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HYPERSONIC STABILITY DERIVATIVES FOR A STANDARD 10 DEGREE CONE

OTTO WALCHNER
FRANK SAWYER
BRIAN QUINN
HYPERSONIC RESEARCH LABORATORY

ERIC FRIBERG
FLUID DYNAMICS FACILITIES RESEARCH LABORATORY

Project No. 7064

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AEROSPACE RESEARCH LABORATORIES
OFFICE OF AEROSPACE RESEARCH
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

FOREWARD

This report was prepared by Otto Walchner, Frank Sawyer, Eric Friberg, and Brian Quinn of the Aerospace Research Laboratories under Project 7064.

The authors gratefully acknowledge the competent assistance of many of the Fluid Dynamics Facilities Research Laboratory' s technicians and the Hypersonic Research Laboratory' s secretaries.

ABSTRACT

This report describes experiments on the stability of an STA standard 10° cone. The free oscillation experiments on a sting mounted, open base model used an Optron tracker to register the model's oscillation about zero angle of attack. Values of the static (C_{m_α}) and dynamic ($C_{m_q} + C_{m_{\dot{\alpha}}}$) pitching moment stability derivatives are given for independent combinations of nine initial oscillation amplitudes (between ½° and 5°), five reduced frequencies ($\omega d/2V$ between .0025 and .007), two pivot axis locations (x_{cg}/ℓ = 55% and 60%), and two nominal Mach numbers (M_∞ = 12 and 14).

NOMENCLATURE

A	base area of cone
C_m	pitching moment coefficient, $M/q_\infty Ad$
C_{m_α}	$\partial C_m/\partial \alpha$
C_{m_q}	$\partial C_m/\partial (q d/2 v)$
$C_{m_{\dot{\alpha}}}$	$\partial C_m/\partial (\dot{\alpha} d/2 v)$
d	model base diameter
f	frequency
I	moment of inertia
k	spring constant
ℓ	model length
M	pitching moment
M_∞	free stream Mach number
p_b	model base pressure
p_∞	free stream static pressure
q	pitching speed
q_∞	free stream dynamic pressure, $\frac{1}{2}\rho V^2$
$Re_{\infty\ell}$	Reynolds number based on model length and free stream conditions
r_b	model base radius
r_N	model nose radius
V	free stream velocity
x_{cg}	pitch axis location aft of nose
α	angle of attack

α_0	initial oscillation amplitude
γ	ratio of specific heats
δ	logarithmic decrement
θ	angular deflection
θ_c	cone half angle
ω	circular frequency

Subscripts

$\dot{\theta}$	$\partial/\partial\dot{\theta}$
$\dot{\alpha}$	$\partial/\partial\dot{\alpha}$

INTRODUCTION

The dynamic stability of reentry configurations is a recurring subject at technical meetings and in the aerospace literature. The parameters involved in dynamic stability testing are numerous and researchers are currently reporting their observations of the effects of body geometry, Mach number, viscosity, mass addition, and many other variables. Two different experiments, each of whose object is to determine the effect of a given parameter on dynamic stability, are each designed around distinct measuring and data reduction techniques which themselves can be variables in the sense that they are capable of influencing the experimental results. Experiments with both small and large oscillation amplitudes have been reported, for example, using such diverse techniques as sting mounted wind tunnel models under forced or free oscillation, free flight models, and even wind tunnel models mounted on axles passing through their bodies.

The Supersonic Tunnel Association's Committee on Dynamic Stability (STA) has recommended a standard correlation model whose purpose is to assess the effects of experimental techniques and facilities on reported dynamic stability data. The model suggested by the STA is a 10 degree circular cone of spherical nose bluntness ratio, Nose Radius / Base Radius = 0.0167, pitched about an axis located 55% of the model length aft of the nose.

This report presents the results of an experimental investigation performed at the Aerospace Research Laboratories on the dynamic stability of an STA correlatic model. The free oscillation experiments on a sting mounted, open base model used an Optron tracker to register the model's oscillation about zero angle of attack. The design of the experiment allowed testing at independent combinations of nine initial amplitudes ($\alpha_0 = \frac{1}{2}°$ to $5°$), five oscillation frequencies ($f = 8$ to 26 hertz) and two pivot axis locations ($x_{cg}/\ell = 55\%$ and 60%) at each of two nominal Mach numbers ($M_\infty = 12$ and 14).

APPARATUS

1. WIND TUNNEL

The ARL 20-inch hypersonic wind tunnel, described fully in Ref. 1, was used for the experiments. The facility is a blowdown, free jet air tunnel with a 2000°R total temperature and capable of operating for two minutes at a Reynolds number on the order of 6×10^5 per foot.

Two contoured nozzles were used in these experiments. Total pressures for the nominal Mach 12 and 14 nozzles were around 1000 and 1500 psi, respectively. Figure 1 shows the Mach number distribution for each nozzle and Figure 2 shows typical experimental operating conditions.

2. MODEL AND FLEXURE

The model was constructed according to the recommended STA specifications. Its physical dimensions may be seen in Figure 3. A thin (.05") aluminum 10° conical shell was rigidly fastened to either of two mounting devices which positioned the pivot axis either at 55% or 60% of the model length aft of the nose. Balance weights, shown in the model schematic, Fig. 4, were adjusted to position the model's center of gravity on the pitching axis. All of the model's moveable parts were rigidly tightened so as not to absorb any vibrational energy. The model could be displaced to nine different initial amplitudes between (½° and 6°) by a sting-fixed, remotely actuated cam riding against one of nine cone-fixed, interchangeable fingers. The shape of the cam, which can be seen in Figure 4, assured a quick and clean release from the initial displacement.

Base pressure was monitored by a Hastings gage connected to a .078 inch orifice located approximately one inch aft the model in a plane perpendicular to the pitch plane (Fig. 4). The gage signal was recorded on an x-y plotter.

Five torsion bar flexures, each with a different spring constant, were used at different times to anchor the model assembly to a rigid sting. Structural damping was minimized by machining each flexure from solid beryllium-copper stock followed by heat treatment (600°F for three hours, then air cooled) and by restricting the pitch oscillation to amplitudes which stressed the flexure to no more than the arbitrary level of 36,000 psi. The flexure geometry is shown in Figure 5 along with values of the spring constant for each flexure.

3. OPTRON TRACKER AND ATTENDANT EQUIPMENT

The pitching motion of the model was optically followed by an Optron tracker located outside of the tunnel test cabin and focused on a small illuminated target attached to the base of the model. An electrical signal whose voltage is proportional to the displacement of the target is generated by the optron tracker. The response is flat between zero and 7000 hertz. This signal, amplified by a Preston Scientific Model 8300 differential amplifier, was recorded on a Consolidated Electrodynamic oscillograph. With this equipment, a continuous time history of several hundred cycles of the oscillation was permanently recorded.

DATA REDUCTION EQUATIONS

Expressions relating the measurable quantities of frequency, logarithmic decrement and flow conditions to the static and dynamic pitching moment derivatives have been derived in Reference (3). Briefly,

$$C_{m_q} + C_{m_{\dot{\alpha}}} = - \frac{8}{\pi} \frac{d}{2} \frac{\omega_1}{V} \frac{I}{\rho A d^3} \left[\delta_1 - \left(\frac{\omega_2}{\omega_1}\right)^2 \delta_2 \right]$$

$$C_{m_\alpha} = - 8 \left(\frac{d}{2} \frac{\omega_1}{V}\right)^2 \frac{I}{\rho A d^3} \left[1 - \left(\frac{\omega_2}{\omega_1}\right)^2 \right]$$

where subscript 1 refers to wind on conditions and subscript 2 refers to wind off conditions.

EXPERIMENTAL METHOD

Oscillograph traces of the model's motion corresponding to a given initial amplitude and a given flexure were recorded for both wind-on and wind-off conditions. Values of the logarithmic decrements and frequencies were computed from not less than 200 cycles of the oscillation. Substitution of these values, along with both the model inertial and geometric characteristics and the tunnel flow parameters into the above equations readily yielded values for the static and dynamic stability derivatives.

The experimental program was run during the month of February 1966 and began with the Mach 12 nozzle and the 55% pivot axis location. Typically, the test procedure involved making a wind-off (approximately 1 mm Hg) run, and then a wind-on run using a given flexure and a given initial amplitude finger. After the wind-on run, the model was cooled and the finger replaced by another one. This procedure was continued until all of the necessary fingers had been used. The flexure was then changed. Once all of the flexure-finger combinations had been exhausted, the same combinations were repeated using the Mach 14 nozzle. This same procedure was followed subsequent to repositioning the pitch axis at the x_{cg}/ℓ = 60% position.

In all instances, the base pressure ratio p_b/p_∞ was less than unity and typically around 80%.

RESULTS AND DISCUSSION

In Figures 6 through 9, the experimental data obtained for both Mach numbers and both x_{cg}/ℓ positions plotted against the initial pitch amplitude can be seen. No dependence of the static and dynamic stability derivative on the initial amplitude can be seen within the scatter of the data, so that if such a dependence exists, it is a higher order effect.

Values of the static derivative, C_{m_α}, given by flexure number 5 lie below those given by the other flexures in Figures 7 and 9. This discrepancy was unfortunately not discovered until the experimental program had been completed and the wind tunnel equipped to run another project. It was not until nearly a year later that the experiment using flexure number 5 could be repeated. On 9 January 1967, two runs were made: one with flexure number 2, the other with flexure number 5. Results of these experiments are tabulated below.

flexure	$\frac{\omega d}{2V}$	$C_{m_q} + C_{m_{\dot{\alpha}}}$	C_{m_α}	$(\alpha_0)^\circ$	x_{cg}/ℓ	M_∞
2	.00351	-2.65	-.50	2	.6	14.32
5	.00678	-2.70	-.485	2	.6	14.32

TABLE I

The repeatability of the flexure number 2 data was satisfactory and the value of C_{m_α} with flexure number 5 was more in line with the static derivative obtained with the other flexures. Although this might point to a procedural error in the February 1966 tests with flexure number 5, the authors are not aware of the error but state simply that the flexure number 5 data are questionable and not subject to further discussion.

Average values of the dynamic and static pitching moment derivatives have been tabulated and compared with the Newtonian impact ($C_p = 2 \sin^2 \Theta_c$) predictions in Table II. The columns labeled SCATTER give the half width of the band that contains all data points. For example, with $M_\infty = 12.55$ and $x_{cg}/\ell = 0.55$ all $C_{m_q} + C_{m_{\dot{\alpha}}}$ data points are within ± 12% of the average value, -3.04. As expected, the

M_∞	x_{cg}/ℓ	$(C_{m_q}+C_{m_{\dot{\alpha}}})_{avg}$	Scatter %	$(C_{m_\alpha})_{avg}$	Scatter %	$C_{m_{q_{Newt.}}}$	$C_{m_{\alpha_{Newt.}}}$
12.55	.55	-3.04	12.0	-.73	5.5	-2.24	-.663
14.24	.55	-2.98	16.6	-.72	8.3	-2.24	-.663
12.55	.60	-2.74	7.25	-.48	9.4	-1.94	-.379
14.24	.60	-2.62	5.72	-.444	10.0	-1.94	-.379

TABLE II

Newtonian impact theory consistently underpredicts both the static and dynamic stability derivatives.

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2. Daum, F. L., " The Condensation of Air in a Hypersonic Wind Tunnel," Aerospace Research Laboratories' Report No. ARL 63-42, 1963.
3. Walchner, O., Sawyer, F. M., and Koob, S. J., " Dynamic Stability Testing in a Mach 14 Blowdown Wind Tunnel," Aerospace Research Laboratories' Report No. ARL 64-221, 1964.

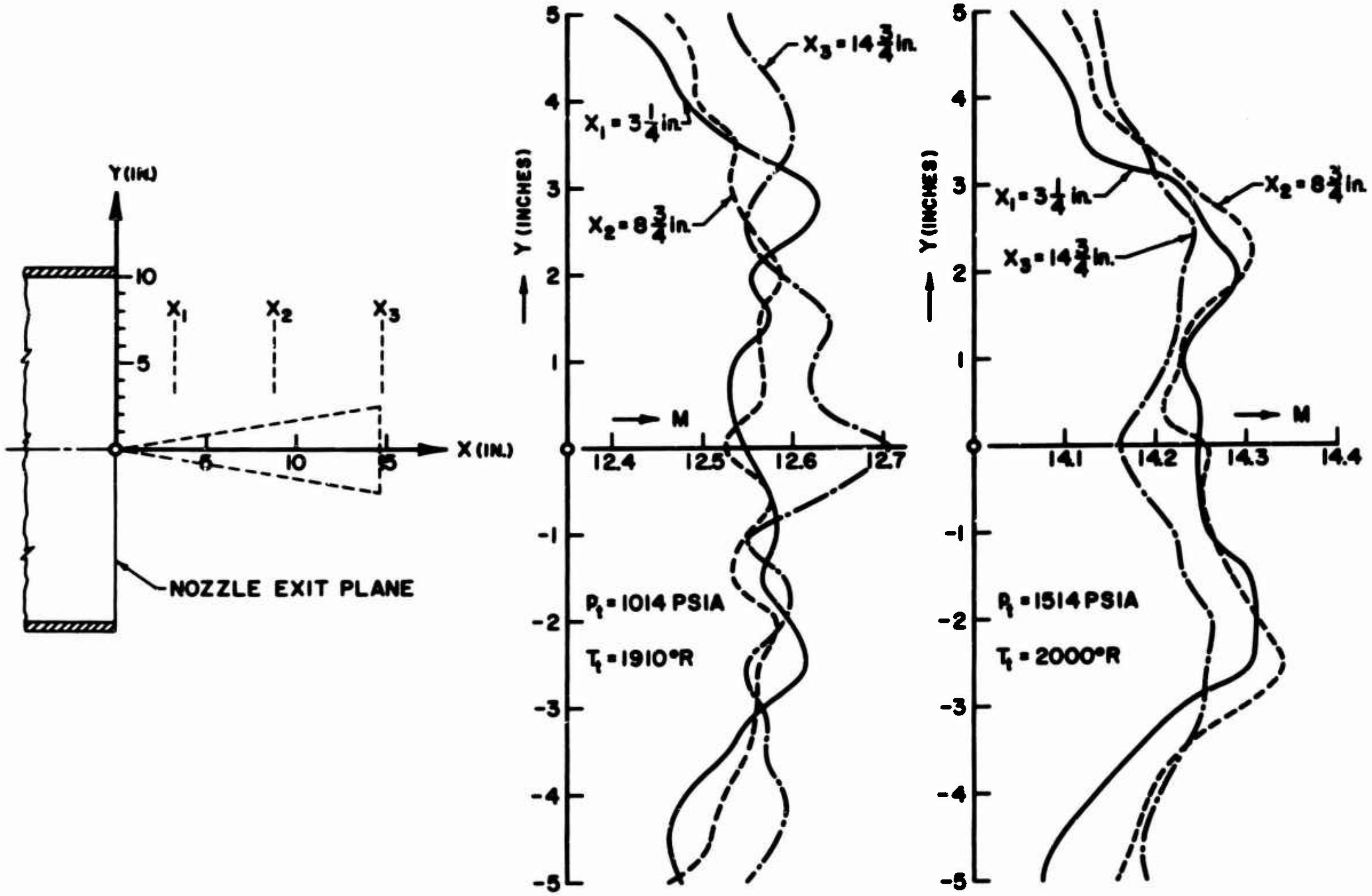


Figure 1. Mach Number Distribution for the Mach 12 and the Mach 14 Nozzles

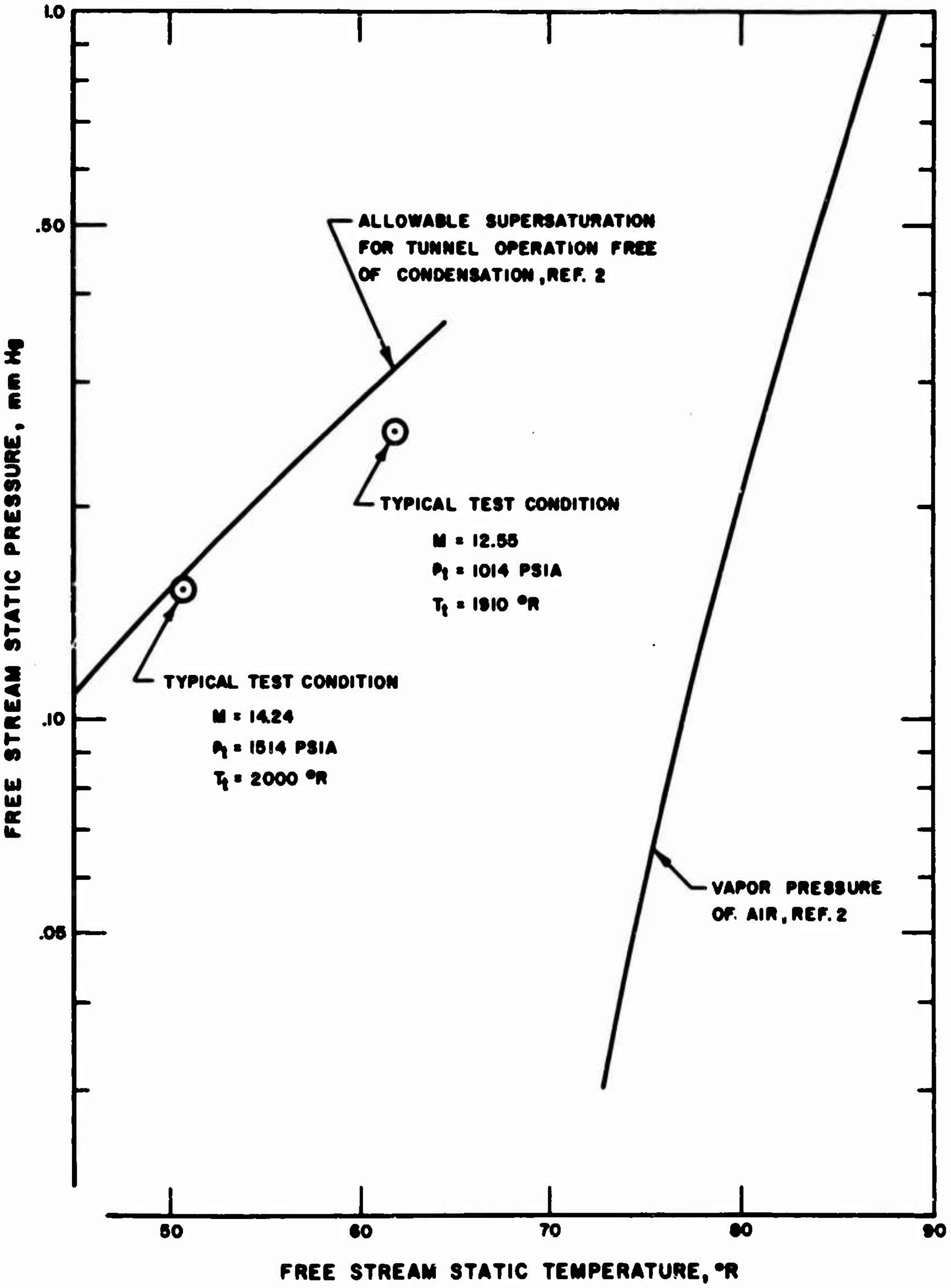
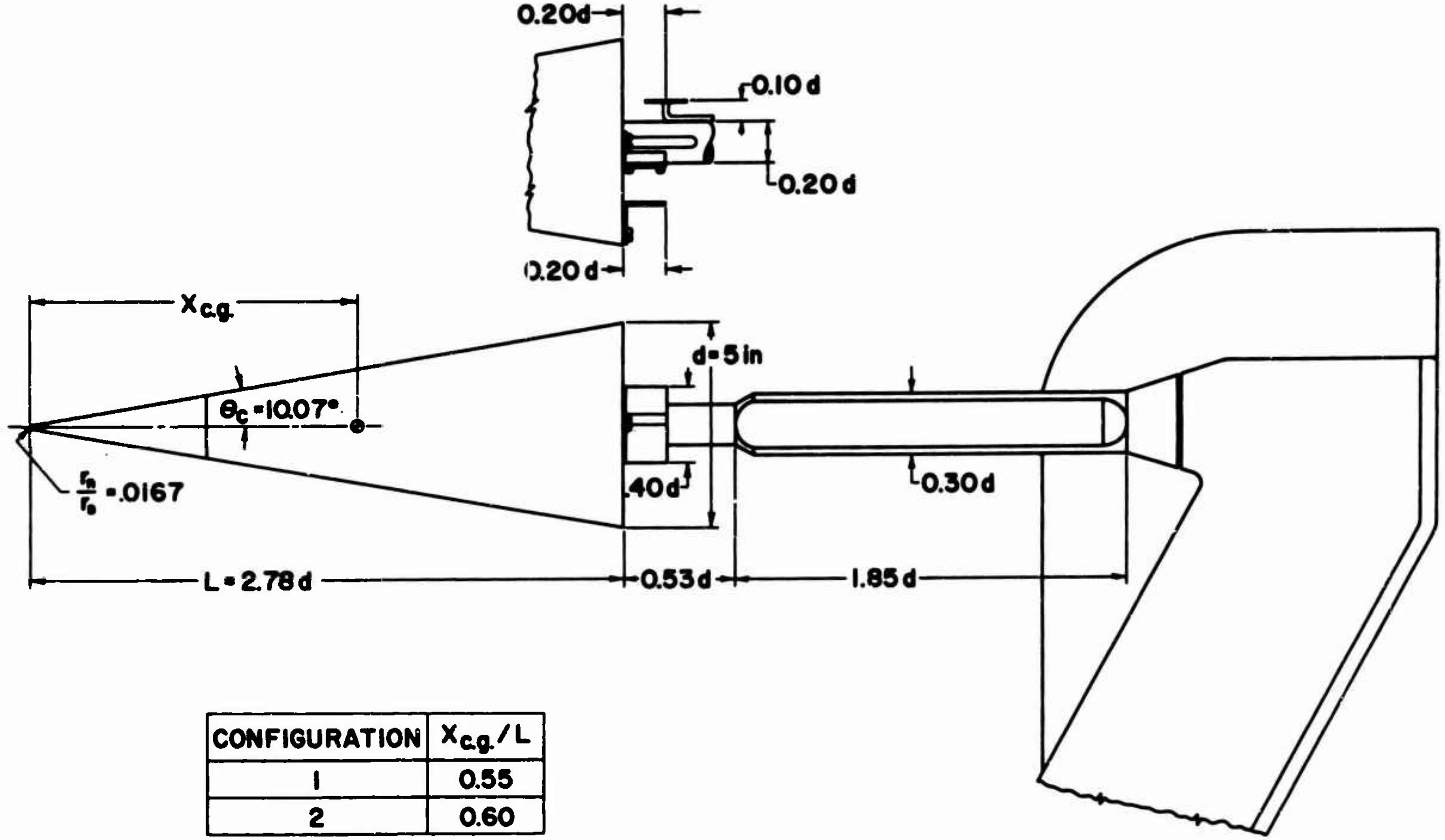


Figure 2. Experimental Test Conditions



CONFIGURATION	$X_{c.g.}/L$
1	0.55
2	0.60

Figure 3. Model and Sting Dimensions

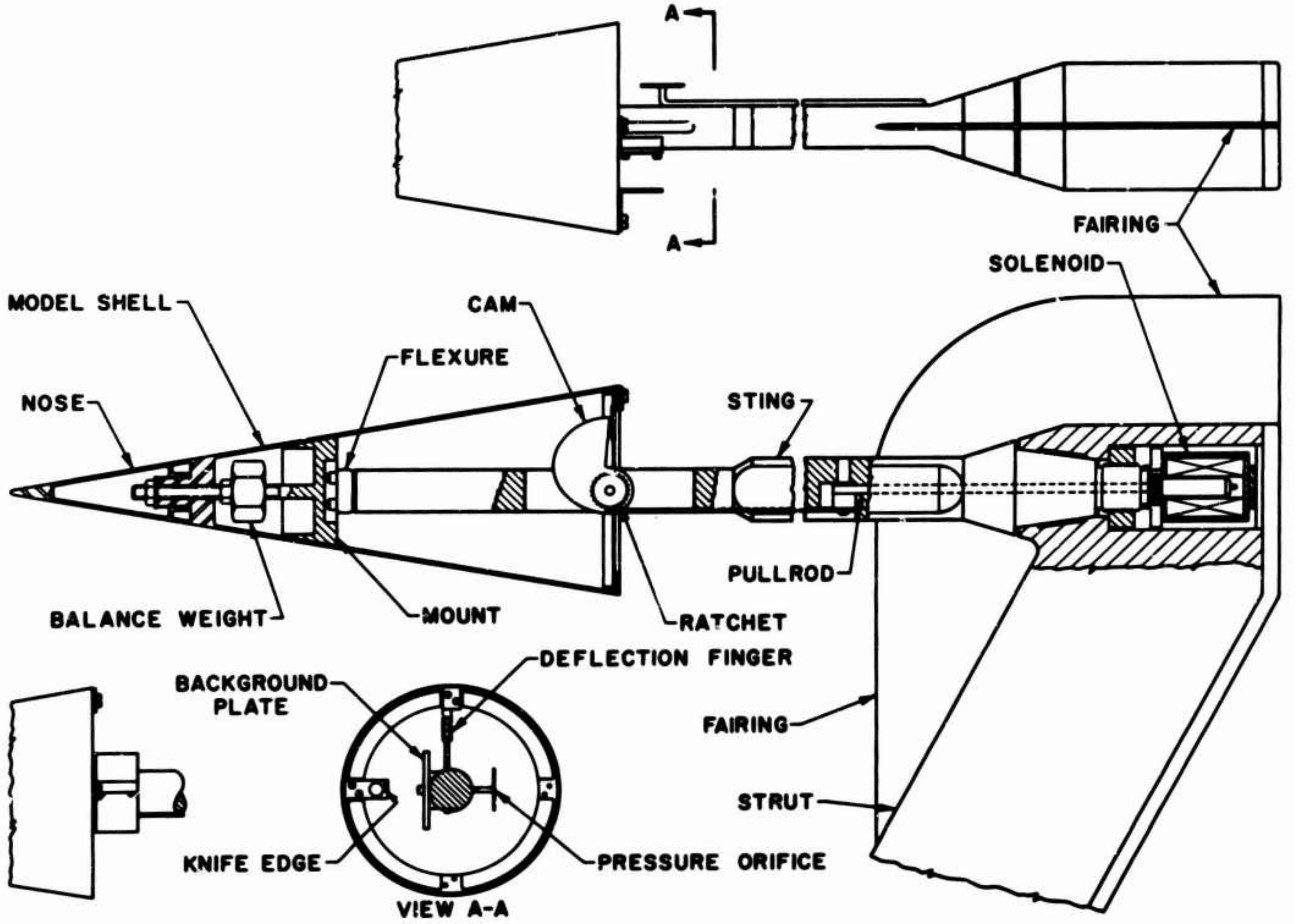
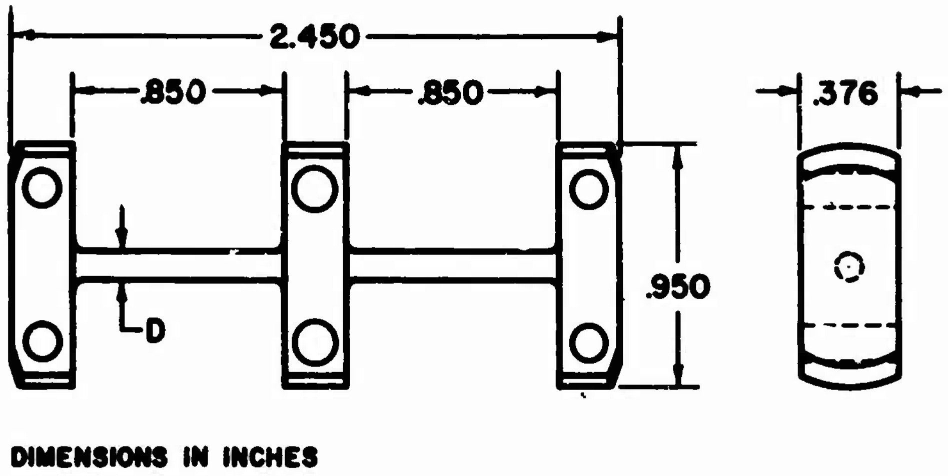


Figure 4. Model Schematic



FLEXURE	D (Inches)	k (Ft.-Lb./RAD.)
1	.088	8.02
2	.108	18.34
3	.125	33.14
4	.139	50.24
5	.153	75.12

Figure 5. Flexures and Spring Constants

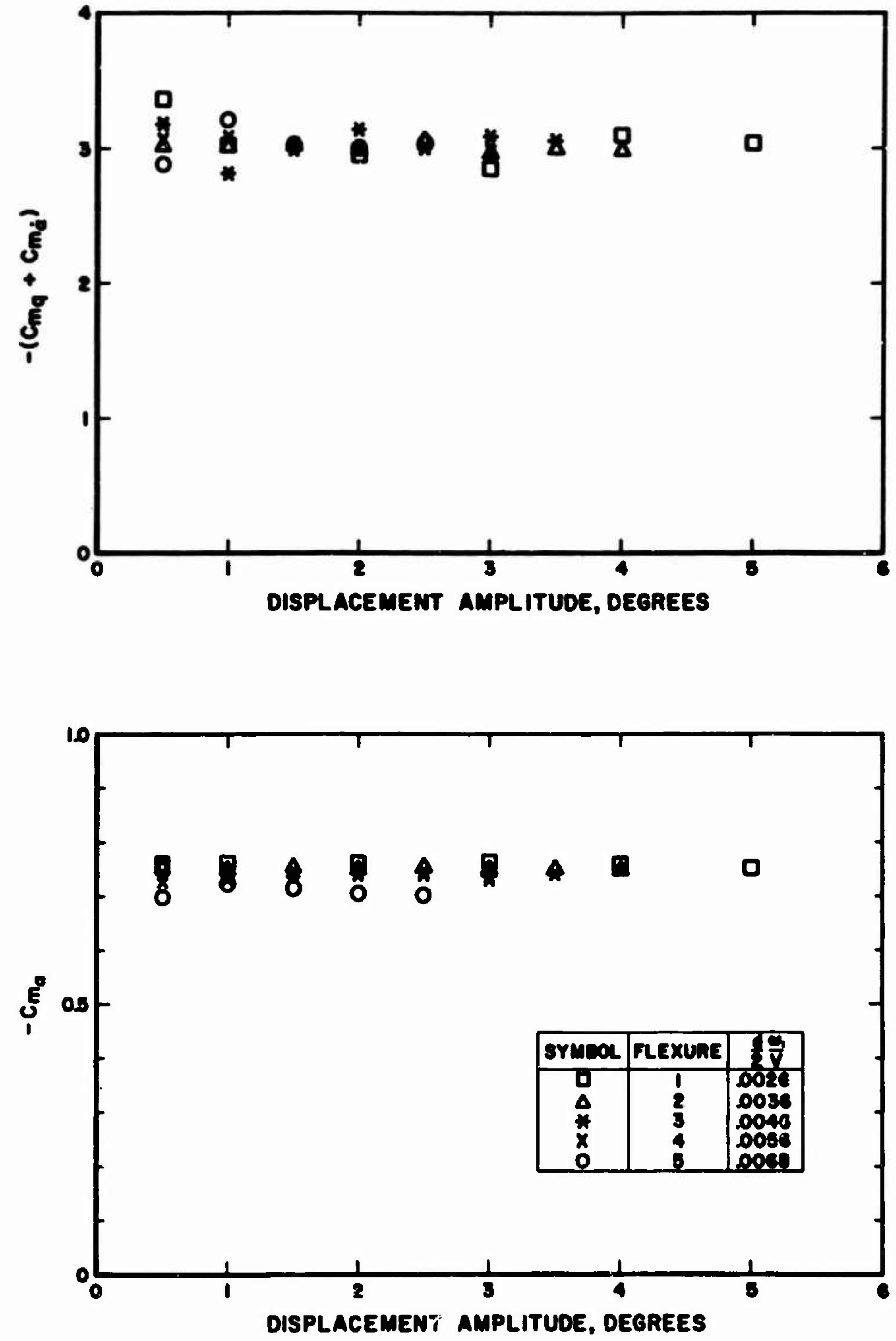


Figure 6. Experimental Dynamic ($C_{m_q} + C_{m_{\dot{\alpha}}}$) and Static ($C_{m_\alpha}$) Stability Derivatives. M = 12.55, x_{cg}/ℓ = .55

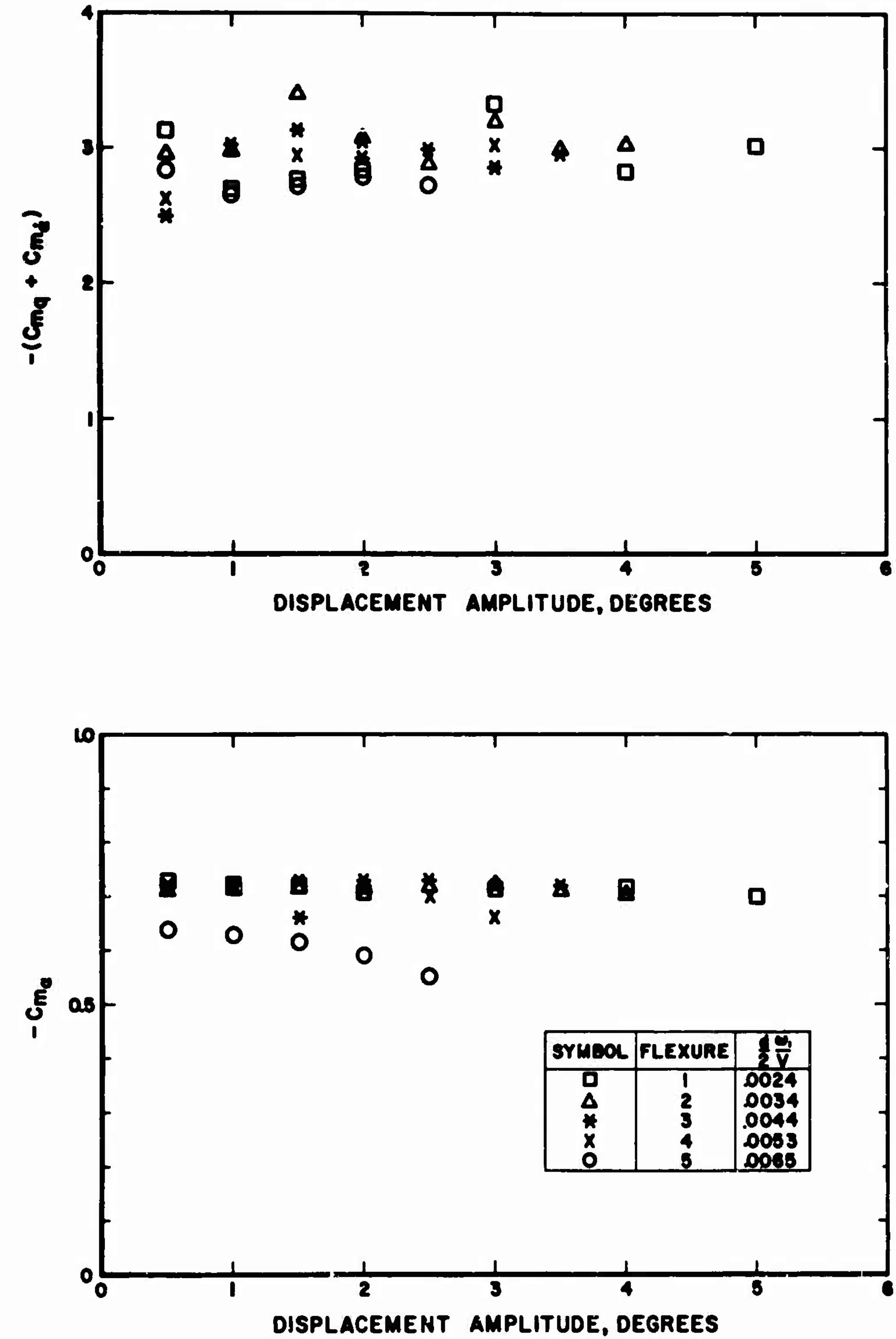


Figure 7. Experimental Dynamic ($C_{m_q} + C_{m_{\dot{\alpha}}}$) and Static ($C_{m_\alpha}$) Stability Derivatives. M = 14.24, x_{cg}/ℓ = .55

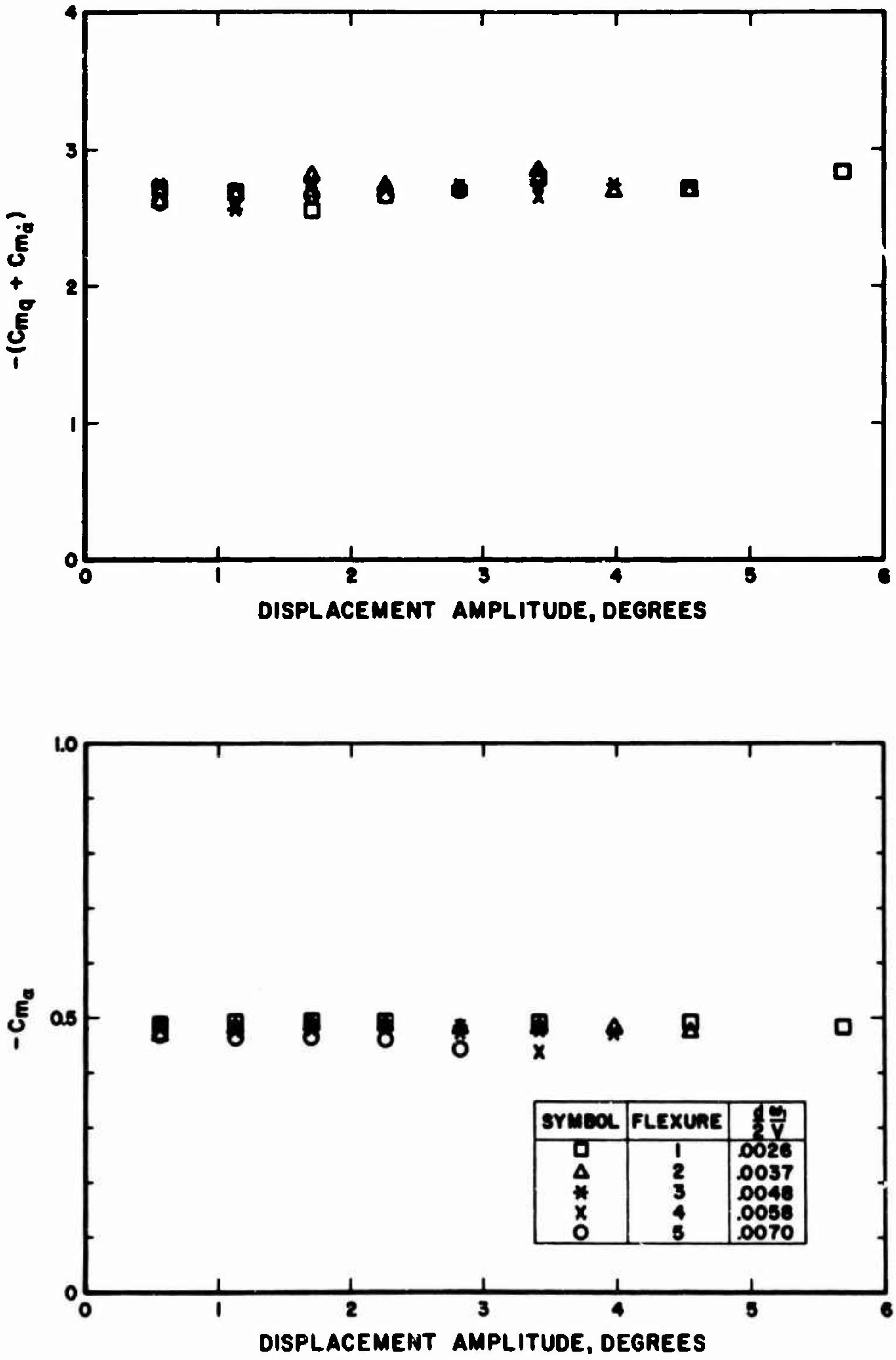


Figure 8. Experimental Dynamic ($C_{m_q} + C_{m_{\dot{\alpha}}}$) and Static ($C_{m_\alpha}$) Stability Derivatives. M = 12.55, x_{cg}/ℓ = .6

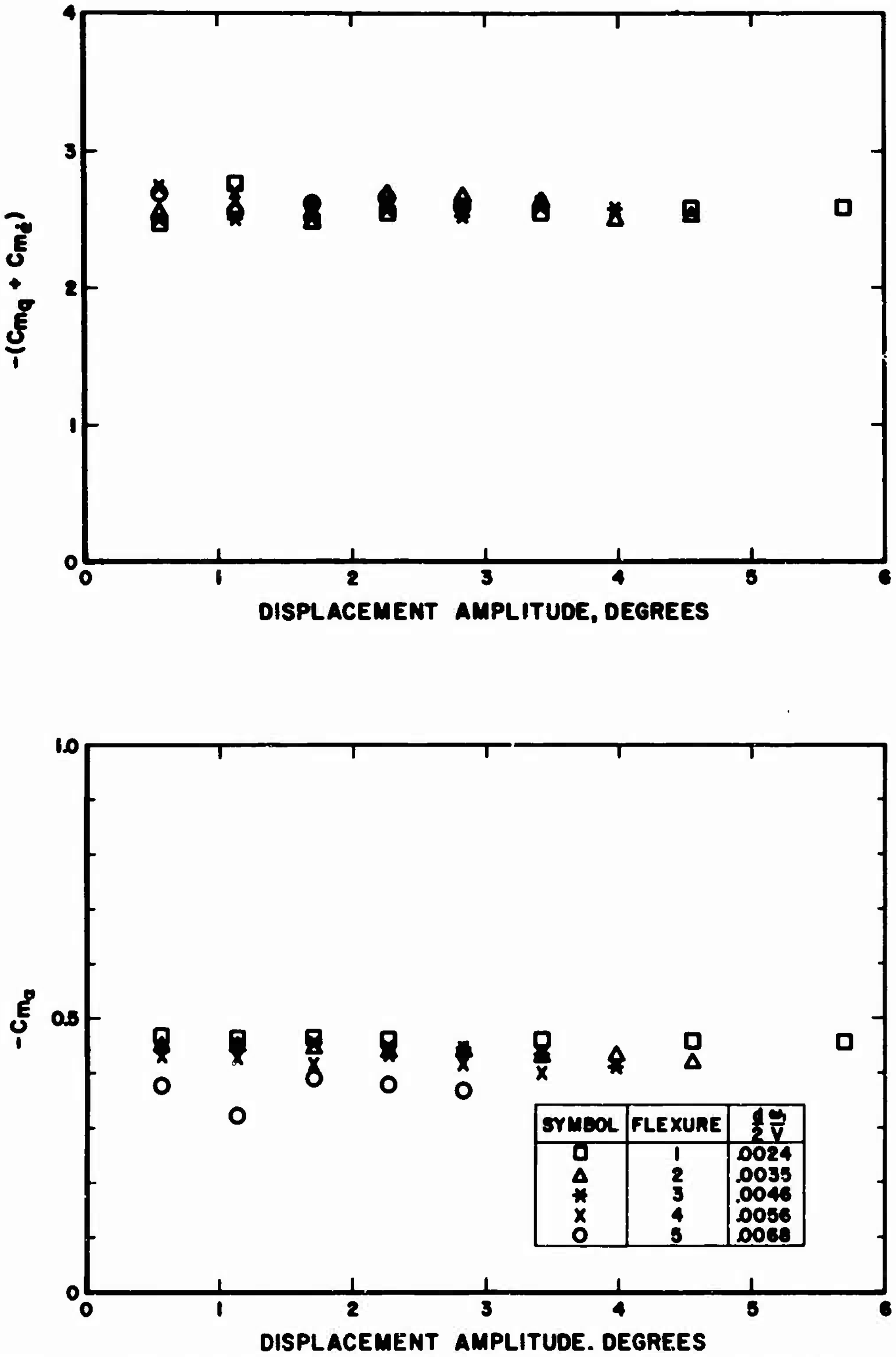


Figure 9. Experimental Dynamic ($C_{m_q} + C_{m_{\dot{\alpha}}}$) and Static ($C_{m_\alpha}$) Stability Derivatives. $M = 14.24$, $x_{cg}/\ell = .6$

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