NACA

RESEARCH MEMORANDUM

A STUDY OF A MISSILE DESIGNED TO FLY AT LOW SPEED WITH ITS LONGITUDINAL AXIS ALINED WITH THE FLIGHT PATH

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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A STUDY OF A MISSILE DESIGNED TO FLY AT LOW SPEED WITH ITS LONGITUDINAL AXIS ALINED WITH THE FLIGHT PATH

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SUMMARY

An experimental investigation was undertaken to explore the practicability of a low-speed missile designed to fly with its longitudinal axis pointing along the flight path. A cruciform arrangement of the wing and tail surfaces was studied, the incidence of the surfaces being selected to trim the missile at the desired normal-force coefficient with the body at an angle of attack of 0°. Maneuvering in the vertical or horizontal planes was to be accomplished by deflection of the wing flaps, a design requirement of the flaps being that they produce no pitching or yawing moment. Two tails of different size were investigated, both in line and interdigitated 45° with respect to the wings. The results include measurements of the normal forces, the pitching moments, and the longitudinal forces at a Mach number of 0.32.

A simplified analysis is given in which the requirements of a low-speed missile designed to fly with its longitudinal axis pointing along the flight path are defined. The method used in arriving at the required wing incidence, tail incidence, and center-of-gravity position for missiles which have nonlinear normal-force curves is described. Finally, it is shown that it is practical to design such a missile.

INTRODUCTION

A design requirement for missiles having fixed target seekers is that the seeker always point along the line of flight. If the target-seeker axis is alined with the longitudinal axis of the missile, then it follows that the body must fly essentially at an angle of attack of 0° and an angle of yaw of 0° in both steady and maneuvering flight. In reference 1 it was shown theoretically that a missile employing a tail can accomplish this by use of variable-incidence wings or by wing controls provided that (1) the center of gravity is so positioned that the wing pitching moment is exactly equal in magnitude but opposite in sign to the tail pitching moment and (2) the wing and tail incidences are set at certain prescribed values. Hereinafter, a missile for which there is no change in pitching moment or yawing moment resulting from a deflection of the wing controls and which always flies with its longitudinal axis pointing along the flight path is referred to as a "self-balancing" missile.

The experimental results presented herein were obtained in one of the Ames 7- by 10-foot wind tunnels. The main emphases of this investigation were directed toward (1) determining the feasibility of a self-balancing missile designed to have plain wing flaps and (2) measuring the forces and moments for such a missile at low subsonic Mach numbers.

NOTATION

C_N normal-force coefficient, $\frac{N}{qS_w}$

$C_{N_{des}}$ design normal-force coefficient for level flight

C_m pitching-moment coefficient, $\frac{M}{qS_w\bar{c}}$

C_X longitudinal-force coefficient, $\frac{X}{qS_w}$

$\bar{c}$ mean aerodynamic chord

i incidence measured between the wing- or tail-chord planes and the body axis (positive with their leading edges above the body axis)

M pitching moment about a lateral axis passing through a point on the body axis at a longitudinal distance from the wing leading edge indicated by the subscript on C_m (positive subscript indicates distance behind the wing leading edge)

N force normal to the lateral plane passing through the body axis

n normal acceleration factor, $\frac{C_N}{C_{N_{des}}} - 1$

q free-stream dynamic pressure

S_t area of one set of tails including the area blanketed by the body

S_W area of one set of wings including the area blanketed by the body

$T_1{}^0$ small tail[1] in line with wing-chord planes, $i_W = 0^0$

$T_2{}^0$ large tail[1] in line with wing-chord planes, $i_W = 0^0$

$T_1{}^{45}$ small tail[1] interdigitated 45^0 with respect to the wing-chord planes, $i_W = 0^0$

$T_2{}^{45}$ large tail[1] interdigitated 45^0 with respect to the wing-chord planes, $i_W = 0^0$

X force parallel to the body axis (positive in the rearward direction)

α angle of attack of the body

δ_f deflection of horizontal-wing flap (positive with the wing trailing edge deflected below the wing-chord plane)

Subscripts

t tail

w wing

MODEL AND APPARATUS

The model was mounted on a sting support in one of the Ames 7- by 10-foot wind tunnels as shown in figure 1. A four-component strain-gage balance attached to the end of the sting and contained within the model was used to measure the aerodynamic forces and moments. Because of the position of the wing-incidence and flap-drive mechanisms within the model, it was necessary to place the pitching-moment strain gage a considerable distance (1.6 mean aerodynamic chords or 16.93 inches) behind the wing leading edge. This necessitated larger moment transfers than are usually required and resulted in greater than normal scatter in the pitching-moment data.

The model had cruciform wings and tails mounted on a body of revolution as shown in figure 2. The wings and tails had the NACA 0012 profile. The wings had an aspect ratio of 3.2, a taper ratio of 1.0, and no sweepback. Two tails having different spans but the same chord were investigated on the model. Each of these tails was tested in line with the

[1]Dimensional data for the tails are given in figure 3.

wing-chord planes, and interdigitated 45° with respect to the wing-chord planes. For changes in the wing and tail incidences these surfaces were pivoted about their quarter-chord lines. End plates which were attached to the wing tips of both the horizontal and vertical wings had the plan form shown in figure 3. The wing flaps had their hinge lines located at 70.2-percent wing chord. Complete dimensional data for the model are given in figure 3.

TEST PROCEDURE

During the first part of the investigation, measurements were made with the angle of attack of the body held at 0° and the wing flaps set at either +15° or -15° for various combinations of wing and tail incidences. Analysis of these data permitted the selection of a wing incidence, a tail incidence, and a center-of-gravity position for which the trimmed normal-force coefficient at an angle of attack of 0° would be 0.2 and for which deflection of the wing flaps to ±15° would produce no pitching moment. For the second part of the investigation measurements were made with the wing and tail surfaces set at these incidences throughout an angle-of-attack range from -6° to 6° for flap deflections of 0°, +15° and -15°. The investigation was conducted at a Mach number of 0.31 which corresponds to a Reynolds number of 1.9 million, based on the mean aerodynamic chord of the wing.

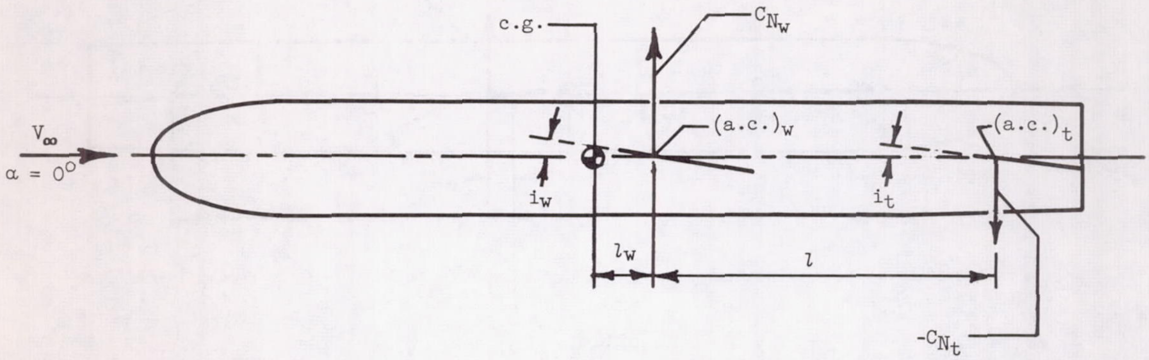
CORRECTIONS

Data presented herein were corrected for wind-tunnel-wall effects by the method of reference 2. The angle of attack was also corrected for deflection of the sting and the strain-gage balance, and the longitudinal-force coefficients were corrected to the condition of ambient static pressure on the base of the model.

RESULTS AND DISCUSSION

Description of a Self-Balancing Missile

This experimental investigation was undertaken primarily to substantiate the hypothesis that it might be possible to design a practical self-balancing missile which would generate its vertical and lateral accelerations from the deflection of the horizontal- and vertical-wing flaps and which would fly essentially at an angle of 0° relative to the flight direction. Requirements for such a missile will be described in the following discussion. To simplify the discussion it will be assumed that (1) all aerodynamic derivatives are constant for small angular deflections, (2) there is no loss in the free-stream dynamic pressure at the tail, (3) the body normal force is included in the wing and tail normal forces, and (4) the wing and tail surfaces have no geometric twist or camber. With these assumptions, consider the vertical forces acting on a self-balancing missile designed to fly with flaps neutral at a particular normal-force coefficient as shown in sketch (a) below:



Sketch (a)

where

c.g. center of gravity position for self-balancing missile

$(a.c.)_w$ aerodynamic center of wing

$(a.c.)_t$ aerodynamic center of tail

C_{N_w} wing normal-force coefficient due to wing incidence

C_{N_t} tail normal-force coefficient due to tail incidence

V_∞ free-stream velocity

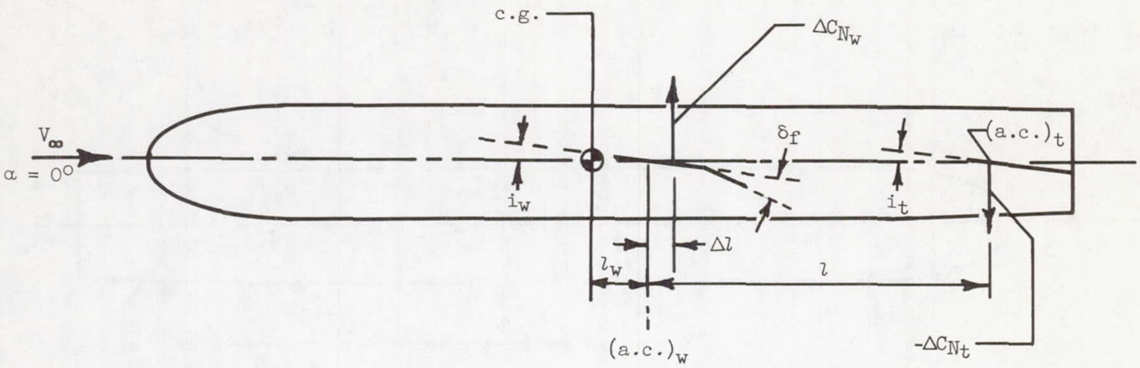
The design normal-force coefficient is

$$C_{N_{des}} = C_{N_w} + C_{N_t}\frac{S_t}{S_w} = \frac{\partial C_{N_w}}{\partial i_w} i_w + \frac{\partial C_{N_t}}{\partial i_t}\left(i_t - \frac{\partial \epsilon}{\partial i_w} i_w\right)\frac{S_t}{S_w} \tag{1}$$

where ϵ is the effective downwash acting on the tail. Also, since the sum of the pitching-moment coefficients must be zero,

$$C_{N_t}\left(\frac{l + l_w}{\bar{c}}\right)\frac{S_t}{S_w} + C_{N_w}\frac{l_w}{\bar{c}} = \frac{\partial C_{N_t}}{\partial i_t}\left(i_t - \frac{\partial \epsilon}{\partial i_w} i_w\right)\left(\frac{l + l_w}{\bar{c}}\right)\frac{S_t}{S_w} + \frac{\partial C_{N_w}}{\partial i_w} i_w \frac{l_w}{\bar{c}} = 0 \tag{2}$$

For accelerated flight[2] an additional condition must be satisfied; namely, that the center of gravity be so positioned that the wing pitching moment due to flap deflection be exactly equal to and opposite in sign to the tail pitching moment produced by the flap deflection. These forces are shown in sketch (b) below:



Sketch (b)

where

ΔC_{N_w} incremental normal-force coefficient on wing due to flap deflection

ΔC_{N_t} incremental normal-force coefficient on tail due to flap deflection

Again the sum of pitching-moment coefficients must be zero:

$$\Delta C_{N_t}\left(\frac{l + l_w}{\bar{c}}\right)\frac{S_t}{S_w} + \Delta C_{N_w}\left(\frac{l_w + \Delta l}{\bar{c}}\right) = \frac{\partial C_{N_t}}{\partial i_t}\left(i_t - \frac{\partial \epsilon}{\partial \delta_f}\delta_f\right)\left(\frac{l + l_w}{\bar{c}}\right)\frac{S_t}{S_w} + \frac{\partial C_{N_w}}{\partial \delta_f}\delta_f\left(\frac{l_w + \Delta l}{\bar{c}}\right) = 0 \tag{3}$$

For a self-balancing missile designed to fly at a given $C_{N_{des}}$, the above three equations can be solved simultaneously for the unknown quantities i_t, i_w, and l_w, since all other quantities can be either measured

[2]Calculations of the change in the angle of attack due to curvature of the flight path of the missile in steady turning accelerated flight in which $n = 2.0$ (where $n = (C_N/C_{N_{des}}) - 1$) indicated that this change would be less than 0.25^o for the missile investigated herein. This angle change was not included in the above analysis since it is considered small enough to ignore.

or predicted. Actually, for a practical missile, the above analysis is oversimplified because the normal-force curves are nonlinear when the flap is deflected.

Experimental Results

The normal-force and pitching-moment results used for establishing the required center-of-gravity position, and for selecting the desired wing incidence and tail incidence for the missile with each of the four tail arrangements are presented in figure 4. The longitudinal-force results are also presented for completeness. For the model with the flap deflected -15°, some nonlinearity can be noted in the variation of normal force with wing incidence which is believed to be associated with flow separation over the flapped wing.

A graphical solution was employed, using the data in figure 4, to arrive at the center-of-gravity position, wing incidence, and tail incidence required for a self-balancing missile. This solution was used instead of a simultaneous solution of equations (1) to (3) because of the above-mentioned nonlinearities. A typical graphical solution for the missile with the small tail in line with the wing is presented in figure 5. The first step was to construct the three-dimensional plot shown on the left-hand side of figure 5. In this plot, average values of the normal-force coefficient for flap deflections of $+15^{\circ}$ and -15° were used. These average values may differ from the normal-force coefficients obtained with the flaps neutral because of the nonlinear variation of normal force with flap deflection. From this three-dimensional plot, the intercept of the surface with the design normal-force coefficient was determined and replotted on the upper right-hand side of figure 5. In this case a design normal-force coefficient of 0.2 was assumed. This plot gives a range of possible combinations of wing and tail incidences required for a $C_{N_{des}} = 0.2$. The next step was to construct four more three-dimensional plots in which the ordinate was the values of pitching-moment or normal-force coefficient corresponding to flap deflections of $+15^{\circ}$ and -15°. From these plots, the normal-force and pitching-moment coefficients corresponding to several of the permitted combinations of wing and tail incidences given at the right top of figure 5 were selected for further analysis. Ratios of these pitching-moment coefficients to normal-force coefficients as a function of i_W are plotted at the lower right-hand side of figure 5. The point of intersection of the two curves gives a common value of wing incidence and a common value of the stability parameter C_m/C_N for the missile with the horizontal-wing flap deflected $+15^{\circ}$ and -15°. With the required wing incidence determined, the corresponding value of the tail incidence can be read from the upper right-hand plot, and from the common value of C_m/C_N the position of the center of gravity to give zero pitching moment can be determined. Thus, the three variables (wing incidence, tail incidence, and center-of-gravity position) necessary to make the missile self balancing have been found.

Tests were then conducted throughout a range of angles of attack with the wing and tail incidences and center-of-gravity positions adjusted to the values determined by the above procedure. Experimental results for the missile with the various tail arrangements are presented in figure 6. It can be noted that the angle of attack for trim is 1° or less for flap deflections of 0°, $+15^\circ$, or -15°, thereby satisfying the requirements for a self-balancing missile. This result substantiates the belief that it is possible to design a low-speed missile which will fly with its longitudinal axis pointing along the flight path even when developing a normal acceleration factor of about 2n.

In the design of a self-balancing missile, many factors must be considered including (1) the amount of longitudinal stability, and (2) the practicability of the center-of-gravity position. The slopes of the pitching-moment curves (dC_m/dC_N) and the center-of-gravity positions required to satisfy the condition of self-balancing for each tail configuration are summarized in the table below:

Tail	$(dC_m/dC_N)_{\alpha=0^\circ}$	Center of gravity from wing leading edge (minus values forward of leading edge)
$T_1{}^{0}$	-0.65	$-0.32\bar{c}$
$T_2{}^{0}$	-1.01	$-.68\bar{c}$
$T_1{}^{45}$	-.38	$.10\bar{c}$
$T_2{}^{45}$	-.57	$-.02\bar{c}$

Ames Aeronautical Laboratory
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REFERENCES

1. Bollay, Dr. William, Feldmann, Dr. Fritz K., Escher, Peter H., and Kendrick, James B.: Feasibility Study of the Dart Anti-Tank Missile. Aerophysics Development Corp. Rep. No. 106-5, Aug. 15, 1952.

2. Swanson, Robert S., and Schuldenfrei, Marvin: Jet-Boundary Corrections to the Downwash Behind Powered Models in Rectangular Wind Tunnels With Numerical Values for 7- by 10-Foot Closed Wind Tunnels. NACA WR L-711, 1942.

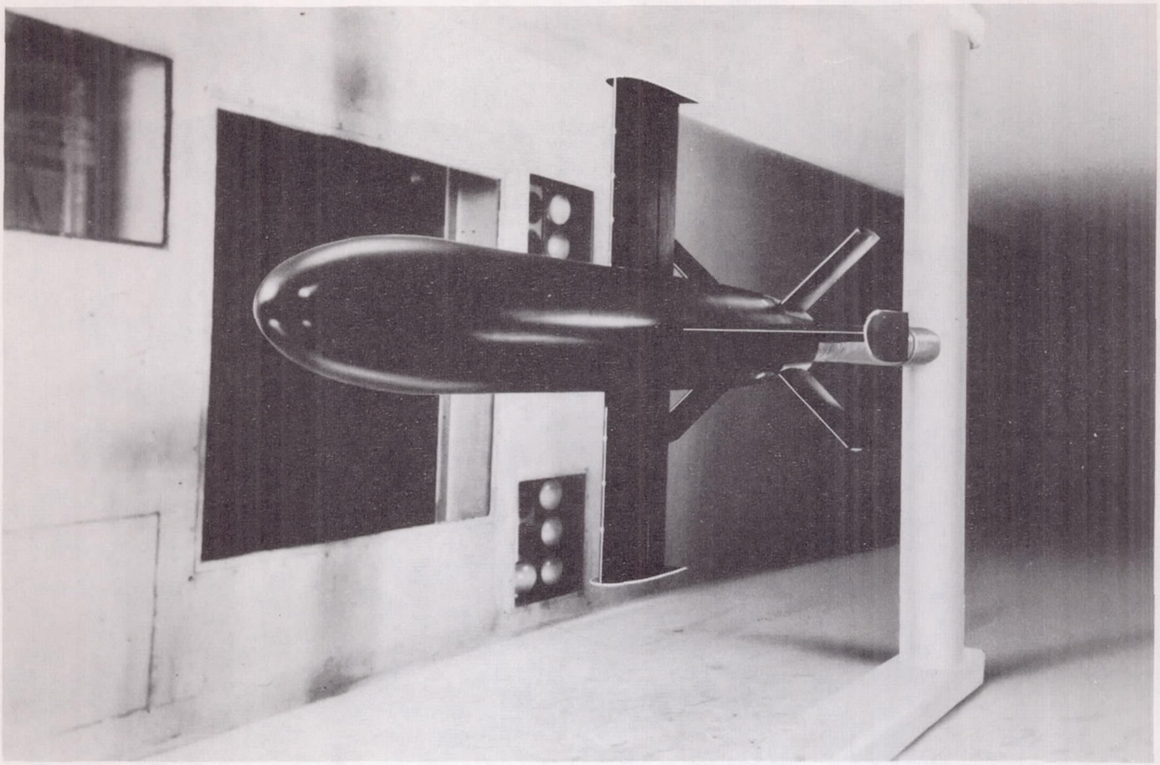

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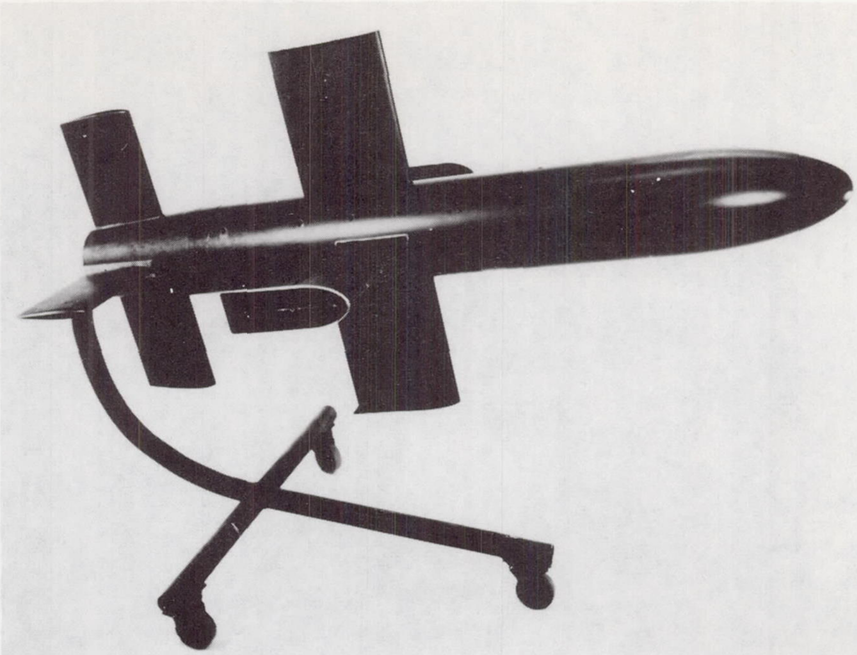
Figure 1.- The missile with the small interdigitated tail mounted in one of the Ames 7- by 10-foot wind tunnels.



(a) Tail in line.

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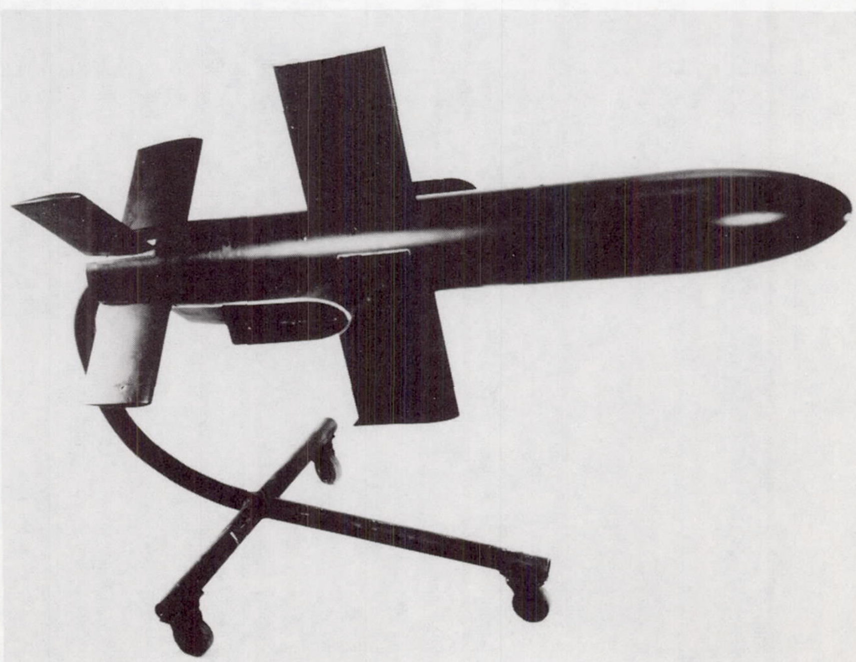

(b) Tail interdigitated 45°.

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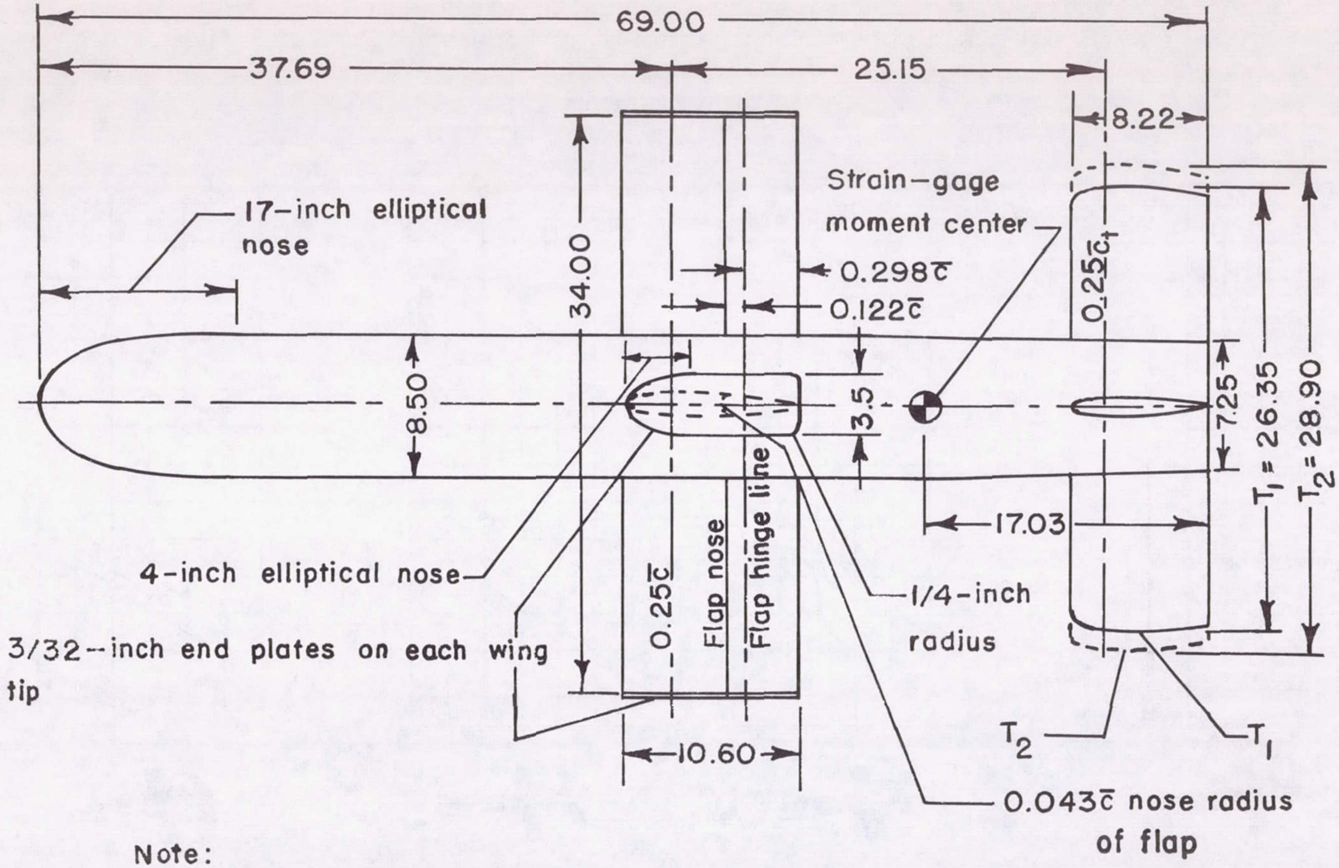
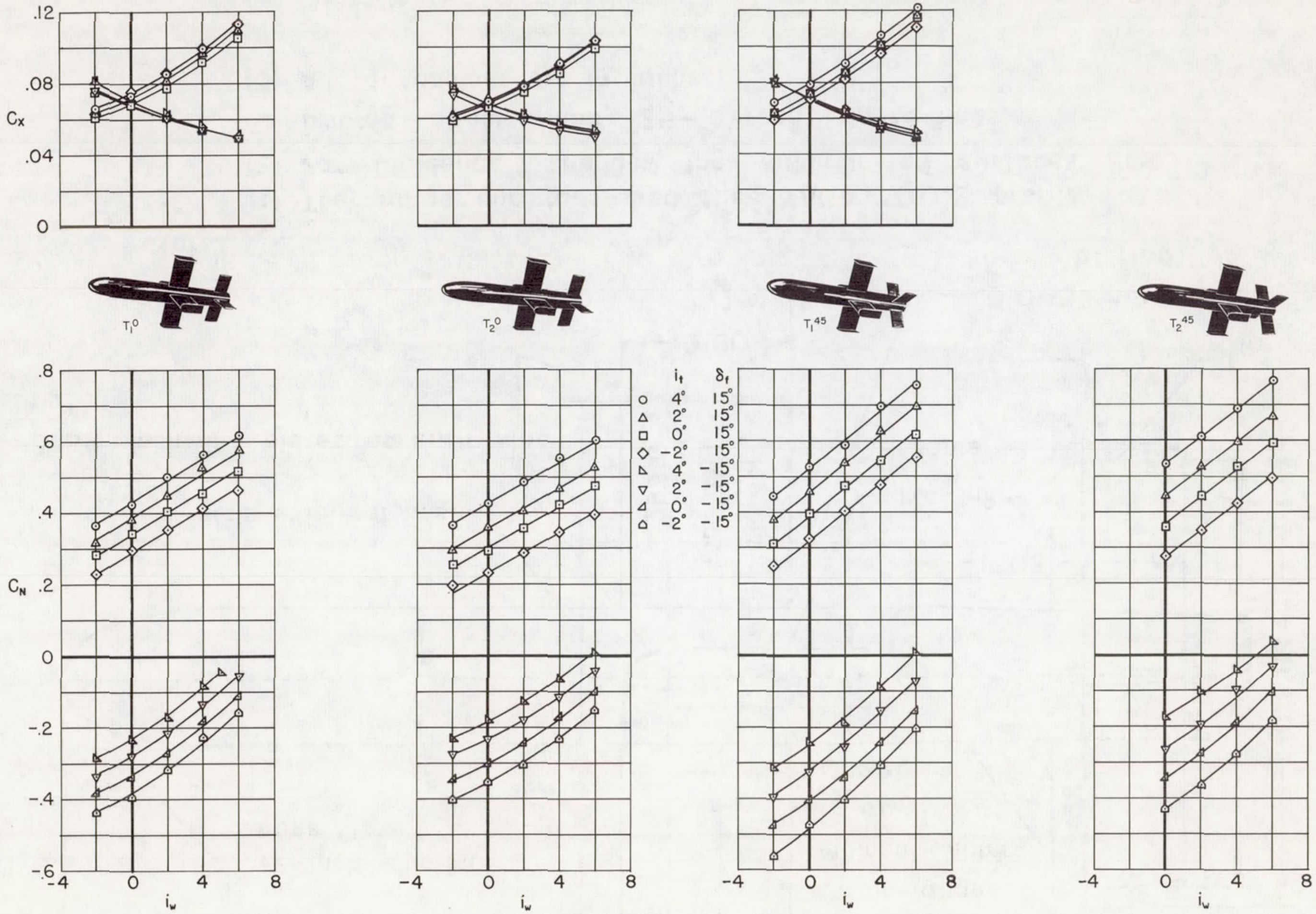
Figure 2.- The missile with the large tail.



Note:

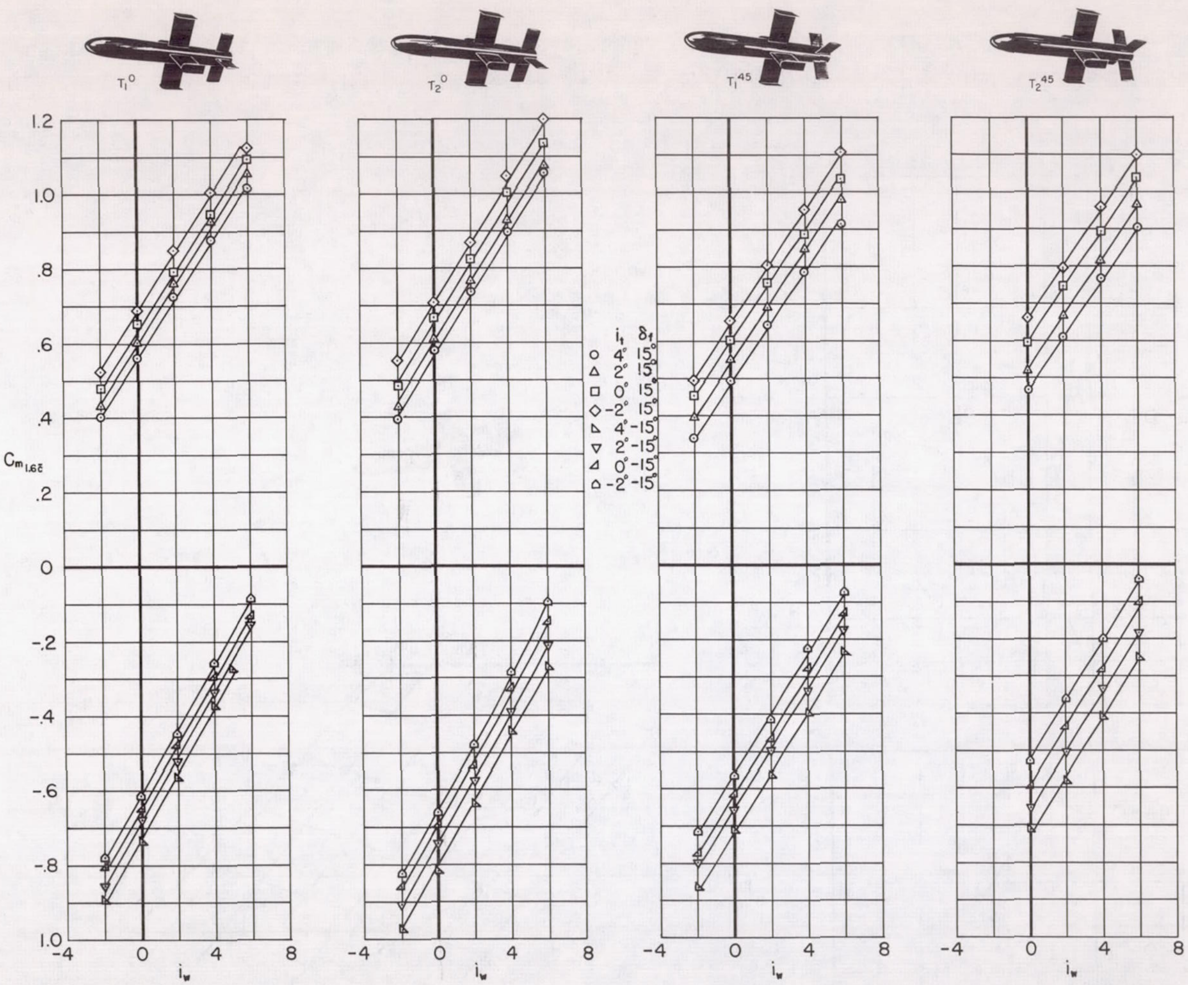
(1) The wings and tails had the NACA 0012 profile.
(2) For incidence changes the wing or tail surfaces were pivoted about their 25-percent chord lines.
(3) All dimensions are in inches.

Figure 3.- Dimensional data for the missile.



(a) C_N and C_X vs. i_w

Figure 4.- Variation with wing incidence of normal-force, longitudinal-force, and pitching-moment coefficients for the missile with the various tail configurations; $\alpha = 0^{\circ}$.



(b) $C_{m_{1.6\bar{c}}}$ vs. i_W

Figure 4.- Concluded.

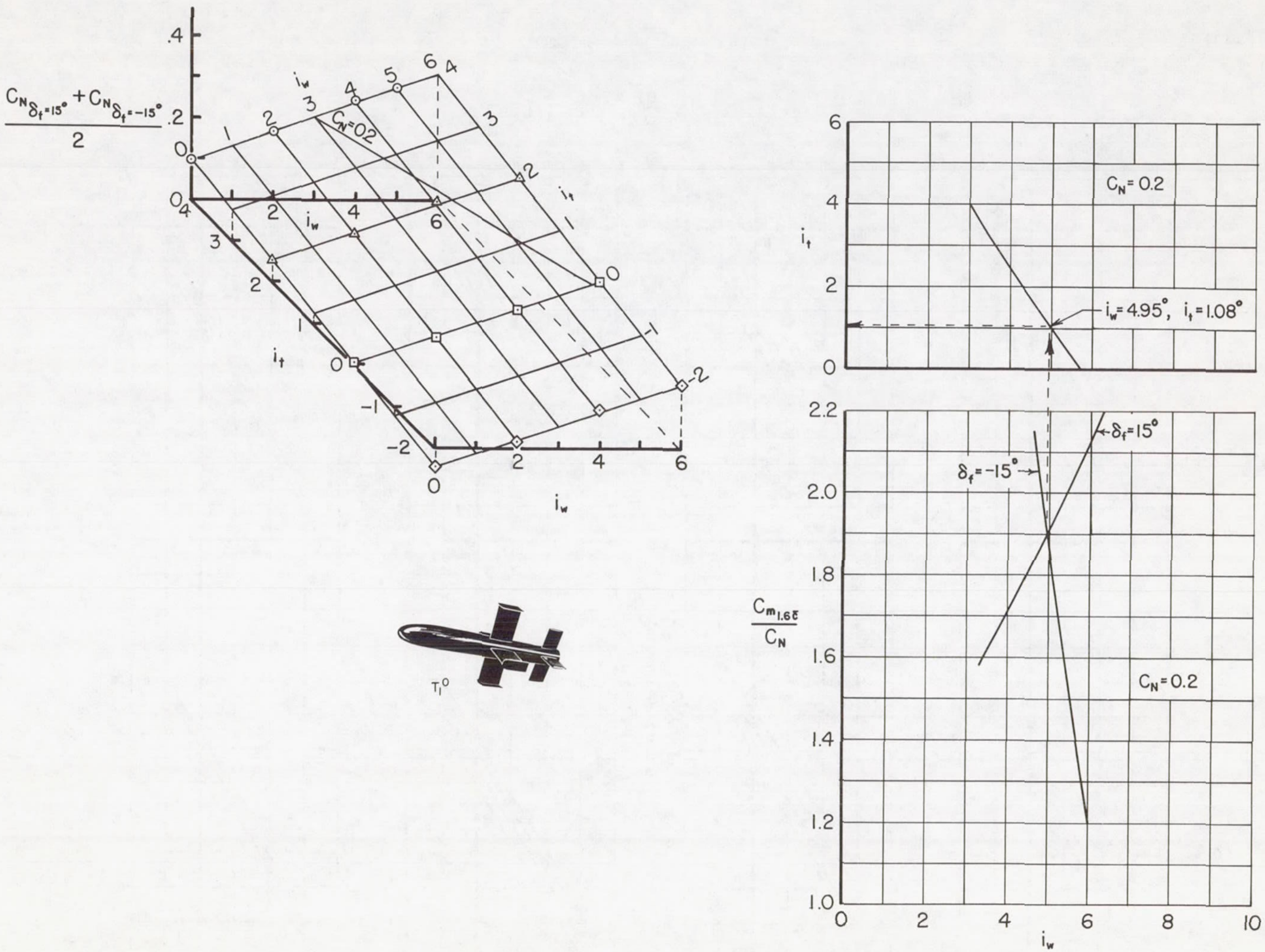
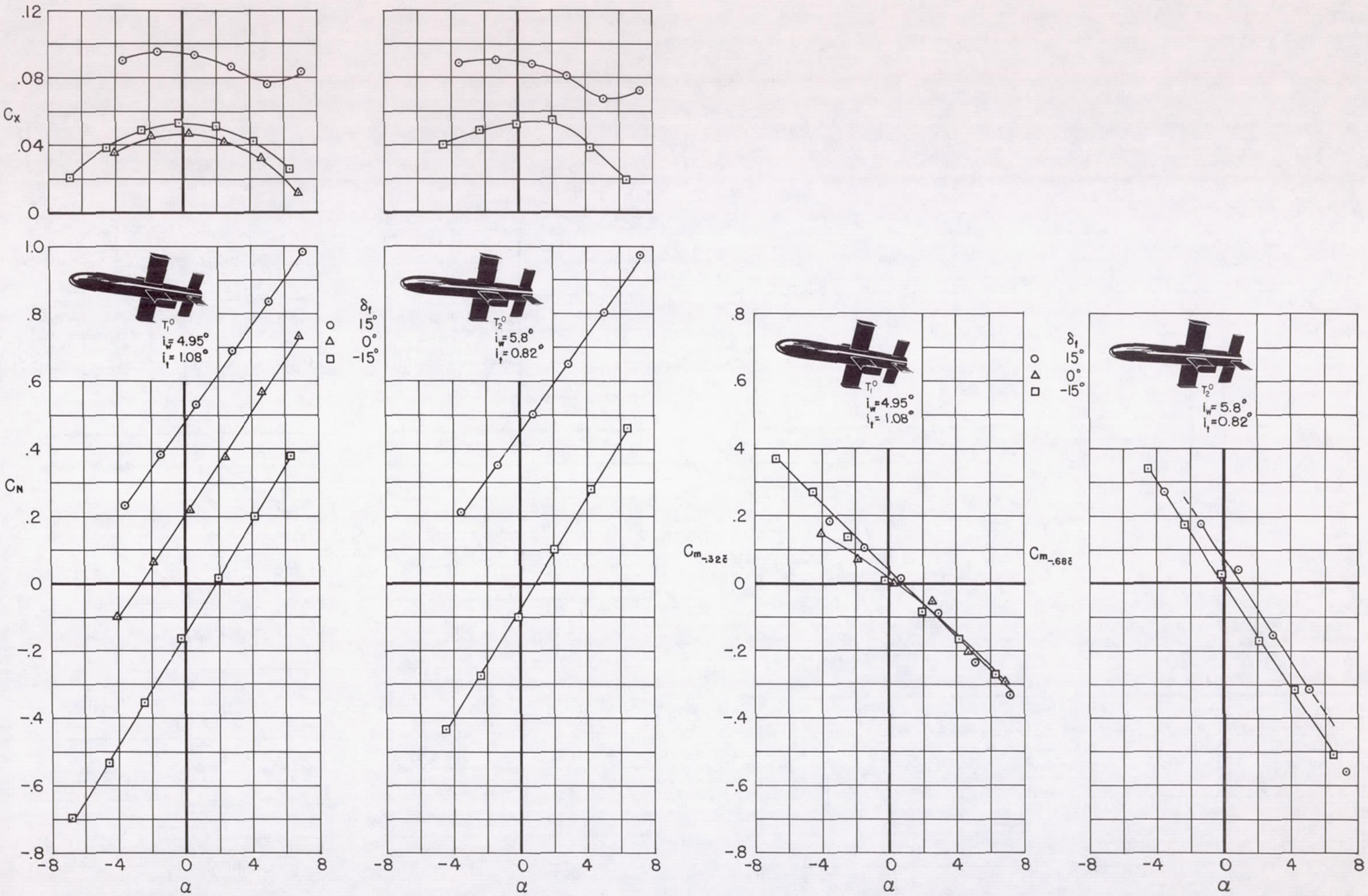
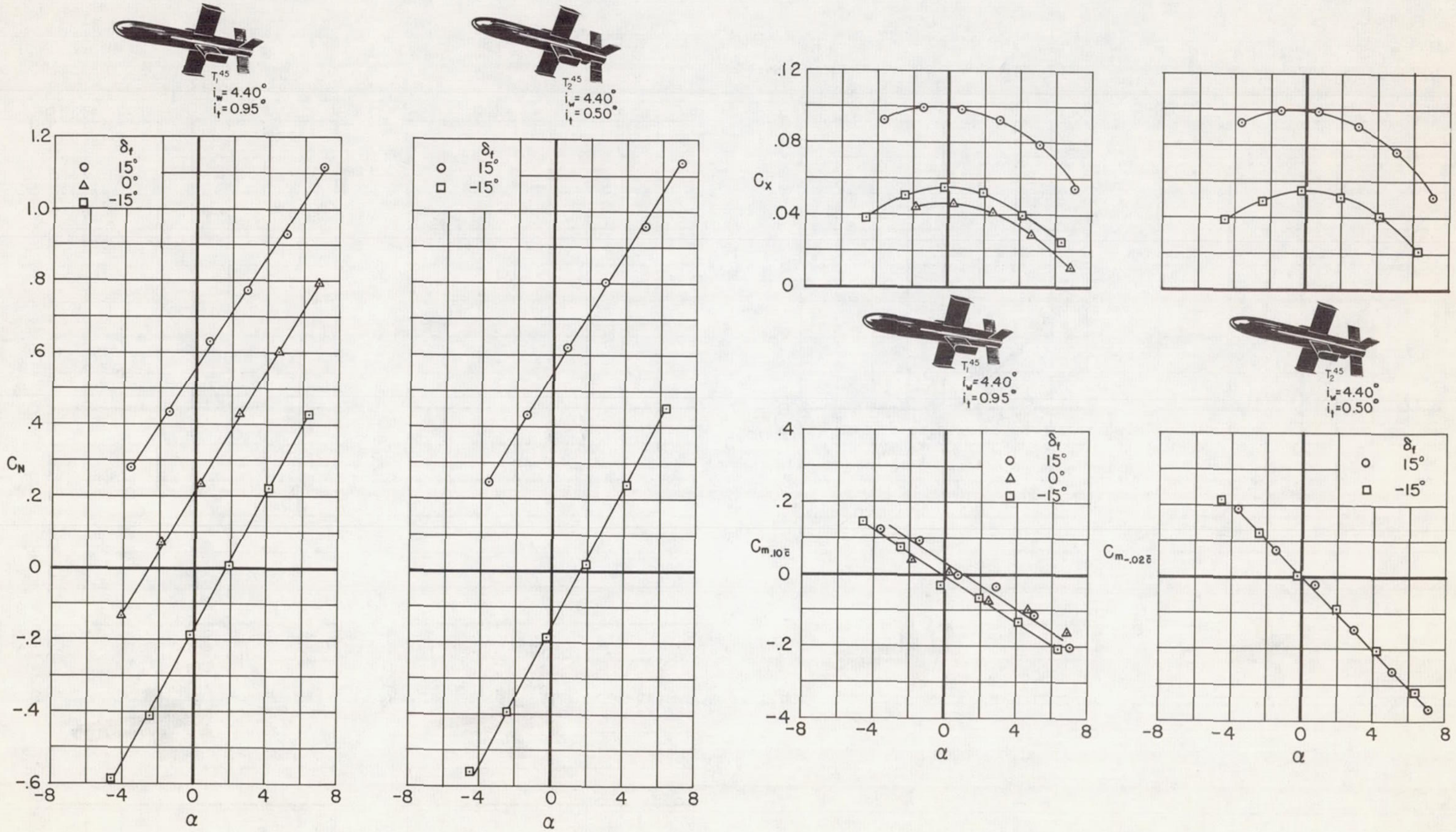


Figure 5.- Curves used in determining the wing and tail incidences and the center-of-gravity position for the missile with the small tail in line with the wing; $\alpha = 0^{\circ}$.



(a) Tail in line with wing.

Figure 6.- Variation of normal-force, longitudinal-force, and pitching-moment coefficients with angle of attack for the missile with the various tail configurations.



(b) Tail interdigitated 45° with respect to the wing.

Figure 6.- Concluded.