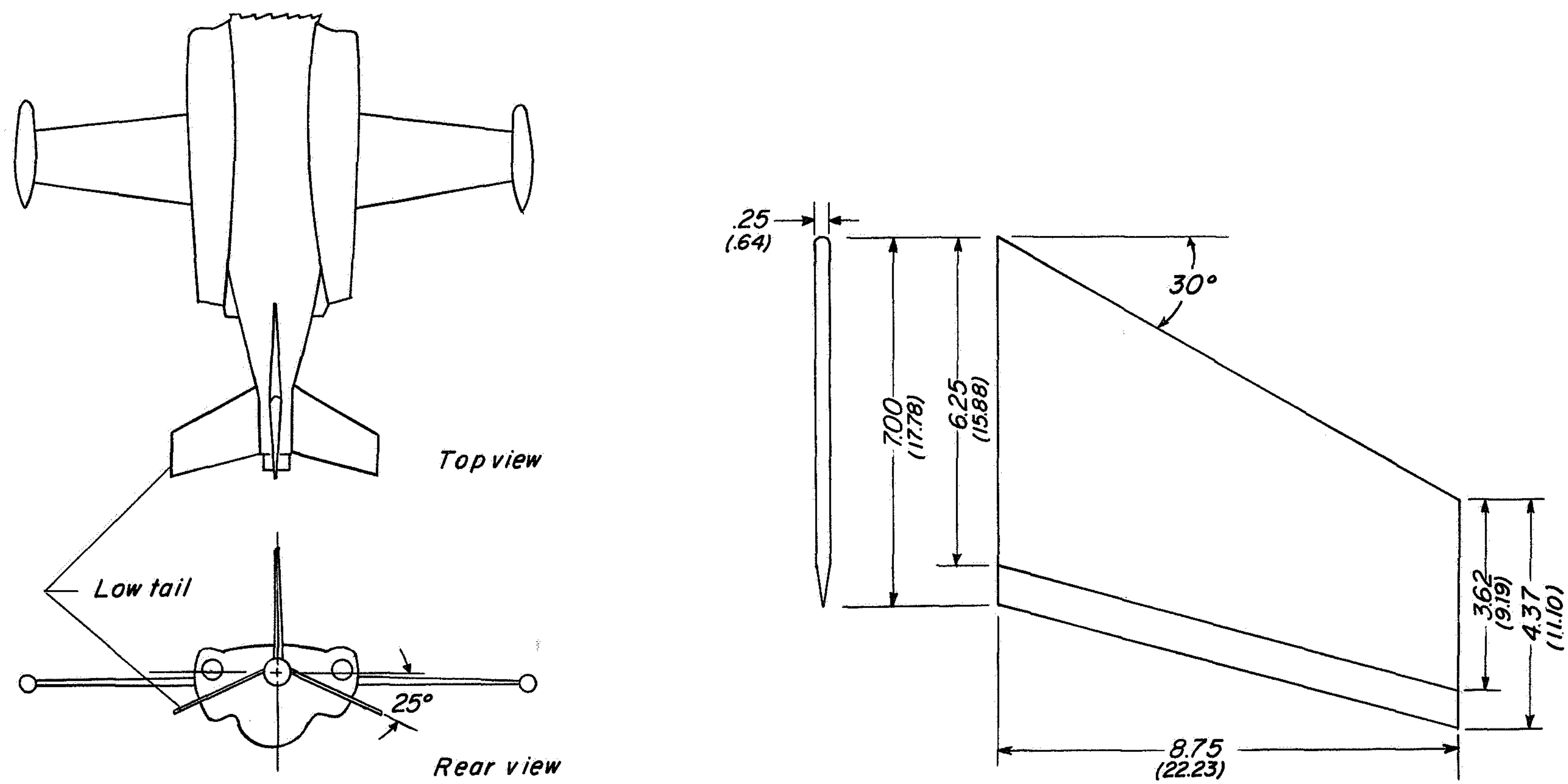
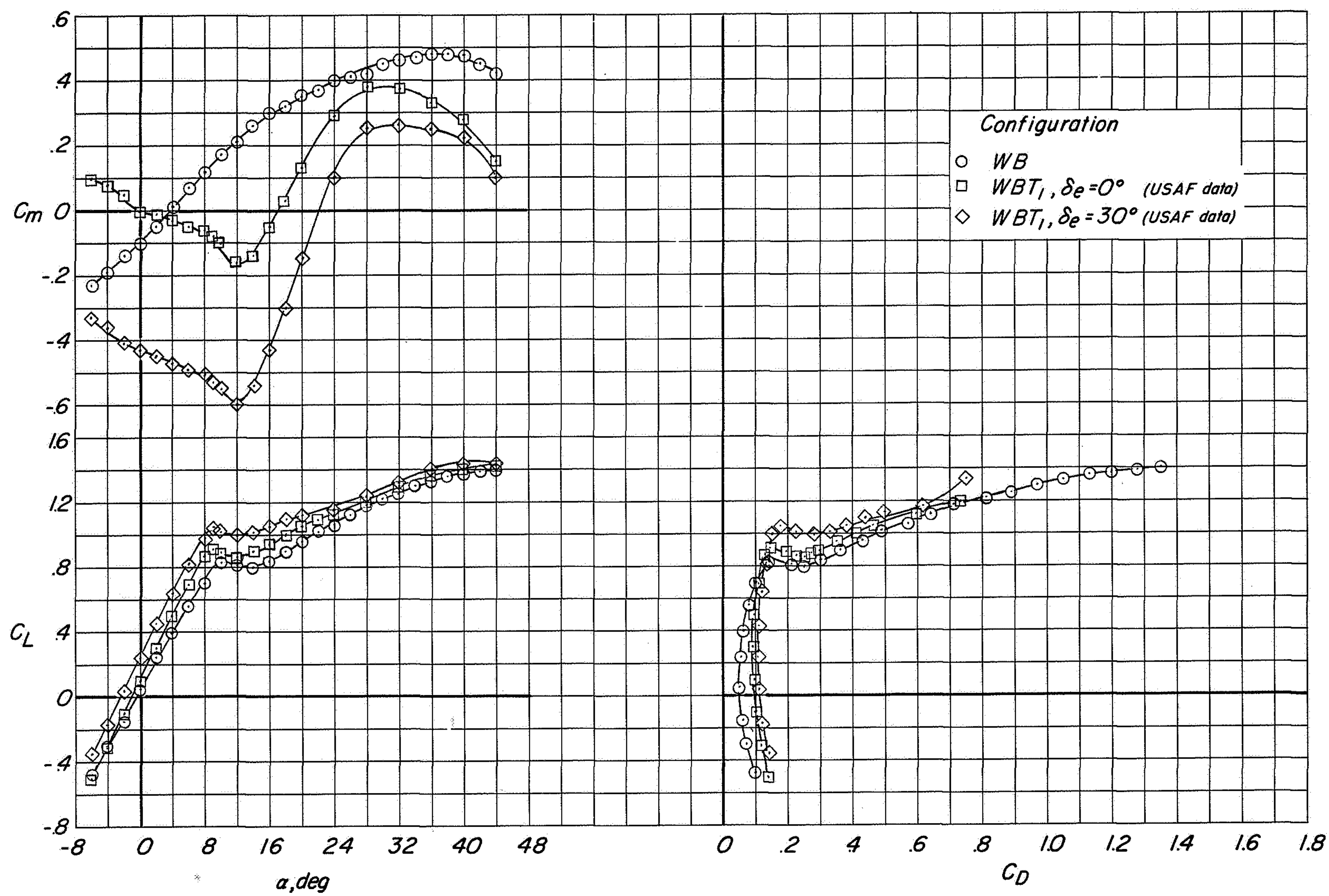
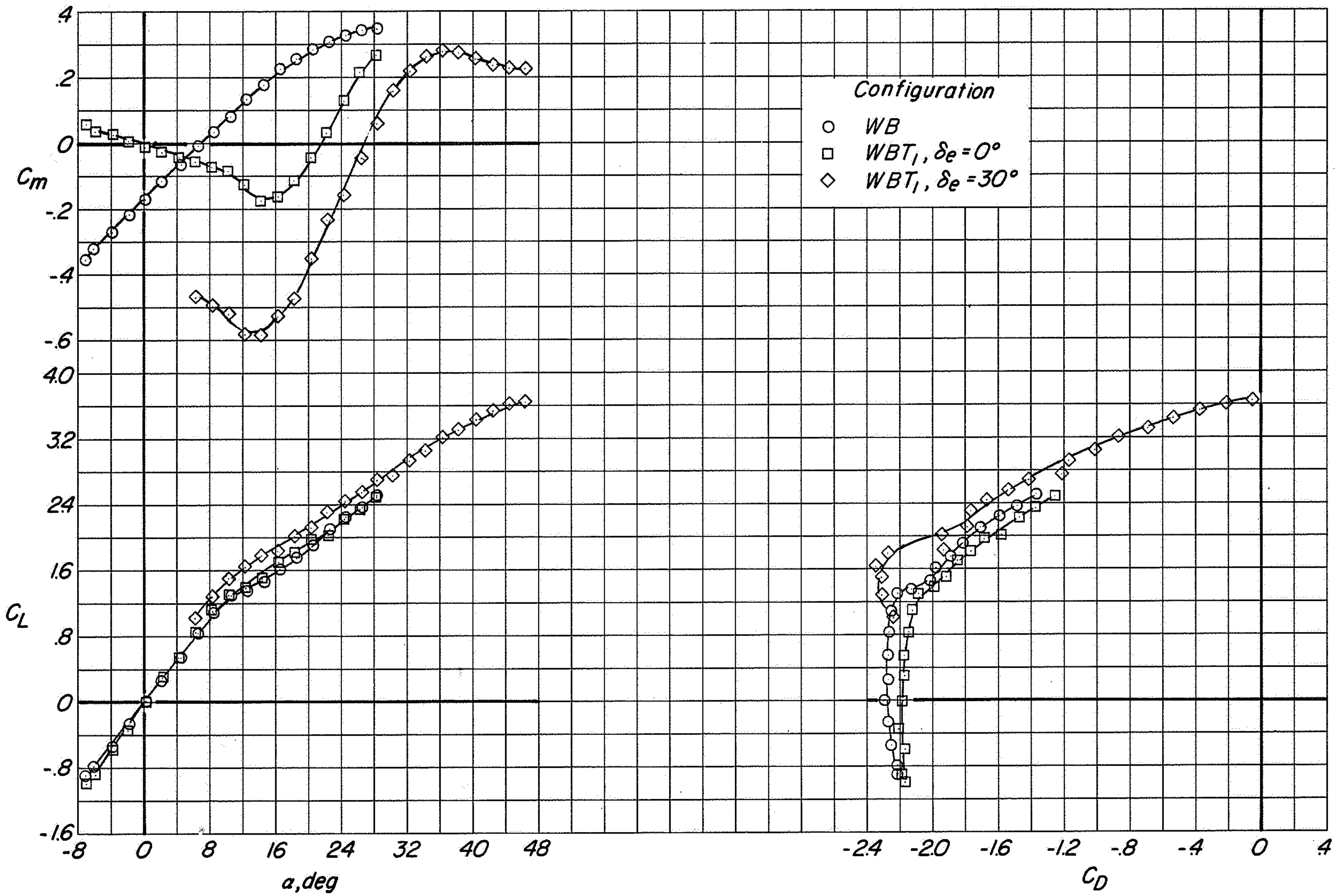


Figure 4.- Alternate tail dimensions and installation. Dimensions are in inches (centimeters).



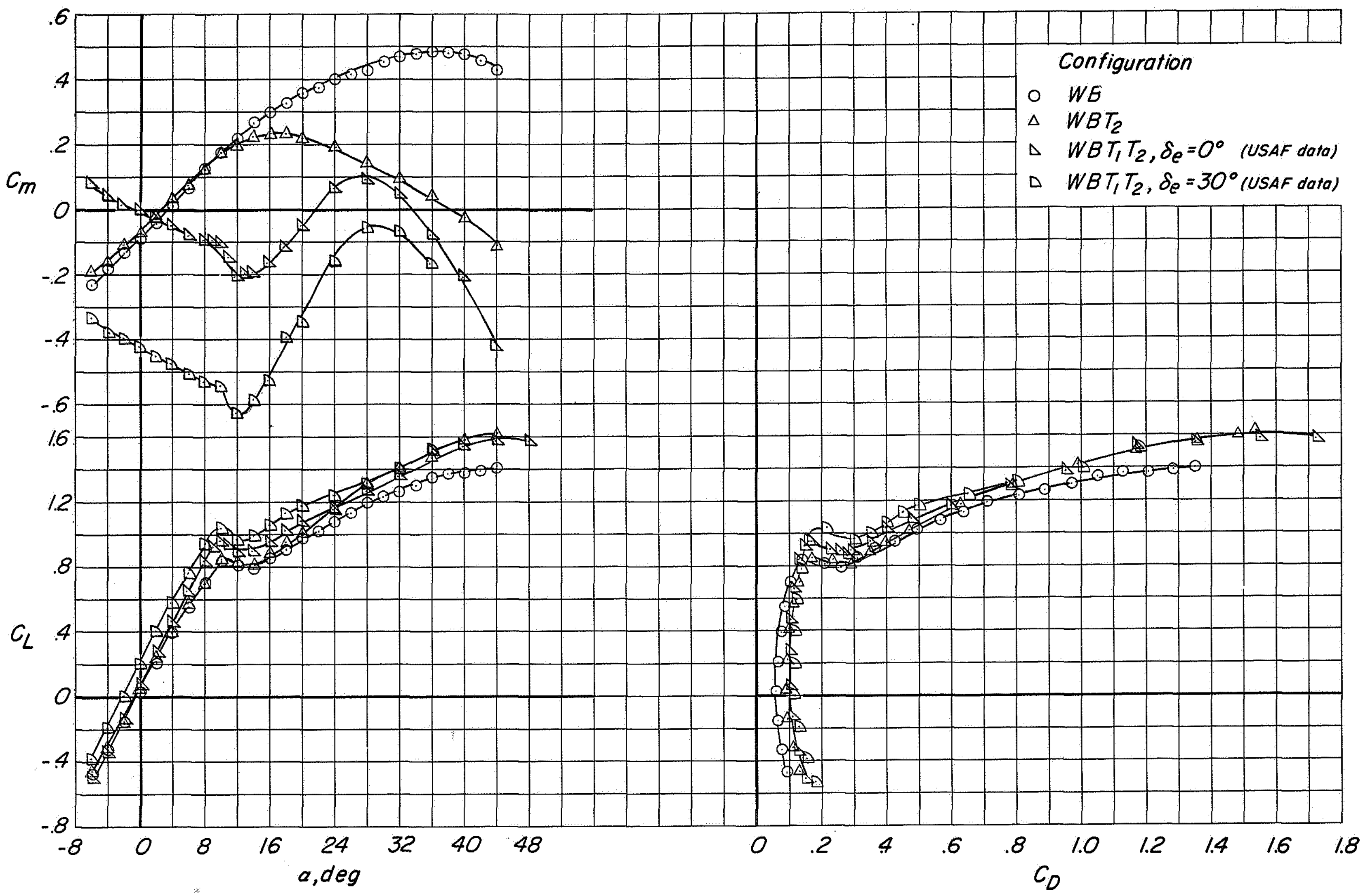
(a) $C_T = 0$.

Figure 5.- Longitudinal characteristics of the basic model showing the effect of maximum elevator deflection.



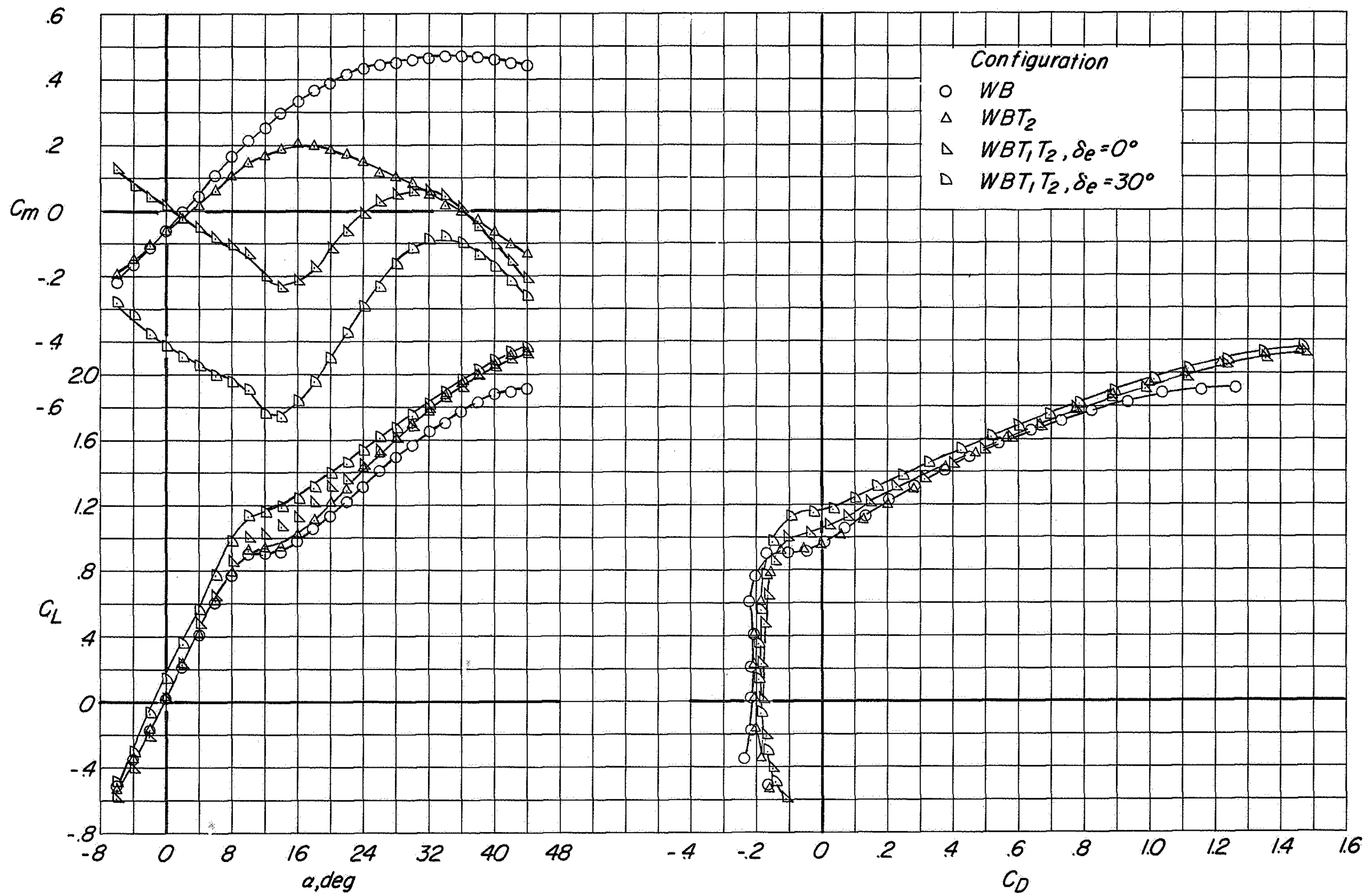
(b) $C_T = 2.60$.

Figure 5.- Concluded.



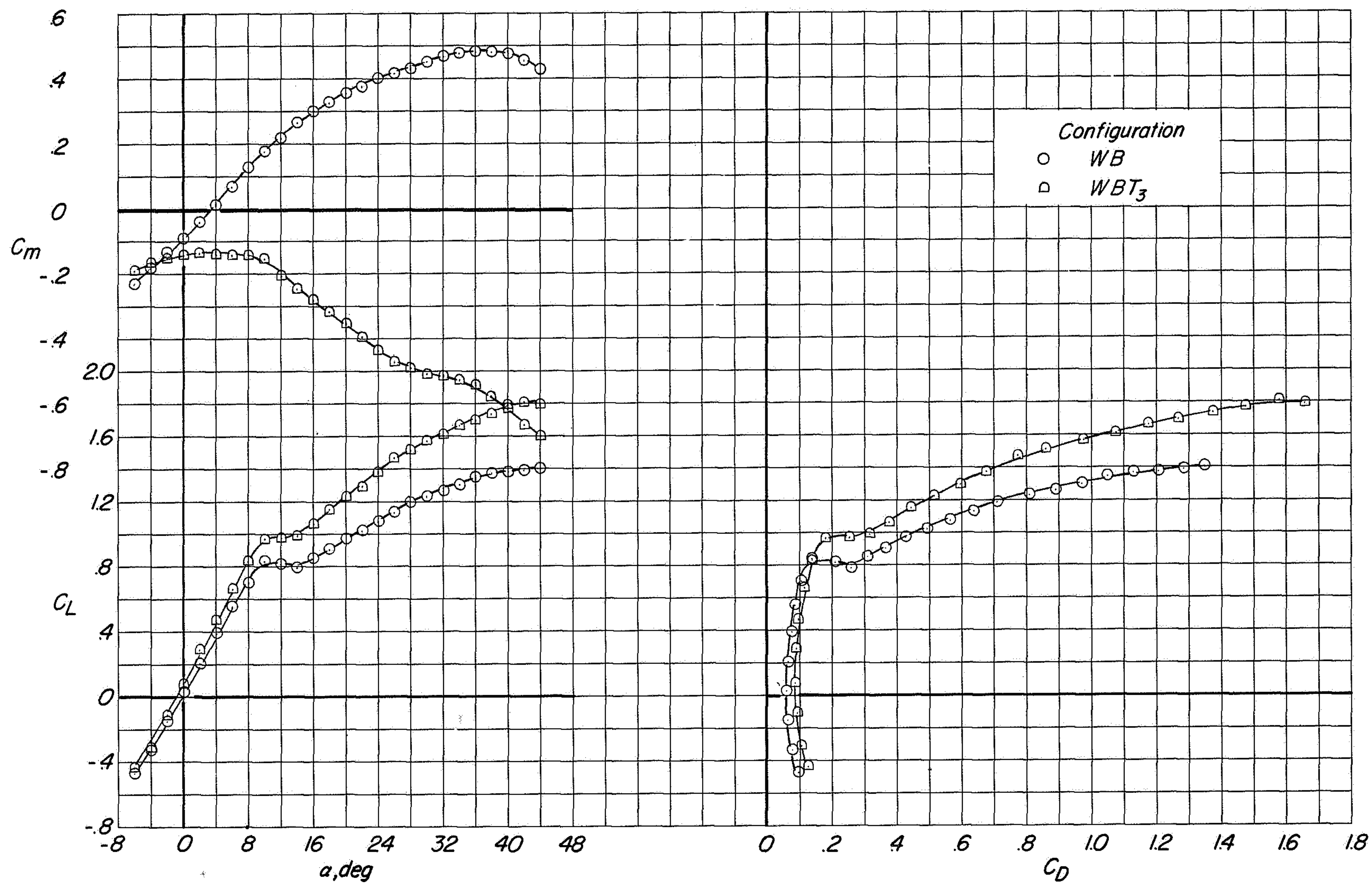
(a) $C_T = 0$.

Figure 6.- Longitudinal characteristics of the basic model with strakes installed.



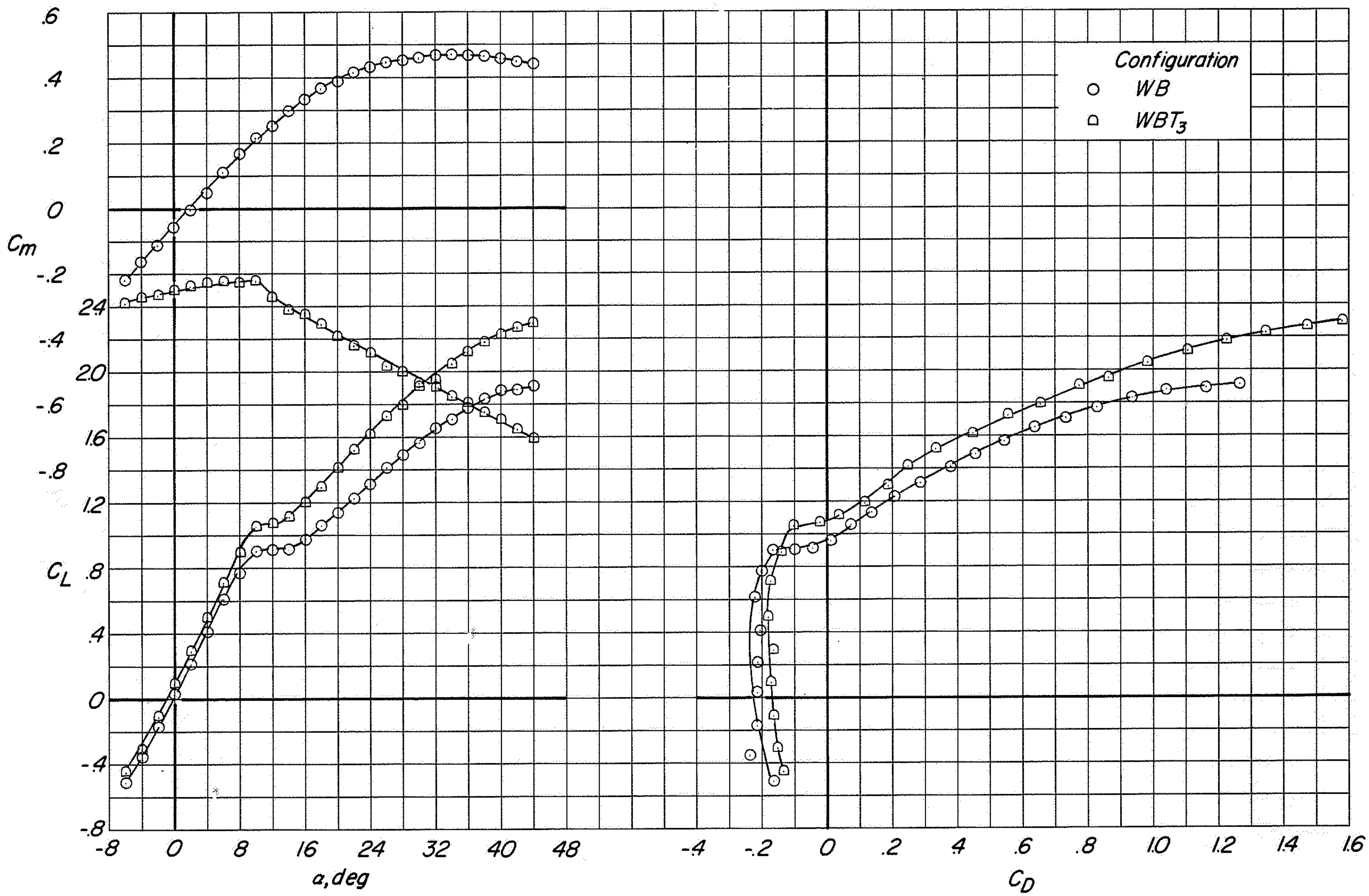
(b) $C_T = 0.38$.

Figure 6.- Concluded.



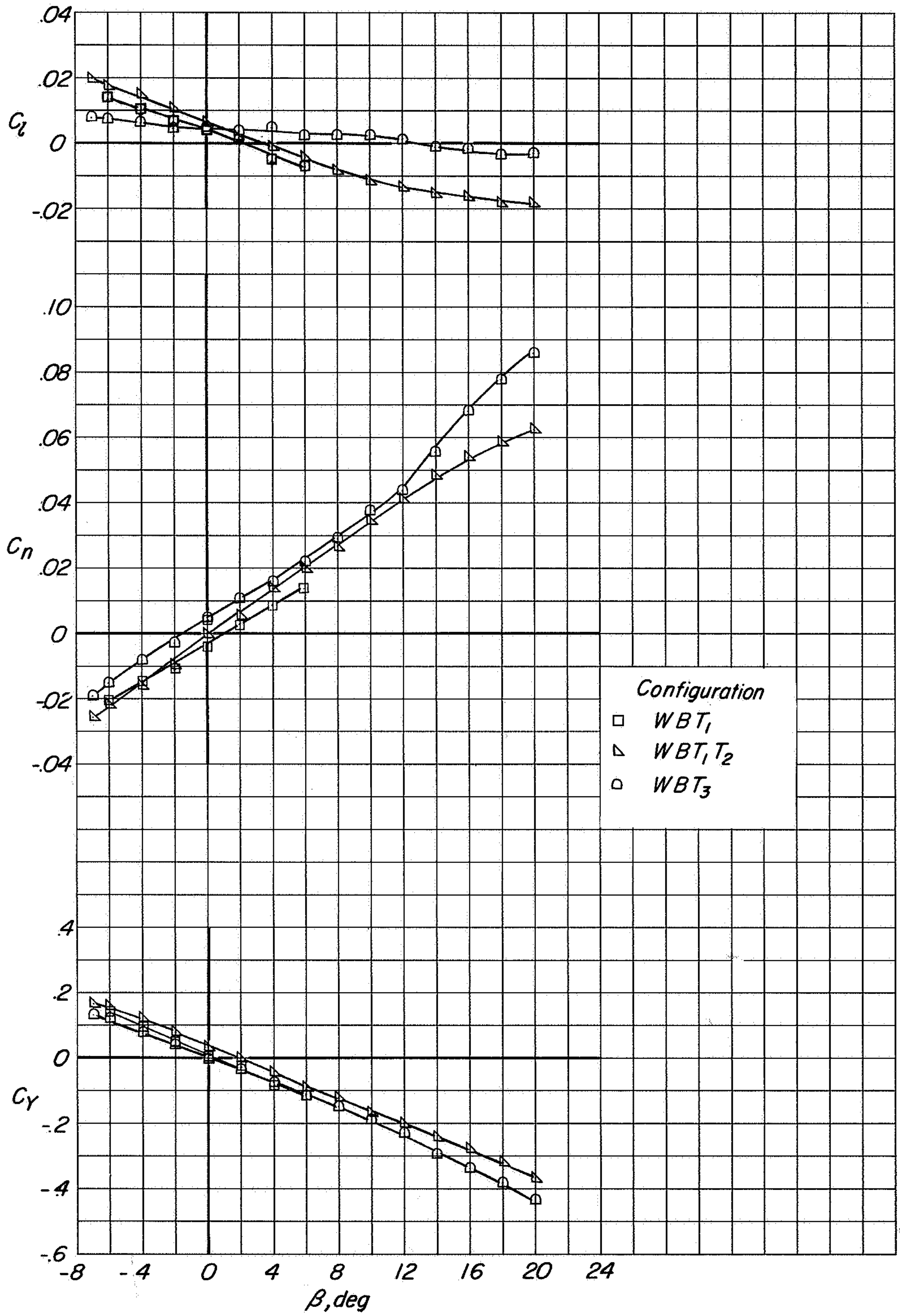
(a) $C_T = 0.$

Figure 7.- Longitudinal characteristics of the basic model with alternate low tail installed.



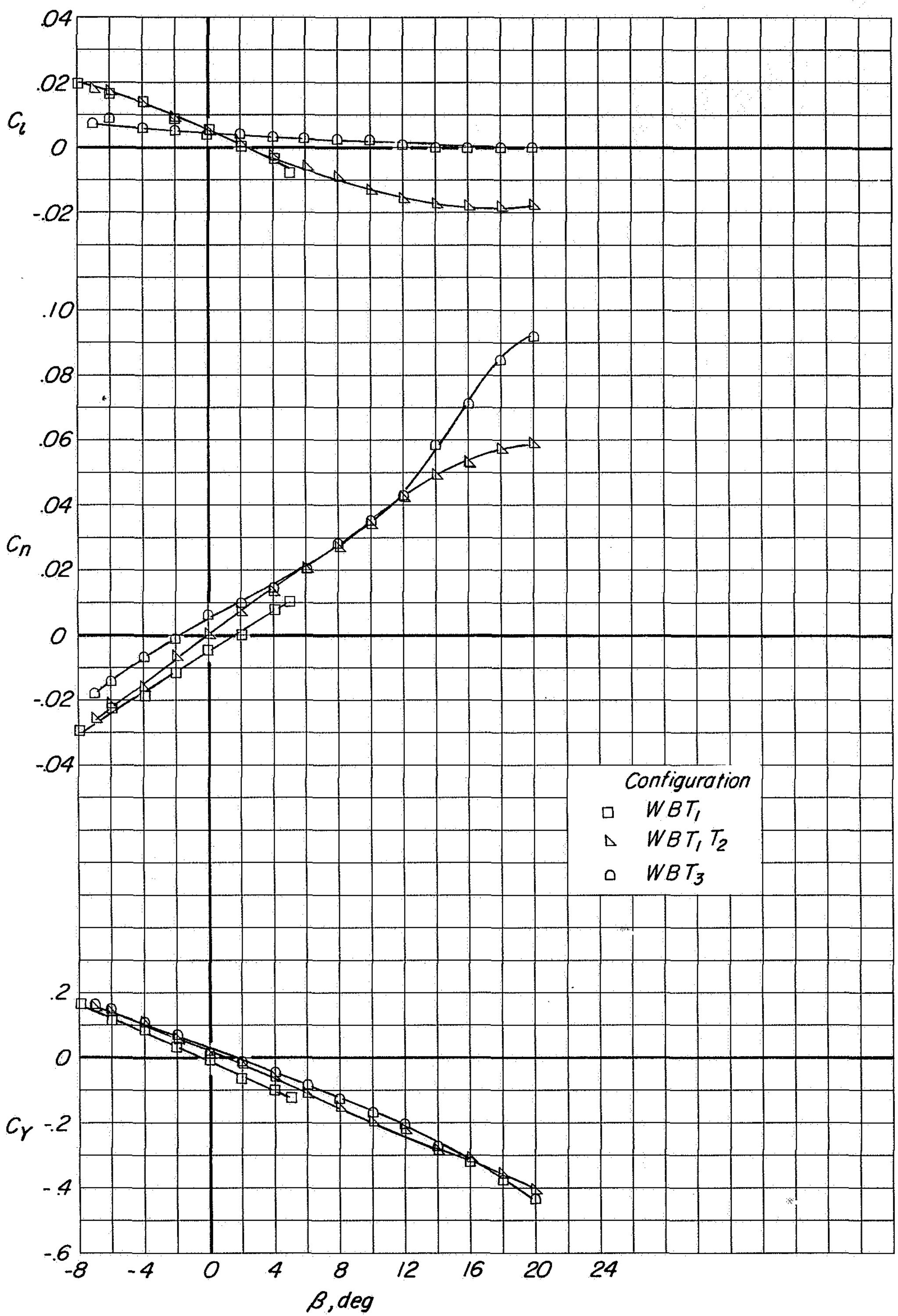
(b) $C_T = 0.38$.

Figure 7.- Concluded.



(a) $C_T = 0$.

Figure 8.- Lateral-directional characteristics showing the effects of tail modifications. $\alpha = 0^0$; $\delta_e = 0^0$.



(b) $C_T = 0.38$.

Figure 8.- Concluded.

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