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SUPERSONIC AERODYNAMIC DAMPING AND OSCILLATORY STABILITY IN PITCH AND YAW FOR A MODEL OF A VARIABLE-SWEEP FIGHTER AIRPLANE WITH TWIN VERTICAL TAILS

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16. Abstract

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The results of the investigation indicate that the basic configuration has positive damping and positive oscillatory stability in pitch for all test conditions. In yaw, the damping is generally positive except near an angle of attack of 0° at a Mach number of 1.60. The oscillatory stability in yaw is positive except at angles of attack above 16° at Mach numbers of 2.02 and 2.36. The addition of external stores generally causes increases in both pitch and yaw damping. The oscillatory stability in pitch is reduced throughout the angle-of-attack range by the addition of the external stores. The effect of adding stores on the oscillatory stability in yaw is a function of angle of attack and Mach number. The effect of changing horizontal-tail incidence on the pitch parameters is also very dependent on angle of attack and Mach number.

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SUMMARY

Wind-tunnel measurements of the aerodynamic damping and oscillatory stability in pitch and yaw for a 1/22-scale model of a proposed carrier-based variable-sweep fighter airplane have been made by using a small-amplitude forced-oscillation technique. Tests were made with a wing leading-edge sweep angle of 68° at angles of attack from about -1.5° to 15.5° at a Mach number of 1.60 and at angles of attack from about -3° to 21° at Mach numbers of 2.02 and 2.36.

The results of the investigation indicate that the basic configuration has positive damping and positive oscillatory stability in pitch for all test conditions. In yaw, the damping is generally positive except near an angle of attack of 0° at a Mach number of 1.60. The oscillatory stability in yaw is positive except at angles of attack above 16° at Mach numbers of 2.02 and 2.36. The addition of external stores generally causes increases in both pitch and yaw damping. The oscillatory stability in pitch is reduced throughout the angle-of-attack range by the addition of the external stores. The effect of adding stores on the oscillatory stability in yaw is a function of angle of attack and Mach number. The effect of changing horizontal-tail incidence on the pitch parameters is also very dependent on angle of attack and Mach number.

INTRODUCTION

Studies are being made by the National Aeronautics and Space Administration to determine the aerodynamic characteristics of a proposed carrier-based variable-sweep fighter airplane. As a part of these studies, wind-tunnel measurements of the aerodynamic damping and oscillatory stability characteristics are being made at subsonic, transonic, and supersonic speeds.

This paper presents the damping and oscillatory stability results in pitch and yaw for a 1/22-scale model of the proposed airplane obtained at supersonic speeds in the Langley Unitary Plan wind tunnel. The tests were made at Mach numbers from 1.60 to

2.36 at angles of attack from approximately -3° to 21° by using a small-amplitude forced-oscillation technique.

COEFFICIENTS AND SYMBOLS

Measurements were made and are presented herein in the International System of Units (SI). Details concerning the use of SI, together with physical constants and conversion factors, are given in reference 1.

The aerodynamic parameters, which are referred to the body system of axes, are shown in figure 1. These axes originate at the oscillation center of the model as shown in the drawings which are presented in figure 2(a). The longitudinal location of the oscillation center is coincident with the 16.5 percent mean geometric chord station with the wing in the 20° sweep position. The reference dimensions are based on the geometric characteristics of the wing of the model in the 20° sweep position.

b	span, 0.8885 meter
$\bar{c}$	mean geometric chord, 0.1358 meter
f	frequency of oscillation, hertz
i_t	tail incidence, degrees
k	reduced-frequency parameter $\left(\frac{\omega\bar{c}}{2V}, \text{ in pitch; } \frac{\omega b}{2V}, \text{ in yaw}\right)$, radians
M	free-stream Mach number
q	angular velocity about Y-axis, radians/second
q_{∞}	free-stream dynamic pressure, newtons/meter^2
R	Reynolds number based on $\bar{c}$
r	angular velocity about Z-axis, radians/second
S	area, 0.1085 meter^2
V	free-stream velocity, meters/second

α angle of attack, degrees or radians, or mean angle of attack, degrees

β angle of sideslip, radians

ω angular velocity, $2\pi f$, radians/second

C_m pitching-moment coefficient, $\frac{\text{Pitching moment}}{q_\infty S\bar{c}}$

$C_{m_q} = \frac{\partial C_m}{\partial\left(\frac{q\bar{c}}{2V}\right)}$, per radian

$C_{m_{\dot{q}}} = \frac{\partial C_m}{\partial\left(\frac{\dot{q}\bar{c}^2}{4V^2}\right)}$, per radian

$C_{m_q} + C_{m_{\dot{\alpha}}}$ damping-in-pitch parameter, per radian

$C_{m_\alpha} = \frac{\partial C_m}{\partial \alpha}$, per radian

$C_{m_{\dot{\alpha}}} = \frac{\partial C_m}{\partial\left(\frac{\dot{\alpha}\bar{c}}{2V}\right)}$, per radian

$C_{m_\alpha} - k^2 C_{m_{\dot{q}}}$ oscillatory longitudinal stability parameter, per radian

C_n yawing-moment coefficient, $\frac{\text{Yawing moment}}{q_\infty Sb}$

$C_{n_r} = \frac{\partial C_n}{\partial\left(\frac{rb}{2V}\right)}$, per radian

$C_{n_{\dot{r}}} = \frac{\partial C_n}{\partial\left(\frac{\dot{r}b^2}{4V^2}\right)}$, per radian

$C_{n_r} - C_{n_{\dot{\beta}}} \cos\alpha$ damping-in-yaw parameter, per radian

$C_{n_\beta} = \frac{\partial C_n}{\partial \beta}$, per radian

$C_{n_{\dot\beta}} = \frac{\partial C_n}{\partial\left(\frac{\dot\beta b}{2V}\right)}$, per radian

$C_{n_\beta} \cos \alpha + k^2 C_{n_{\dot r}}$ oscillatory directional stability parameter, per radian

A dot over a quantity indicates a first derivative with respect to time. The expression "cos α" appears in the lateral parameters since these parameters are referred to the body-system axes.

MODEL AND APPARATUS

Model

The model which was tested is a 1/22-scale version of the proposed variable-sweep airplane and is geometrically similar to the proposed airplane except for aft fuselage modifications necessary for sting clearance. Drawings of the model showing important design dimensions are presented in figure 2 and photographs of the model are presented in figure 3. Additional information on the geometric characteristics of the wings, vertical tails, and horizontal tails is presented in tables I, II, and III, respectively.

The model was tested with the wings in the 68° sweep position and with the vanes extended from the fixed inboard wing panels as shown in figure 2(a). Details of the wing in the reference 20° sweep position are given in figure 2(b) and in table I. The flow-through ducts shown in the photographs of figures 3(d) and 3(e) have two-dimensional inlets and are canted up 0° 44' and out 0° 51' at the exit plane.

The twin vertical tails are mounted on the duct center lines with 5° outboard cant. Details of the vertical tails are given in figure 2(c) and in table II. Details of the horizontal tails, which can be set at 0°, -10°, or -20° incidence, are given in figure 2(d) and in table III. Details of the twin ventral fins are given in figure 2(e).

Store configurations consisted of two nacelle-mounted fuel tanks and two missiles mounted on the fixed inboard wing panels. Details of store geometry and location are shown in figures 3(c) and 3(d).

Three-dimensional roughness in the form of sparsely distributed No. 60 carborundum grains was applied to the wings, vertical and horizontal tails, and ventral fins in bands 0.16 cm wide located approximately 1 cm from the leading edges in the streamwise direction. Similar bands were applied to the engine inlets and to the vanes extending from the fixed inboard wing panels. Individual particles of No. 45 carborundum grains spaced approximately 0.16 cm apart were applied to the fuselage in a ring approximately 3 cm from the nose. The size and location of the roughness were computed by using the method of reference 2 to insure a turbulent boundary layer aft of the applied roughness.

Oscillation-Balance Mechanism

A view of the forward section of the oscillation-balance mechanism which was used for these tests is presented in figure 4. Since the oscillation amplitude is small, the rotary motion of a variable-speed electric motor is used to provide essentially sinusoidal motion to the balance through the crank and crosshead mechanism. Amplitudes from near zero to about 2° can be obtained by using cranks having different throws. An amplitude of slightly less than 1° was used for this investigation. The oscillatory motion is about the pivot axis shown in figure 4 which was located at the model station identified as "oscillation center and center of moments" in figures 1 and 2(a).

The strain-gage bridge which measures the torque required to oscillate the model is located between the model attachment surface and the pivot axis. This torque-bridge location eliminates the effects of pivot friction and the necessity to correct the data for the changing pivot friction associated with changing aerodynamic loads. Although the torque bridge is physically forward of the pivot axis, the electrical center of the bridge is located at the pivot axis so that all torques are measured with respect to the pivot axis.

A mechanical spring, which is an integral part of the fixed balance support, is connected to the oscillation balance at the point of model attachment by means of a flexure plate. After assembly of the oscillation balance and fixed-balance support, the mechanical spring and flexure plate were electron-beam welded in place in order to minimize mechanical friction. A strain-gage bridge, fastened to the mechanical spring, provides a signal proportional to the model angular displacement with respect to the sting.

Although the forced-oscillation balance may be oscillated through a frequency range from near zero to about 30 Hz, as noted in reference 3, the most accurate measurements of the damping coefficient are obtained at the frequency of velocity resonance. For these tests, the frequency of oscillation varied from 2.67 Hz to 8.50 Hz.

Wind Tunnel

The data presented herein were obtained in test section 1 of the Langley Unitary Plan wind tunnel. This single-return tunnel has a test section about 1.2 meters square and about 2.1 meters long. An asymmetric sliding block is used to vary the area ratio in order to change the Mach number from about 1.47 to 2.87. The angle-of-attack mechanism which was used for these tests had a total range of about 25° when used in conjunction with the oscillation-balance mechanism. A more complete description of the Langley Unitary Plan wind tunnel is given in reference 4.

MEASUREMENTS AND REDUCTION OF DATA

For the pitching tests, measurements were made of the amplitude of the torque required to oscillate the model in pitch T_y, the amplitude of the angular displacement in pitch ϕ, the phase angle η between T_y and ϕ, and the angular velocity of the forced oscillation ω. Reference 5 gives the method of making these measurements and the procedure to calculate the oscillatory pitch parameters, $C_{m_q} + C_{m_{\dot{\alpha}}}$ and $C_{m_\alpha} - k^2 C_{m_{\dot{q}}}$, from these measurements.

For the yawing tests, measurements were made of the amplitude of the torque required to oscillate the model in yaw T_z, the amplitude of the angular displacement in yaw of the model ψ, the phase angle λ between T_z and ψ, and the angular velocity of the forced oscillation ω. Again reference 5 shows the procedure to calculate the oscillatory yaw parameters, $C_{n_r} - C_{n_{\dot{\beta}}} \cos \alpha$ and $C_{n_\beta} \cos \alpha + k^2 C_{n_{\dot{r}}}$, from these measurements.

DATA CORRECTIONS AND PRECISION

Effects due to aft fuselage modifications necessary for sting clearance and effects due to model-support interference are assumed to be small and no corrections for these effects have been made to the data. The values of α (mean angle of attack for the tests in pitch and angle of attack for the tests in yaw) have been corrected for flow angularity in the test section as follows:

Mach number, M	Flow angularity correction, deg
1.60	0.45
2.02	1.25
2.36	1.35

These corrections apply for a model at a given tunnel station at the vertical center of the test section; however, since the model was never far from the tunnel center line because of the small angle-of-attack range, the corrections were applied to all the measured values of α as a first-order correction.

For the data presented herein, values of the probable error of the various quantities are as follows:

	Probable error
Mach number, M	± 0.002
Angle of attack or mean angle of attack, α, deg	± 0.3
Reynolds number, R	$\pm 0.002 \times 10^6$
Damping-in-pitch parameter, $C_{m_q} + C_{m_{\dot{\alpha}}}$, per radian	± 0.5
Oscillatory longitudinal stability parameter, $C_{m_\alpha} - k^2 C_{m_{\dot{q}}}$, per radian	± 0.003
Reduced-frequency parameter in pitch, k, radians	± 0.00001
Damping-in-yaw parameter, $C_{n_r} - C_{n_{\dot{\beta}}} \cos \alpha$, per radian	± 0.07
Oscillatory directional stability parameter, $C_{n_\beta} \cos \alpha + k^2 C_{n_{\dot{r}}}$, per radian	± 0.001
Reduced-frequency parameter in yaw, k, radians	± 0.0001

TESTS

The dynamic-stability parameters in pitch were measured through a range of mean angle of attack at an angle of sideslip of 0° with the model oscillating in pitch about the body Y-axis. The forward section of the oscillation-balance mechanism was rolled 90° within the model to provide model oscillations in yaw about the body Z-axis. The dynamic-stability parameters in yaw were then measured through a range of angle of attack at a mean angle of sideslip of 0°. The tests were made at oscillation amplitudes of 0.95° to 0.98°. Tunnel stagnation temperature was held constant at 333° K. Stagnation pressure and Reynolds number based on the mean geometric chord of the wing in the 20° sweep position for the various Mach numbers were, except as noted, as follows:

Mach number, M	Stagnation pressure, kN/m^2	Reynolds number, R
1.60	67.1	1.12×10^6
2.02	77.3	1.10
2.36	91.7	1.10

The angle of attack was varied from about -3° to 21° except at $M = 1.60$ where angle of attack was restricted to a range from about -1.5° to about 15.5° because of shock reflections from the tunnel walls.

The reduced-frequency parameter varied from 0.0033 to 0.0076 in pitch and from 0.0136 to 0.0359 in yaw. As previously mentioned, all tests were made with the vanes extended from the fixed inboard wing panels as shown in figure 2(a) and with bands of three-dimensional roughness applied to the model to insure a turbulent boundary layer.

Horizontal-tail, vertical-tail, and ventral-fin effectiveness as well as the effect of horizontal-tail incidence were investigated.

RESULTS AND DISCUSSION

Longitudinal Stability Characteristics

Longitudinal stability parameters.- The damping-in-pitch parameter $C_{m_q} + C_{m_{\dot{\alpha}}}$ is a measure of the effective damping experienced by the model while being forced to oscillate through an angle-of-attack range from $\alpha - \theta$ to $\alpha + \theta$, where α is the mean angle of attack and θ is the amplitude of the forced oscillation. Since θ is small, the value of $C_{m_q} + C_{m_{\dot{\alpha}}}$ is essentially a measure of the damping at a discrete angle of attack. A negative value of $C_{m_q} + C_{m_{\dot{\alpha}}}$ at any mean angle of attack α indicates that the model experiences a net positive aerodynamic damping in pitch during the oscillations about that value of α.

The oscillatory longitudinal stability parameter $C_{m_\alpha} - k^2 C_{m_{\dot{q}}}$ is a function of the variation of oscillatory pitching moment with angle of attack through the angle-of-attack range from $\alpha - \theta$ to $\alpha + \theta$. A negative value of this parameter at any mean angle of attack α indicates that the oscillating model is aerodynamically stable with respect to that α.

Basic characteristics.- The longitudinal stability parameters for the basic configuration with $i_t = 0^\circ$ are shown in figure 5. The damping in pitch is always positive and generally shows an increase with increasing α above $\alpha = 12^\circ$. The dependence of damping on Mach number is generally small and inconsistent with α. The oscillatory stability decreases with increasing Mach number except at the highest values of α. Generally, similar trends in both damping and oscillatory stability are reported in reference 5 for a similar configuration over a similar Mach number and angle-of-attack range.

Effect of horizontal-tail incidence.- The effect of increase in horizontal-tail incidence from 0° to -10° and -10° to -20° on the damping in pitch is erratic and inconsistent for the Mach number angle-of-attack range covered (fig. 6). The oscillatory stability decreases slightly as tail incidence is increased near an angle of attack of 0° and at the higher angles of attack at Mach numbers of 2.02 and 2.36.

Effect of stores.- Although having no pronounced effects, the addition of the missiles and nacelle-mounted tanks generally produced a slight increase in damping in pitch and a decrease in stability in pitch for Mach numbers of 1.60 and 2.02 (fig. 7).

Contributions of wing and horizontal tail.- The effect of removing the wing and removing the horizontal tail on the oscillatory pitch parameters is shown in figure 8 for a Mach number of about 2.0. Incremental wing and tail contributions are presented in figure 9. Removing the horizontal tail reduces the damping at all angles of attack except in the range from 0^o to 2^o. Removal of the wing has a very irregular effect on the damping through the angle-of-attack range. Removal of either the wing or the horizontal tail reduces the level of stability throughout the angle-of-attack range. Of interest is the fact that the destabilizing increment is the same no matter which component is removed.

Directional Stability

Directional stability parameters.- The interpretation of the directional stability parameters is analogous to the interpretation of the longitudinal stability parameters. A negative value of the damping-in-yaw parameter $C_{n_r} - C_{n_{\dot{\beta}}} \cos \alpha$ at any angle of attack α indicates that the model experiences a net positive aerodynamic damping in yaw during the yawing oscillations about $\beta = 0^o$ at that α. A positive value of the oscillatory directional stability parameter $C_{n_\beta} \cos \alpha + k^2 C_{n_{\dot{r}}}$ at any α indicates that the oscillating model is aerodynamically stable with respect to $\beta = 0^o$ at that α.

Basic characteristics.- The effect of changing Mach number on the directional stability parameters for the basic configuration is shown in figure 10(a) for $i_t = 0^o$ and in figure 10(b) for $i_t = -20^o$. The damping in yaw is generally positive and increases with increasing angle of attack. There is no large or consistent effect of Mach number on damping in yaw. The stability in yaw is positive except at angles of attack above about 17^o. The stability in yaw decreases with both increasing angle of attack and increasing Mach number. Deflection of the horizontal tail to -20^o slightly decreased the yaw damping but increased the stability.

Effect of stores.- The effect of adding external stores on the directional stability parameters is shown in figure 11 for Mach numbers of 1.60 and 2.02. The addition of stores generally increases the damping in yaw for values of α up to about 6^o. At $M = 1.60$, the addition of stores decreases the stability near $\alpha = 0^o$ but generally increases stability for angles of attack between 6^o and 12^o. At $M = 2.02$, however, the addition of stores has little effect on stability near $\alpha = 0^o$ whereas it decreases the stability for all values of α greater than 4^o. This trend at the higher angles of attack is opposite to that which is obtained at $M = 1.60$.

Vertical-tail and ventral-fin contributions.- The effect of removing the vertical tails and ventral fins on the directional stability parameters is shown in figures 12(a), 12(b), and 12(c) for Mach numbers of 1.60, 2.02, and 2.36, respectively. Incremental vertical-tail contribution is presented in figure 13 for the three test Mach numbers. Removal of the vertical tails and ventral fins is seen to have slight and inconsistent effects on the damping in yaw. Removal of the vertical tail produces a configuration that is directionally unstable at all angles of attack. An additional removal of the ventral fins decreases further the level of stability by a small amount.

CONCLUDING REMARKS

Wind-tunnel measurements of the aerodynamic damping and oscillatory stability in pitch and yaw for a 1/22-scale model of a proposed carrier-based variable-sweep fighter airplane have been made by using a small-amplitude forced-oscillation mechanism. Tests were made with a wing leading-edge sweep angle of 68° at angles of attack from about -1.5° to 15.5° at a Mach number of 1.60 and at angles of attack from about -3° to 21° at Mach numbers of 2.02 and 2.36.

The results of the investigation indicate that the basic configuration has positive damping and positive oscillatory stability in pitch for all test conditions. In yaw, the damping is generally positive except near an angle of attack of 0° at a Mach number of 1.60. The oscillatory stability in yaw is positive except at angles of attack above 16° at Mach numbers of 2.02 and 2.36. The addition of external stores generally causes increases in both pitch and yaw damping. The oscillatory stability in pitch is reduced throughout the angle-of-attack range. The effect of stores on oscillatory stability in yaw is a function of angle of attack and Mach number. The effect of changing horizontal-tail incidence on the pitch parameters is also very dependent on angle of attack and Mach number.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., April 4, 1972.

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TABLE I.- GEOMETRIC CHARACTERISTICS OF WINGS WITH A LEADING-EDGE SWEEP OF 20°

Area, S, m^2	0.1085
Span, b, m	0.8885
Mean geometric chord, m	0.1358
Root chord, m	0.1928
Tip chord, m	0.0511
Dihedral, deg	0
Airfoil section at root	(1.74)(35)(9.6)
Airfoil section at tip	(1.27)(30)(9.0)
Camber in percent chord	
Location of maximum camber in percent chord	
Thickness in percent chord	
Incidence from root to 0.461 b/2, deg	0.43
Incidence from 0.461 b/2 to tip, deg	0
Twist from root to 0.461 b/2, deg	0
Twist from 0.461 b/2 to tip, deg	-4.1
Cant of pivot, deg	Outboard 1.3

TABLE II.- GEOMETRIC CHARACTERISTICS OF TWIN VERTICAL TAILS

Area of one panel, m^2	0.01133
Height, m	0.1178
Root chord, m	0.1420
Tip chord, m	0.0508
Leading-edge sweep, deg	46.8
Trailing-edge sweep, deg	16.2
Cant angle, deg	Outboard 5
Airfoil section	NACA 65A0045

TABLE III.- GEOMETRIC CHARACTERISTICS OF HORIZONTAL TAIL

Area of both panels, m^2	0.02687
Span, m	0.2602
Root chord, m	0.1716
Tip chord, m	0.0366
Leading-edge sweep, deg	51.1
Trailing-edge sweep, deg	11.4
Anhedral, deg	3.5
Airfoil section at root	NACA 65A004.643
Airfoil section at tip	NACA 65A003.161

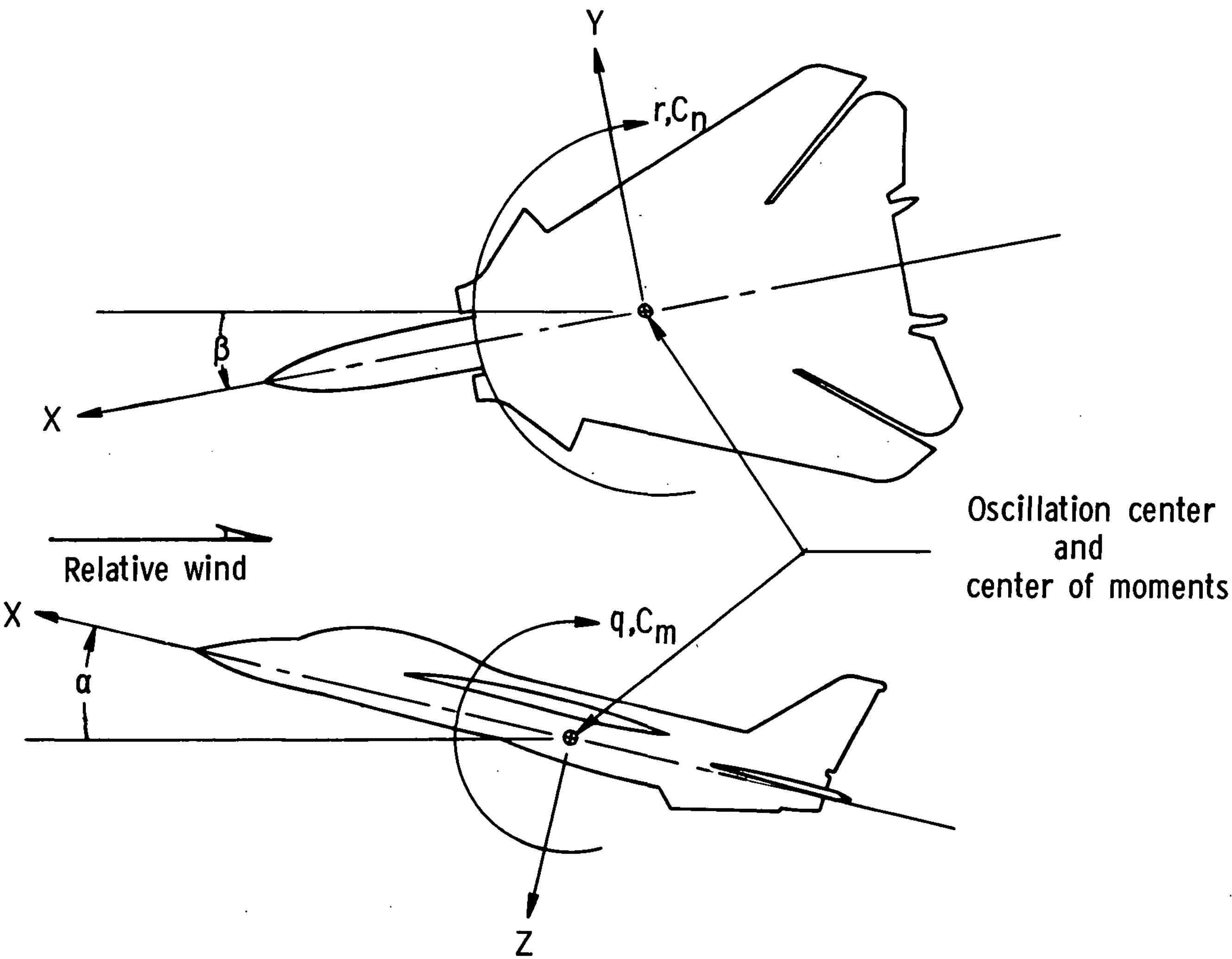
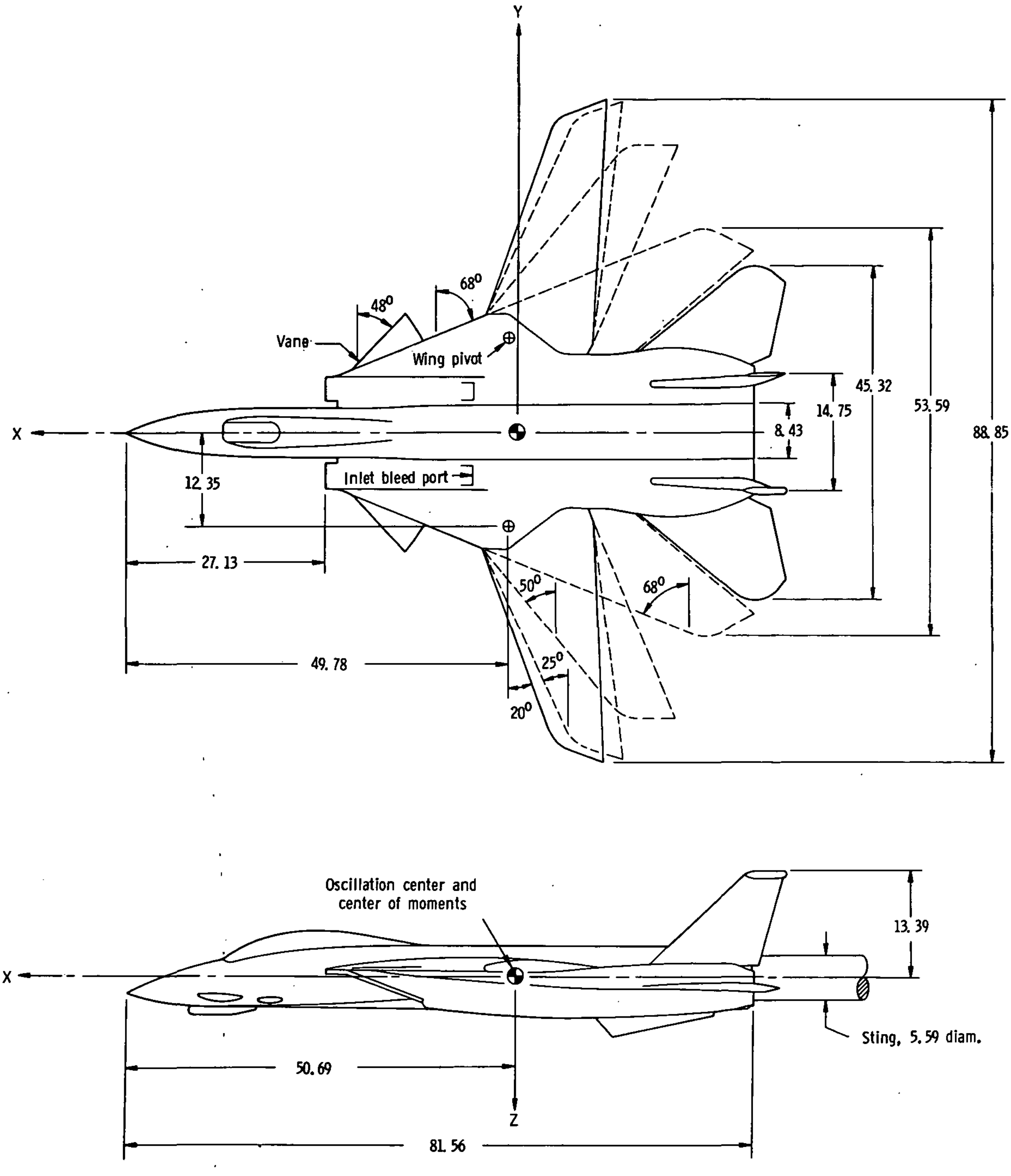
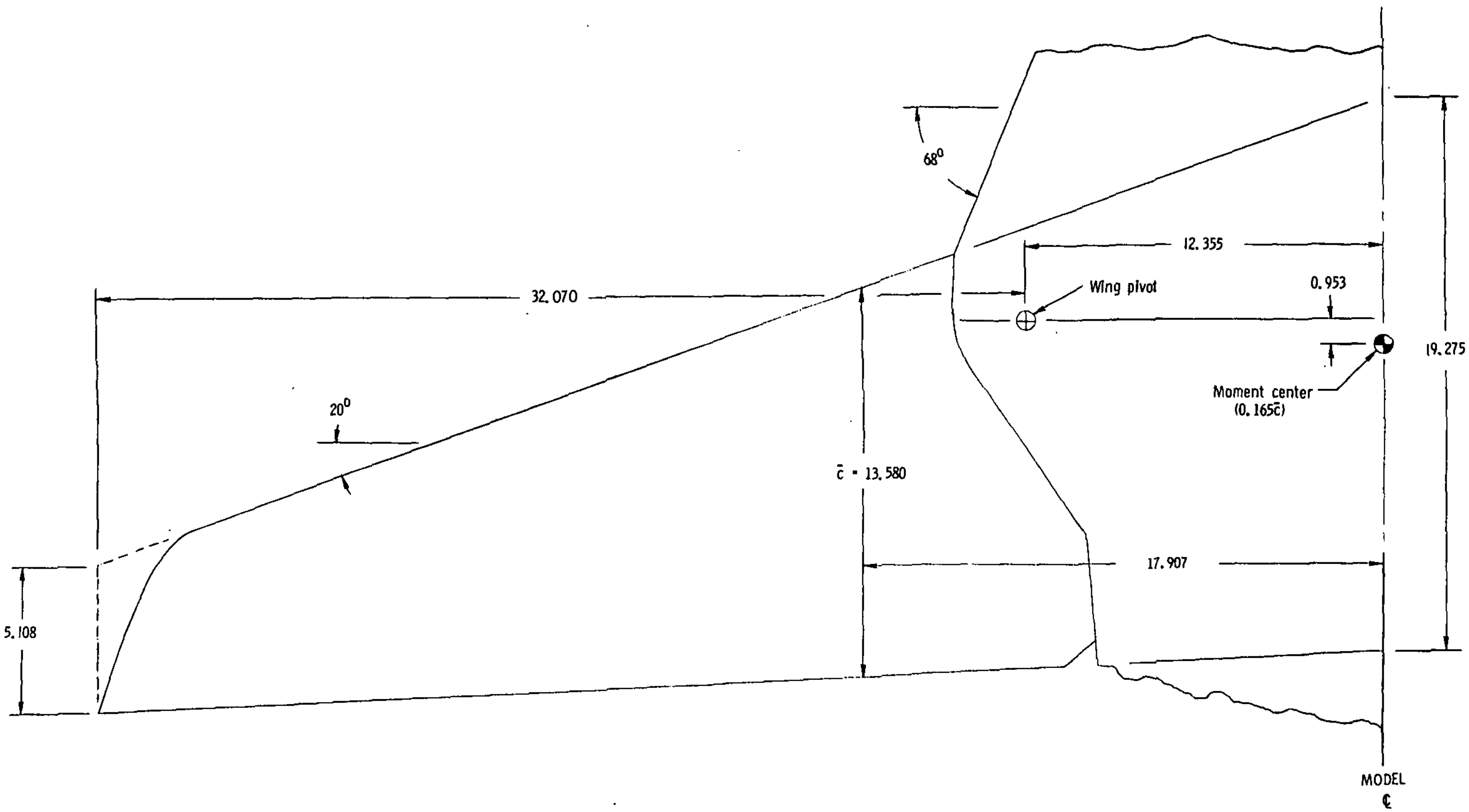


Figure 1.- Body system of axes showing positive direction of angles, angular velocities, and coefficients.



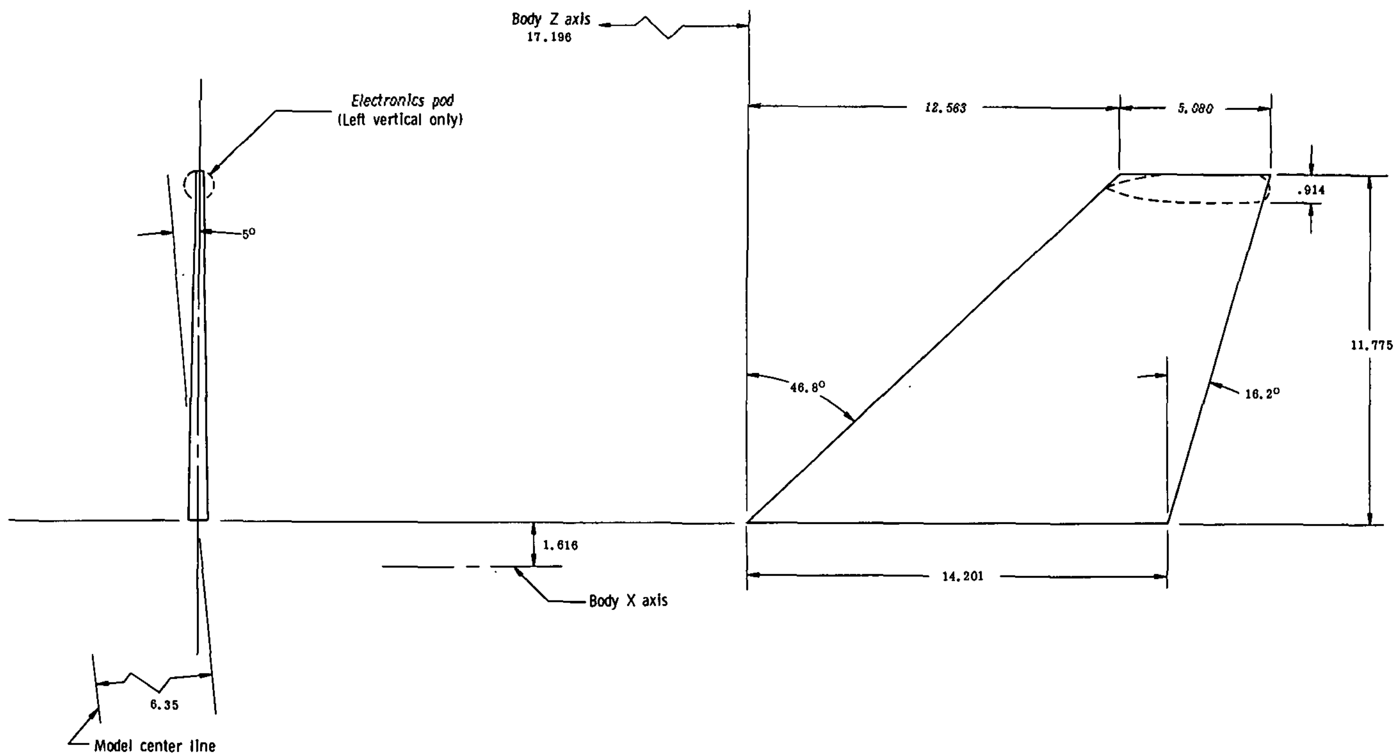
(a) Top and side views.

Figure 2.- Drawings of model showing important design dimensions. All linear dimensions are in centimeters.



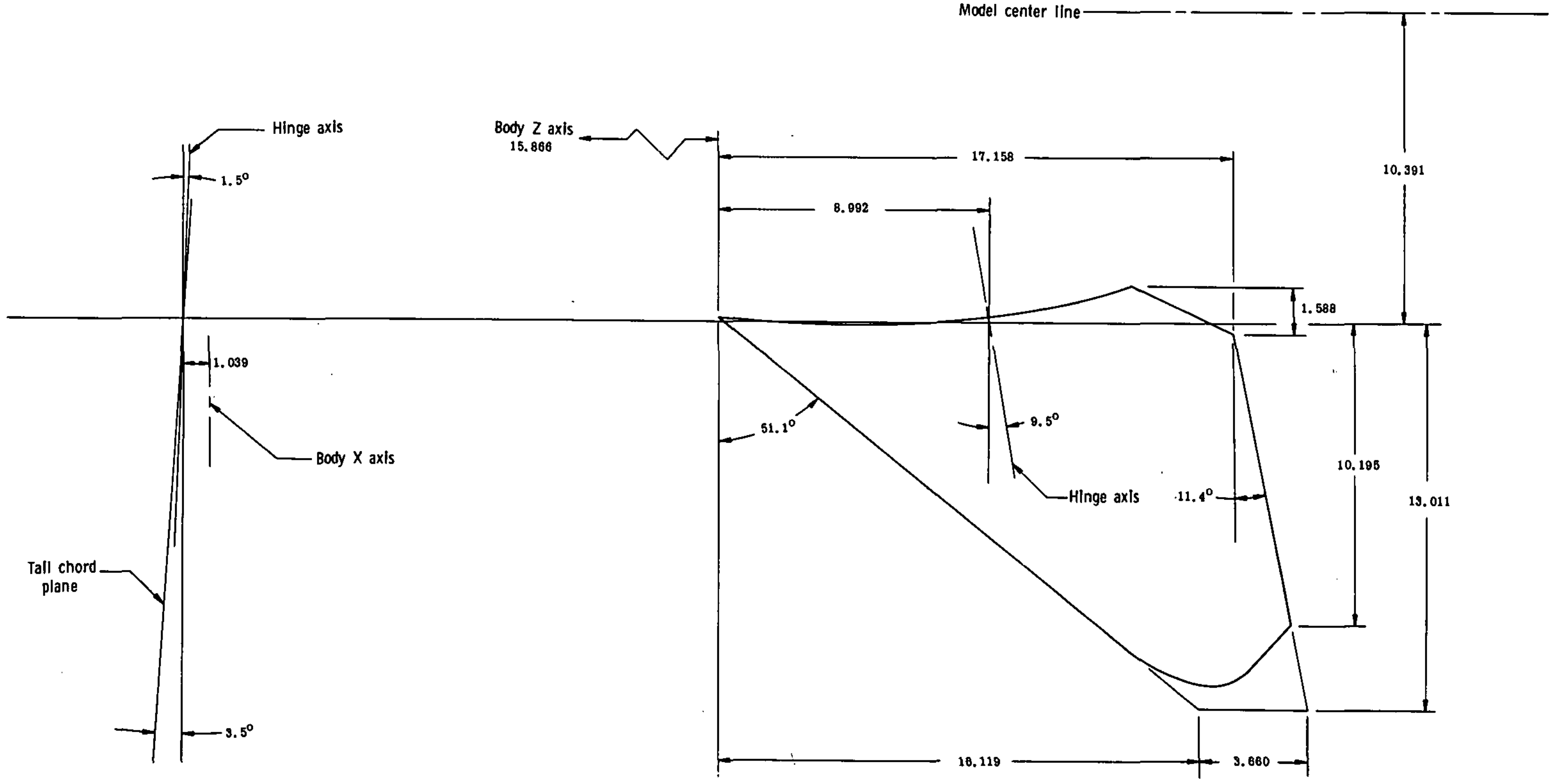
(b) Wing in reference 20°-sweep position.

Figure 2.- Continued.



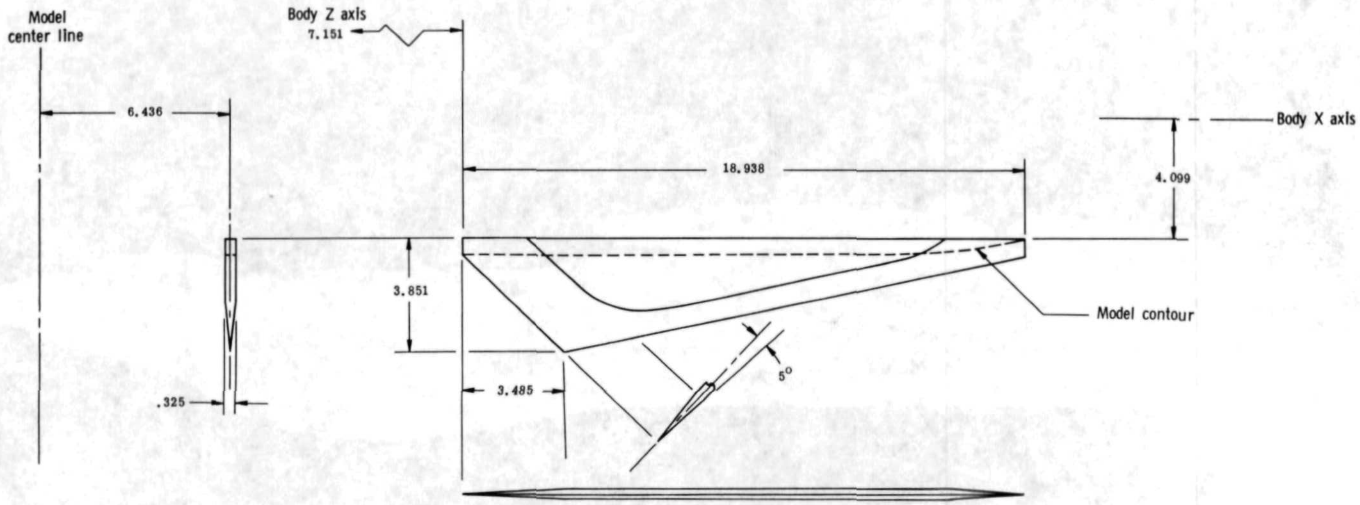
(c) Detail of vertical tails. NACA 65A0045 airfoil section.

Figure 2.- Continued.



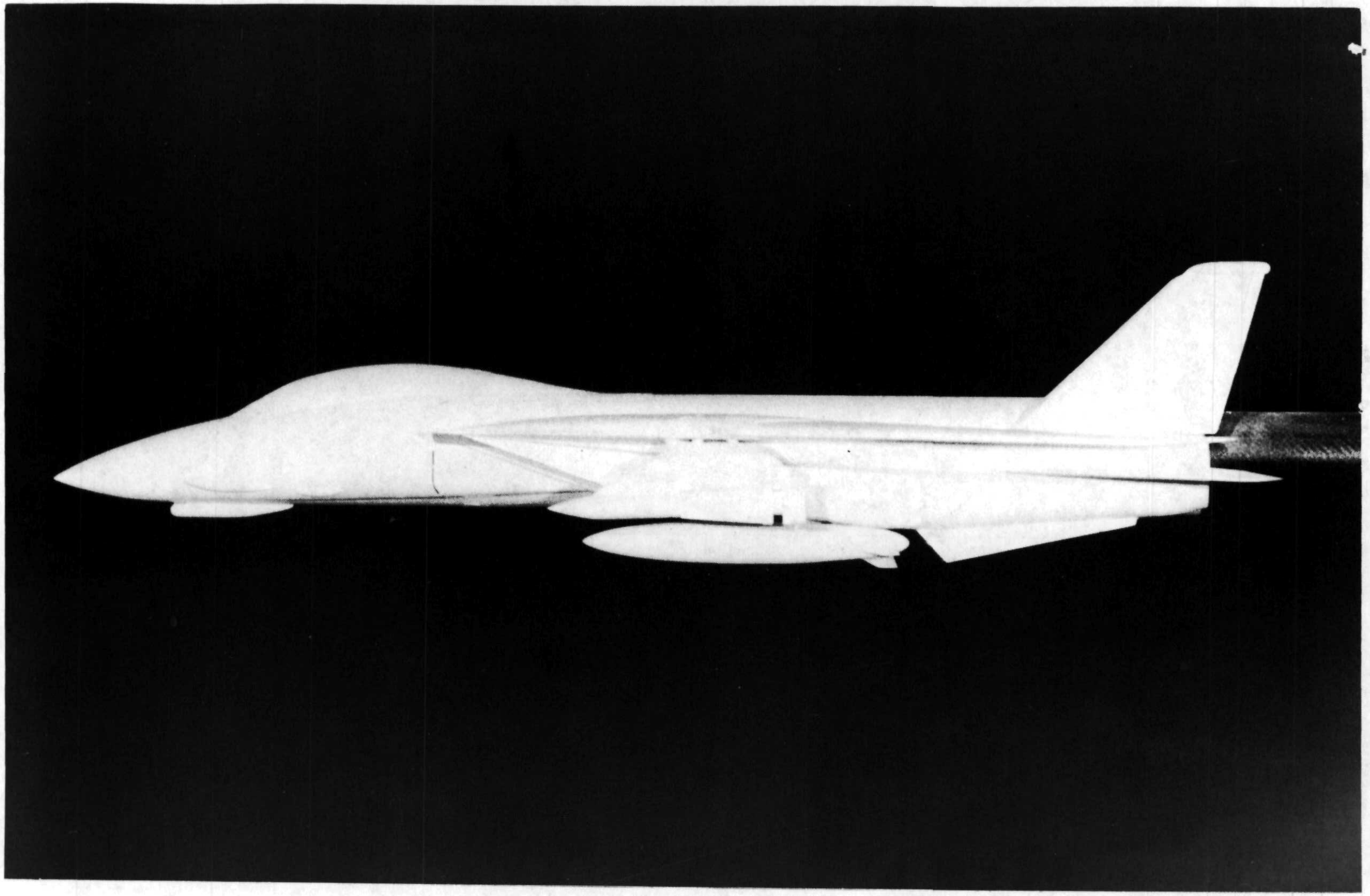
(d) Detail of horizontal tails. NACA 65A004.643 airfoil section at root; NACA 65A003.161 airfoil section at tip.

Figure 2.- Continued.



(e) Detail of ventral fins.

Figure 2.- Concluded.



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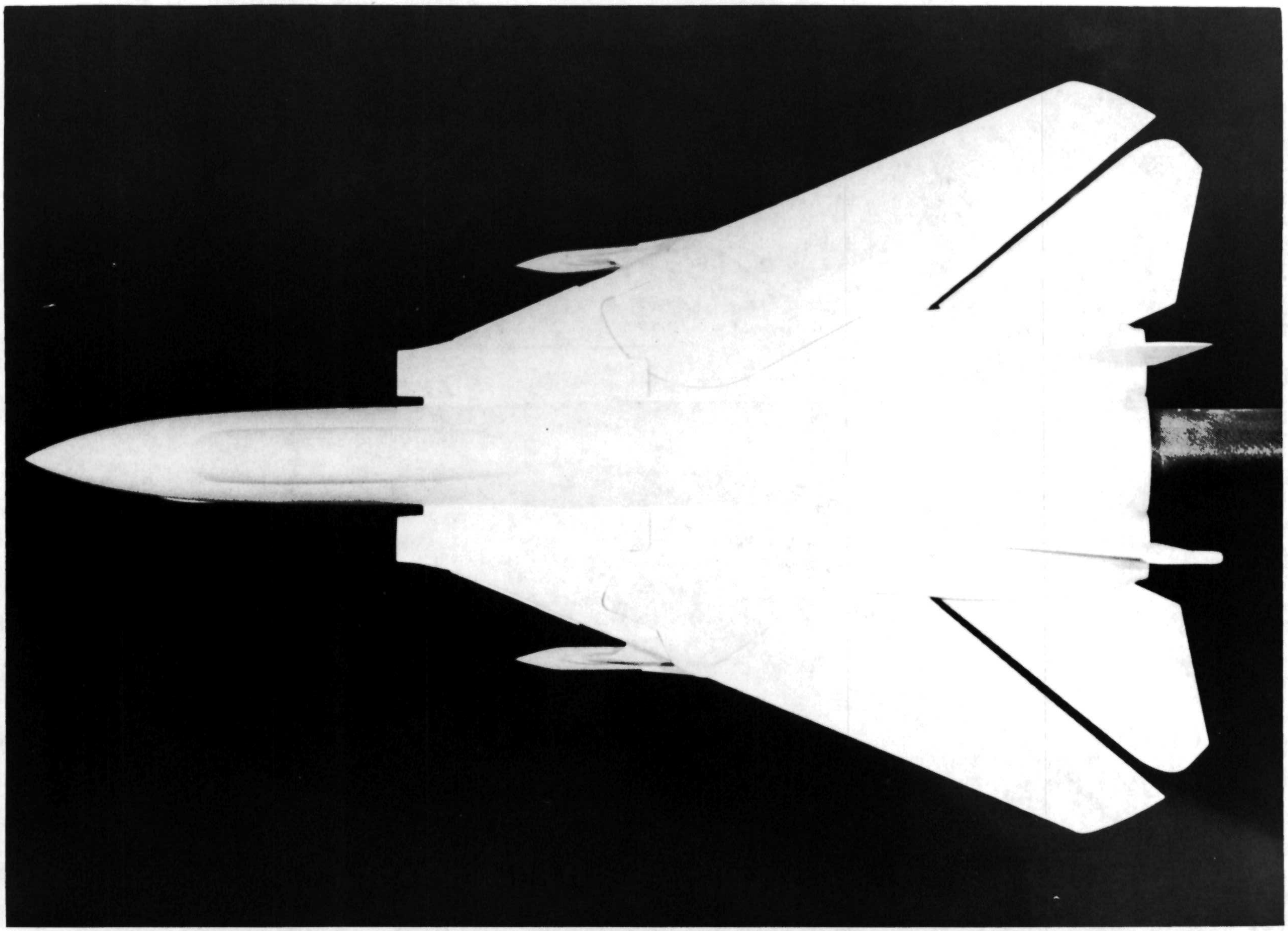
(a) Side view.

Figure 3.- Photographs of model.



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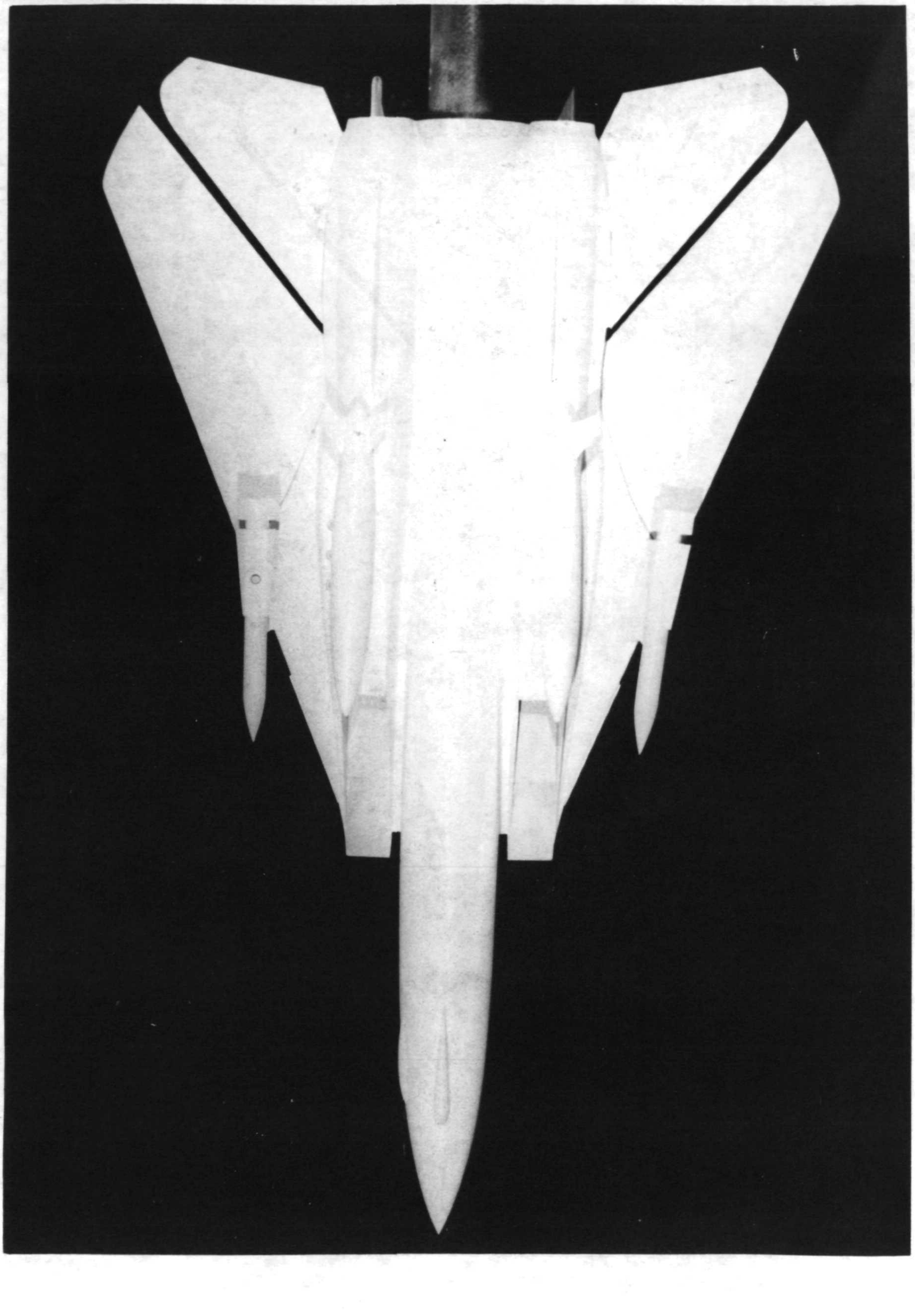
(b) Top view.

Figure 3.- Continued.



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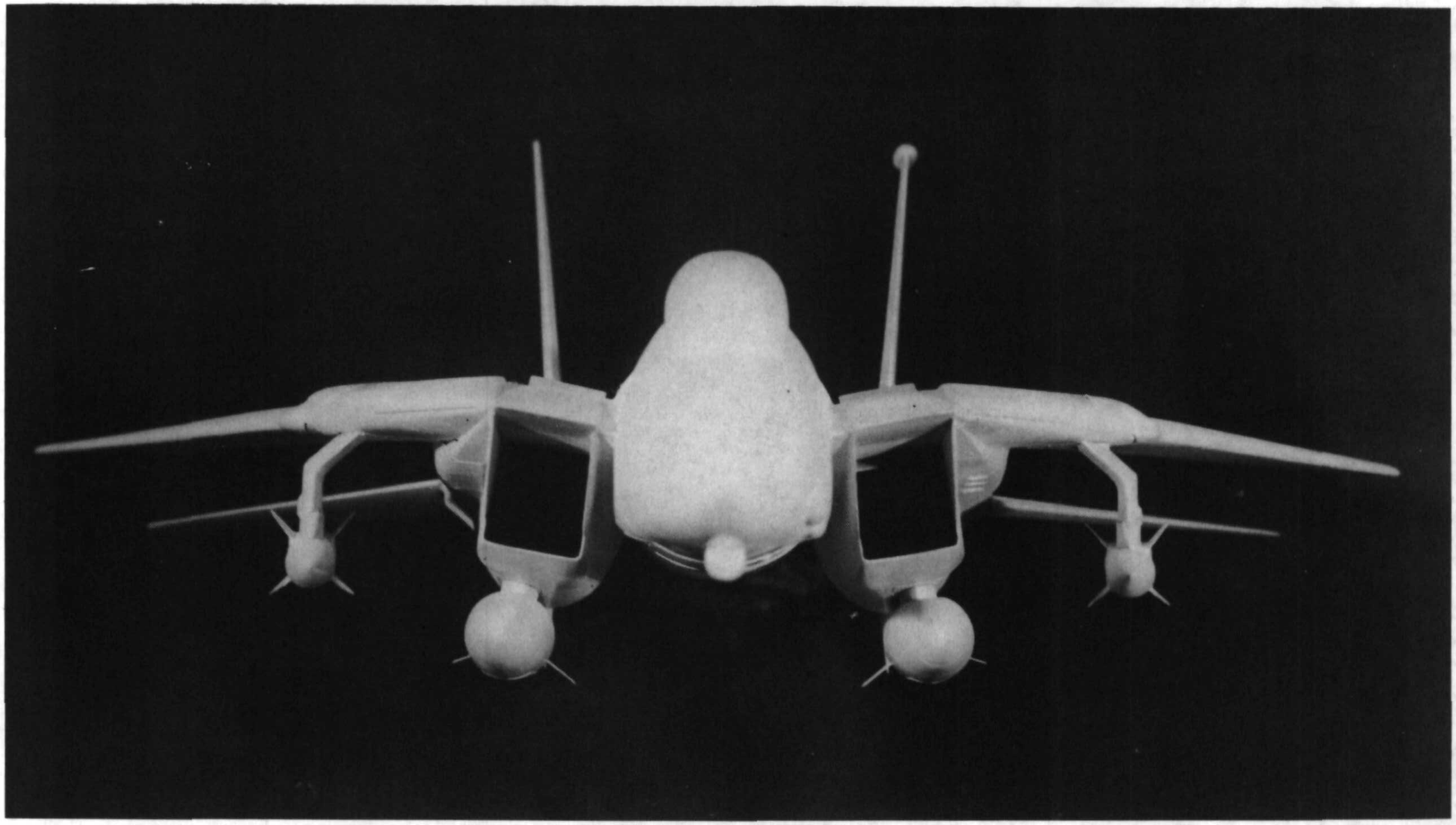
(c) Bottom view.

Figure 3.- Continued.



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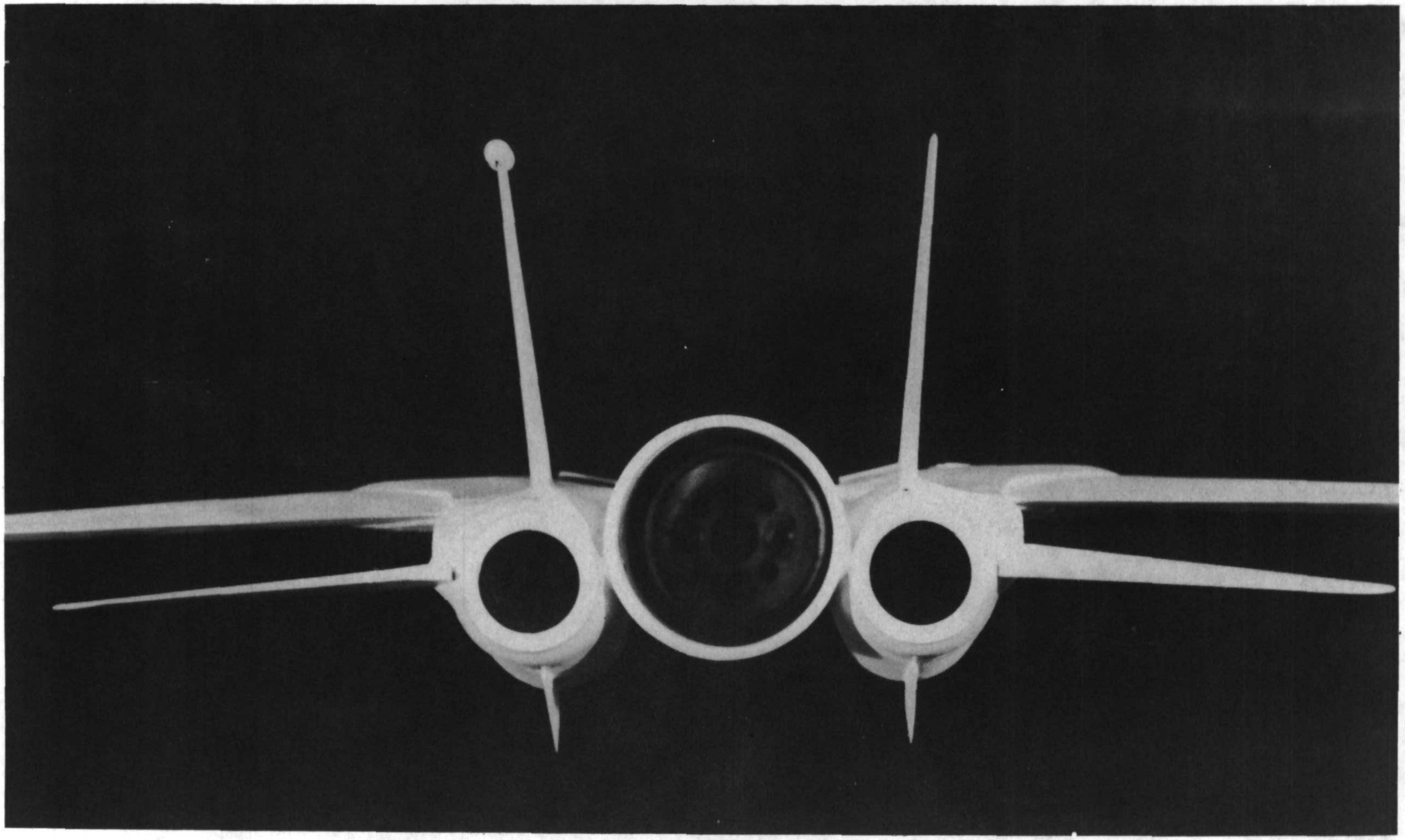
(d) Front view.

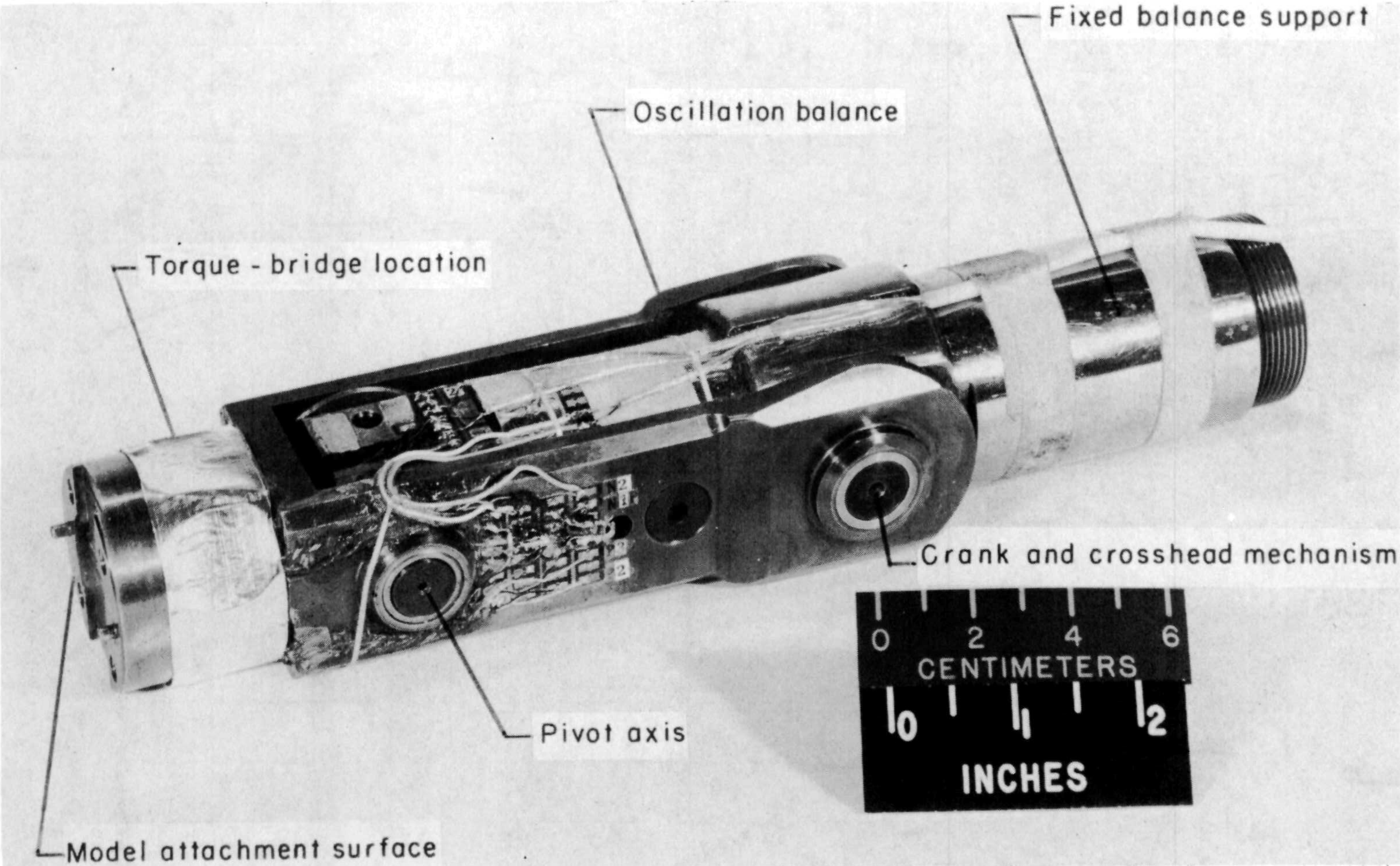
Figure 3.- Continued.



L-70-7061

(e) Rear view.

Figure 3.- Concluded.



L-65-1376.1

Figure 4.- Forward section of oscillation-balance mechanism.

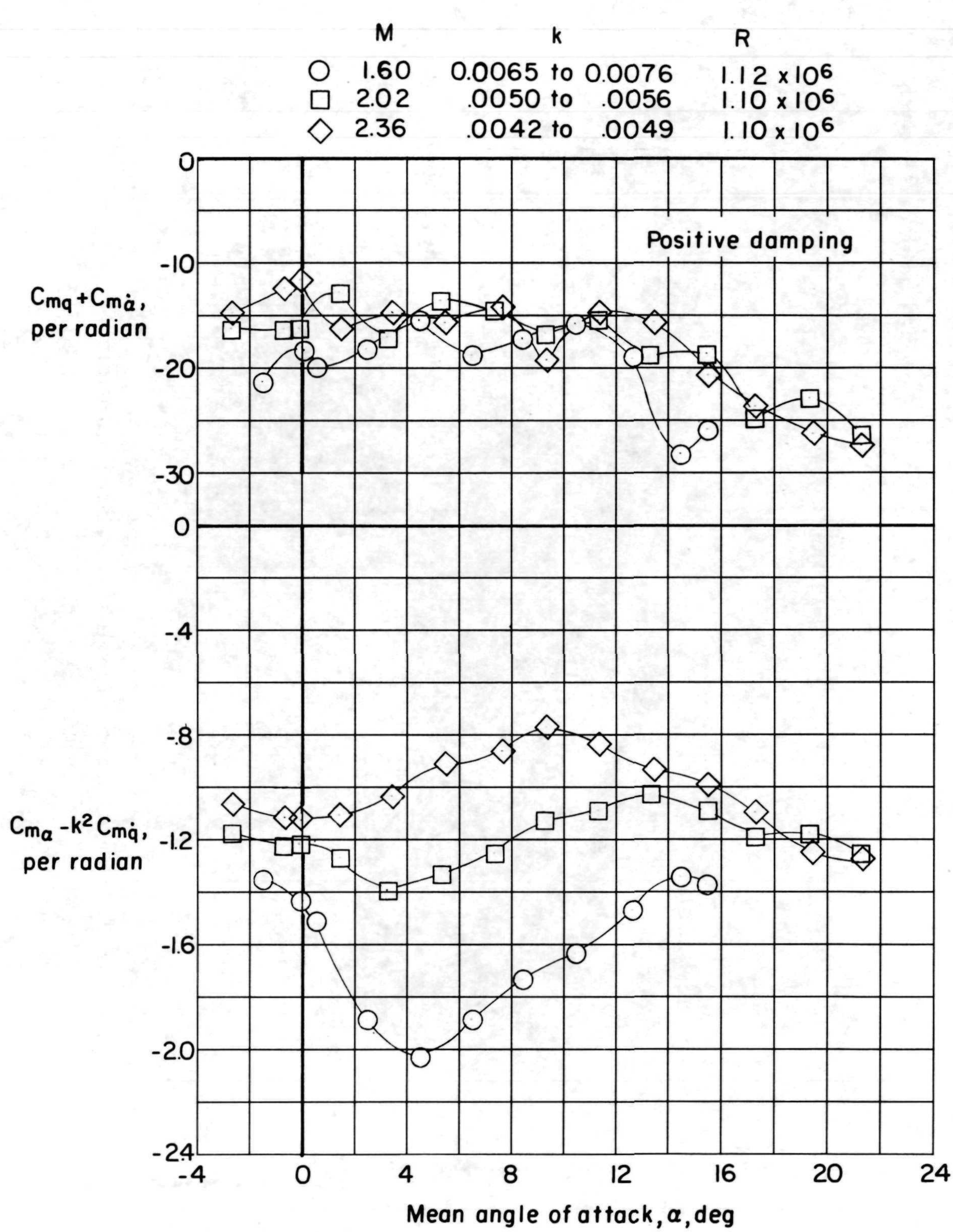
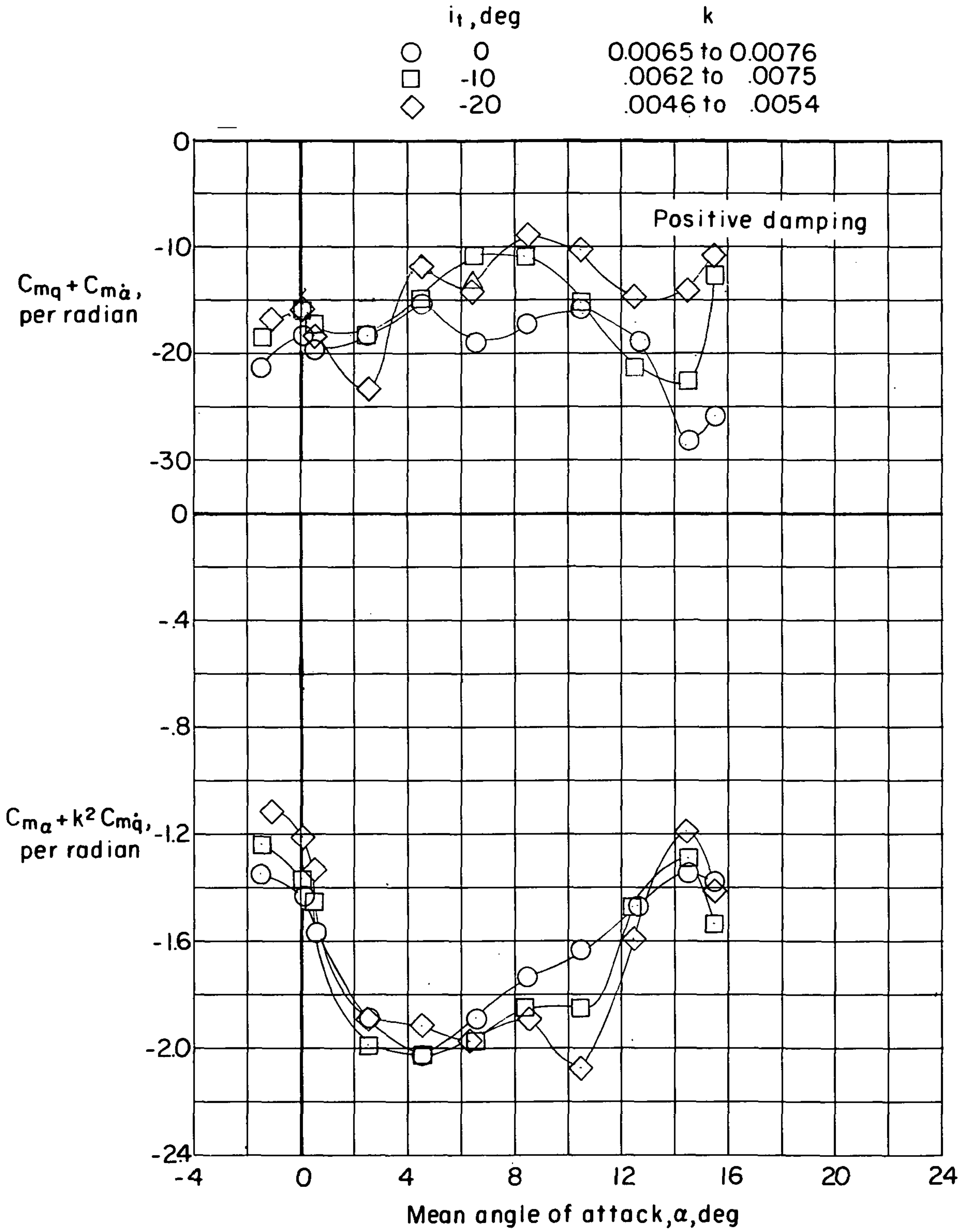
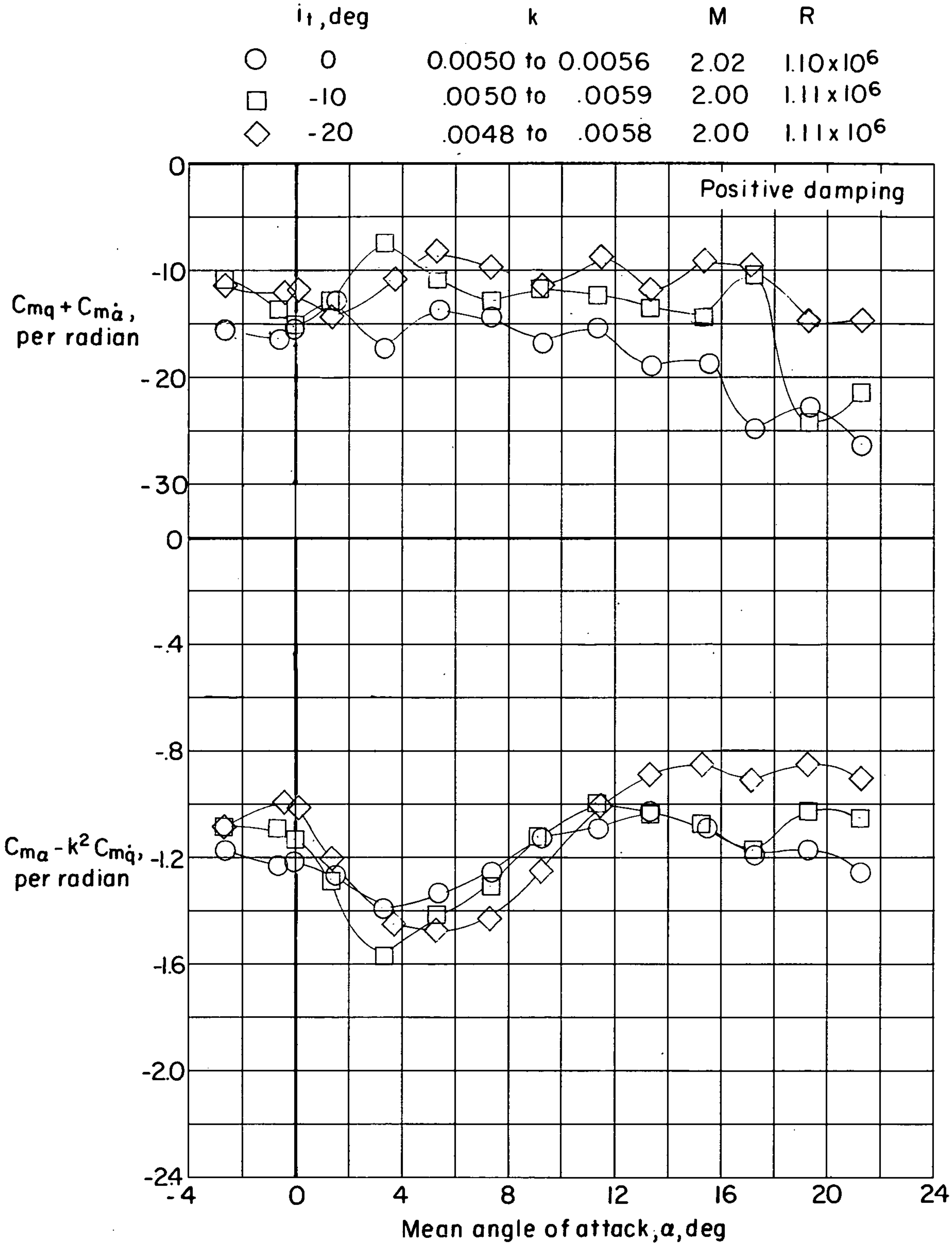


Figure 5.- Damping-in-pitch and oscillatory longitudinal stability characteristics for basic configuration. $i_t = 0^{o}$.



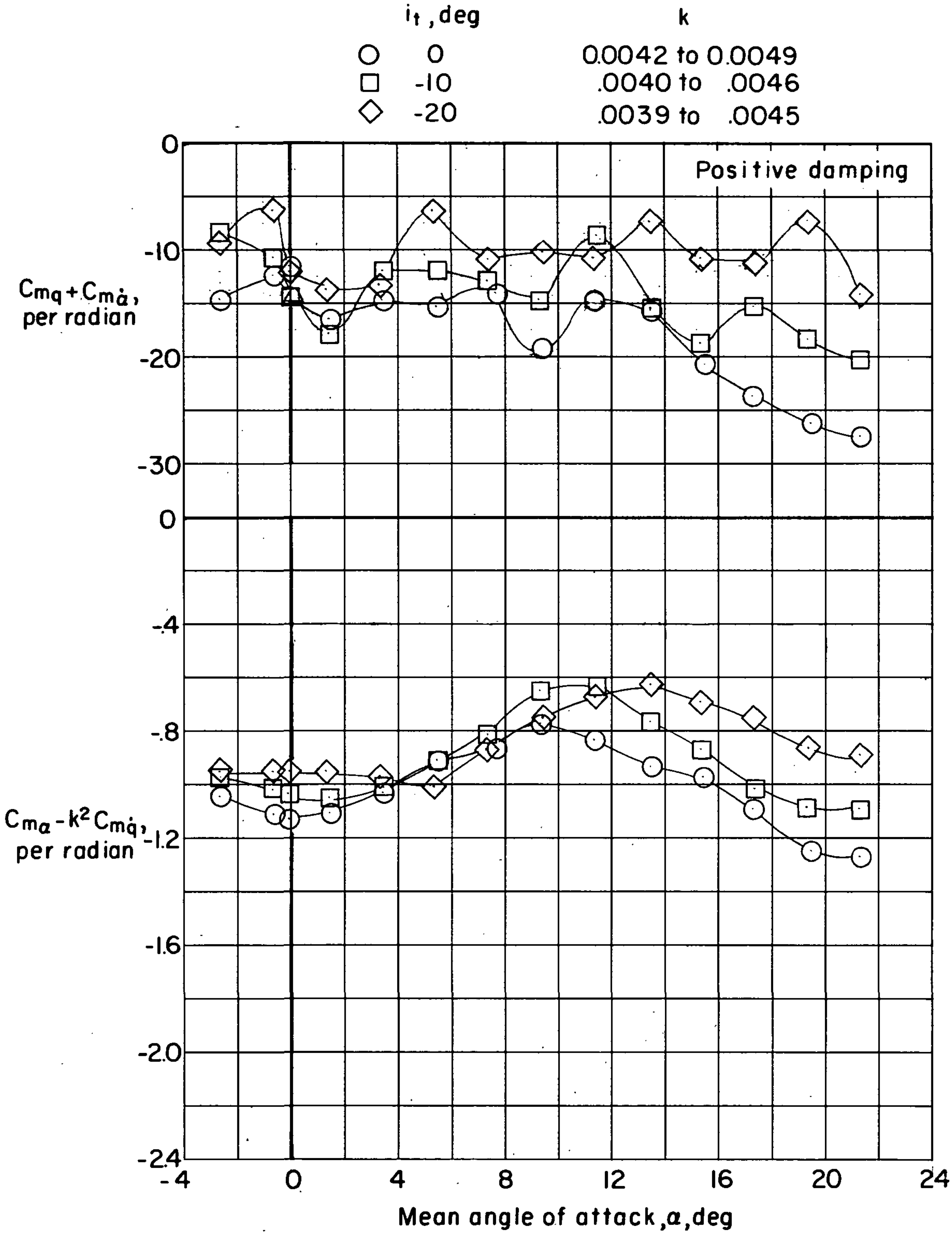
(a) $M = 1.60$; $R = 1.12 \times 10^6$.

Figure 6.- Effect of horizontal-tail incidence on damping-in-pitch and oscillatory longitudinal stability characteristics of basic configuration.



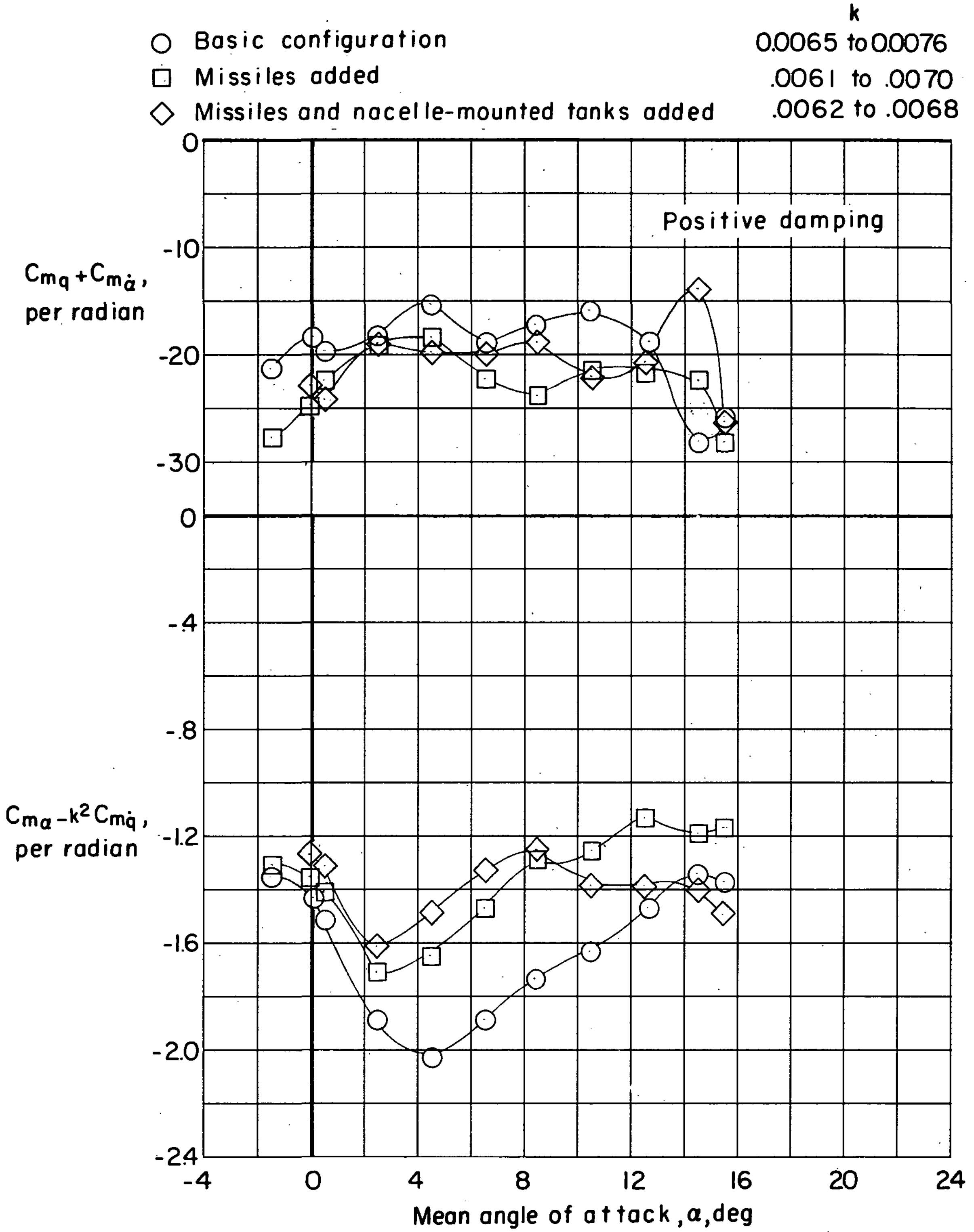
(b) $M \approx 2.02$.

Figure 6.- Continued.



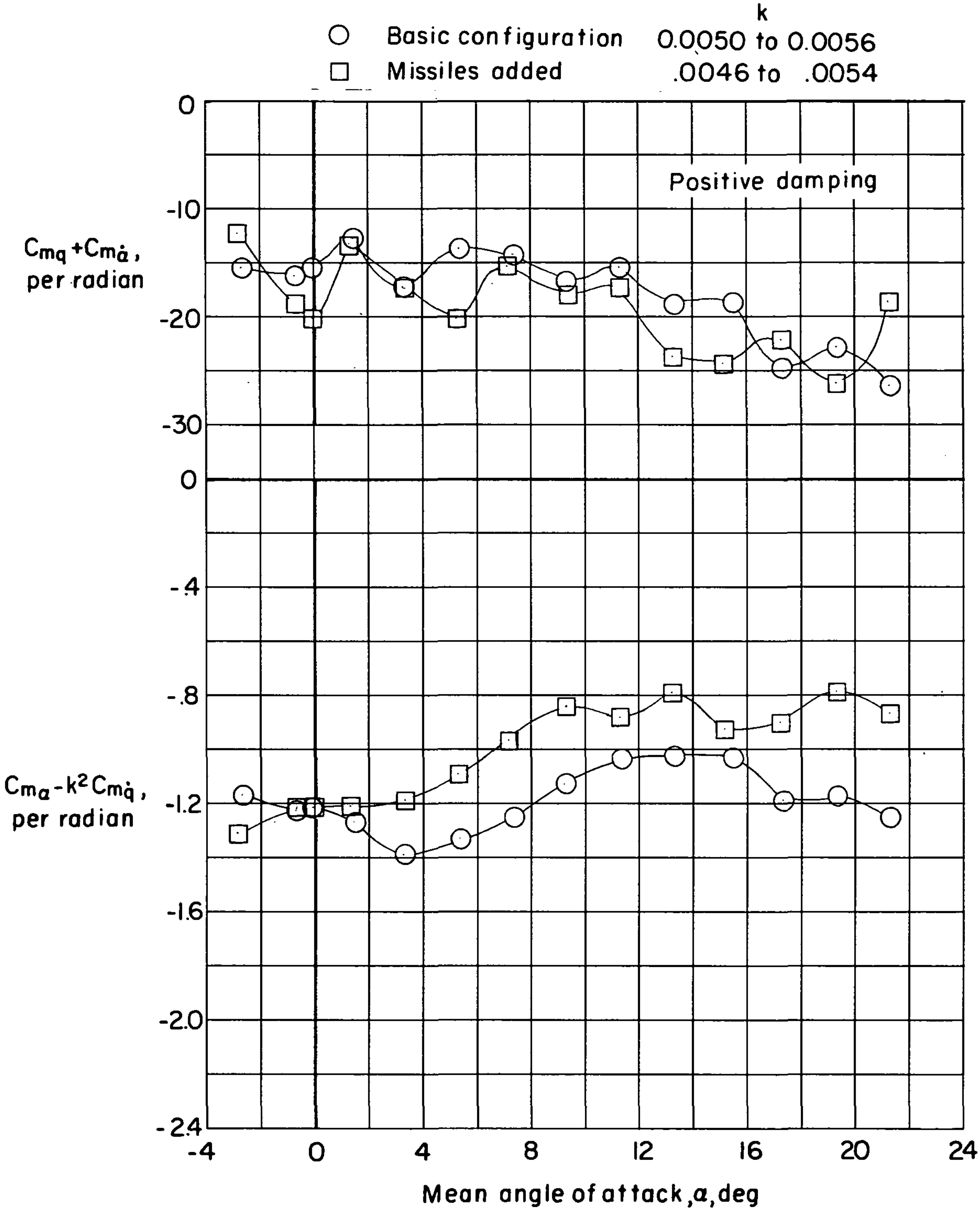
(c) $M = 2.36$; $R = 1.10 \times 10^6$.

Figure 6.- Concluded.



(a) $M = 1.60$; $R = 1.12 \times 10^6$.

Figure 7.- Effects of external stores on damping-in-pitch and oscillatory longitudinal stability characteristics of basic configuration. $i_t = 0^o$.



(b) $M = 2.02$; $R = 1.10 \times 10^6$.

Figure 7.- Concluded.

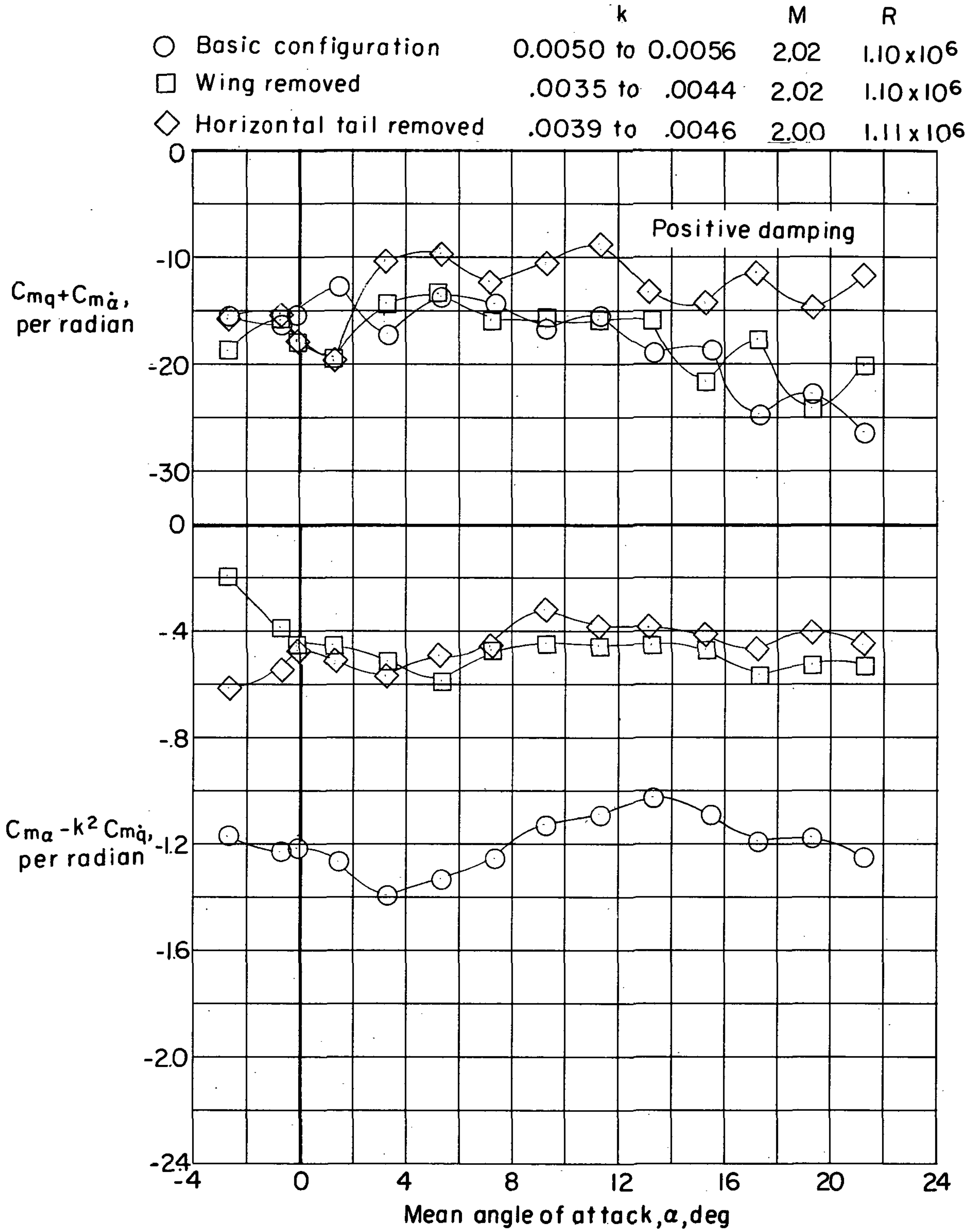


Figure 8.- Effects of removing horizontal tail and wing on damping-in-pitch and oscillatory longitudinal stability characteristics.

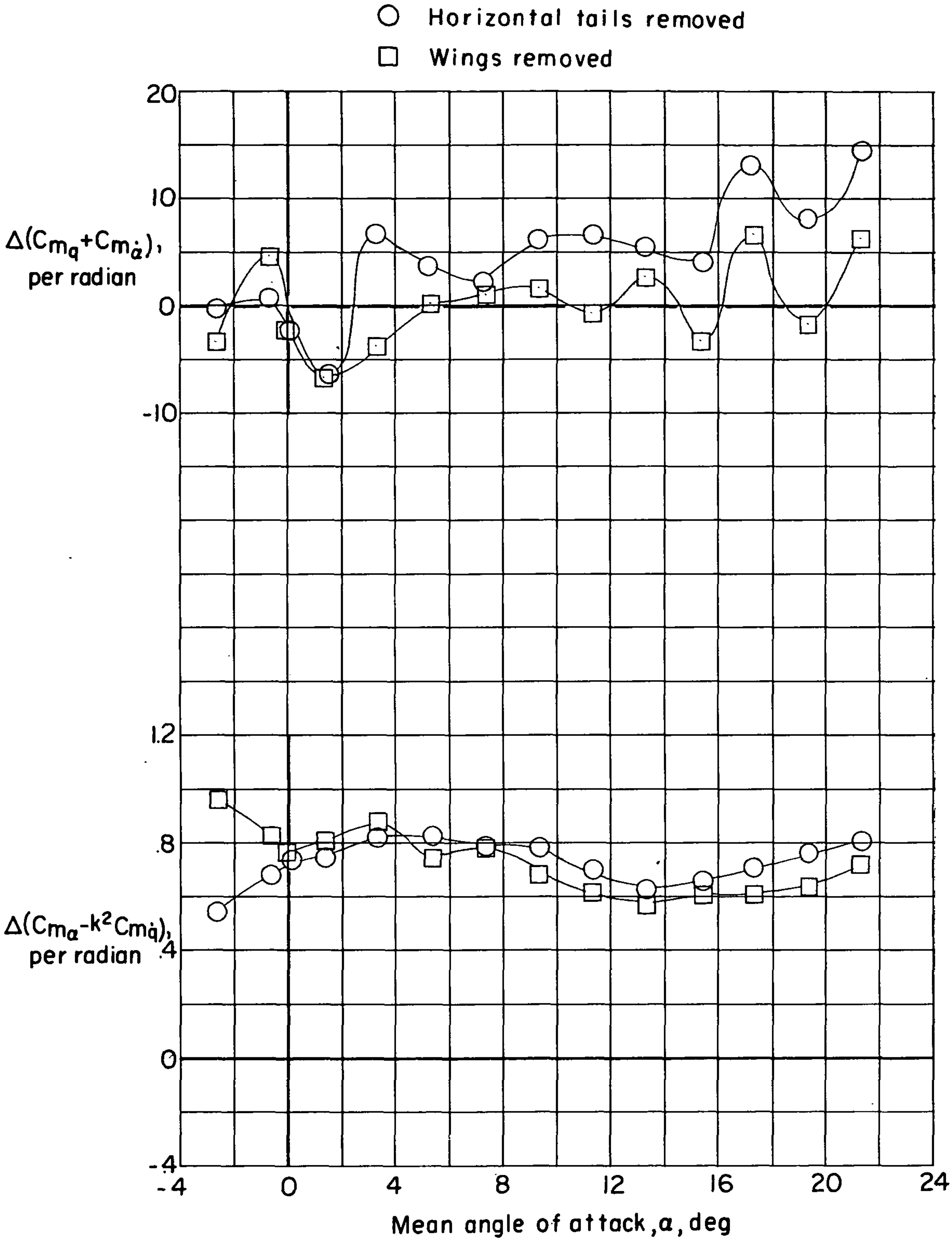
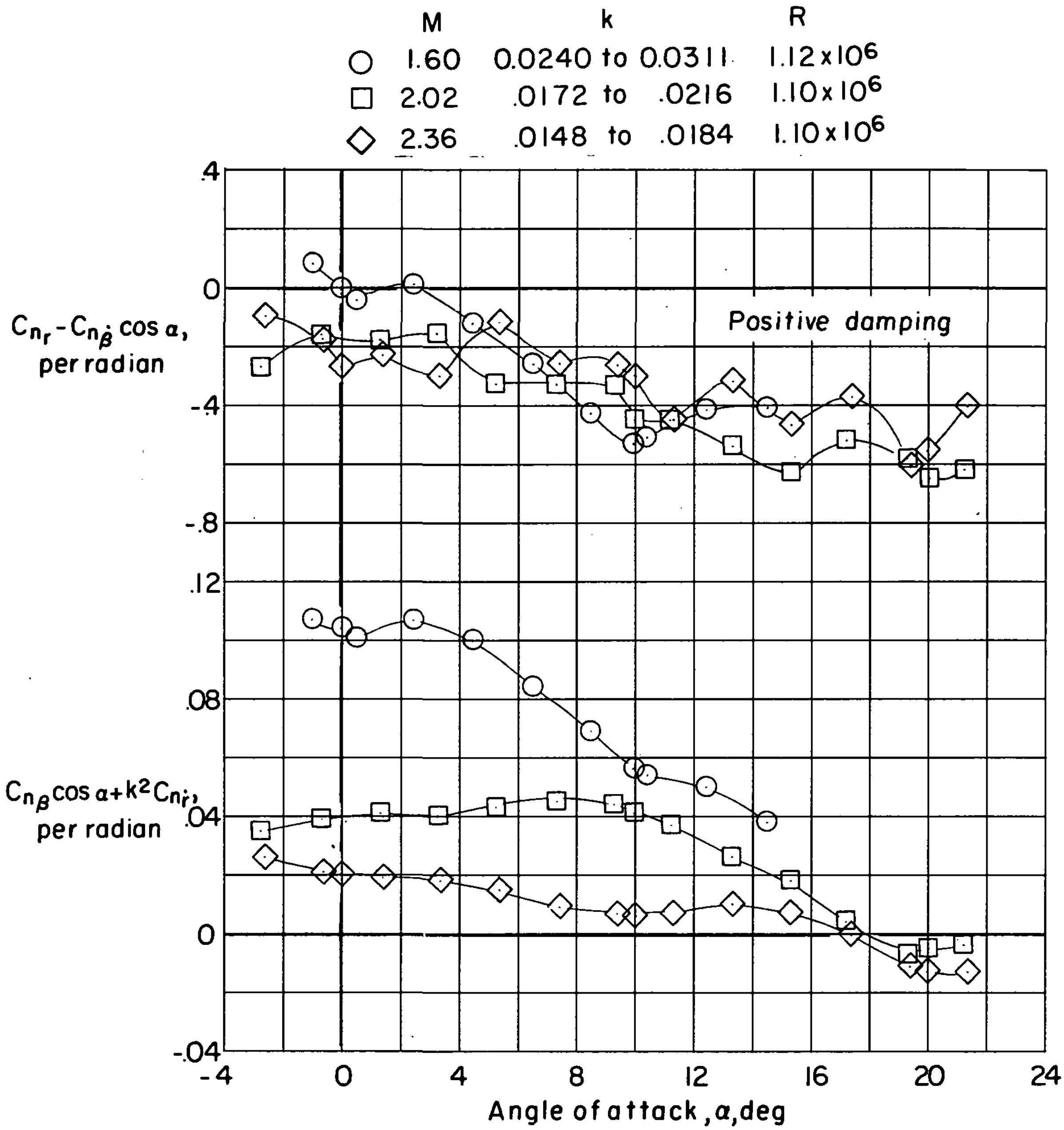
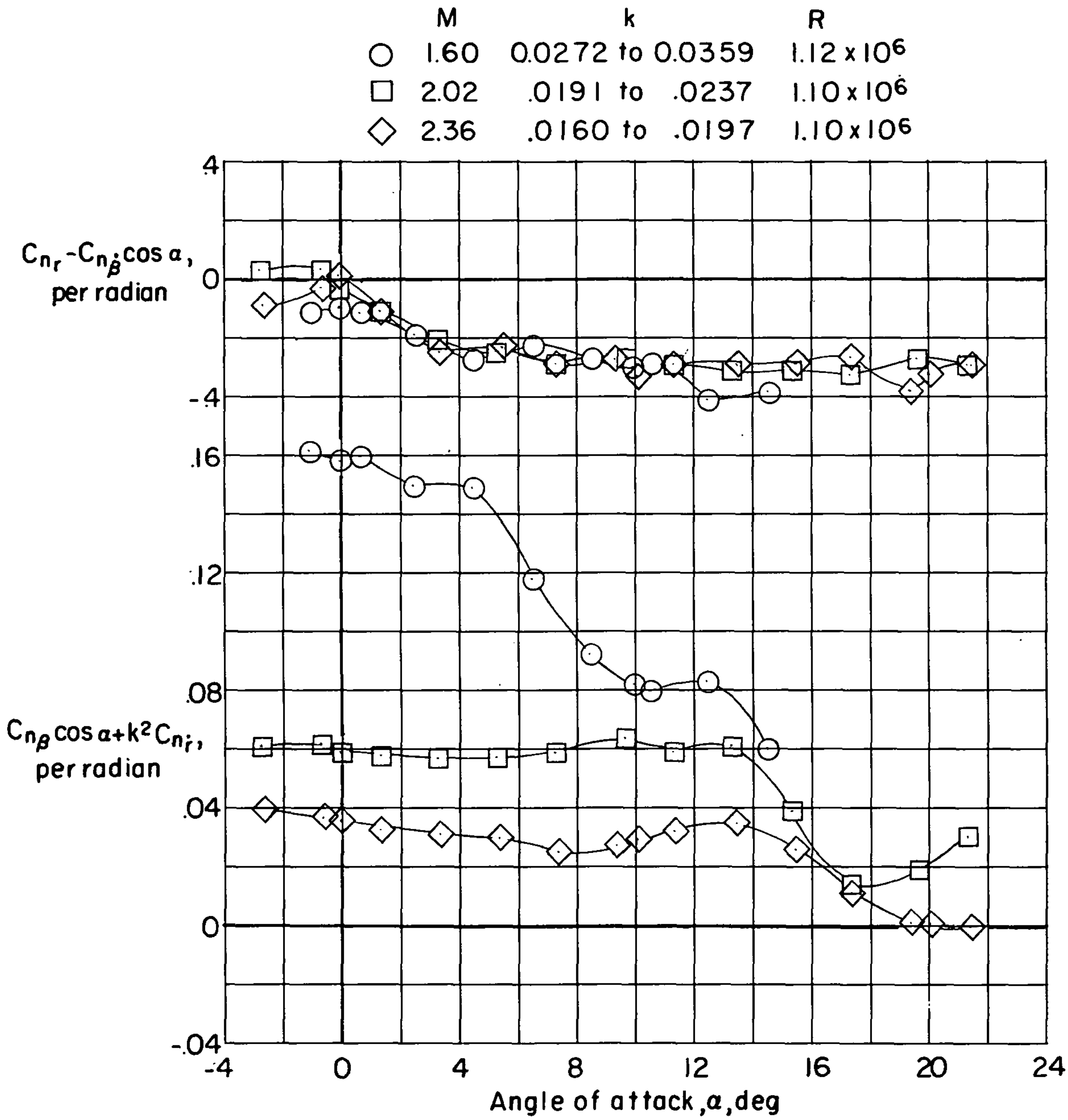


Figure 9.- Incremental effects of removing horizontal tail and wing on damping-in-pitch and oscillatory longitudinal stability characteristics. $M \approx 2.02$.



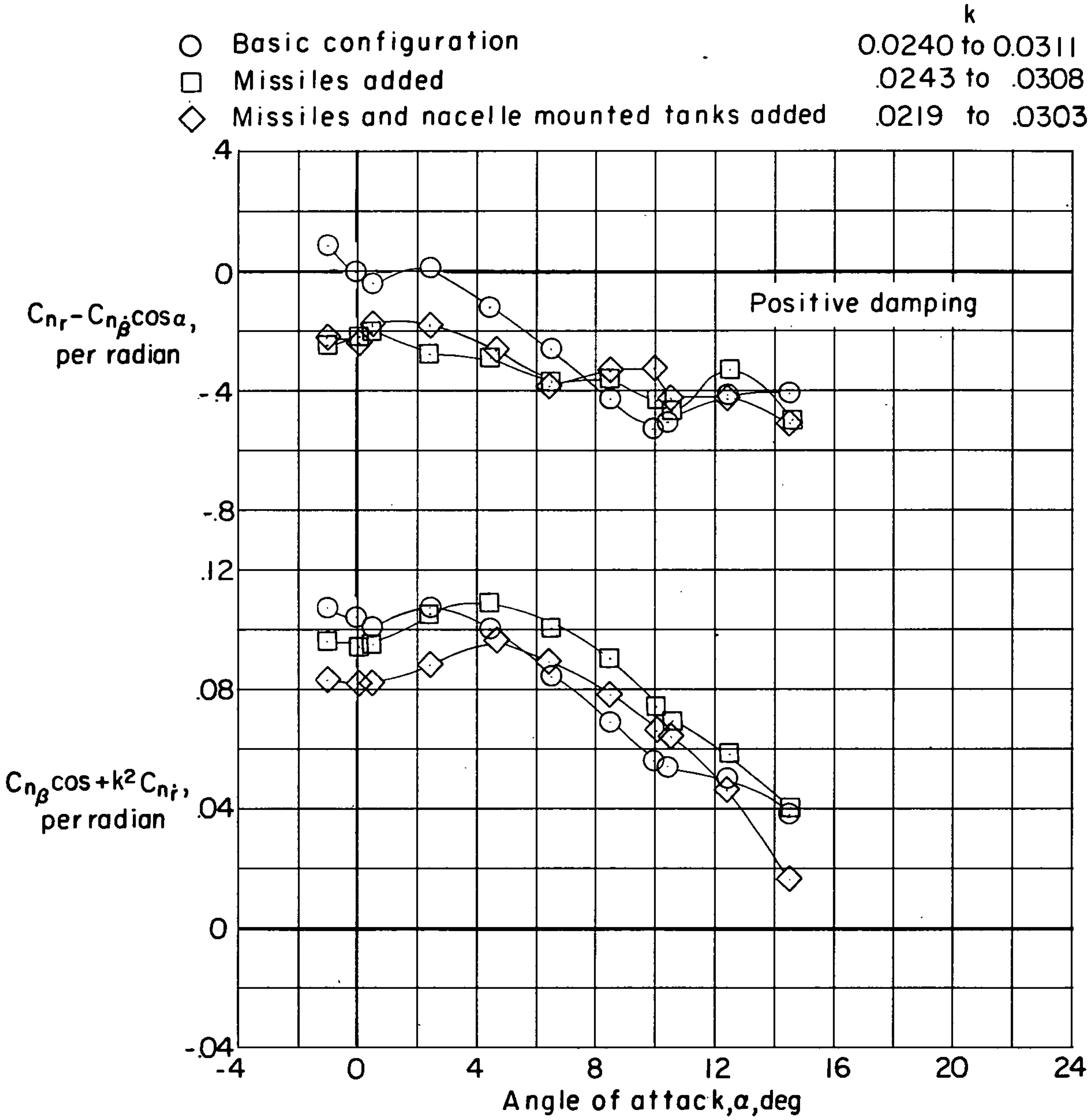
(a) $i_t = 0^o$.

Figure 10.- Damping-in-yaw and oscillatory directional stability characteristics of basic configuration.



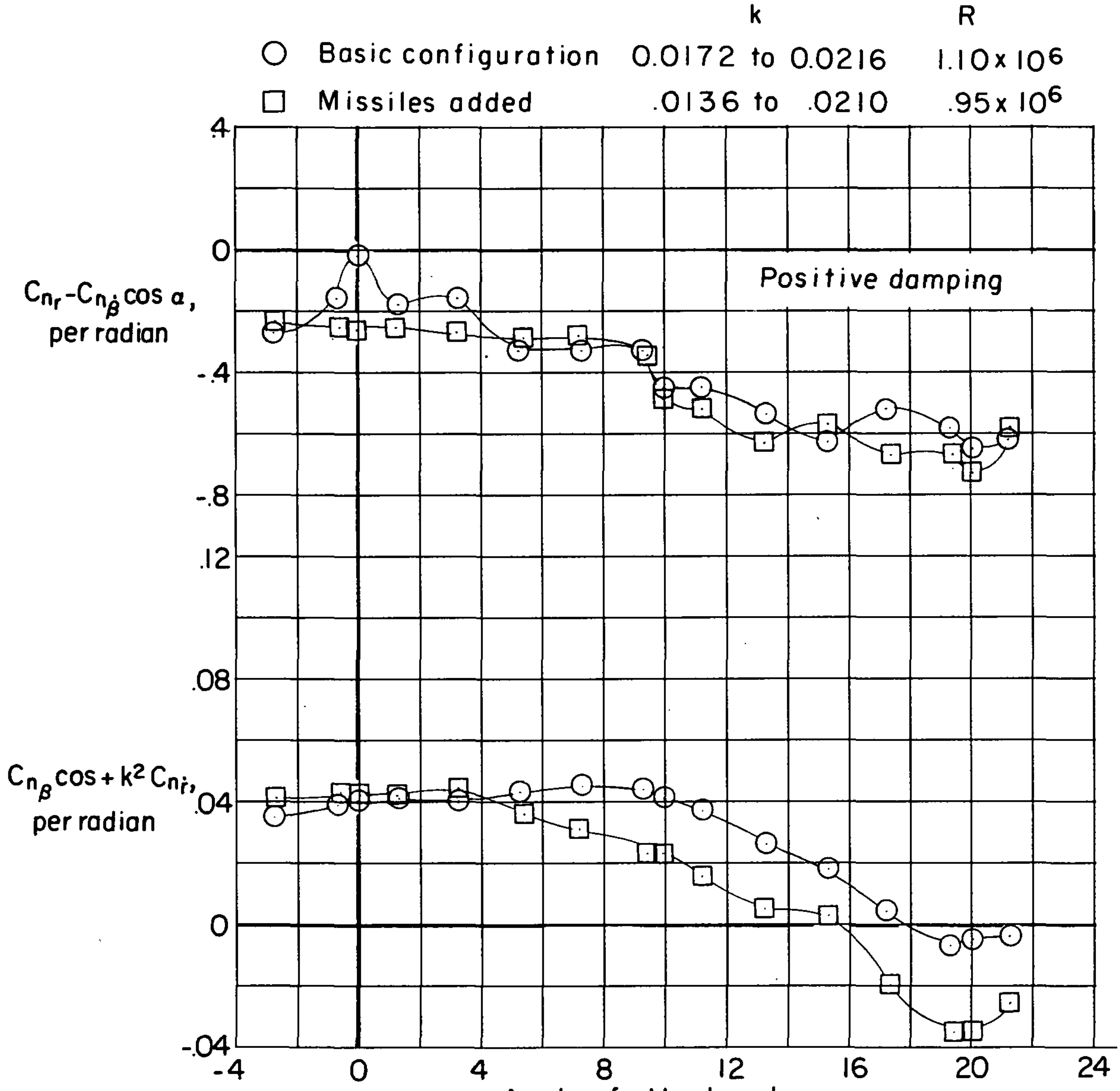
(b) $i_t = -20^{\circ}$.

Figure 10.- Concluded.



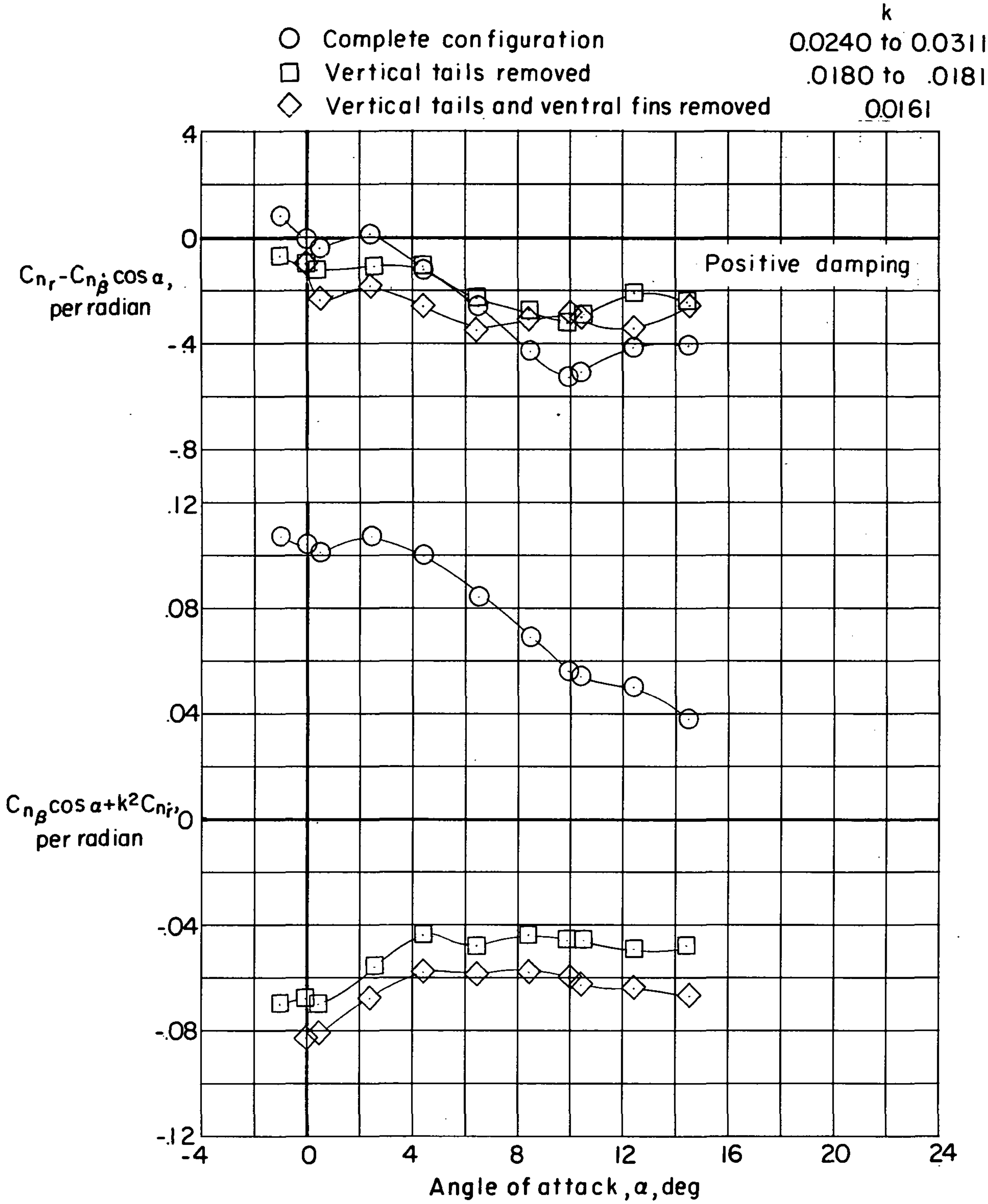
(a) M = 1.60; R = 1.12×10^6.

Figure 11.- Effects of external stores on the damping-in-yaw and oscillatory directional stability characteristics of basic configuration. $i_t = 0^{\circ}$.



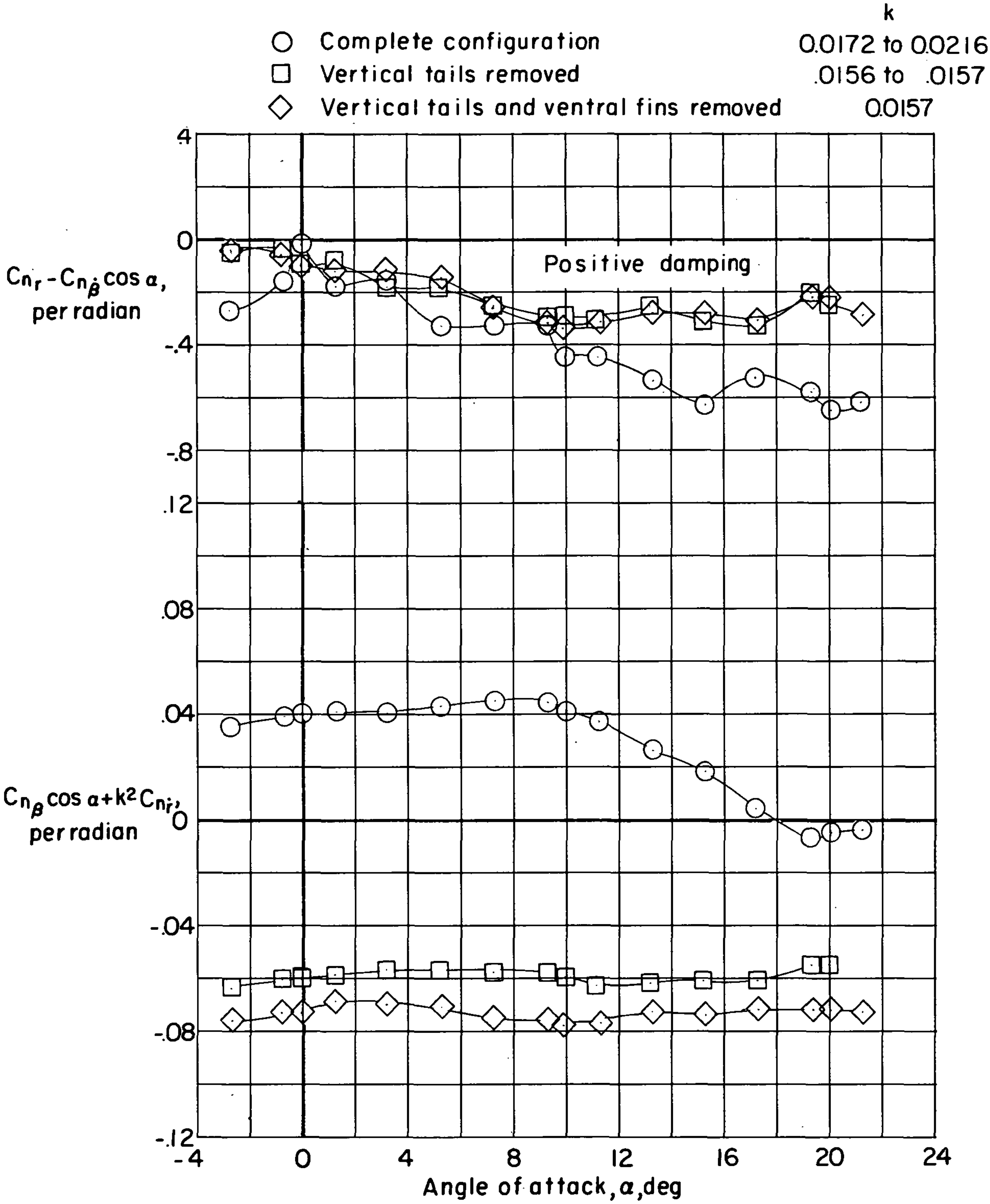
(b) M = 2.02.

Figure 11.- Concluded.



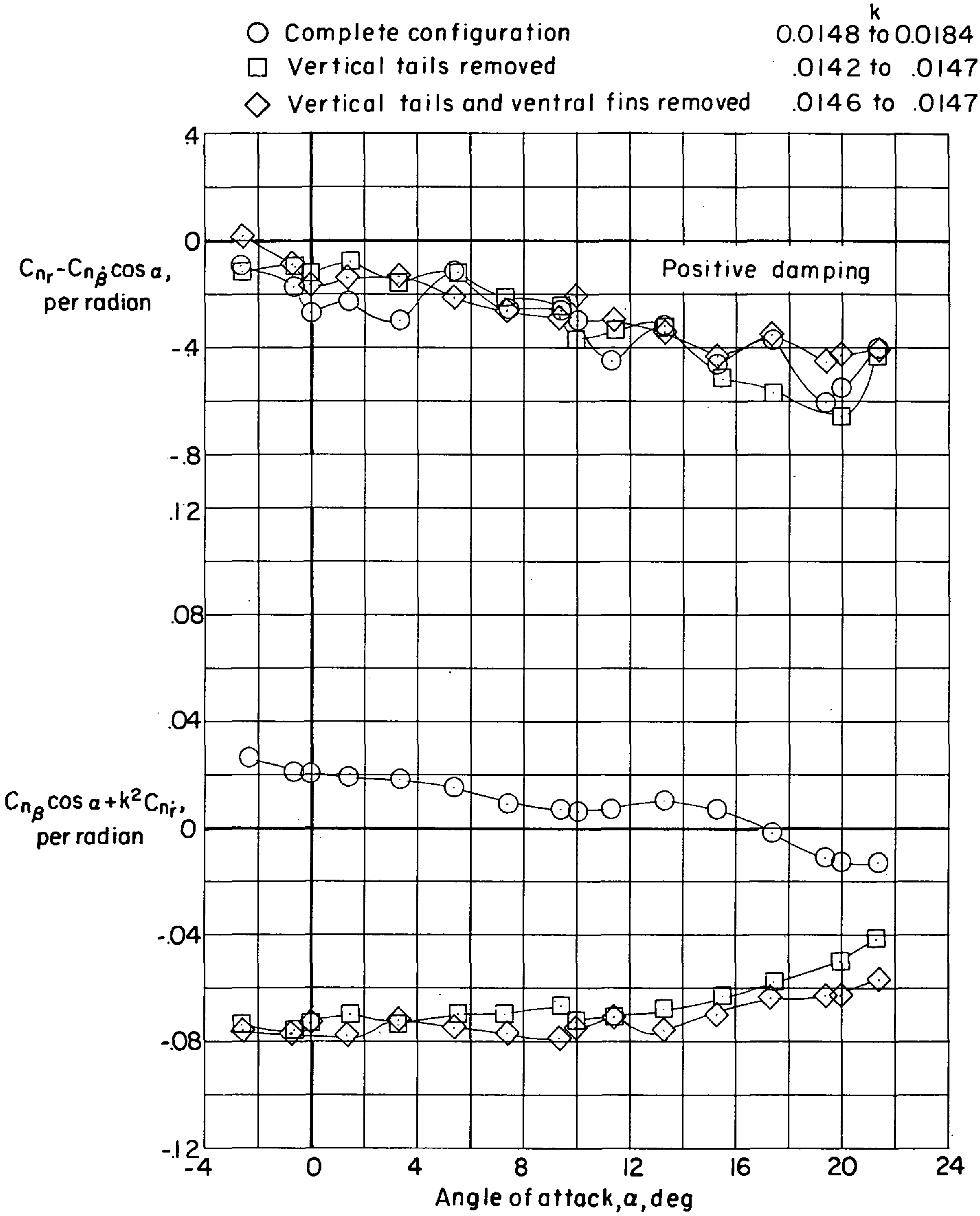
(a) $M = 1.60$; $R = 1.12 \times 10^6$.

Figure 12.- Effects of removal of vertical tail and ventral fins on damping-in-yaw and oscillatory directional stability characteristics of basic configuration. $i_t = 0^\circ$.



(b) $M = 2.02$; $R = 1.10 \times 10^6$.

Figure 12.- Continued.



(c) $M = 2.36$; $R = 1.10 \times 10^6$.

Figure 12.- Concluded.

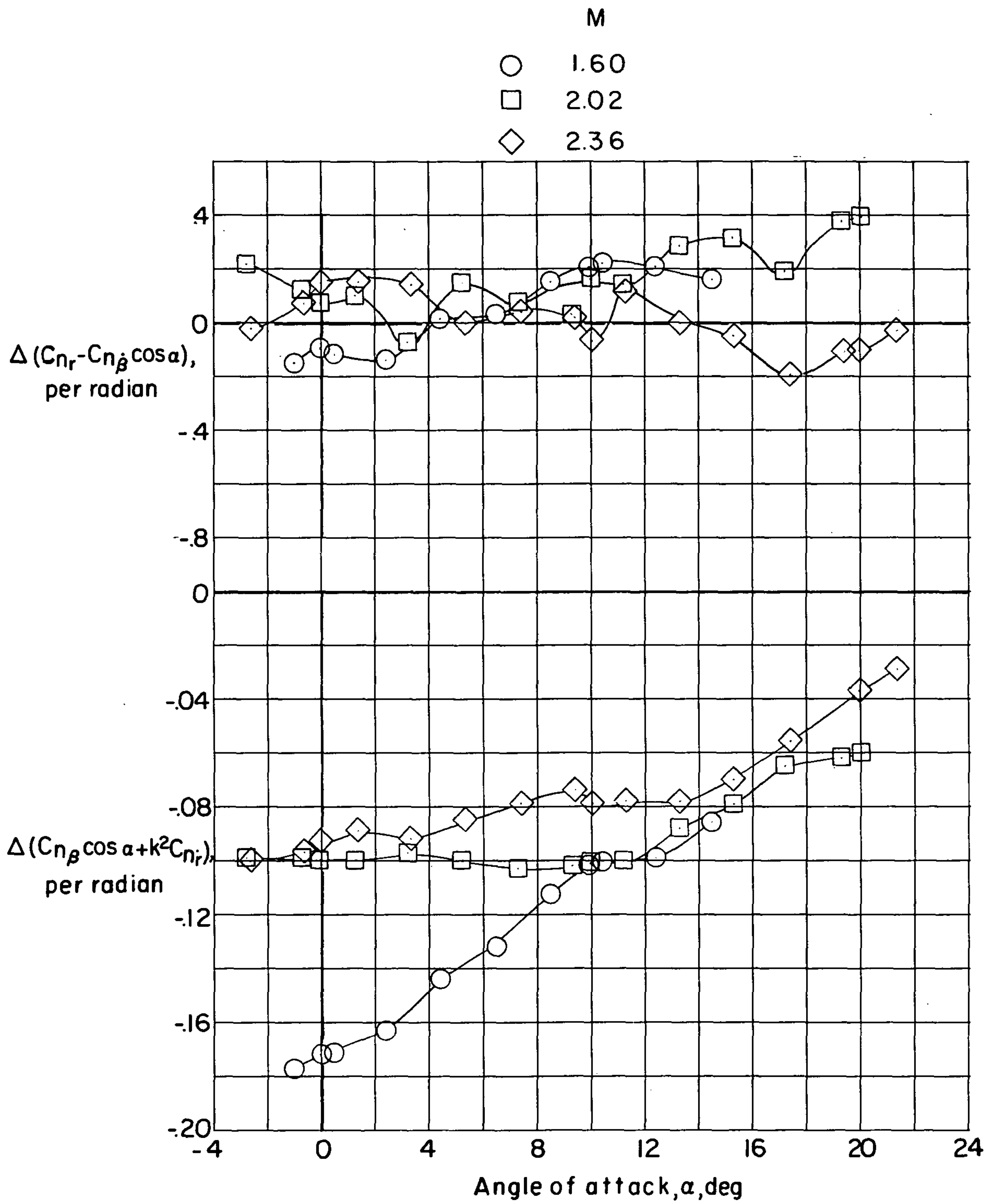


Figure 13.- Incremental effects of removing the vertical tails on the damping-in-yaw and oscillatory lateral stability characteristics.

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