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TRANSONIC DYNAMIC STABILITY CHARACTERISTICS OF SEVERAL MODELS OF PROJECT MERCURY CAPSULE CONFIGURATIONS

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WASHINGTON [redacted] August 1961

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TECHNICAL MEMORANDUM X-554

TRANSONIC DYNAMIC STABILITY CHARACTERISTICS OF SEVERAL MODELS OF PROJECT MERCURY CAPSULE CONFIGURATIONS*

By William B. Igoe and Ernest R. Hillje

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SUMMARY

The oscillatory longitudinal stability (pitching moment in phase with displacement) and damping in pitch of 1/9-scale models of three basic Project Mercury configurations (reentry, exit, and escape) and three modified reentry configurations were measured at Mach numbers from 0.30 to 1.20 at angles of attack from 0° to 14°. Short tests of the oscillatory directional stability (yawing moment in phase with displacement) and damping in yaw were also made for the basic reentry configuration. The models were sting mounted and rigidly forced to perform a 2° constant amplitude, single-degree-of-freedom oscillation at reduced frequencies from 0.0208 to 0.1849.

Results show that the reentry configuration generally had marginal or negative damping in pitch and slight positive oscillatory longitudinal stability except for instability at $\alpha = 4^{\circ}$. Results were generally independent of surface conditions, reduced frequency, and Reynolds number for Reynolds numbers above about 1.10×10^{6}. Modifications to the reentry body caused detailed changes in the measured parameters but did not significantly improve the damping or oscillatory stability. The reentry configuration with the antenna and parachute canisters removed did show that the afterbody can significantly affect damping. The basic exit configuration had positive damping in pitch but negative oscillatory longitudinal stability at all test conditions. The basic escape configuration had positive damping and positive oscillatory stability in pitch except for instability above $\alpha = 10^{\circ}$. A general trend with angle of attack for all configurations in pitch was for an increase (or decrease) in the damping to be accompanied by a decrease (or increase) in the oscillatory stability.

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INTRODUCTION

The National Aeronautics and Space Administration has conducted a broad research program associated with the development of the Project Mercury, a manned, nonlifting, reentry satellite vehicle. Reference 1 discusses some of the wind-tunnel and flight phases of this program. One important aspect of the wind-tunnel studies was to determine the stability characteristics of the various configurations of the Project Mercury capsule. For example, reference 2 presents the results of a
static stability investigation at transonic speeds. This paper presents L
the results of an investigation at transonic speeds of some pitching 1
and yawing oscillation derivatives measured in phase and out of phase 6
with displacement for 1/9-scale models of several configurations of the 2
Mercury capsule obtained in the Langley 8-foot transonic pressure tunnel. 1

Models of the basic Mercury reentry, exit, and escape configurations and three modified reentry configurations were tested by using a forced-oscillation technique (ref. 3). Tests were made at Mach numbers from 0.30 to 1.20 at angles of attack from 0° to 14° for various reduced frequencies. Reynolds number, based on the capsule heat-shield diameter, was varied from 0.55×10^{6} to 3.50×10^{6}. All models were oscillated in pitch or yaw at an amplitude of approximately 2° about axes passing through the full-scale center-of-mass positions.

SYMBOLS

The data presented herein are referred to the body system of axes with moments referred to the oscillation axis. The coefficients and symbols used are defined as follows:

A	cross-sectional area based on d, 0.374 sq ft
d	heat-shield diameter, 0.690 ft
f	frequency of oscillation, cps
k	reduced-frequency parameter, $\frac{\omega d}{V}$
M	free-stream Mach number
q	angular velocity in pitch, radians/sec
r	angular velocity in yaw, radians/sec

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R	Reynolds number based on d
V	free-stream velocity, ft/sec
α	angle of attack
β	angle of sideslip
ρ	free-stream mass density of air, $\frac{\text{lb-sec}^2}{\text{ft}^4}$
ω	angular velocity, $2\pi f$, radians/sec
C_m	pitching-moment coefficient, $\dfrac{\text{Pitching moment about oscillation axis}}{\frac{1}{2}\rho V^2 Ad}$

$$C_{m_q} = \frac{\partial C_m}{\partial\left(\frac{qd}{V}\right)}$$

$$C_{m_{\dot{q}}} = \frac{\partial C_m}{\partial\left(\frac{\dot{q}d^2}{V^2}\right)}$$

$$C_{m_\alpha} = \frac{\partial C_m}{\partial \alpha}$$

$$C_{m_{\dot{\alpha}}} = \frac{\partial C_m}{\partial\left(\frac{\dot{\alpha}d}{V}\right)}$$

$C_{m_q} + C_{m_{\dot{\alpha}}}$	damping-in-pitch parameter (component of pitching oscillation moment derivative out of phase with displacement), per radian
$C_{m_\alpha} - k^2 C_{m_{\dot{q}}}$	oscillatory longitudinal stability parameter (component of pitching oscillation moment derivative in phase with displacement), per radian
C_n	yawing-moment coefficient, $\dfrac{\text{Yawing moment about oscillation axis}}{\frac{1}{2}\rho V^2 Ad}$

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$$C_{n_r} = \frac{\partial C_n}{\partial\left(\frac{rd}{V}\right)}$$

$$C_{n_{\dot{r}}} = \frac{\partial C_n}{\partial\left(\frac{\dot{r}d^2}{V^2}\right)}$$

$$C_{n_\beta} = \frac{\partial C_n}{\partial \beta}$$

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$$C_{n_{\dot{\beta}}} = \frac{\partial C_n}{\partial\left(\frac{\dot{\beta}d}{V}\right)}$$

$C_{n_r} - C_{n_{\dot{\beta}}} \cos \alpha$ damping-in-yaw parameter (component of yawing oscillation moment derivative out of phase with displacement), per radian

$C_{n_\beta} \cos \alpha + k^2 C_{n_{\dot{r}}}$ oscillatory directional stability parameter (component of yawing oscillation moment derivative in phase with displacement), per radian

A dot used over a symbol indicates a first derivative with respect to time.

MODELS, APPARATUS, AND PROCEDURE

Models

Drawings of the 1/9-scale models of the basic Project Mercury capsule in the reentry, exit, and escape configurations and the three variations of the reentry configuration which were tested are shown in figure 1. Slight modifications necessary to provide for sting clearance during oscillation are apparent in figure 1.

Test modifications to the basic reentry configuration included removal of the antenna and parachute canisters (fig. 1(d)), addition of a 16.2° included-angle, solid diverging conical flare behind the heat shield (fig. 1(e)), and installation of a 1/4-inch-thick vented, spherical-segment heat shield mounted 0.21 inch forward of the basic heat shield by means of six equally spaced mounting bolts and spacers on a 6-inch-diameter circle and one on the center line (fig. 1(f)).

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The axis of rotation for forced oscillation of the models was normal to the longitudinal center line of the models at the proposed center-of-mass position of the full-scale capsule. The modified versions of the reentry configuration used the same oscillation-center location as the basic reentry configuration.

Apparatus and Procedure

Oscillation apparatus.- The models were mounted on an oscillation balance which was forced to perform an essentially sinusoidal, single-degree-of-freedom motion of constant amplitude. A motor-driven Scotch yoke arrangement provided oscillatory motion and allowed control of oscillation frequencies up to 21 cycles per second. Strain-gage signals of the model angular displacement and of the moment required to sustain oscillation were resolved into orthogonal components so that the moments in phase and out of phase with the displacement could be determined. The in-phase component, when corrected for the mechanical spring constant and model inertia, gave a measure of the oscillatory aerodynamic stability. The out-of-phase component, when corrected for the tare or wind-off damping, gave a measure of the aerodynamic damping. A description of the oscillation mechanism, the technique of taking measurements, and data-reduction procedures are given in references 3 and 4.

The oscillating balance and models were mounted on a sting-support strut which is capable of an angle-of-attack range of -4° to 14°. Center of rotation of the support strut was about 2 feet behind the model oscillation axis. This location resulted in a slight displacement of the model center from the tunnel center line as the angle of attack was varied.

Wind tunnel.- The tests were made in the Langley 8-foot transonic pressure tunnel. This tunnel has a rectangular test section with slots in the upper and lower walls allowing continuous operation through the transonic speed range with negligible choking and blockage effects.

TESTS

The tests were made at Mach numbers from 0.30 to 1.20, at angles of attack from 0° to 14°, and at oscillation frequencies from 6 to 15 cycles per second which gives a range of reduced frequency parameter k from 0.0208 to 0.1849. The amplitude of forced oscillation in pitch or yaw was 2°. Tunnel stagnation temperature was maintained at 122° F and, for most of the tests, the tunnel stagnation pressure was one atmosphere. A limited amount of data was obtained for the basic

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reentry configuration at stagnation pressures of 0.25, 0.5, and 1.6 atmospheres. Reynolds number, based on heat-shield diameter, was varied from 0.55×10^6 to 3.50×10^6 as shown in figure 2. For some tests, transition-causing roughness in the form of sparsely distributed No. 36 carborundum grains was applied to the heat-shield face in a 1/8-inch-wide band on a circle approximately 6 inches in diameter. The roughness size was estimated on the basis of the criteria presented in reference 5.

A list of the configurations and test conditions for which data are presented is given in table I. All six configurations were oscillated in pitch to determine $C_{m_q} + C_{m_{\dot{\alpha}}}$ and $C_{m_\alpha} - k^2 C_{m_{\dot{q}}}$. In addition, the basic reentry configuration was oscillated in yaw to determine $C_{n_r} - C_{n_{\dot{\beta}}} \cos \alpha$ and $C_{n_\beta} \cos \alpha + k^2 C_{n_{\dot{r}}}$.

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RESULTS AND DISCUSSION

The test results are presented in terms of the variations of the oscillatory stability and damping parameters with angle of attack for various reduced frequencies and Mach numbers. A list of figures presented for the various test conditions is in table I. The sign conventions are such that negative values of the damping-in-pitch parameter $C_{m_q} + C_{m_{\dot{\alpha}}}$ and the damping-in-yaw parameter $C_{n_r} - C_{n_{\dot{\beta}}} \cos \alpha$ mean positive damping. Negative values of the oscillatory longitudinal stability parameter $C_{m_\alpha} - k^2 C_{m_{\dot{q}}}$ and positive values of the oscillatory directional stability parameter $C_{n_\beta} \cos \alpha + k^2 C_{n_{\dot{r}}}$ indicate positive oscillatory stability.

Dynamic Characteristics

Reentry configuration.- The basic reentry configuration had negligible or negative pitch damping at all Mach numbers and angles of attack, except for positive damping at $\alpha = 4^\circ$ for Mach numbers above 0.60. (See fig. 3.) Low oscillatory longitudinal stability was evident throughout except for instability at angles of attack of about 4°. The static C_{m_α} for the reentry configuration of reference 2 shows a similar tendency at angles of attack near 4°, although the static data do not show an actual change in sign. Reduced frequency had no appreciable effect on either parameter. There was no noticeable difference in

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results of tests with and without transition roughness. (See figs. 3 and 4.)

The effects of Reynolds number are shown in figure 5 for tests at tunnel stagnation pressures of 0.25, 0.50, 1.00, and 1.60 atmospheres for Mach numbers of 0.60 and 1.20. The primary effect of decreasing Reynolds number from the values obtained at a stagnation pressure of one atmosphere to the lowest test values appears to be an increase in the effect of reduced frequency on the oscillatory longitudinal stability.

On the modified reentry configurations, the removal of the antenna and parachute canisters from the basic reentry configuration showed an increase in the oscillatory longitudinal stability and a decrease in the damping in pitch at 4° angle of attack. The effects upon these parameters emphasize the importance of afterbody shape for configurations of this type. (See figs. 3 and 6.) The addition of a diverging conical flare to the basic reentry configuration caused detailed changes in the damping and oscillatory stability but no significant improvements in either parameter. (See figs. 3 and 7.) The use of a vented heat shield showed no particular change in damping or oscillatory stability except for a small decrease in pitch damping near $\alpha = 4^{\circ}$. (See figs. 3 and 8.)

A general trend with angle of attack for all configurations was for an increase (or decrease) in the damping in pitch to be accompanied by a decrease (or increase) in the oscillatory longitudinal stability. This same trend is also shown in the data of reference 6.

Comparison between pitch and yaw oscillation data (see figs. 3 and 9) shows the same level of damping and oscillatory stability at $\alpha = 0^{\circ}$ which is to be expected for a body of revolution. The increase in positive damping that occurred during the pitch tests at an angle of attack of 4° was reduced in magnitude during the yaw tests and occurred at an angle of attack of about 8°.

<u>Exit configuration</u>.- The basic exit configuration had positive pitch damping (a negative coefficient) and oscillatory longitudinal instability (a positive coefficient) for all the test Mach numbers and angles of attack. (See fig. 10.) There was no appreciable effect of reduced frequency.

<u>Escape configuration</u>.- The limited data for the escape configuration in figure 11 indicate that for all Mach numbers the model had positive pitch damping at all angles of attack and oscillatory longitudinal stability except at angles of attack higher than about 10°. The static data for the escape configuration of reference 2 show the

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same results. Reduced frequency effects on both parameters were negligible.

Comparison of Oscillatory and Static Stability Results

The static stability derivative C_{m_α} which was obtained from reference 2 is compared with the oscillatory longitudinal stability parameter $C_{m_\alpha} - k^2 C_{m_{\dot{q}}}$ in figure 12 for $\alpha = 0^\circ$. Static C_{m_α} may be thought of as the oscillatory stability parameter at a reduced frequency k of 0. The static and oscillatory longitudinal stability parameters are in good agreement showing that there are no appreciable frequency effects for these test conditions. (See fig. 12.)

SUMMARY OF RESULTS

The transonic damping and oscillatory stability characteristics of the reentry, exit, escape, and three modified reentry configurations of a 1/9-scale model of the Mercury capsule have been investigated by using a forced-oscillation technique. Tests were made at Mach numbers from 0.30 to 1.20, Reynolds numbers from 0.55×10^6 to 3.50×10^6, reduced frequency parameter from 0.0208 to 0.1849, and at angles of attack from 0° to 14°.

The results are summarized as follows:

1. The reentry configuration had marginal or negative damping in pitch except for positive damping near $\alpha = 4^\circ$ above $M = 0.60$ and had slight positive oscillatory longitudinal stability throughout except near $\alpha = 4^\circ$. The damping in pitch and the oscillatory longitudinal stability were generally independent of reduced frequency and model surface conditions for Reynolds numbers above about 1.10×10^6.

2. Addition of a diverging conical flare or a vented heat shield to the basic reentry body caused detailed changes in pitch damping and oscillatory longitudinal stability but did not improve either parameter sufficiently to warrant consideration. Removal of the antenna and parachute canisters showed an appreciable effect of afterbody on damping.

3. The basic exit configuration had positive damping in pitch but negative oscillatory longitudinal stability (instability) at all angles of attack and Mach numbers.

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4. The basic escape configuration had positive damping at all angles of attack and Mach numbers and had positive oscillatory longitudinal stability for all Mach numbers at angles of attack below about 10°.

5. A general trend with angle of attack was for increases (or decreases) in the damping in pitch to be accompanied by decreases (or increases) in the oscillatory longitudinal stability for all configurations of the investigation.

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Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., May 17, 1961.

REFERENCES

1. Bond, A. C., and Kehlet, A. B.: Review, Scope and Recent Results of Project Mercury Research and Development Program. Paper Number 60-35, Inst. Aero. Sci., Jan. 1960.

2. Pearson, Albin O.: Wind-Tunnel Investigation at Mach Numbers From 0.50 to 1.14 of the Static Aerodynamic Characteristics of a Model of a Project Mercury Capsule. NASA TM X-292, 1960.

3. Bielat, Ralph P., and Wiley, Harleth G.: Dynamic Longitudinal and Directional Stability Derivatives for a 45° Sweptback-Wing Airplane Model at Transonic Speeds. NASA TM X-39, 1959.

4. Braslow, Albert L., Wiley, Harleth G., and Lee, Cullen Q.: Dynamic Directional Stability Derivatives for a 45° Swept-Wing—Vertical-Tail Airplane Model at Transonic Speeds and Angles of Attack, With a Description of the Mechanism and Instrumentation Employed. NACA RM L58A28, 1958.

5. Braslow, Albert L., and Knox, Eugene C.: Simplified Method for Determination of Critical Height of Distributed Roughness Particles for Boundary-Layer Transition at Mach Numbers From 0 to 5. NACA TN 4363, 1958.

6. Johnson, Joseph L., Jr.: Wind-Tunnel Investigation at Low Subsonic Speeds of the Static and Oscillatory Stability Characteristics of Models of Several Space Capsule Configurations. NASA TM X-285, 1960.

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TABLE I.- TEST CONDITIONS FOR CONFIGURATIONS INVESTIGATED

[All configurations were tested with fixed transition except those presented in figs. 4, 10, and 11. All configurations were tested in pitch oscillation except the one presented in fig. 9]

Figure number	Configuration	Stagnation pressure, atm	Mach number								
			0.30	0.60	0.80	0.90	0.96	1.00	1.03	1.15	1.20
3	Reentry - basic	1.0	√	√	√	√	√	√	√		√
4	Reentry - basic	1.0	√	√	√	√	√	√	√		√
5	Reentry - basic	1.6		√							
5	Reentry - basic	0.5		√							√
5	Reentry - basic	0.25		√							√
6	Reentry - canisters off	1.0	√	√	√	√		√		√	
7	Reentry - conical flare added	1.0	√	√	√	√	√	√	√		√
8	Reentry - vented heat shield added	1.0		√	√			√		√	
9	Reentry - basic	1.0	√	√	√	√				√	
10	Exit - basic	1.0	√	√	√	√	√	√	√		
11	Escape - basic	1.0				√	√		√	√	

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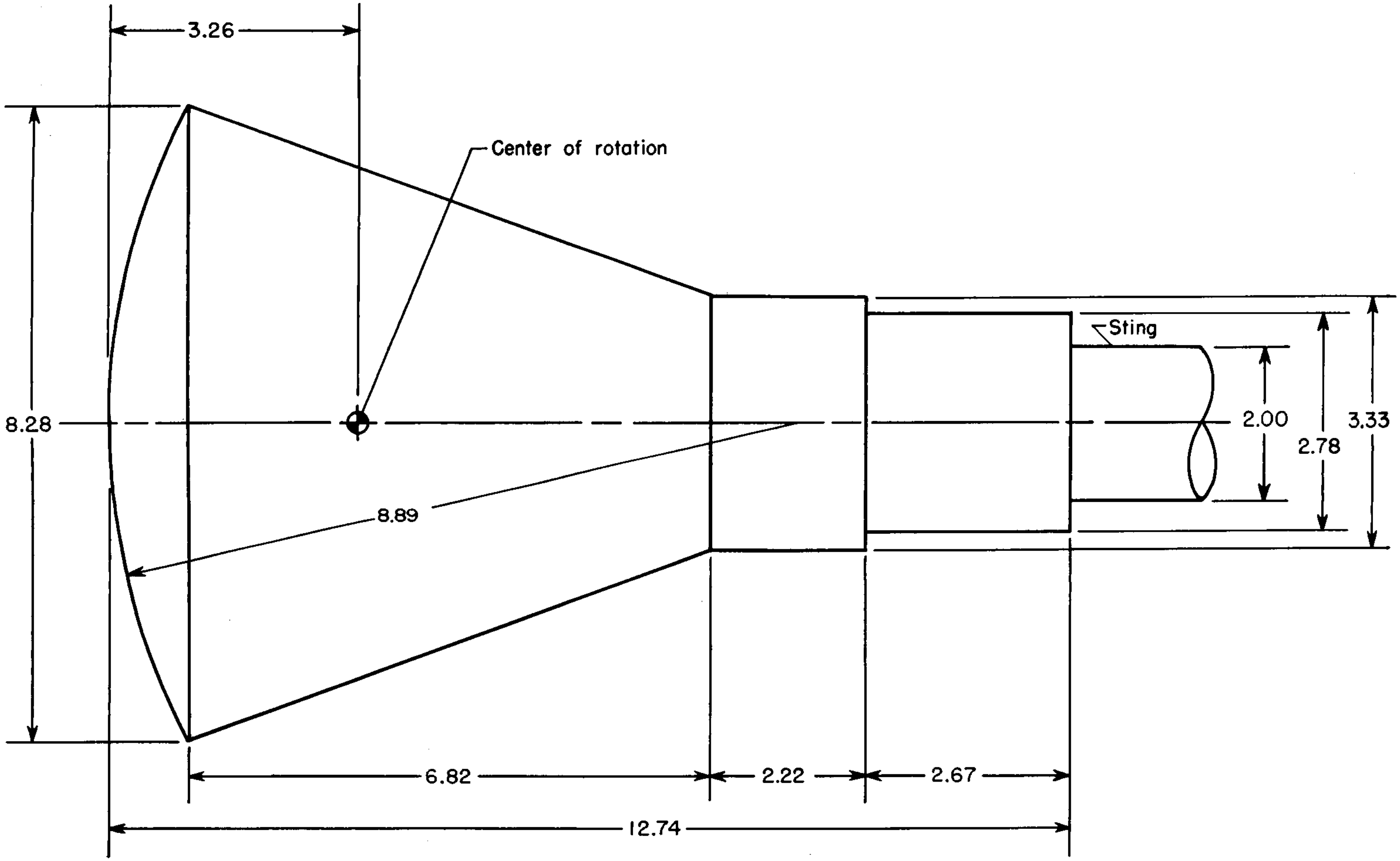

(a) Basic reentry configuration.

Figure 1.- Sketch of 1/9-scale Project Mercury capsule configurations. All dimensions are in inches unless otherwise noted.

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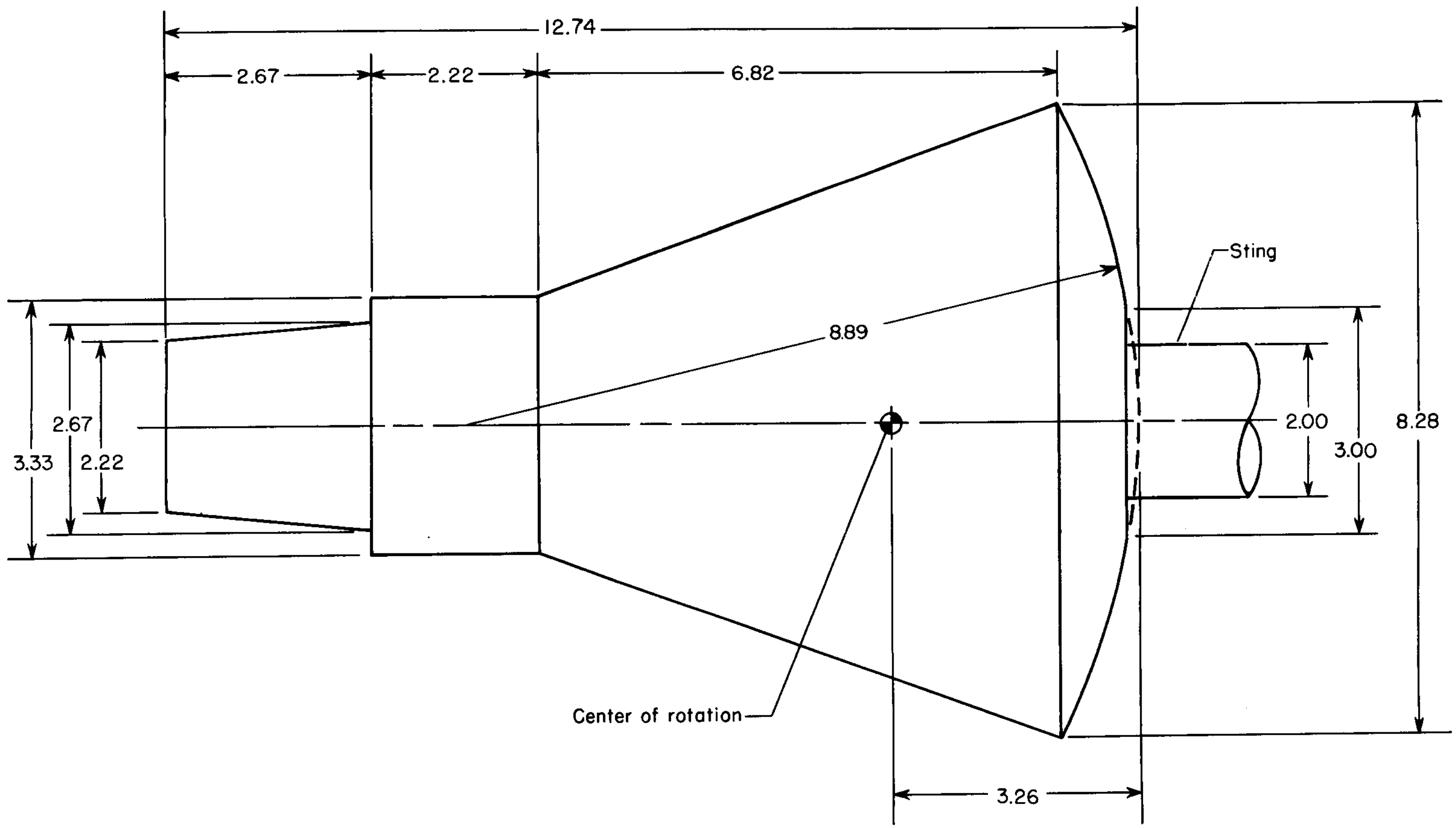

(b) Exit configuration.

Figure 1.- Continued.

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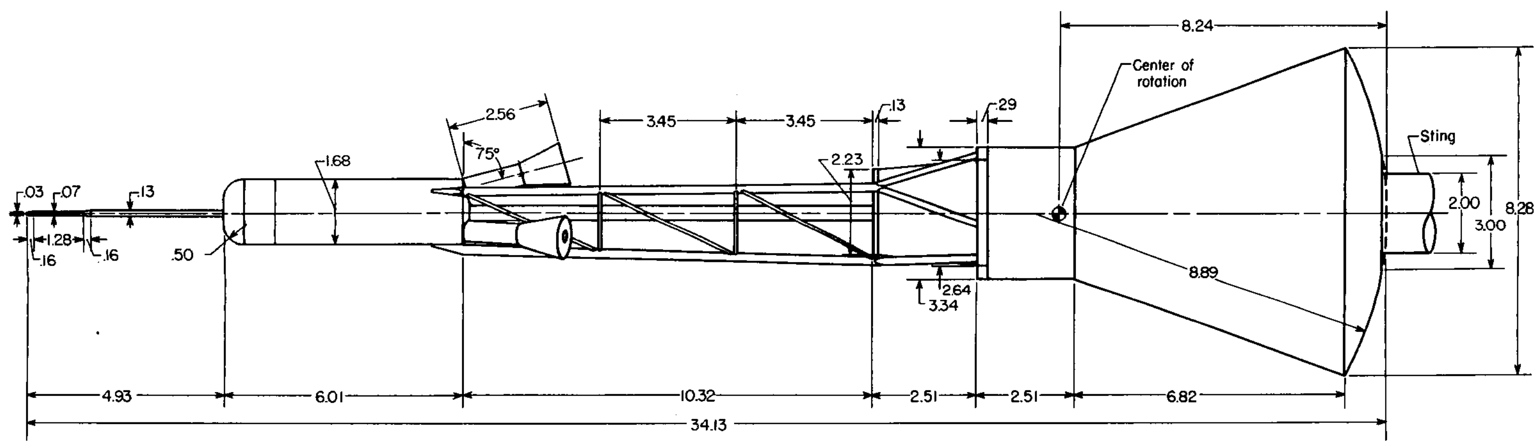

(c) Escape configuration.

Figure 1.- Continued.

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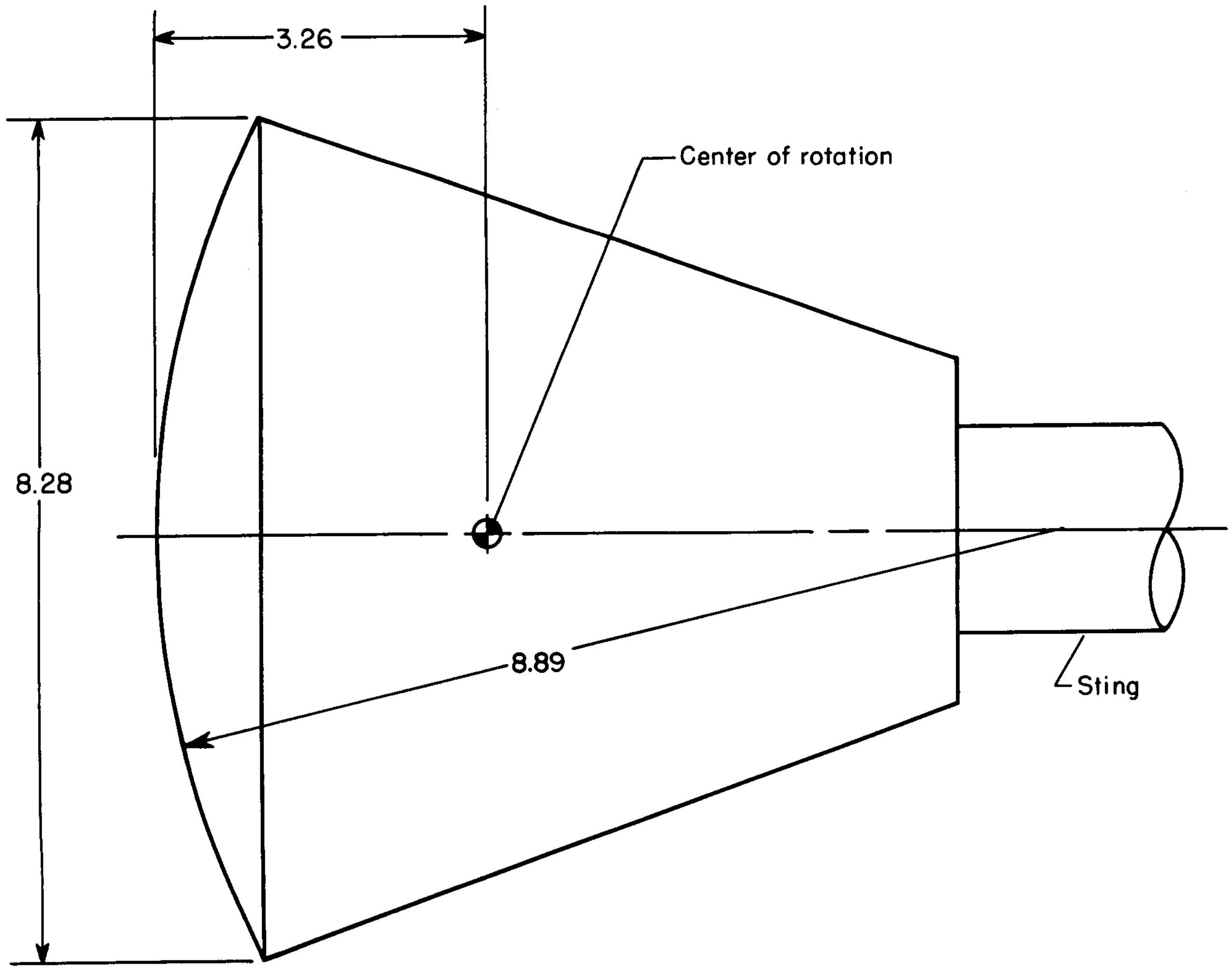

(d) Modified reentry configuration with antenna and parachute canisters off.

Figure 1.- Continued.

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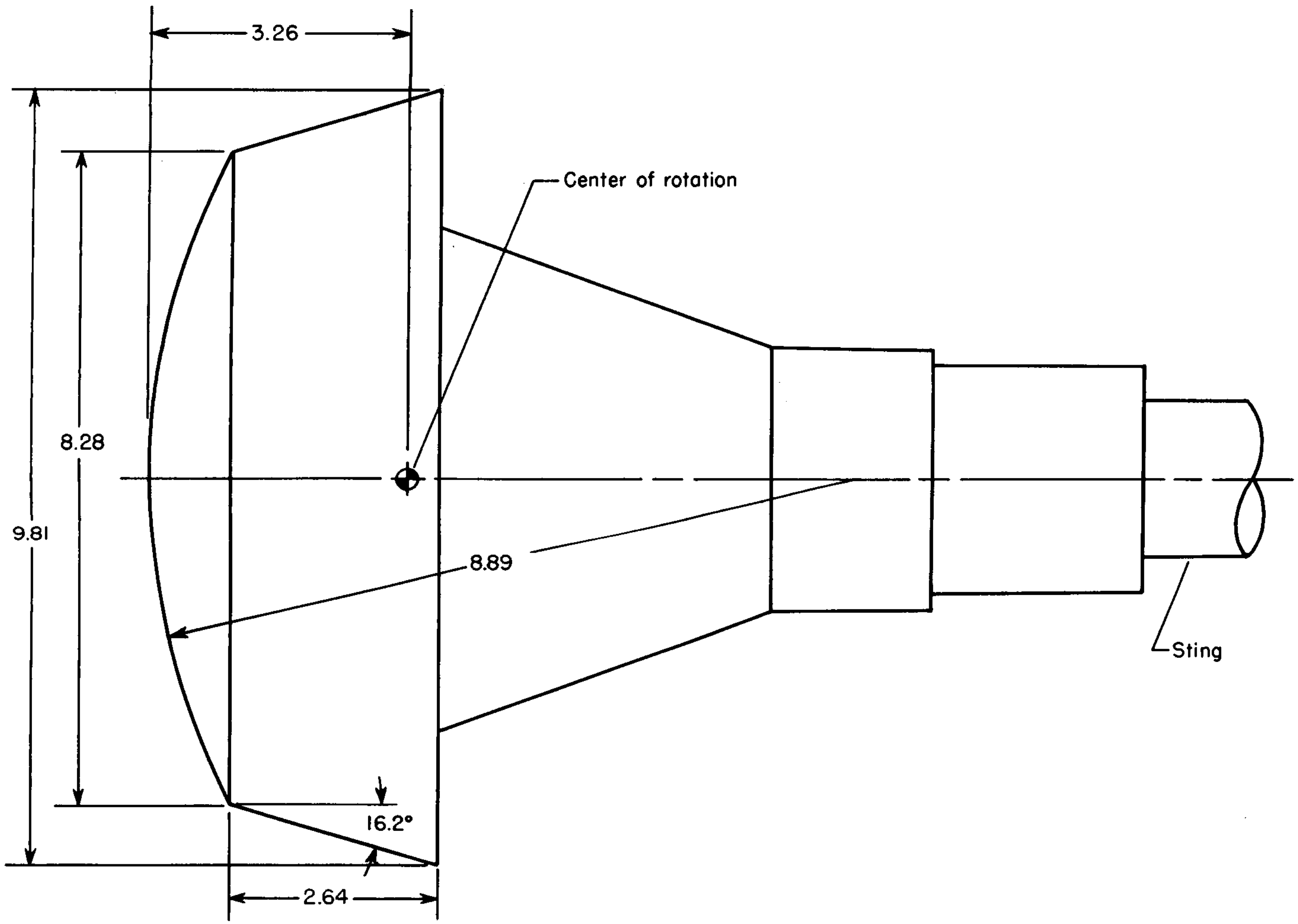
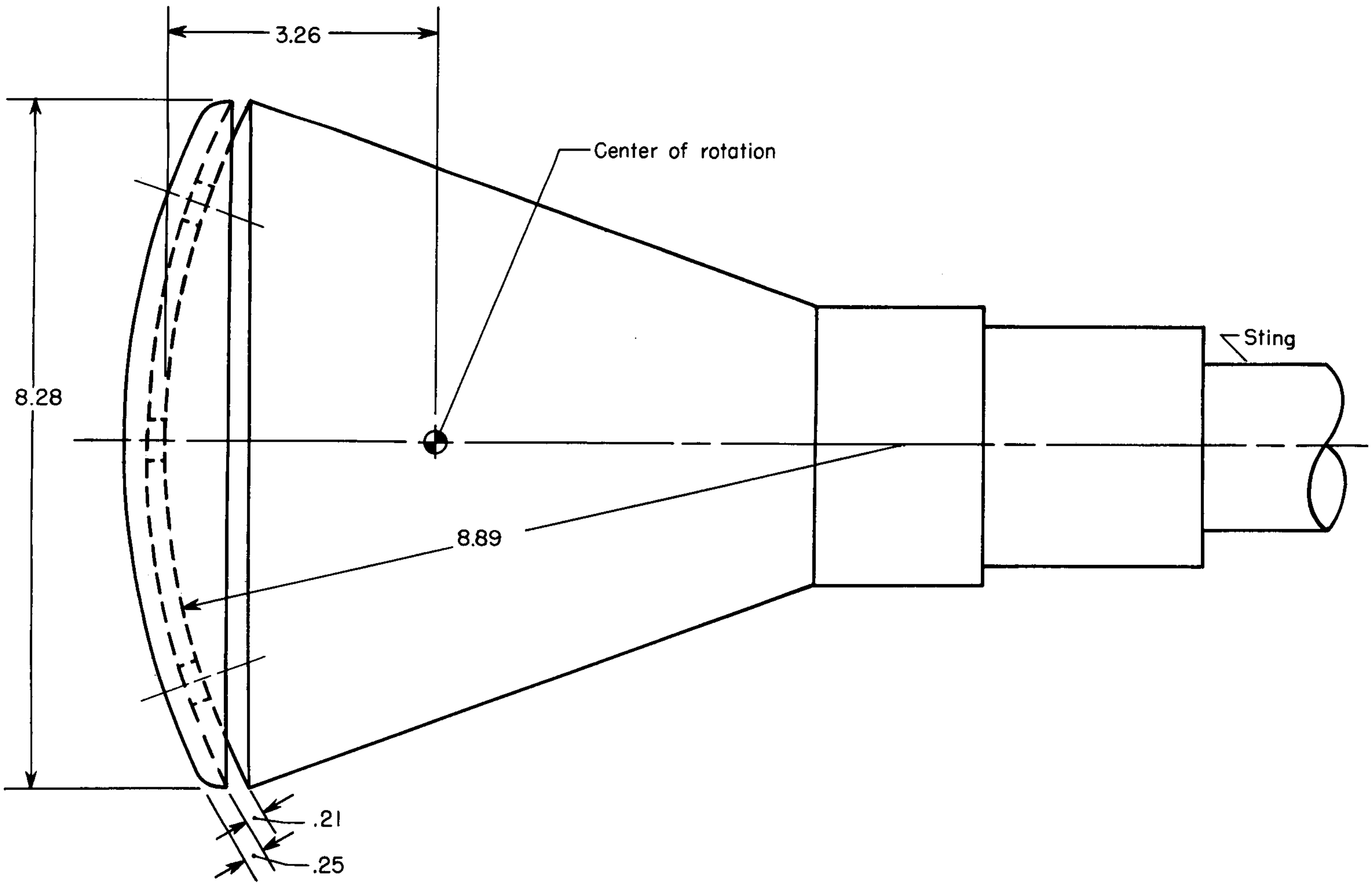


(e) Modified reentry configuration with flare added.

Figure 1.- Continued.



(f) Modified reentry configuration with vented heat shield.

Figure 1.- Concluded.

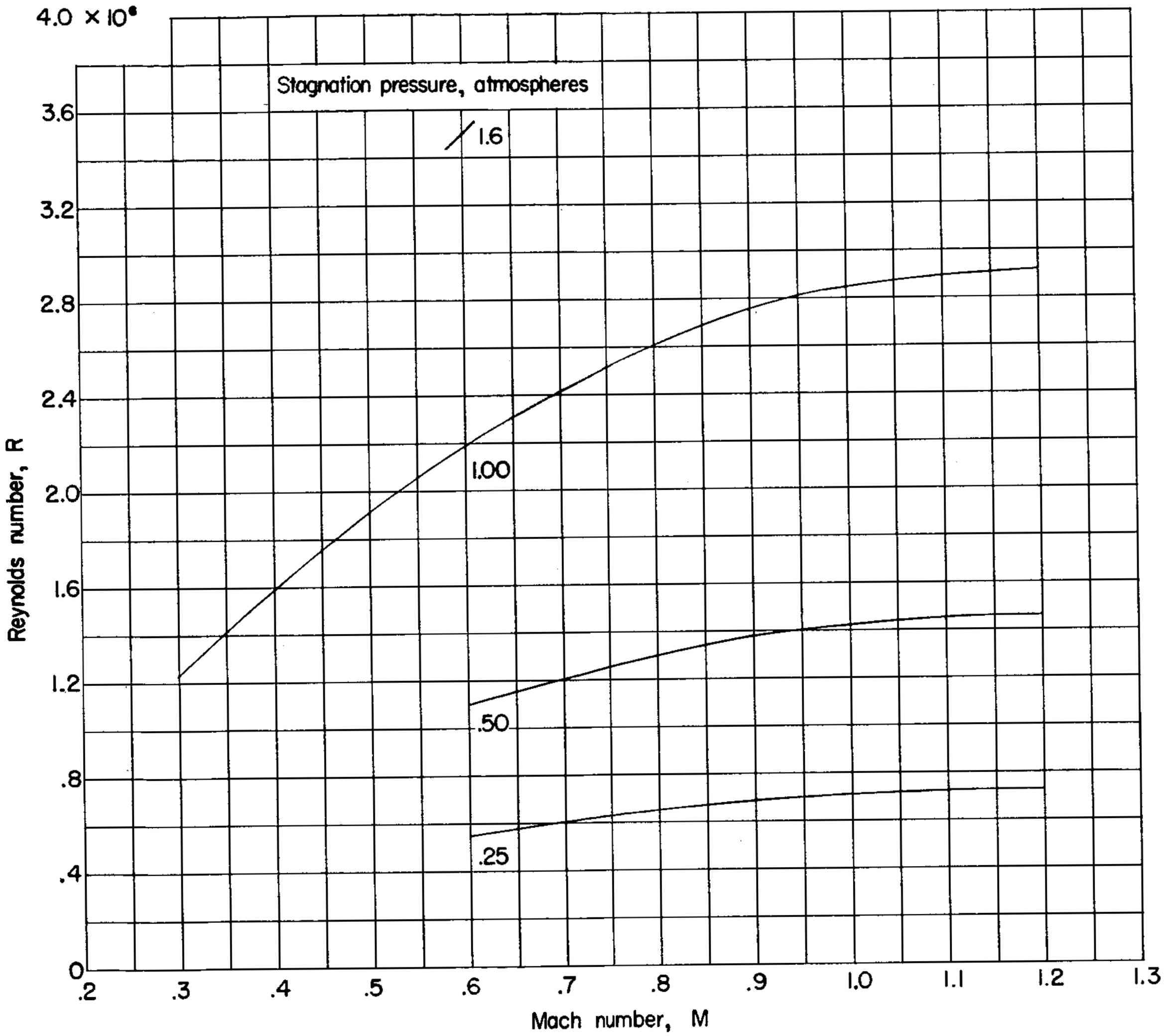


Figure 2.- Variation of Reynolds number with Mach number for test stagnation pressures.

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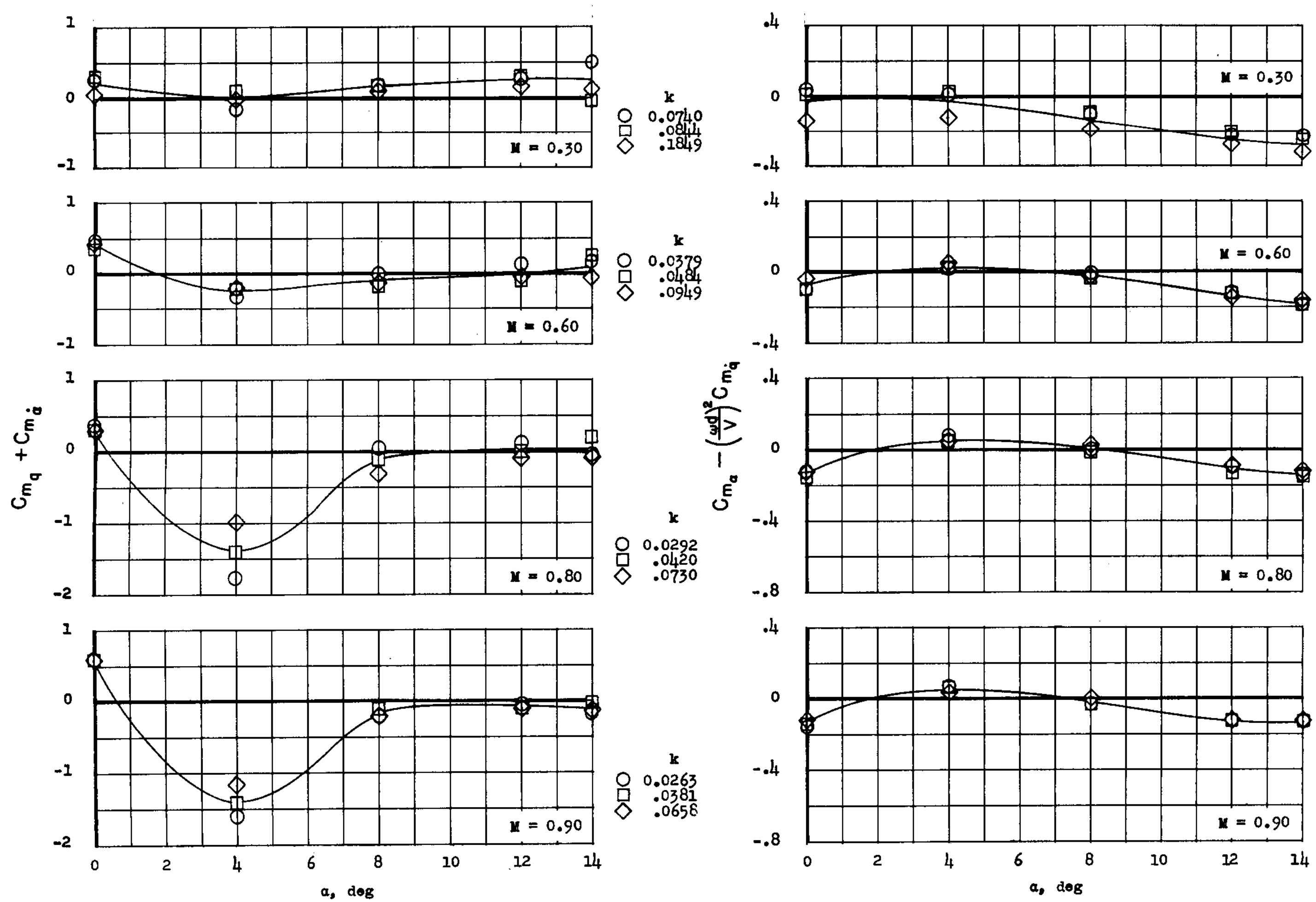
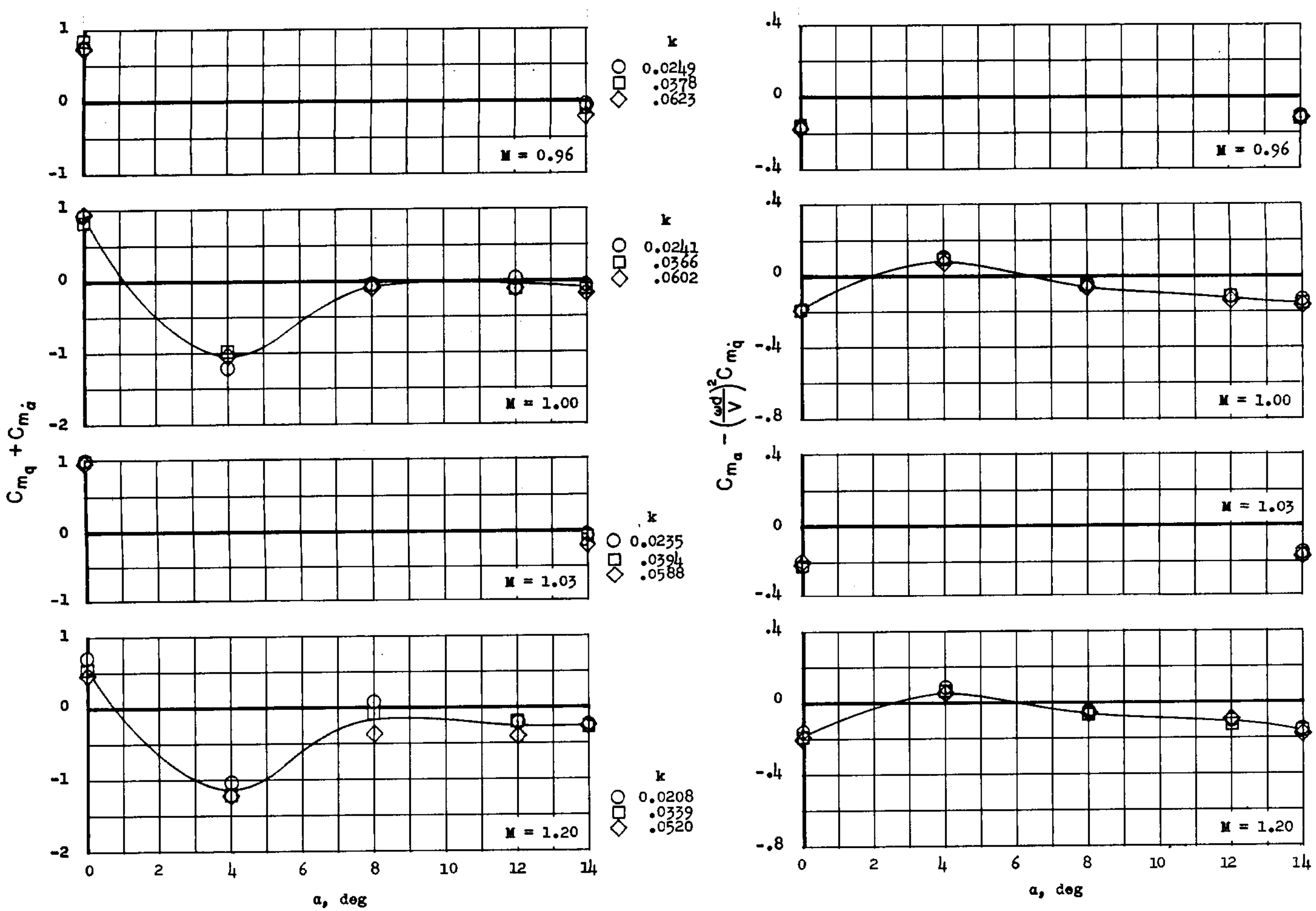


(a) M = 0.30 to 0.90.

Figure 3.- Variation of the damping-in-pitch parameter and oscillatory longitudinal stability parameter with angle of attack for various Mach numbers. Basic reentry configuration. Fixed transition. Stagnation pressure = 1.00 atmosphere.



(b) M = 0.96 to 1.20.

Figure 3.- Concluded.

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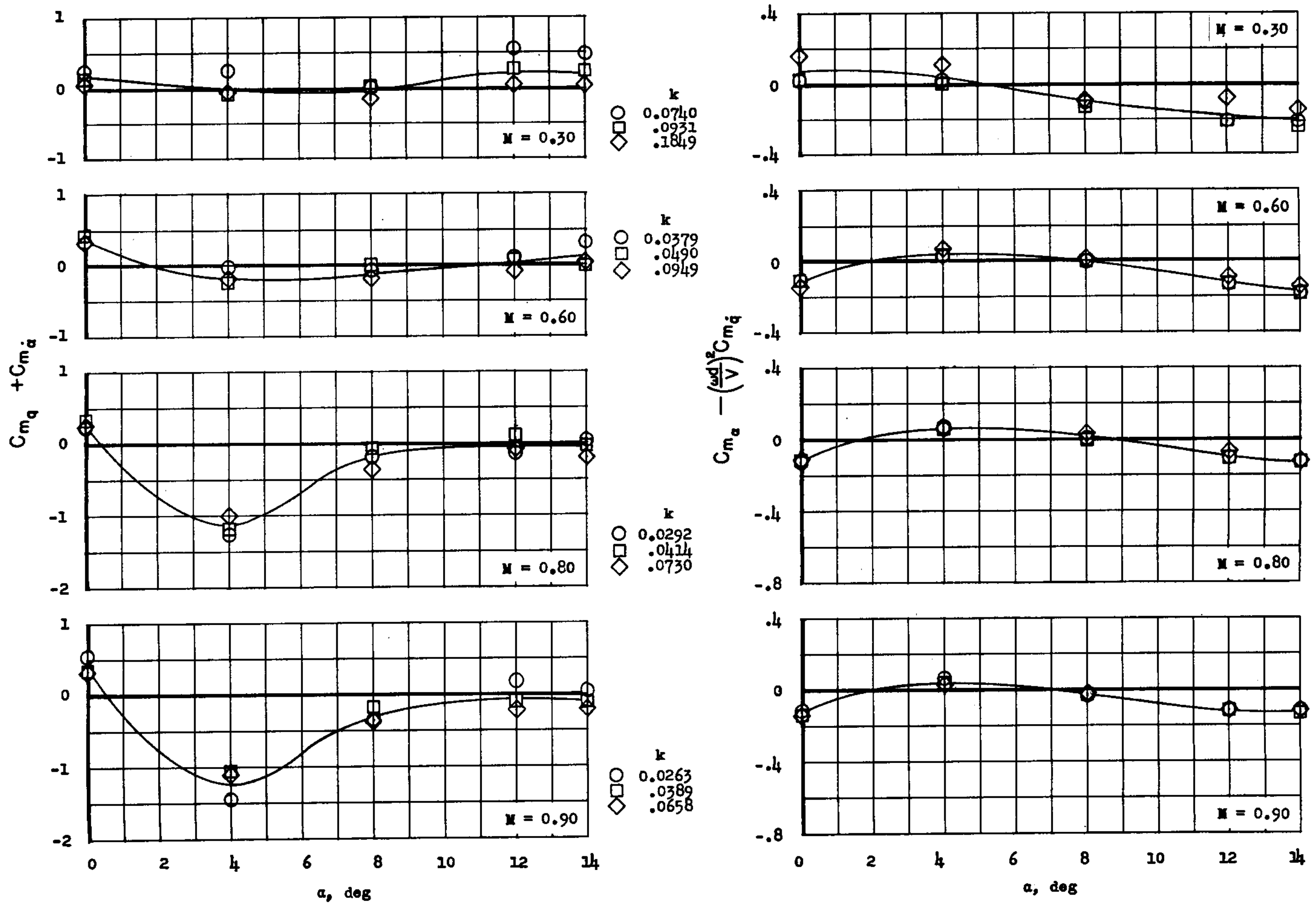

(a) M = 0.30 to 0.90.

Figure 4.- Variation of the damping-in-pitch parameter and oscillatory longitudinal stability parameter with angle of attack for various Mach numbers. Basic reentry configuration. Free transition. Stagnation pressure = 1.00 atmosphere.

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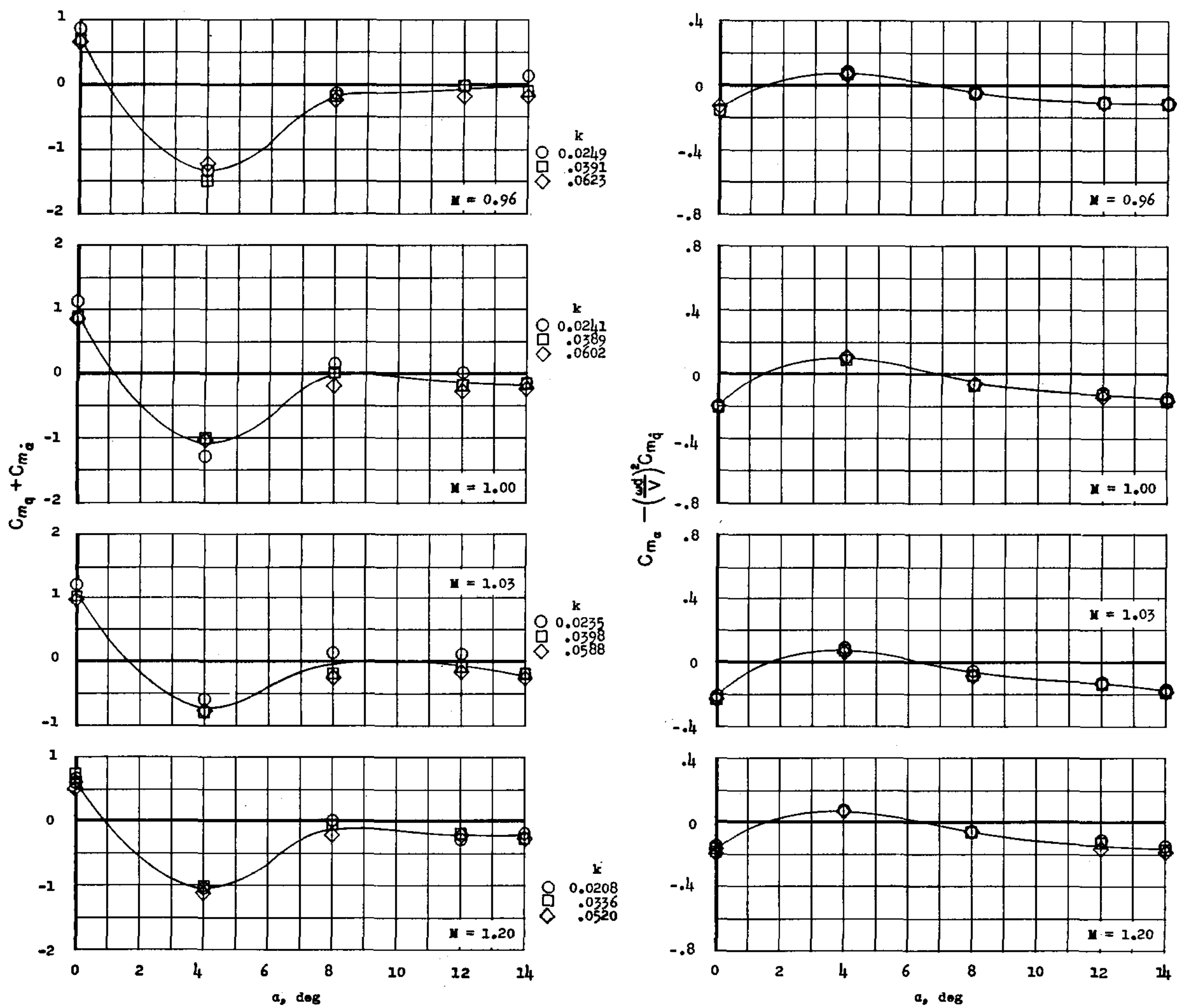

(b) M = 0.96 to 1.20.

Figure 4.- Concluded.

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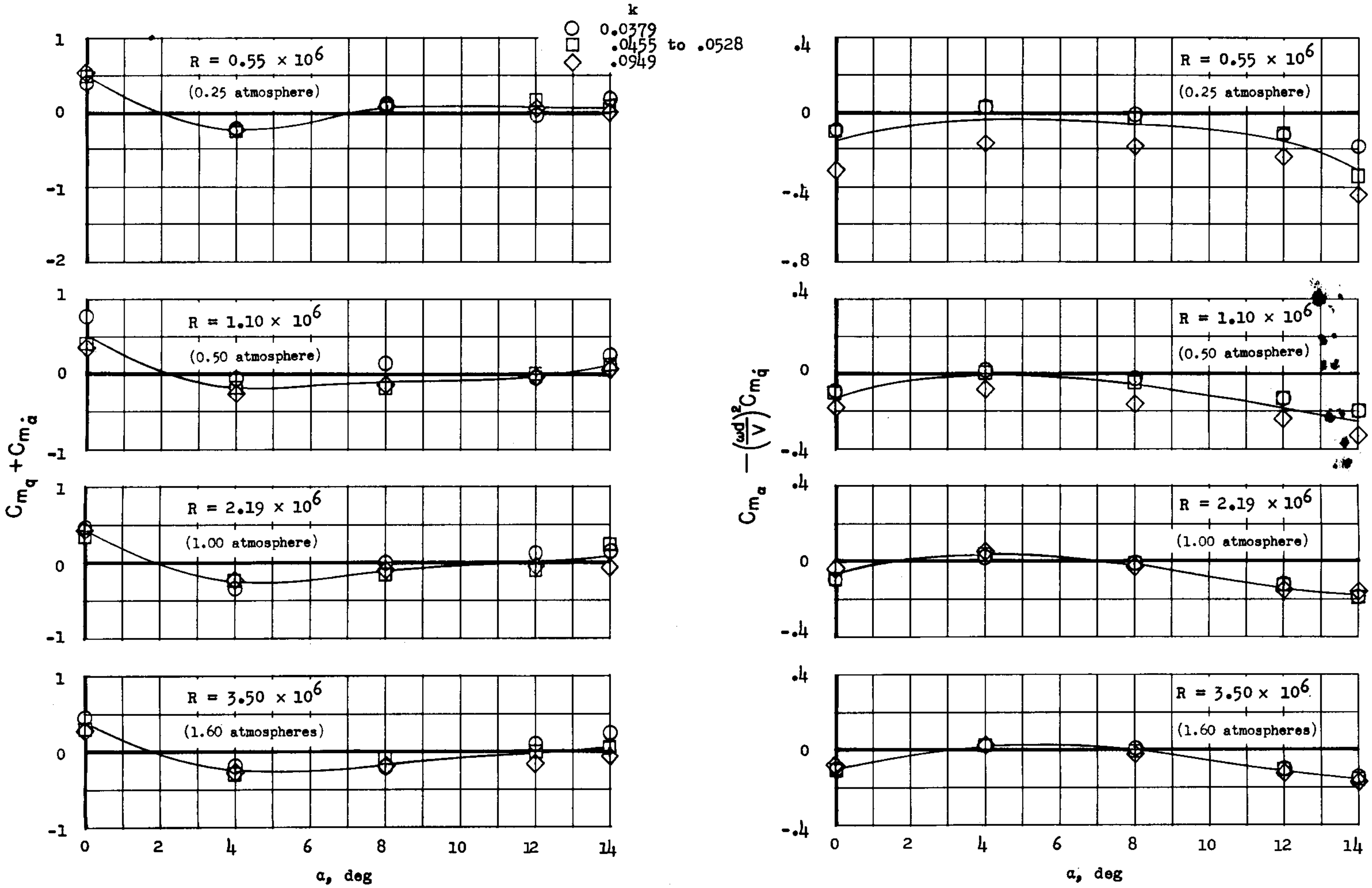
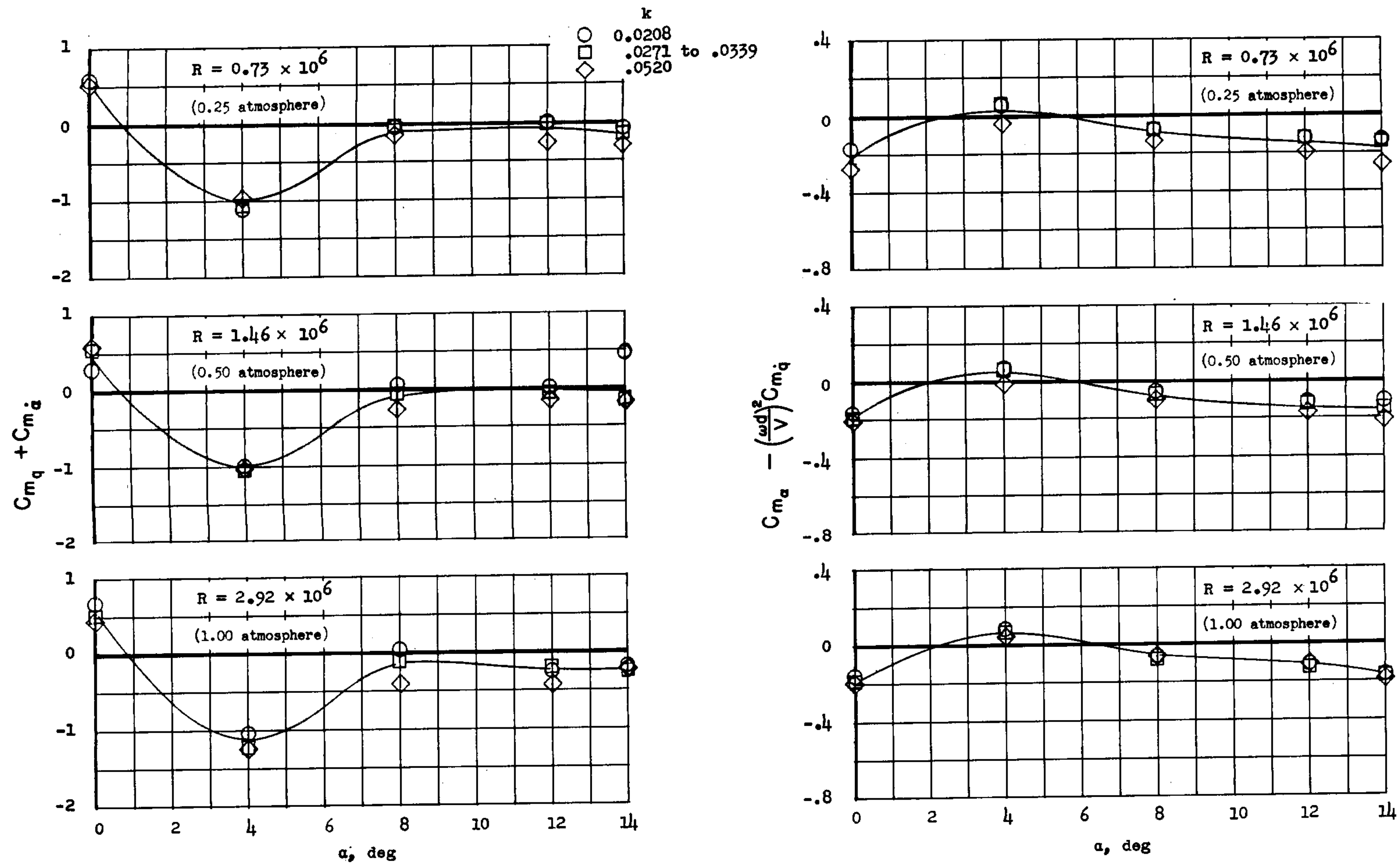


(a) M = 0.60.

Figure 5.- Variation of damping-in-pitch parameter and oscillatory longitudinal stability parameter with angle of attack at various Reynolds numbers for M = 0.60 and 1.20. Basic reentry configuration. Fixed transition.



(b) $M = 1.20$.

Figure 5.- Concluded.

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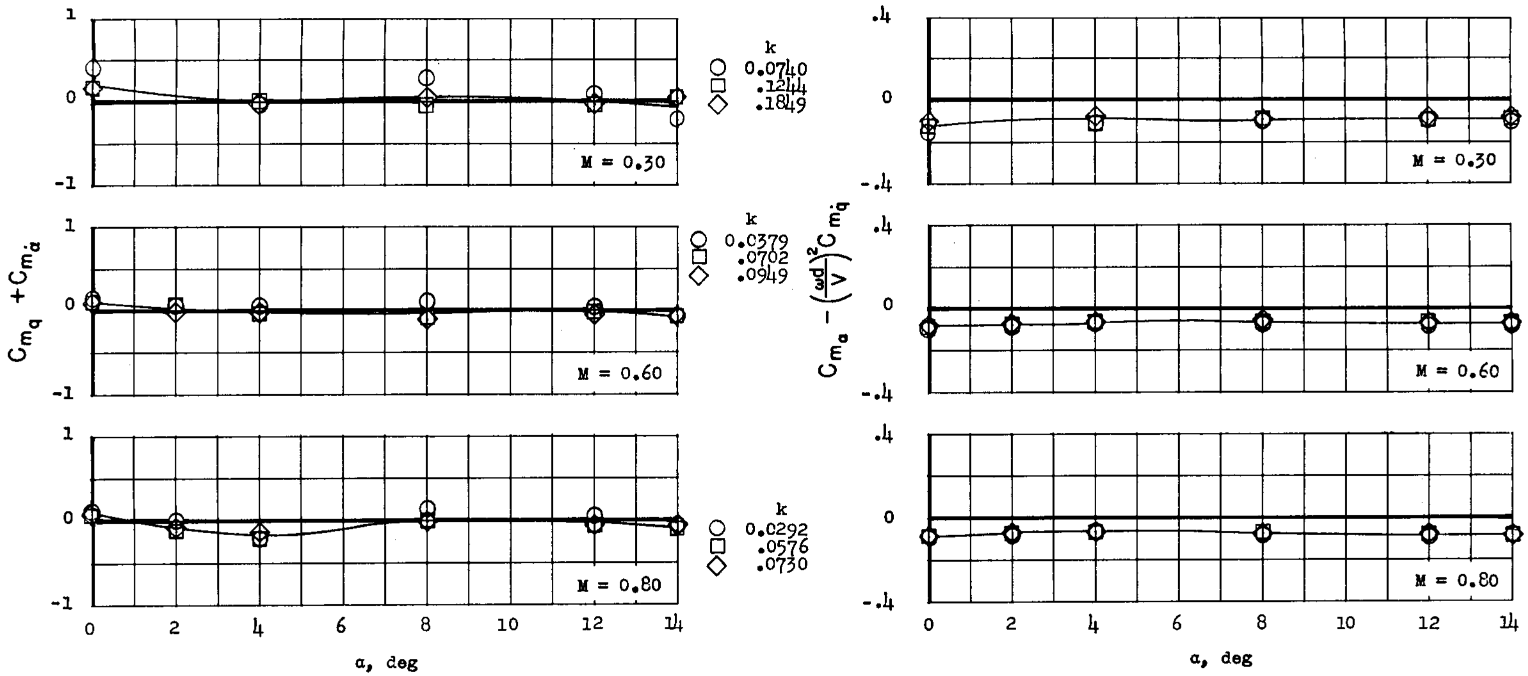
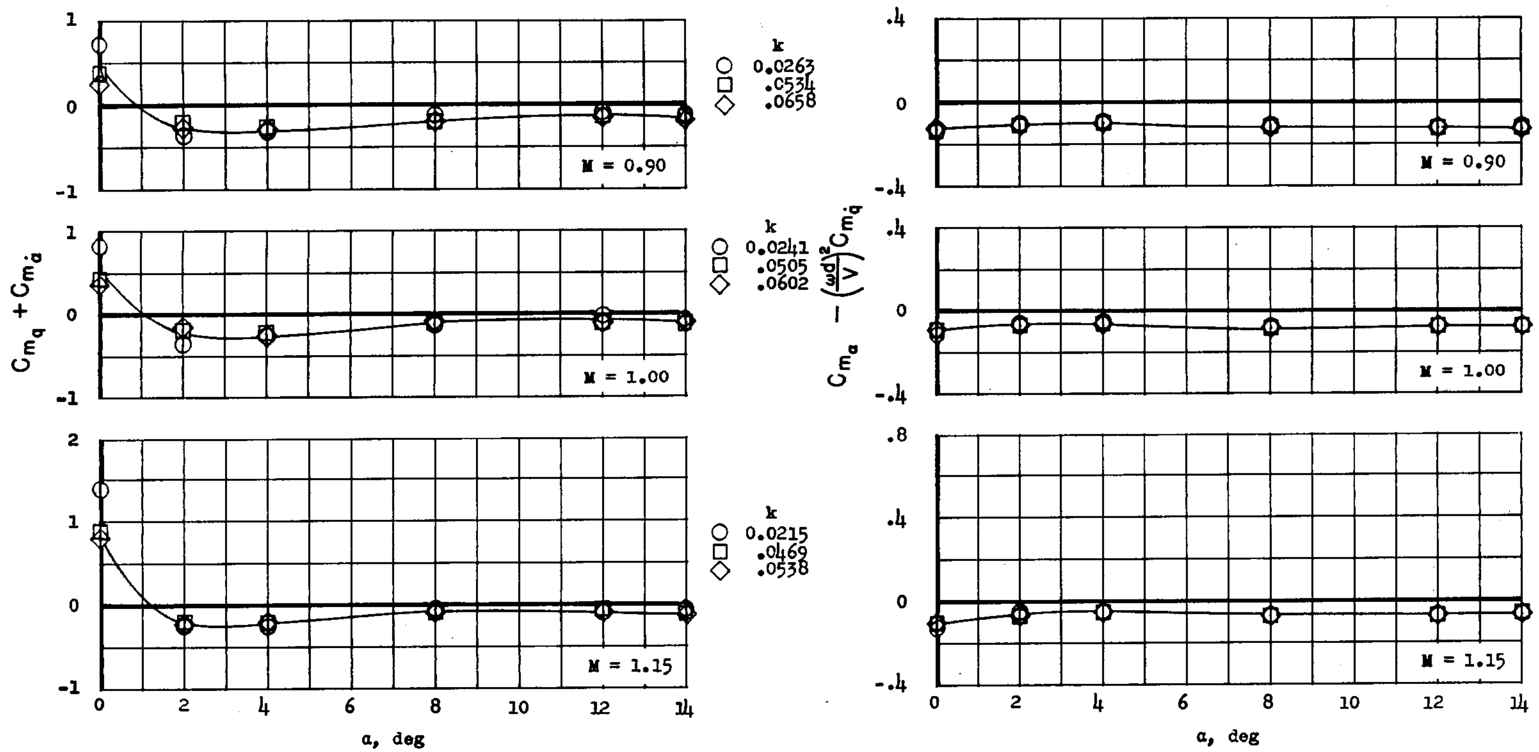


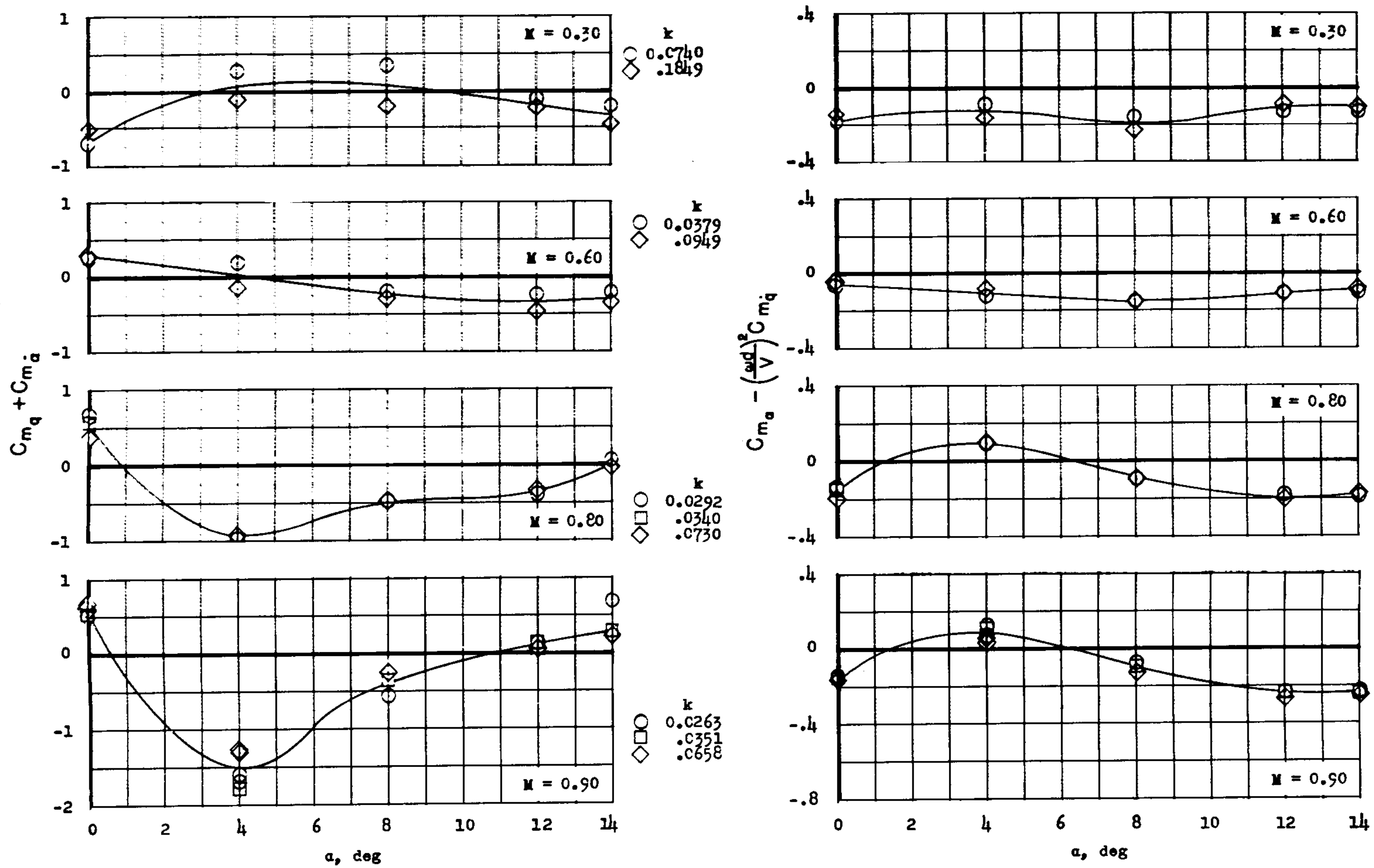
(a) M = 0.30 to 0.80.

Figure 6.- Variation of the damping-in-pitch parameter and oscillatory longitudinal stability parameter with angle of attack for various Mach numbers. Basic reentry configuration with antenna and parachute canisters removed. Fixed transition. Stagnation pressure = 1.00 atmosphere.



(b) M = 0.90 to 1.15.

Figure 6.- Concluded.



(a) M = 0.30 to 0.90.

Figure 7.- Variation of the damping-in-pitch parameter and oscillatory longitudinal stability parameter with angle of attack for various Mach numbers. Basic reentry configuration with conical flare. Fixed transition. Stagnation pressure = 1.00 atmosphere.

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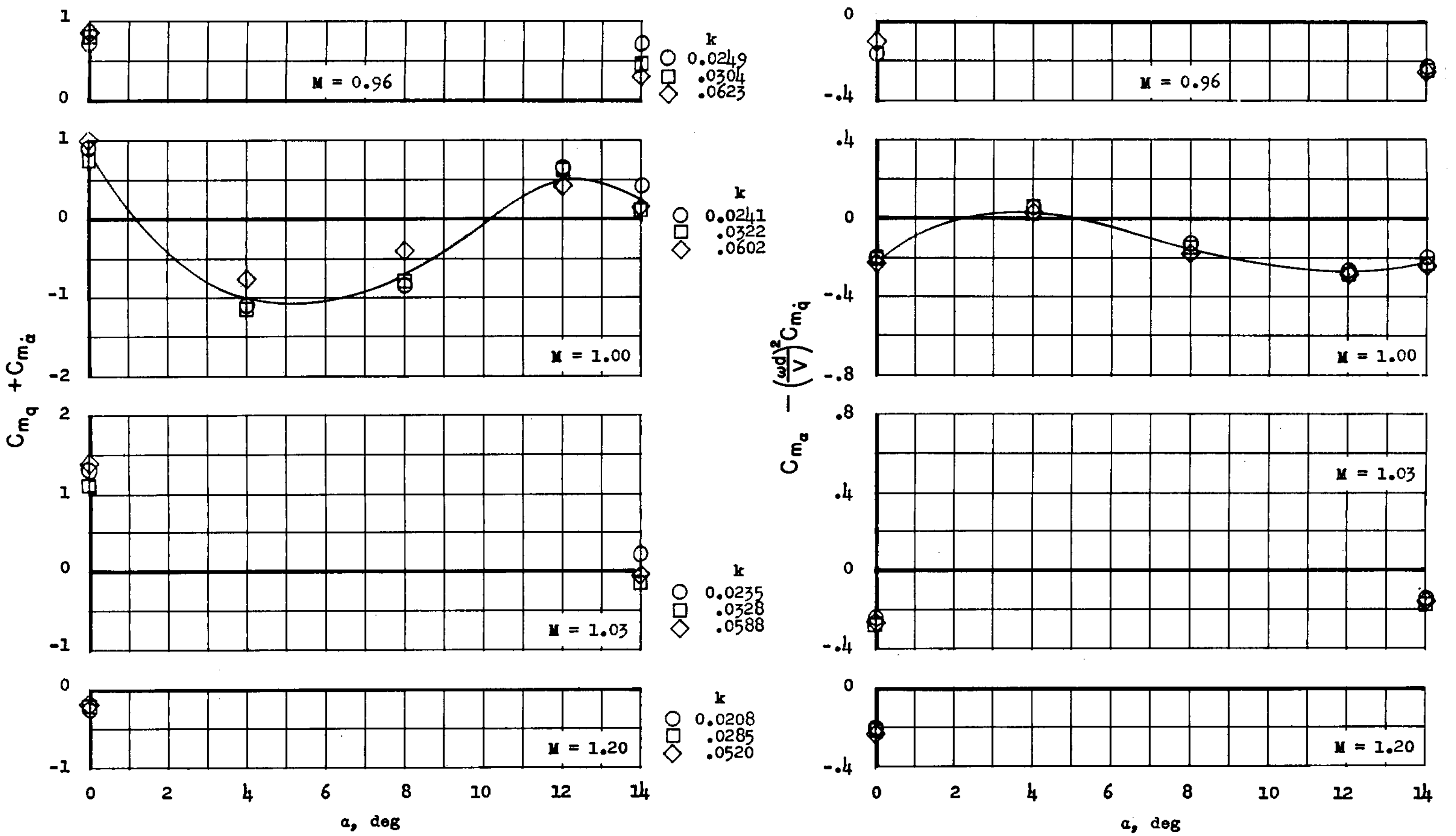

(b) M = 0.96 to 1.20.

Figure 7.- Concluded.

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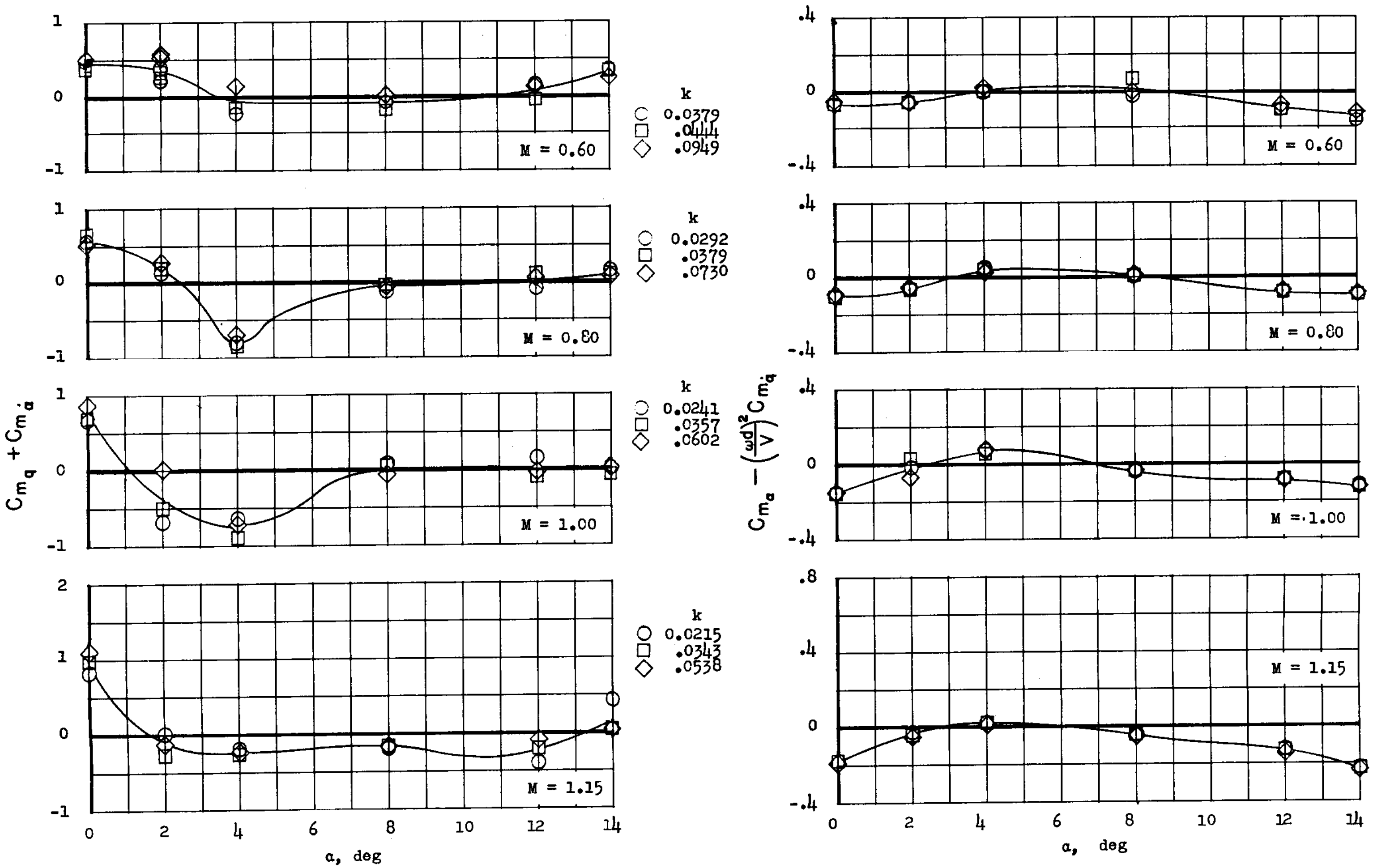

Figure 8.- Variation of the damping-in-pitch parameter and oscillatory longitudinal stability parameter with angle of attack for various Mach numbers. Basic reentry configuration with vented heat shield. Fixed transition. Stagnation pressure = 1.00 atmosphere.

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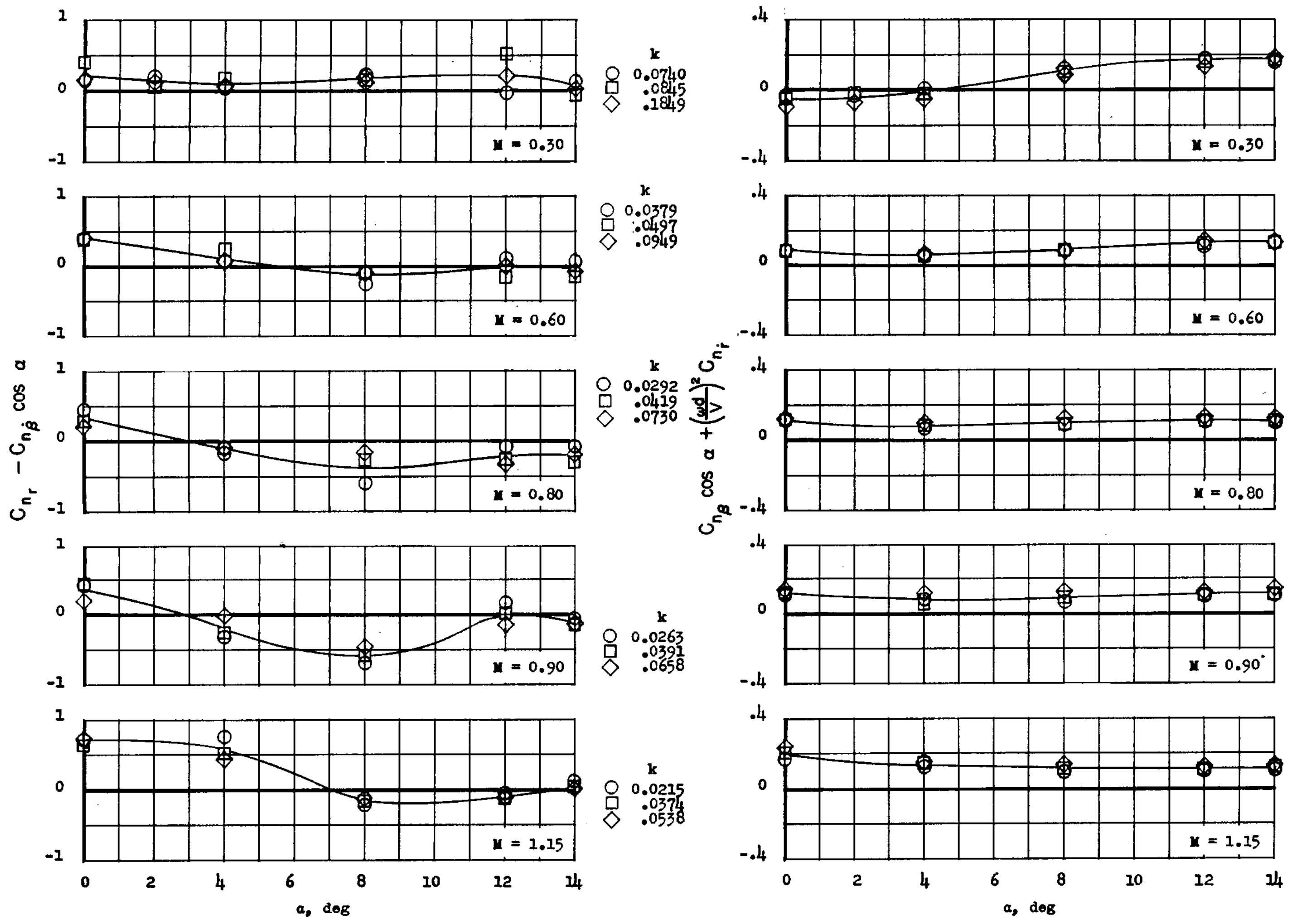

Figure 9.- Variation of the damping-in-yaw parameter and oscillatory directional stability parameter with angle of attack for various Mach numbers. Basic reentry configuration. Fixed transition. Stagnation pressure = 1.00 atmosphere.

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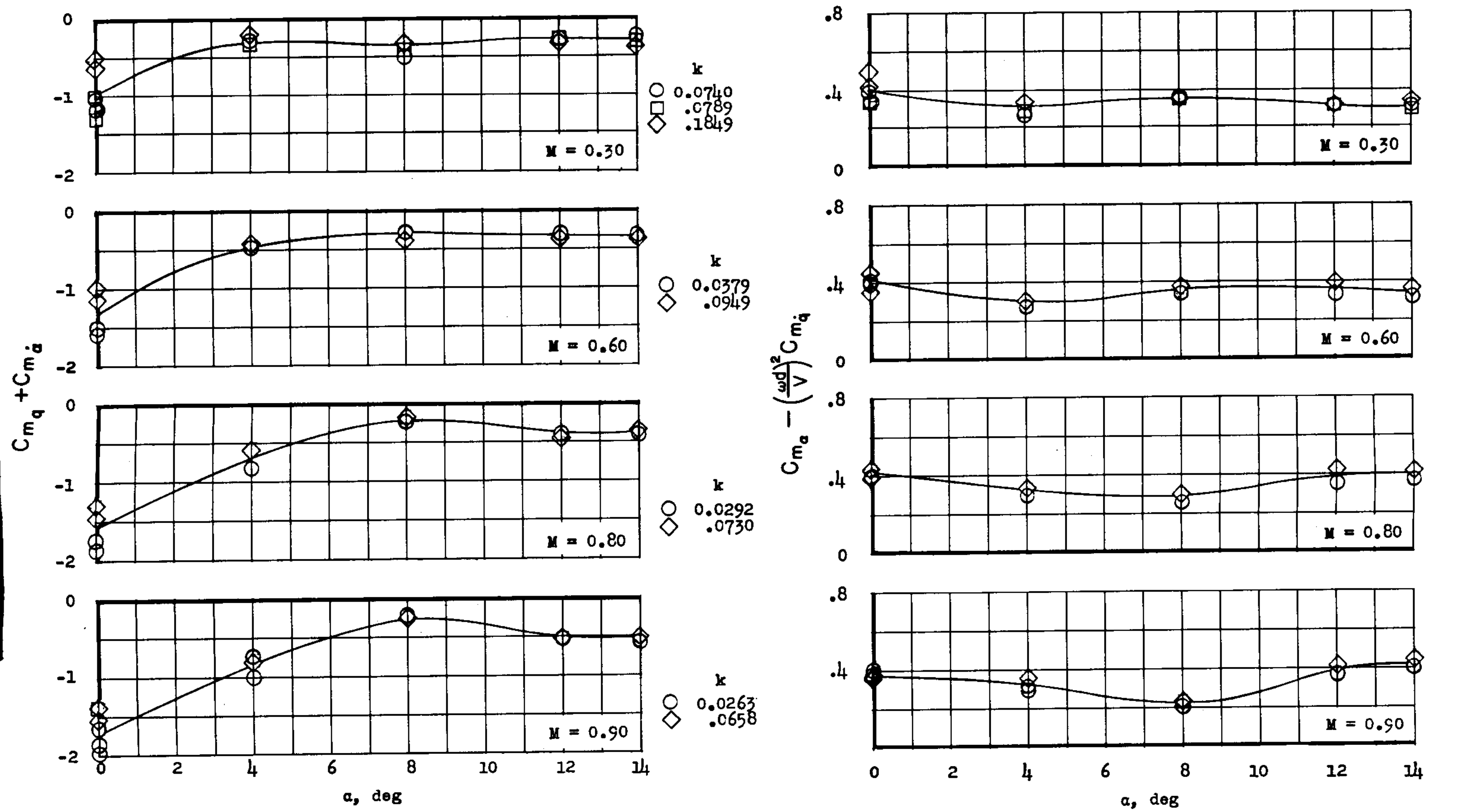
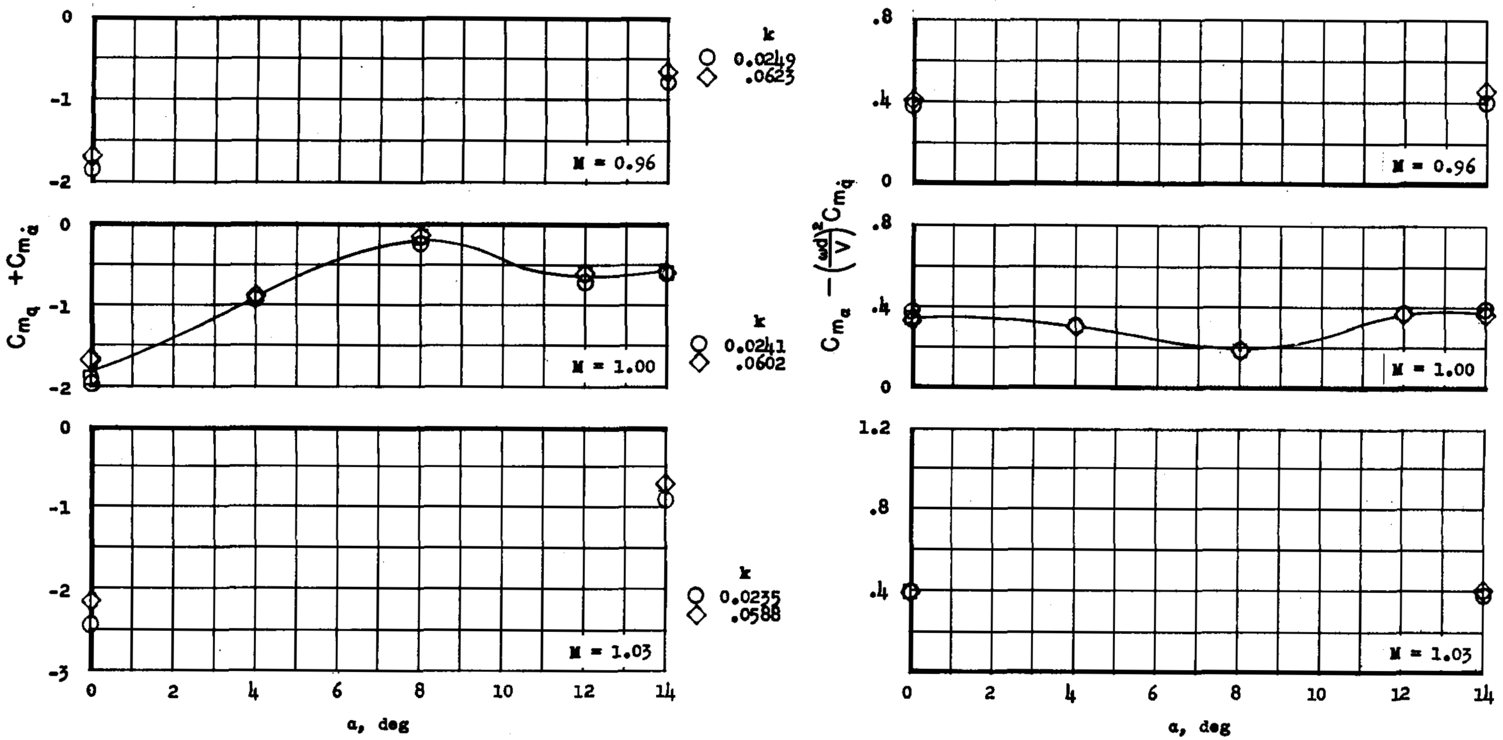


(a) M = 0.30 to 0.90.

Figure 10.- Variation of the damping-in-pitch parameter and oscillatory longitudinal stability parameter with angle of attack for various Mach numbers. Basic exit configuration. Free transition. Stagnation pressure = 1.00 atmosphere.

[redacted]



(b) M = 0.96 to 1.03.

Figure 10.- Concluded.

[redacted]

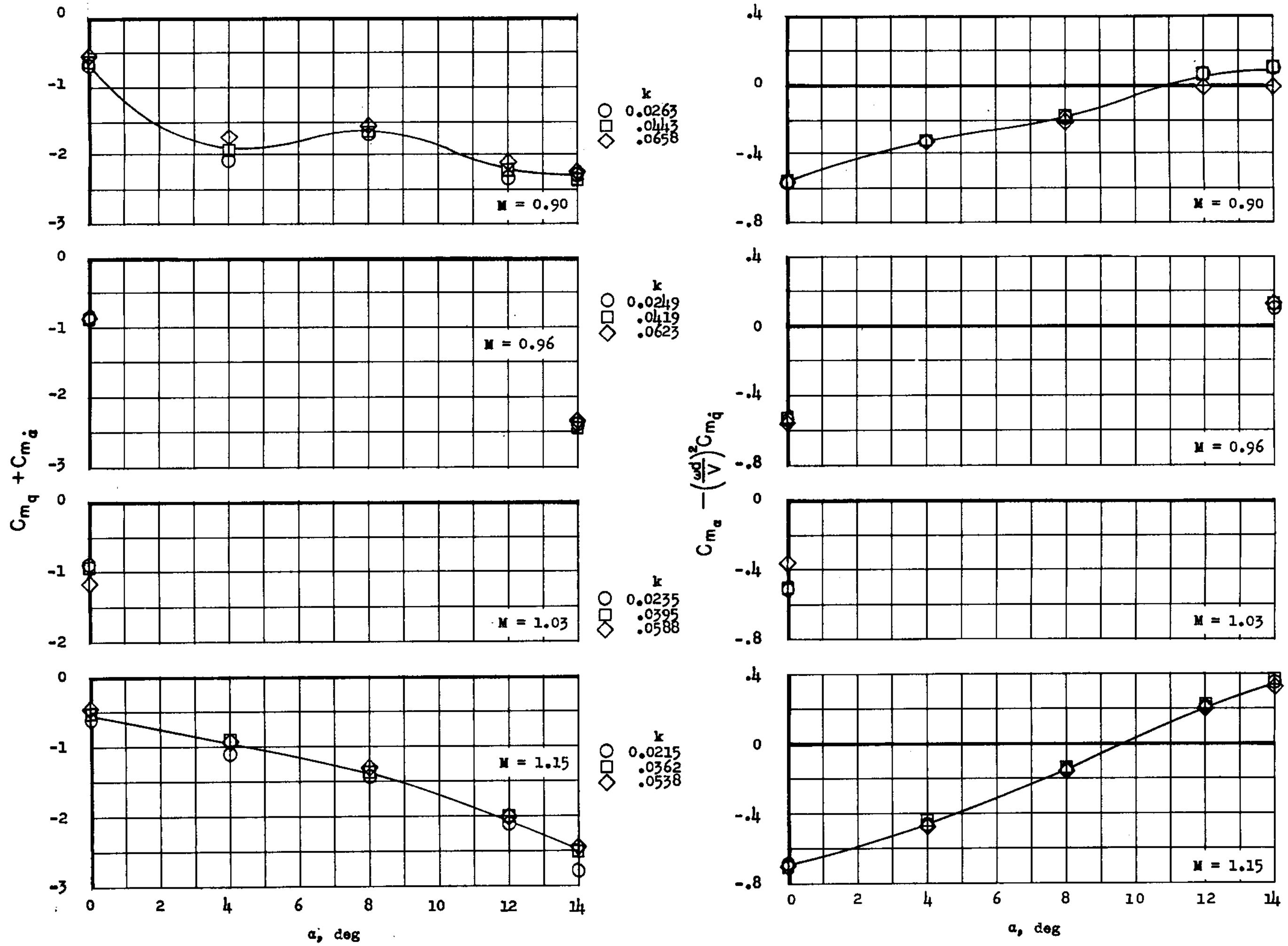


Figure 11.- Variation of the damping-in-pitch parameter and oscillatory longitudinal stability parameter with angle of attack for various Mach numbers. Basic escape configuration. Free transition. Stagnation pressure = 1.00 atmosphere.

[redacted]

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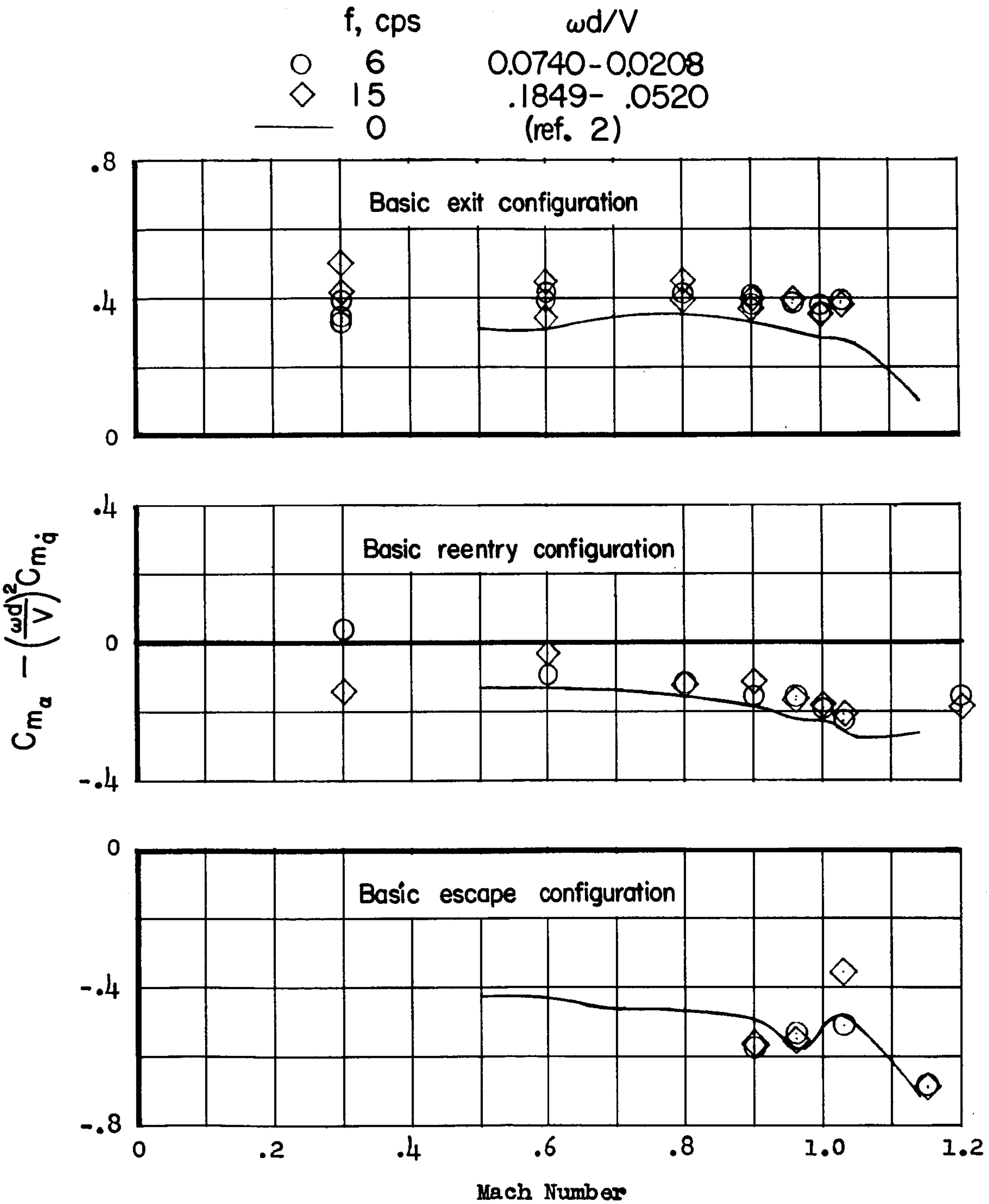

Figure 12.- Comparison of static and dynamic pitching coefficients with Mach number for the exit, reentry, and escape configuration at $\alpha = 0^{\circ}$.