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DYNAMIC STABILITY TESTS ON THE SNAP-27 FUEL CASK CONFIGURATION AT MACH NUMBERS 6 AND 10

B. L. Uselton
ARO, Inc.

August 1966

Per AF Letter dtd 3 January 75. Signed William O. Cole.

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FOREWORD

The work reported herein was done at the request of the Atomic Energy Commission (AEC) for the General Electric Missile and Space Division (GE-MSD) under AEC Activity No. 04.30-01-41.3.

The results of the tests presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract AF40(600)-1200. The tests were conducted under ARO Project No. VT1674 on April 14 and May 25, 1966. The manuscript was submitted for publication on July 20, 1966.

This technical report has been reviewed and is approved.

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ABSTRACT

Tests were conducted in the 40-in. supersonic wind tunnel and the 50-in. Mach 10 wind tunnel (Tunnels A and C) of the von Kármán Gas Dynamics Facility to determine the dynamic stability characteristics of the SNAP-27 fuel cask configuration. These tests were conducted at Mach numbers 6 and 10 using the forced oscillation technique. Data were obtained at angles of attack from 0 to 14 deg for Reynolds numbers, based on centerbody diameter, ranging from 0.19×10^6 to 1.80×10^6.

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NOMENCLATURE

A	Reference area, based on centerbody diameter, 0.0873 ft^2
C_m	Pitching-moment coefficient, pitching moment/$q_\infty Ad$
C_{m_q}	$\partial C_m / \partial(qd/2V_\infty)$ } Damping-in-pitch derivatives, 1/radian
$C_{m_{\dot{\alpha}}}$	$\partial C_m / \partial(\dot{\alpha} d/2V_\infty)$ } Damping-in-pitch derivatives, 1/radian
C_{m_α}	Local slope of pitching-moment curve, 1/radian
d	Reference length, centerbody diameter, 0.333 ft
f	Frequency of oscillation, cycles/sec
I	Model mass moment of inertia about the pivot axis, slug-ft^2
ℓ	Model length, in.
M_θ	Angular restoring-moment parameter, ft-lb/radian
$M_{\dot{\theta}}$	Angular viscous-damping-moment parameter, ft-lb-sec/radian
M_∞	Free-stream nominal Mach number
q	Pitching velocity, radians/sec
q_∞	Free-stream dynamic pressure, lb/ft^2
Re_d	Reynolds number based on centerbody diameter
T	Input torque, ft-lb
t	Time, sec
V_∞	Free-stream velocity, ft/sec
x_{cg}	Distance from model nose to pivot axis, in.
α	Angle of attack, radians or deg
$\dot{\alpha}$	Time rate of change of angle of attack, radians/sec
θ	Angular displacement, radians or deg
$\dot{\theta}$	Angular velocity, radians/sec
$\ddot{\theta}$	Angular acceleration, radians/sec^2
ω	Angular frequency, radians/sec
$\omega d/2V_\infty$	Reduced frequency parameter, radians

SUBSCRIPTS

a	Aerodynamic
o	Maximum conditions
v	Vacuum conditions
w	Wind-on conditions

SECTION I
INTRODUCTION

The SNAP-27 power generator, stored externally on the Lunar Excursion Module (LEM), is to be landed on the moon and assembled by the astronauts. In the event of an aborted mission, the SNAP-27 fuel cask will be separated from LEM and achieve an earth orbit. The fuel cask must, therefore, have the capability to re-enter the earth's atmosphere and to impact undamaged to avoid radioactive contamination of the atmosphere.

In support of an aerodynamic design program conducted by GE-MSD, static force, pressure, and dynamic stability tests were conducted at AEDC at supersonic and hypersonic speeds. The dynamic stability tests described in this report were conducted on the SNAP-27 fuel cask configuration at Mach numbers 6 and 10 at Reynolds numbers, based on the model centerbody diameter, ranging from 0.19×10^6 to 1.80×10^6 for an angle-of-attack range from 0 to 14 deg. The tests, as outlined in Table I, were conducted using a small amplitude (±3-deg), forced oscillation balance.

SECTION II
APPARATUS

2.1 WIND TUNNELS

The 40-in. supersonic and 50-in. Mach 10 tunnels (Gas Dynamic Wind Tunnels, Supersonic (A) and Hypersonic (C)) of the von Kármán Gas Dynamics Facility (VKF) are continuous, closed-circuit, variable density wind tunnels. Tunnel A has a flexible-plate-type nozzle which is automatically driven to produce Mach numbers from 1.5 to 6. The tunnel has a 40- by 40-in. test section and operates at maximum stagnation pressures from about 29 to 200 psia at $M_\infty = 1.5$ to 6 and at stagnation temperatures up to 300°F ($M_\infty = 6$). Minimum operating pressures are about one-tenth of the maximum.

Tunnel C has a 50-in.-diam contoured, axisymmetric, Mach 10 nozzle and operates at stagnation pressures from 200 to 2000 psia and at stagnation temperatures up to about 1450°F. The model support is capable of being retracted into a test section tank which can be sealed from the airflow for model changes. A description of the tunnels and airflow calibration information may be found in Ref. 1.

2.2 FORCED OSCILLATION BALANCE

The small amplitude (±3-deg), forced oscillation balance system used in the test program is a one-degree-of-freedom oscillatory system incorporating a cross-flexure pivot. The balance (Fig. 1) is forced to oscillate by an electromagnetic shaker motor located in the aft portion of the sting. The angular displacement of the model is measured by a strain-gage bridge mounted on a cross flexure, and the input torque to the system is measured by a strain-gage bridge mounted at the minimum cross-sectional area of the torque beam. The forcing system is equipped with a feedback control network, as described in Ref. 2, to provide positive amplitude control for testing either dynamically stable or unstable configurations.

Because of the high stagnation temperatures encountered in Tunnel C, the sting assembly is water cooled. The balance is cooled by air which is directed on the model bulkhead while damping measurements are not being made.

2.3 MODEL

The model, shown in Fig. 2, was supplied by the General Electric Company and was constructed of stainless steel. Provisions were made to add ballast fore and aft to locate the model center of gravity exactly at the balance pivot axis. The model geometry is shown in Fig. 3.

SECTION III
PROCEDURE

The motion of the one-degree-of-freedom, forced oscillation system may be defined by the equation

$$I\ddot{\theta} - M_{\dot{\theta}}\dot{\theta} - M_{\theta}\theta = T\cos\omega t$$

Damping-in-pitch data were obtained throughout the tests at the undamped natural frequency of the model balance system, whereby the inertia term ($I\ddot{\theta}$) exactly balances the restoring-moment term ($M_{\theta}\theta$); thus, the forcing torque is precisely equal to the damping torque of the system for constant amplitude motion. The method for computing the dimensionless damping-in-pitch derivatives for the constant amplitude, forced oscillation tests is indicated by the following expressions:

$$-M_{\dot{\theta}}\dot{\theta} = T\cos\omega t \text{ (at the undamped natural frequency of the system)}$$

$$M_{\dot{\theta}} = -T/\theta_o\omega$$

$$M_{\dot{\theta}_a} = M_{\dot{\theta}_w} - M_{\dot{\theta}_v}(\omega_v/\omega_w)$$

$$C_{m_q} + C_{m_{\dot{\alpha}}} = M_{\dot{\theta}_a}(2V_\infty/q_\infty Ad^2)$$

The expression for obtaining the aerodynamic viscous-damping-moment parameter ($M_{\dot{\theta}_a}$) is based on the premise that the structural damping of a cross-flexure pivot varies inversely with the frequency of oscillation (Ref. 3).

The change in model oscillation frequency from the wind-off to the wind-on condition may be used to obtain the static stability derivative (C_{m_α}) by the following expressions:

$$\omega = \sqrt{-M_\theta/I}$$

$$M_{\theta_a} = M_{\theta_w} - M_{\theta_v}$$

$$M_{\theta_a} = M_{\theta_v}\left[(f_w/f_v)^2 - 1\right]$$

$$C_{m_\alpha} = M_{\theta_a}/q_\infty Ad$$

SECTION IV
PRECISION OF MEASUREMENTS

The balance was calibrated before and after the tests, and check calibrations were made before and after each run. In addition, structural damping values were obtained at vacuum conditions before the tunnel entry to evaluate the still air damping contribution. The estimated maximum deviation in C_{m_α} is ±0.6 and in $C_{m_q} + C_{m_{\dot{\alpha}}}$ is ±6.0.

SECTION V
RESULTS

Figure 4 shows the effect of angle of attack on the damping-in-pitch derivatives ($C_{m_q} + C_{m_{\dot{\alpha}}}$) and the static stability derivative (C_{m_α}) at Mach numbers 6 and 10. The Mach 6 damping data (Fig. 4a) indicate the model to be stable at all conditions tested and the damping to be a nonlinear function of angle of attack. The local slope of the pitching-moment curve (C_{m_α}) at Mach 6 is shown to be a minimum at $\alpha \approx 8$ deg

(Fig. 4a) for Reynolds numbers 0.35×10^6 and 0.73×10^6. The Mach 10 damping data (Fig. 4b) show the model to be stable at the trim angle (α = 0) at all Reynolds numbers tested. Increasing angle of attack (α = 0 to α = 5 deg) decreases stability, and the model is unstable at α = 5 deg ($Re_d = 0.34 \times 10^6$). The model is stable, however, at angles of attack of 8 deg and above. The data obtained at $Re_d = 0.58 \times 10^6$ showed the model to be unstable at α =6 deg; however, the level of the instability was not obtained. The local values of Cm_α obtained at M_∞ = 10 (Fig. 4b) are essentially invariant with angle of attack except at angles of attack of about 5 or 6 deg (negative damping results) where a higher level of Cm_α was obtained.

The data obtained at α = 0 are shown in Fig. 5 as a function of Reynolds number. The damping derivatives are a maximum at a Reynolds number of about 0.6×10^6 for both Mach numbers tested, and the Mach 10 data are at a higher level than the Mach 6 data at comparable Reynolds numbers. The static stability derivative for both Mach numbers decreases with increasing Reynolds number with the Mach 6 data showing a higher level than the Mach 10 data.

REFERENCES

1. Test Facilities Handbook (5th Edition). "von Kármán Gas Dynamics Facility, Vol. 4." Arnold Engineering Development Center, July 1963.
2. Welsh, C. J., Hance, Q. P., and Ward, L. K. "A Forced-Oscillation Balance System for the von Kármán Gas Dynamics Facility 40- by 40-Inch Supersonic Tunnel." AEDC-TDR-61-63 (AD 257380), May 1961.
3. Welsh, C. J. and Ward, L. K. "Structural Damping in Dynamic Stability Testing." AEDC-TR-59-5 (AD 208776), February 1959.

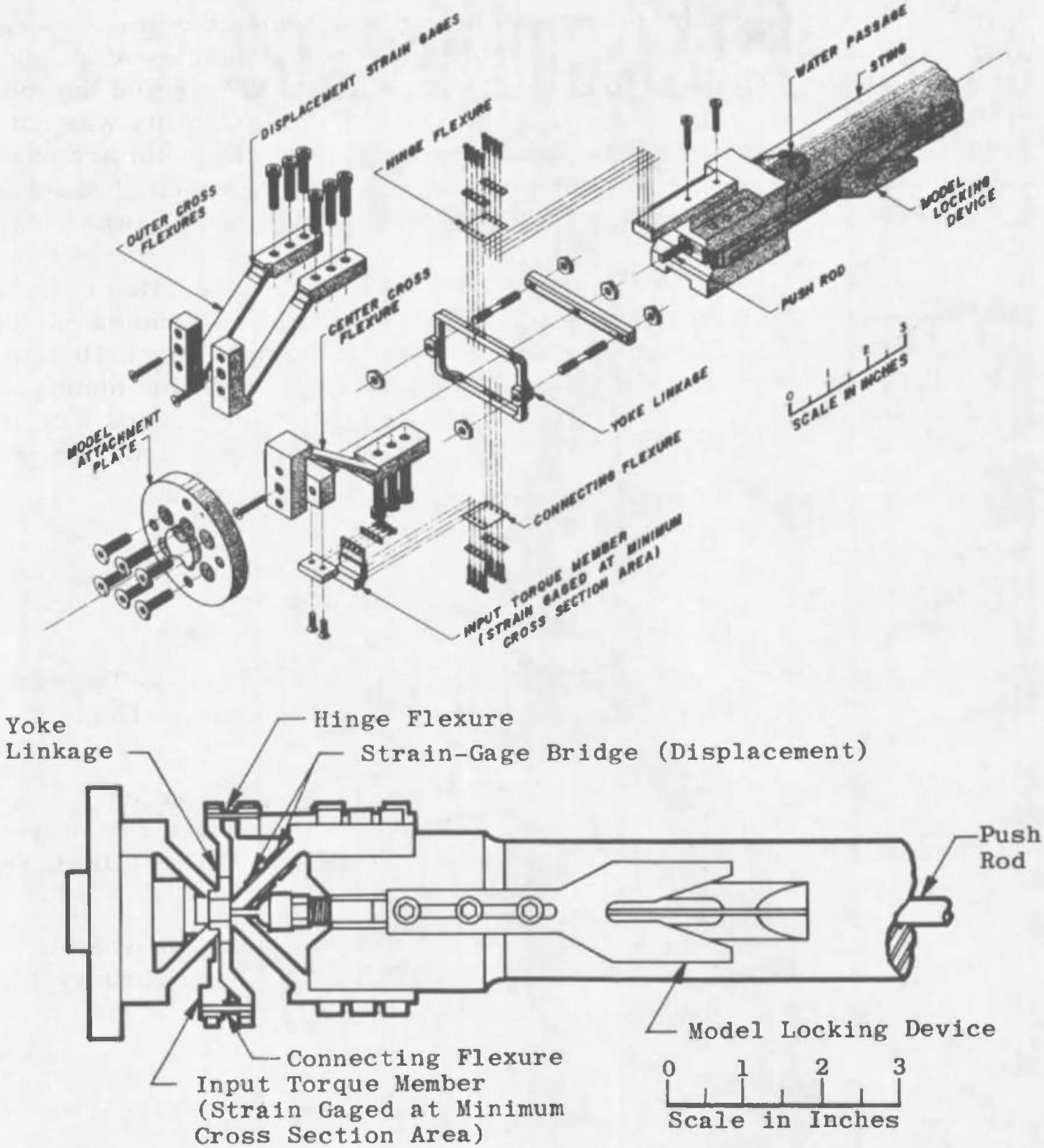


Fig. 1 Small Amplitude (±3-deg), Forced Oscillation Balance

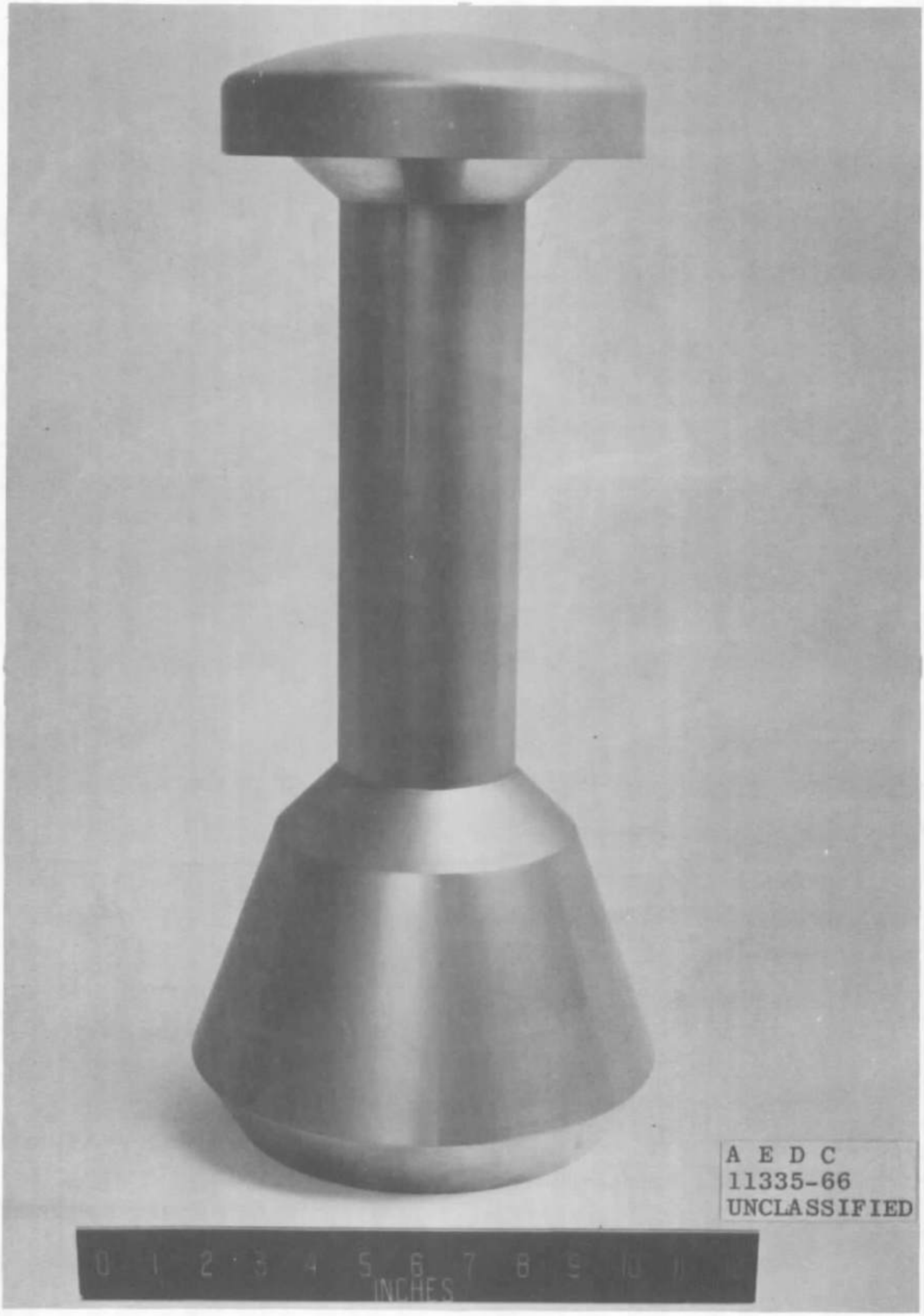


Fig. 2 Photograph of the Model

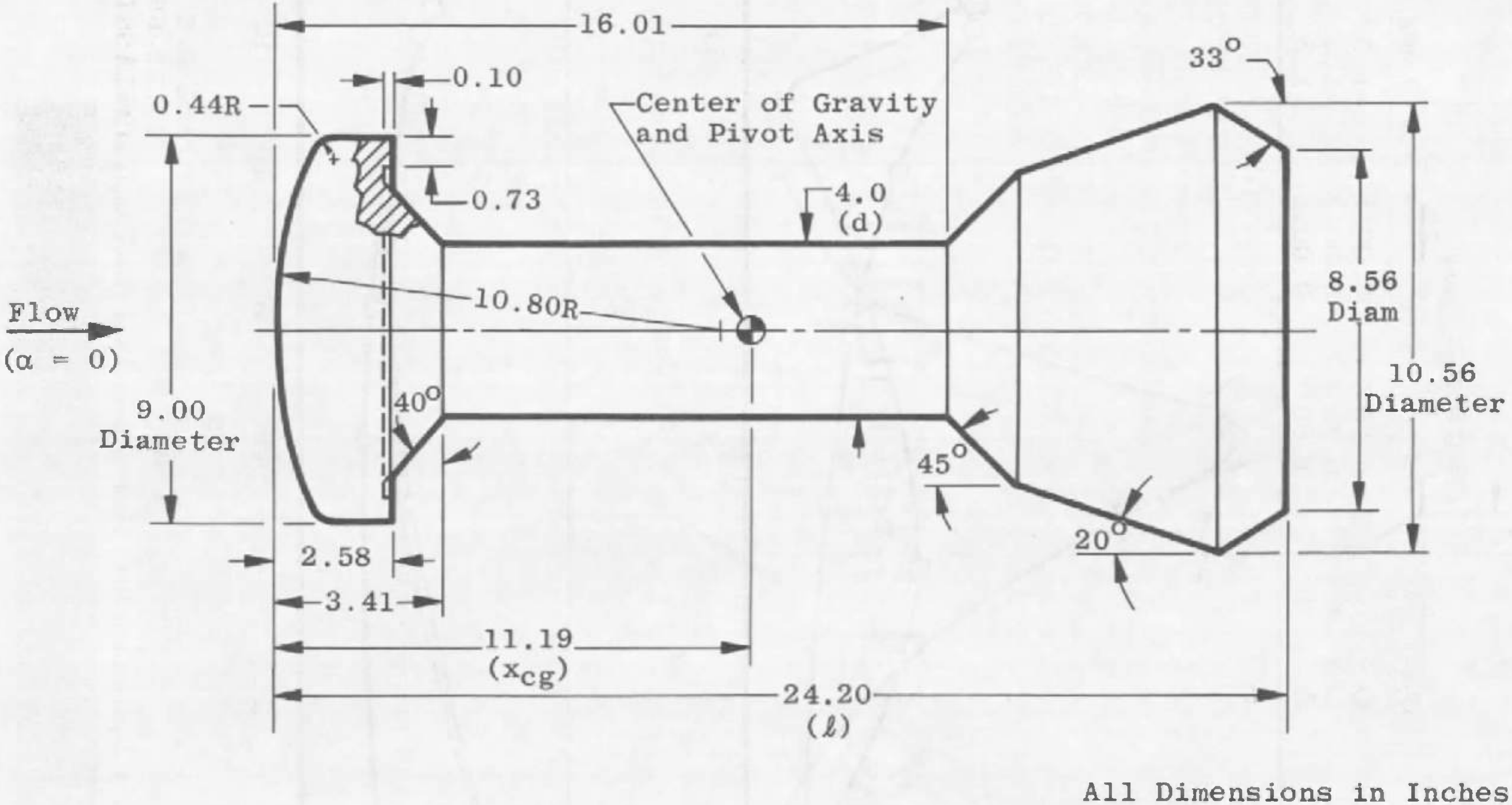
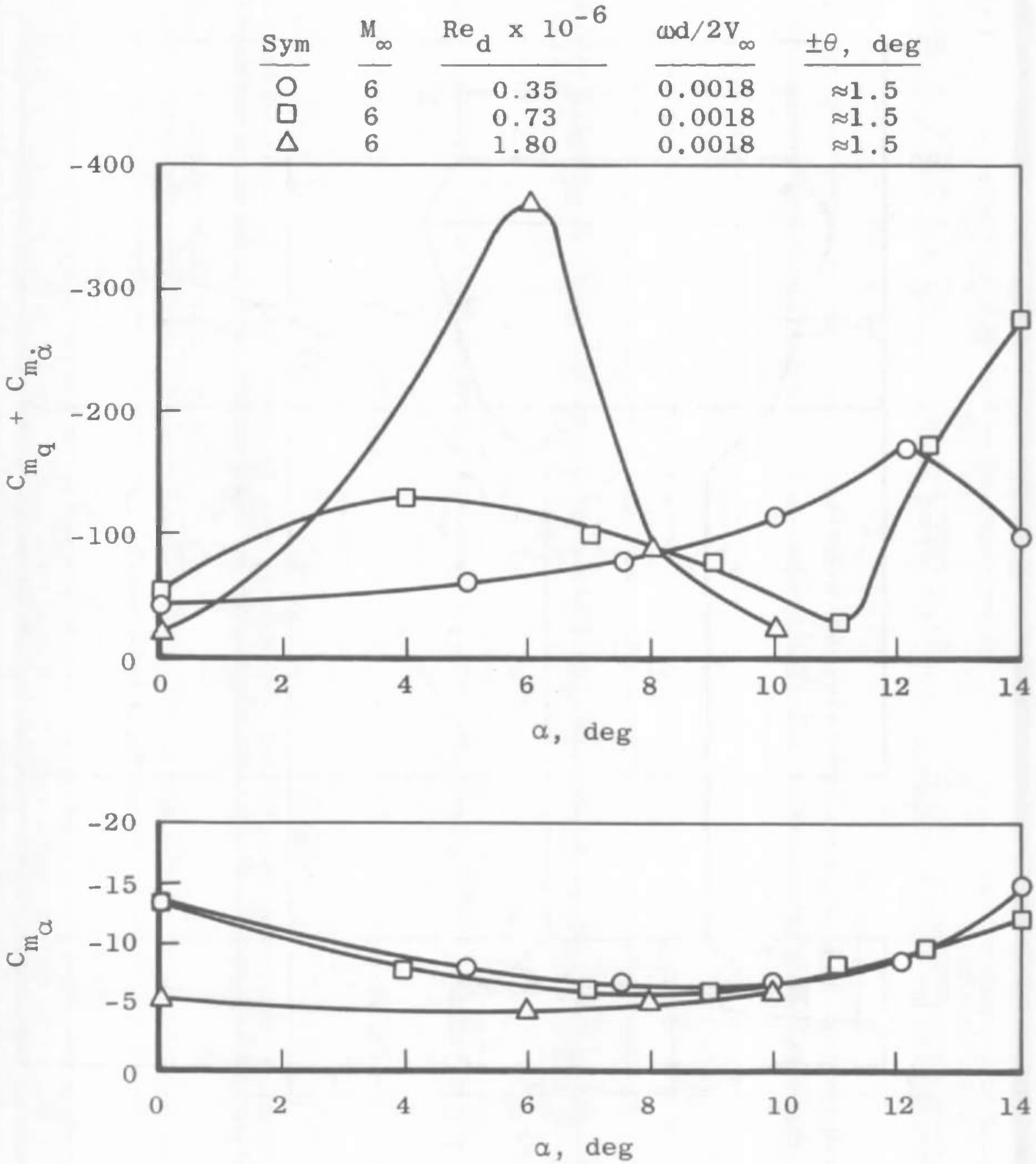
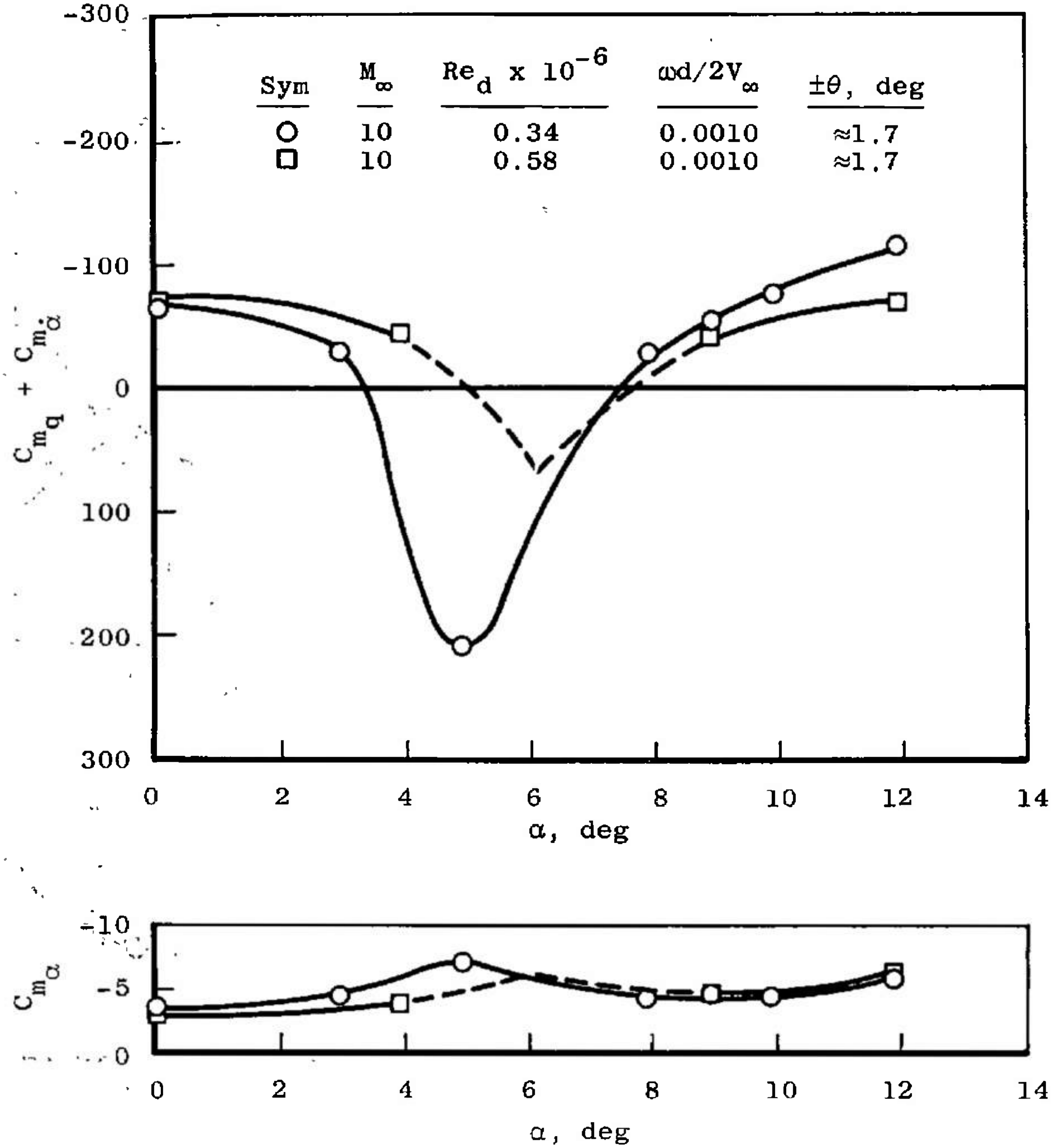


Fig. 3 Model Geometry



a. $M_\infty = 6$

Fig. 4 Dynamic and Static Stability Derivatives versus Angle of Attack



b. M_∞ = 10

Fig. 4 Concluded

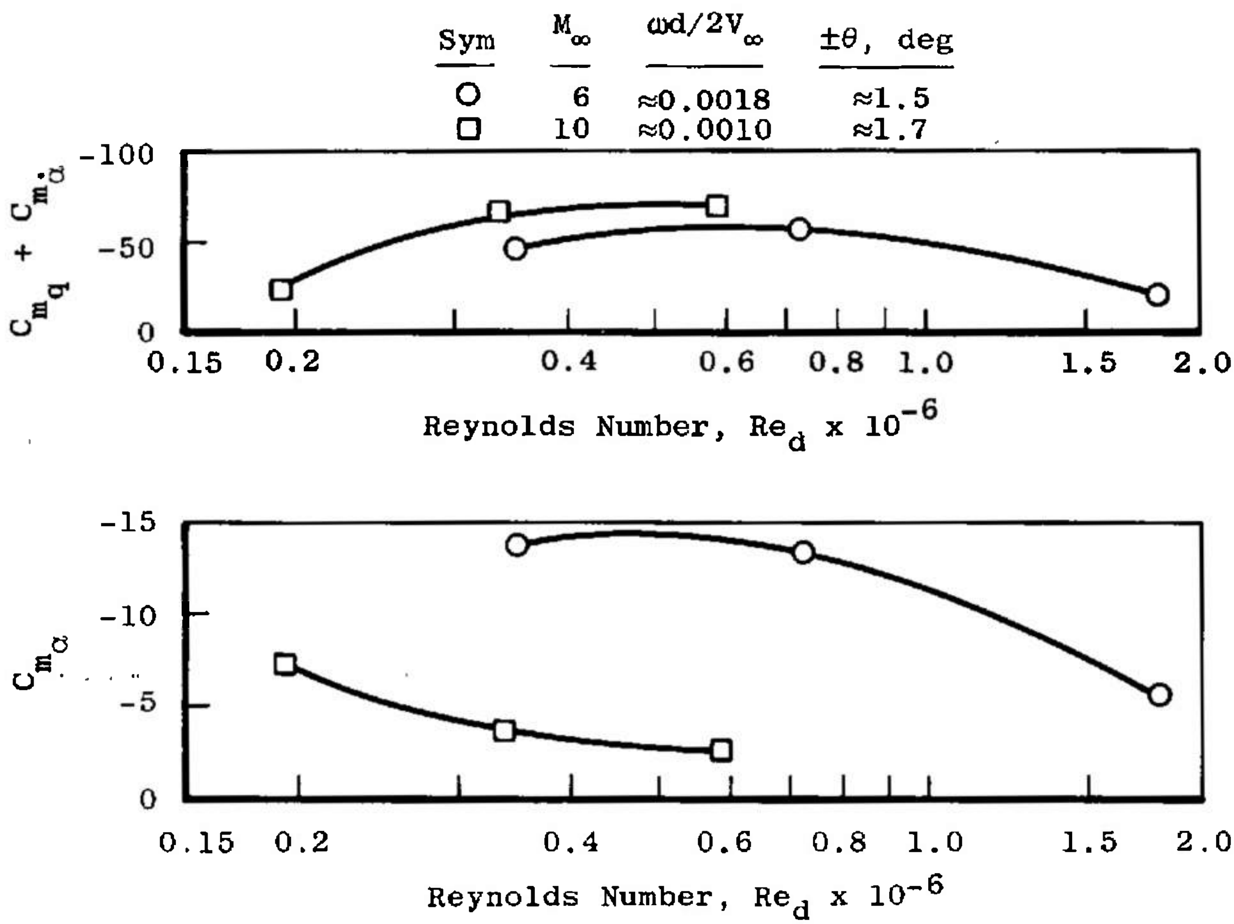


Fig. 5 Dynamic and Static Stability Derivatives versus Reynolds Number, $\alpha = 0$

TABLE I
SUMMARY OF TEST CONDITIONS

M_∞	$Re_d \times 10^{-6}$	α, deg	$\pm\theta$, deg
6	0.35	$0 \rightarrow 14$	≈ 1.5
6	0.73	$0 \rightarrow 14$	≈ 1.5
6	1.80	$0 \rightarrow 10$	≈ 1.5
10	0.19	0	≈ 1.7
10	0.34	$0 \rightarrow 12$	≈ 1.7
10	0.58	$0 \rightarrow 12$	≈ 1.7

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