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Measurements of Oscillatory Derivatives at Mach Numbers up to 2.6 on a Model of a Supersonic Transport Design Study (Bristol Type 198)

by

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MEASUREMENTS OF OSCILLATORY DERIVATIVES AT MACH NUMBERS UP TO 2.6 ON A MODEL OF A SUPERSONIC TRANSPORT DESIGN STUDY (BRISTOL TYPE 198)

by

J. S. Thompson, B.A.

R. A. Fail, B.Sc.

SUMMARY

This Report gives results of oscillatory derivative measurements on a model of a Bristol supersonic transport design type 198. The tests were made in the 8 ft by 8 ft supersonic wind tunnel at R.A.E. Bedford at six Mach numbers from 0.2 to 2.6, and the results include most of the longitudinal and lateral derivatives with respect to angular motion in pitch, yaw, and roll. The method of test has been described in a previous report[1], but some further details are given in this Report.

Replaces R.A.E. Tech. Report No.64048 - A.R.C. 26 761

CONTENTS

1 INTRODUCTION

A method for measuring oscillatory derivatives in the 8 ft supersonic wind tunnel at R.A.E. Bedford has been described in Ref.1, and the present Report gives the results of tests with this rig on a model of the Bristol type 198 supersonic transport design study.

Measurements have been made of longitudinal and lateral derivatives, and include tests with a new roll spring unit. Two appendices give some further details of experimental technique arising from these tests.

2 METHOD OF TEST

For these tests the model was mounted on a spring unit on the end of a sting, and excited at constant amplitude by means of a moving coil vibration generator. The general arrangement for yaw and sideslip tests is shown diagrammatically in Fig.1, in which the spring unit is replaced by its equivalent pivot and spring. The system is treated as having two degrees of freedom, and full details are given in Ref.1.

A new roll spring unit was used for some of the present tests, and details of this are given in Appendix A. This unit was intended to have only one degree of freedom, but in practice it was found to have appreciable flexibility in yaw, so that the system had to be treated as having two degrees of freedom, and measurements were made in the yawing mode at about 12 cps as well as in the rolling mode at 10 cps. Excitation of the yawing oscillations occurred only because of the inertia coupling (I_{zx}) between the two modes. There was also a certain amount of oscillation in sideslip, but there was no provision for exciting or measuring a third (sideslip) mode.

Because of this sideslip motion, no cross derivatives could be measured satisfactorily, and reliable results were obtained only for the direct derivatives $\ell\phi$ and $\ell\dot{\phi}$.

At each test condition the static forces and moments were measured on the appropriate spring units (with ordinary wire resistance strain gauges) for a range of incidence and yaw so that the static derivatives could be obtained from the slopes of the curves.

3 DESCRIPTION OF MODEL

The model, shown in Fig.2, represented a supersonic transport design study undertaken by Bristol Aircraft Ltd. (Type 198). The wing camber was designed by linear theory for $M = 2.2$, $C_{L_D} = 0.02$, and a centre of pressure shift of 0.15 $\bar{\bar{c}}$ at $C_L = 0.1$. Leading dimensions and details of the model are given in Table 1.

No engine nacelles were fitted. In order to provide sufficient clearance between the sting and the inside of the model, the conical sting shield had to be four inches diameter at the tail, thus causing considerable distortion of the rear body. The fin was detachable and the lateral tests were repeated without the fin.

The model was made of fibre-glass with a steel insert for mounting on the spring unit.

4 TEST CONDITIONS

Details of the test conditions are given in Table 2.

Since there seems to be some doubt about the desirability of fixing transition in tests of this kind, no arrangements were made to fix transition in these tests.

At Mach numbers of 0.8 and above, the incidence was limited to a maximum of 8^o on account of the stresses in the spring units produced by the steady aerodynamic loads on the model.

5 PRESENTATION OF RESULTS

The results are presented in Figs.3 to 34, Tables 3 and 4 serving as an index. All of the results are referred to a reference axis at 0.52 C_o. The non-dimensional coefficients are defined under "Notation" below. The static derivatives were obtained from the slopes of the curves of Figs.35 to 39; static pitching moment, normal force and rolling moment were measured over the same range of incidence as in the dynamic tests, but yawing moment and side force were measured only at zero incidence.

Certain derivatives could not be measured satisfactorily; these are also listed in the tables, with appropriate comments, but the results are not presented.

Generally the results are plotted against the normal force coefficient, C_z, so that it has not been necessary to apply any corrections to incidence. In the case of the static tests, however, the values of the incidence and yaw have been corrected for deflections of the sting and spring unit so that the slopes of the curves are directly comparable with the dynamic results.

The question of the reliability and accuracy of this method of testing is fully discussed in Section 5 of Ref.1.

6 DISCUSSION

The results show no unexpected large variations and generally no large irregularities. Comments on some features of the results are given below.

Under certain conditions some of the derivatives decrease sharply near or just above zero lift, possibly because the flow is then attached. Typical examples of this are seen in the case of z_θ at low speed (Fig.3) and ℓ_ϕ at speeds up to $M = 1.4$ (Fig.30).

Except in the tests at $M = 0.2$, the static values of m_θ are about 0.01 more positive than the dynamic values (Fig.5). The same effect was observed in tests of a cambered ogee model[1]. It is still considered doubtful whether this effect is genuine, although the differences are rather too large to be attributed to known experimental errors and no other explanation has been found.

It is interesting to note that most of the variations in n_ψ and $n_{\dot\psi}$ (Figs.16 and 19) with fin on are repeated with fin off, thus leading to smooth curves for the fin contributions and tending to give confidence in the reliability of the measurements. The fin contribution to n_ψ (Fig.22) is almost constant at subsonic speeds but decreases with increasing incidence at supersonic speeds. The fin contribution to $n_{\dot\psi}$ (Fig.24) is larger at subsonic speeds than at speeds of $M = 1.8$ and above, while at $M = 1.4$ the lower value is obtained at low incidences and the higher value at high incidences.

The derivatives ℓ_ϕ referred to sting axes must be equal to $-\ell_\psi \tan \alpha$. (See Ref.1, Appendix IV.) The results, shown in Fig.34, are therefore of little aerodynamic interest, but give another check of the reliability of the measurements.

7 FURTHER DEVELOPMENTS

Two further developments in the technique should remove some of the difficulties referred to in this Report.

A new spring unit has now been made, which is designed to have suitable flexibilities in yaw, sideslip, and roll, with provision for exciting and measuring all three motions. This should avoid the limitations of the roll spring unit (para.2).

New measuring equipment, designed for automatic recording, has also been provided, which is expected to improve the accuracy of measuring small phase angles in the presence of noise (see Tables 3 and 4).

The latest form of the equipment will be used for tests on a model of the Concord.

8 CONCLUSIONS

Measurements have been made of most of the derivatives with respect to angular motion in pitch, yaw, and roll, and the results show no unexpected large variations.

The new roll spring unit has been found to have certain limitations and it seems that the best way to obtain a complete set of lateral derivatives will be to use a combined spring unit with facilities for measurements in yaw, sideslip, and roll. Such a unit has now been made.

Appendix A

DETAILS OF ROLL SPRING UNIT

The roll spring unit, which was used for the first time in these tests, is illustrated in Fig.40. Each of the four cross springs which locate the rolling axis has an effective length (perpendicular to the axis) of 1.5 inches, a width (parallel to the axis) of 2.0 inches, and a thickness of 0.04 inches. The two longitudinal stiffeners are 10 inches long with a section 0.517 inches by 0.285 inches, chamfered off to a 90° angle on the inside, as shown in sketch. The whole unit is machined out of one piece of steel.

The exciting rolling moment is applied by twisting the driving rod. The linkage between the vibration generator and the rear end of the driving rod gives an effective radius arm of about 2.7 inches.

Appendix B

CORRECTIONS FOR VARIATIONS IN MECHANICAL STIFFNESS

Laboratory tests on the spring units have shown that in certain cases the mechanical stiffness of the unit is affected by the application of steady loads. Thus in tunnel tests the steady aerodynamic pitching moment and normal force can produce changes in the mechanical stiffness which will cause errors in the aerodynamic derivatives deduced from the difference between wind-on and wind-off values.

Corrections for these effects have been obtained from laboratory tests and applied to the tunnel results on this model as follows:-

Yaw spring unit

$$\text{Correction to } \ell_\psi: \; 1.00 \{Cm + 0.050\, Cz\}$$

Roll spring unit

$$\text{Correction to } \ell_\varphi: \; -0.0214\, Cz$$

There are also changes in mechanical cross-stiffness of the pitch spring unit which are apparently due to variations in the sting support system and cannot be correlated with steady aerodynamic loads. There are significant differences between the wind-on and wind-off values of Mz, which cannot represent an aerodynamic Mz, since this derivative should be negligibly small. The differences are presumably due to changes in the mechanical Mz, and in fact day-to-day variations of the same order of magnitude* occur in the wind-off measurements of Mz and Z_θ. (These two mechanical cross-stiffnesses are the same.)

The effect of these variations on the measurements of the aerodynamic Z_θ has been eliminated by assuming that the aerodynamic Mz is zero, and writing

$$\text{Aerodynamic } Z_\theta = (Z_\theta - Mz)\ \text{wind-on}$$

$$\text{instead of} \quad (Z_\theta)_{\text{wind-on}} - (Z_\theta)_{\text{wind-off}}$$

---

* ± 100 lb, representing about ± 0.05 in mz and z_θ at M = 1.4

Table 1

MODEL PARTICULARS (BRISTOL TYPE 198)

		Model	Full Scale*
Wing: Centre line chord	c_o	3.066 ft	110.1 ft
Span	b	2.34 ft	84.0 ft
Area	S	3.783 sq ft	4875 sq ft
Aerodynamic mean chord	$\bar{c}$	2.05 ft	73.6 ft
Overall length		5.237 ft	184 ft
Position of reference axis forward of T.E. (i.e. 0.52 C_o from apex)		1.48 ft	53.2 ft
Sting axis inclined 2.1° nose up relative to OH datum " " " 0.05° nose down " " wing root chord			

*Based on model scale ≈ 1/35.9

Table 2

TEST CONDITIONS

Speed (ft/sec) Mach number	240 (0.2)	0.8	1.4	1.8	2.2	2.6
$\frac{1}{2}\rho V^2$ (lb/ft^2)	68	206	274	280	269	252
Range of incidence	0° to 20°	0° to 8° (in most cases)				
$\nu = \frac{\omega c_0}{V}$ Pitch Heave	0.56 1.32	0.17 0.38	0.11 0.24	0.094 0.20	0.082 0.18	0.075 0.17
$\nu = \frac{\omega b}{2V}$ Yaw Sideslip	0.21 0.49	0.060 0.141	0.038 0.089	0.031 0.074	0.028 0.065	0.026 0.063
$\nu = \frac{\omega b}{2V}$ Roll Yaw	0.32	0.092 (no aerodynamic results)	0.058	0.048	0.043	0.040
Reynolds number (based on c_0)	4.5×10^6					

APPROXIMATE VALUES OF OSCILLATION FREQUENCIES AND AMPLITUDES

Type of test	Motion	Frequency (cycles/sec)	Amplitude (peak)
Pitch-heave	Pitch Heave	7.0 to 7.7 16.5	$\pm 1^\circ$ $\pm$ 0.035 in.
Yaw-sideslip	Yaw Sideslip	6.8 16.2	$\pm 1^\circ$ $\pm$ 0.035 in.
Roll-yaw	Roll Yaw	10.4 12.0	$\pm 1^\circ$ $\pm 0.1^\circ$

Table 3

SUMMARY OF RESULTS - LONGITUDINAL DERIVATIVES

		m	z
Pitch - Heave Tests	θ	Satisfactory Figs.4 and 5 (Fig.13)	Satisfactory Figs.3 and 6 (Fig.14)
	θ	Satisfactory Figs.7 and 8 (Fig.12)	M = 0.2 only Fig.10 See note A
	z	Used only to correct z_θ. See Appendix 2	Too small to measure.
	$\dot{z}$	Less reliable than M_θ	Satisfactory Figs.9 and 11 (Fig.14)

Notes: A. - Determination of this derivative involved the measurement of small phase angles in the presence of noise, which could not be done satisfactorily with the available equipment.

The figure numbers in brackets refer to figures showing the variation of the derivatives with Mach number at one or two constant values of Cz.

Table 4

SUMMARY OF RESULTS - LATERAL DERIVATIVES

		n	y	ℓ
Yaw-Sideslip Tests	ψ	Satisfactory Figs.15 and 16 (Fig.25)	Satisfactory Figs.17 and 20 (Fig.26)	Satisfactory Figs.27 and 28 (Fig.31)
Yaw-Sideslip Tests	$\dot{\psi}$	Satisfactory Figs.18 and 19 (Fig.23)	Incomplete Fig.21 See note A	Satisfactory Fig.29 (Fig.32)
Yaw-Sideslip Tests	y	Too small to measure	Too small to measure	Too small to measure
Yaw-Sideslip Tests	$\dot{y}$	Too small to measure	Too small to measure	Less reliable than ℓ_ψ
Roll-Yaw Tests	ϕ	See note B	Not Measured	Roughly equal to $\ell_\psi \tan \alpha$ Fig.34
Roll-Yaw Tests	$\dot{\phi}$	See note B	Not Measured	Satisfactory Fig.30 (Fig.33)
Roll-Yaw Tests	ψ	See note B	Not Measured	Less reliable than in yaw-sideslip tests
Roll-Yaw Tests	$\dot{\psi}$	See note B	Not Measured	Unsatisfactory See note A

Notes:- A - Determination of these derivatives involved the measurement of small phase angles in the presence of noise, which could not be done satisfactorily with the available equipment.

B These derivatives could not be measured properly because no sideslip measurements were made (see Appendix A).

The figure numbers given in brackets refer to figures showing the variation of the derivatives with Mach number at one or two constant values of Cz.

Table 5

NUMERICAL EXAMPLE - ROLL-YAW TEST

		Wind-off	Wind-on
Constants			
I_{xx}	slugs-ft^2	0.1260	
I_{zx}	slugs-ft^2	-0.0703	
Measurements		Wind-off	Wind-on
α	degrees	0	8
Mach no.		0	1.4
V	ft/sec	0	1340
$\frac{1}{2}\rho V^2$	lb/ft^2	0	274
Rolling mode			
ψ/φ		-0.065/0°*	-0.082/0°*
$Le/\dot{\varphi}$	lb-ft-sec^2	0.00156/90°	0.0065/90°
n	cycles/sec	10.260	10.931
Yawing mode			
φ/ψ		2.16/0°*	1.17/0°*
$Le/\dot{\psi}$	lb-ft-sec^2	0.0047/90°	0.0127/90°
n	cycles/sec	12.090	11.925
Derivatives obtained from above measurements			
L_φ	lb-ft	-542	-600
L_ψ	lb-ft	+7	+268
$L_{\dot{\varphi}}$	lb-ft-sec	-0.109	-0.479
$L_{\dot{\psi}}$	lb-ft-sec	[-0.126]*	[-0.399]*

* In these cases no measurements could be made of the small phase angles, and so the values of $L_{\dot{\psi}}$ are not reliable.

NOTATION

Axes

All forces, moments, displacements, derivatives, and coefficients are referred to "sting axes", i.e. a system of earth axes fixed in the mean position of the oscillating model. A set of equations for conversion to other systems of axes is given in Appendix IV of Ref.1.

Displacements and velocities

y	$\dot{y}$	sideslip
z	$\dot{z}$	heave
φ	$\dot{\phi}$	roll
θ	$\dot{\theta}$	pitch
ψ	$\dot{\psi}$	yaw

Forces and moments

Side force	Y	=	$\frac{1}{2}\rho V^2 S C_y$
Normal force	Z	=	$\frac{1}{2}\rho V^2 S C_z$
Rolling moment	L	=	$\frac{1}{2}\rho V^2 Sb C_\ell$
Pitching moment	M	=	$\frac{1}{2}\rho V^2 S c_o C_m$
Yawing moment	N	=	$\frac{1}{2}\rho V^2 Sb C_n$

Derivatives are denoted by suffices, e.g.

$M_\theta = \partial M/\partial\theta$ = pitching moment due to pitch displacement.

Non-dimensional derivatives are denoted by small letters (e.g. m_θ), and have been obtained from the measured aerodynamic values as follows:-

For	m_θ	divide by	$\rho V^2 Sc_o$
	$m_{\dot{\theta}}$	" "	$\rho V Sc_o^2$
	$z\theta$ and $y\psi$	" "	$\rho V^2 S$
	$z_{\dot{\theta}}$	" "	$\rho V Sc_o$
	$n\psi$, $\ell\psi$ and $\ell\varphi$	" "	$\rho V^2 S (\frac{1}{2}b)$
	$n\dot{\psi}$, $\ell\dot{\psi}$ and $\ell\dot{\phi}$	" "	$\rho V S (\frac{1}{2}b)^2$
	$y\dot{\psi}$	" "	$\rho V S (\frac{1}{2}b)$

Other symbols

b	wing span
c_o	wing centre-line chord
I_{xx}	roll moment of inertia of model
I_{zx}	roll-yaw product of inertia of model
L_e	rolling moment excitation
M	Mach number (used where no confusion with pitching moment can arise)
n	oscillation frequency
S	wing area
V	wind velocity
α	angle of incidence
β	angle of sideslip
Δ	fin contribution to a derivative
ν	frequency parameter $\omega\, c_o/V$ longitudinal
	$\omega\, b/2V$ lateral
ρ	air density
ω	circular frequency ($= 2\pi n$)

a

REFERENCE

No.	Author	Title, etc.
1	J. S. Thompson R. A. Fail	Oscillatory-derivative measurements on sting-mounted wind-tunnel models: method of test and results for pitch and yaw on a cambered ogee wing at Mach numbers up to 2.6. A.R.C. R.& M. 3355, July 1962

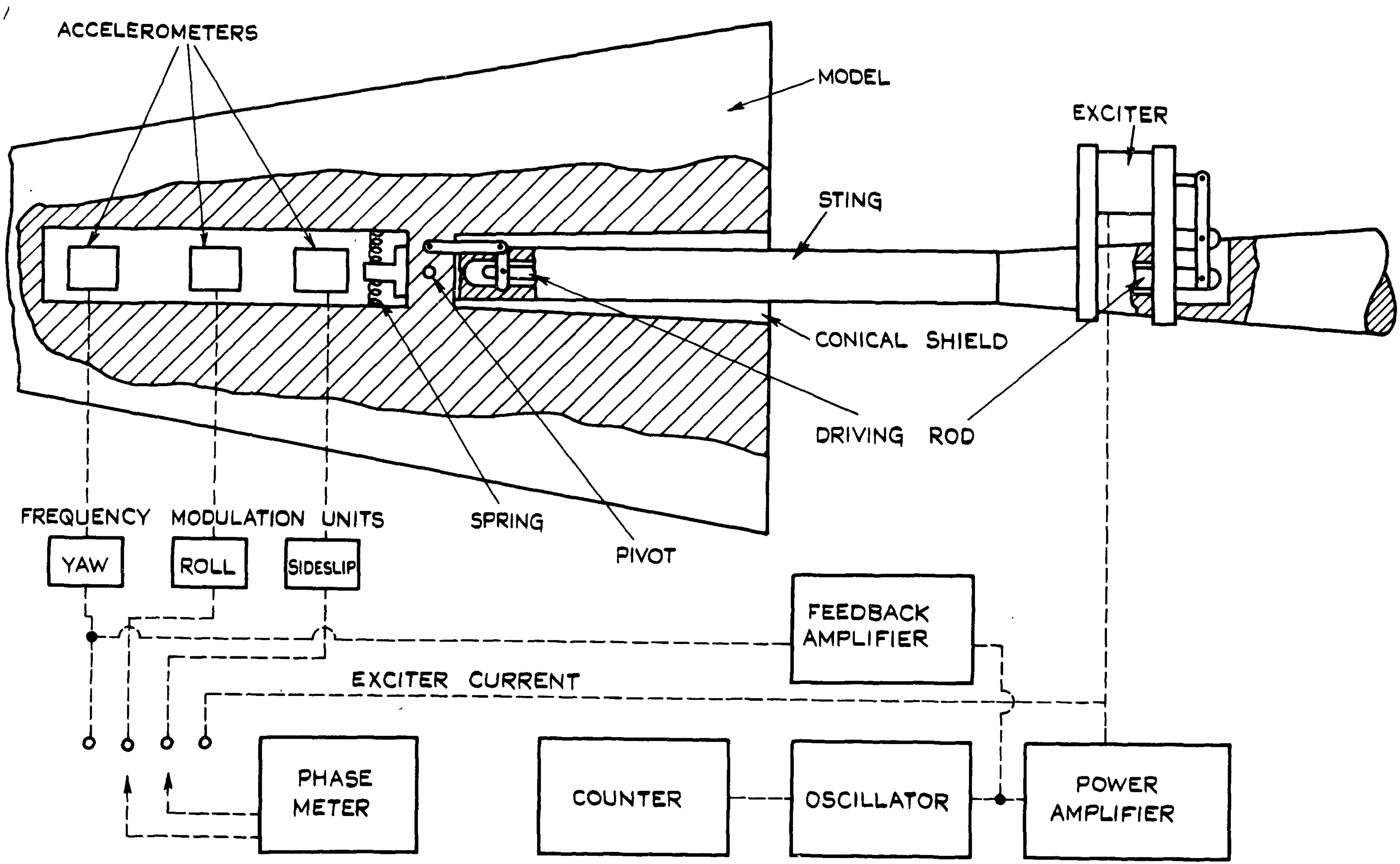


FIG. 1 SCHEMATIC ARRANGEMENT FOR YAW - SIDESLIP OSCILLATIONS

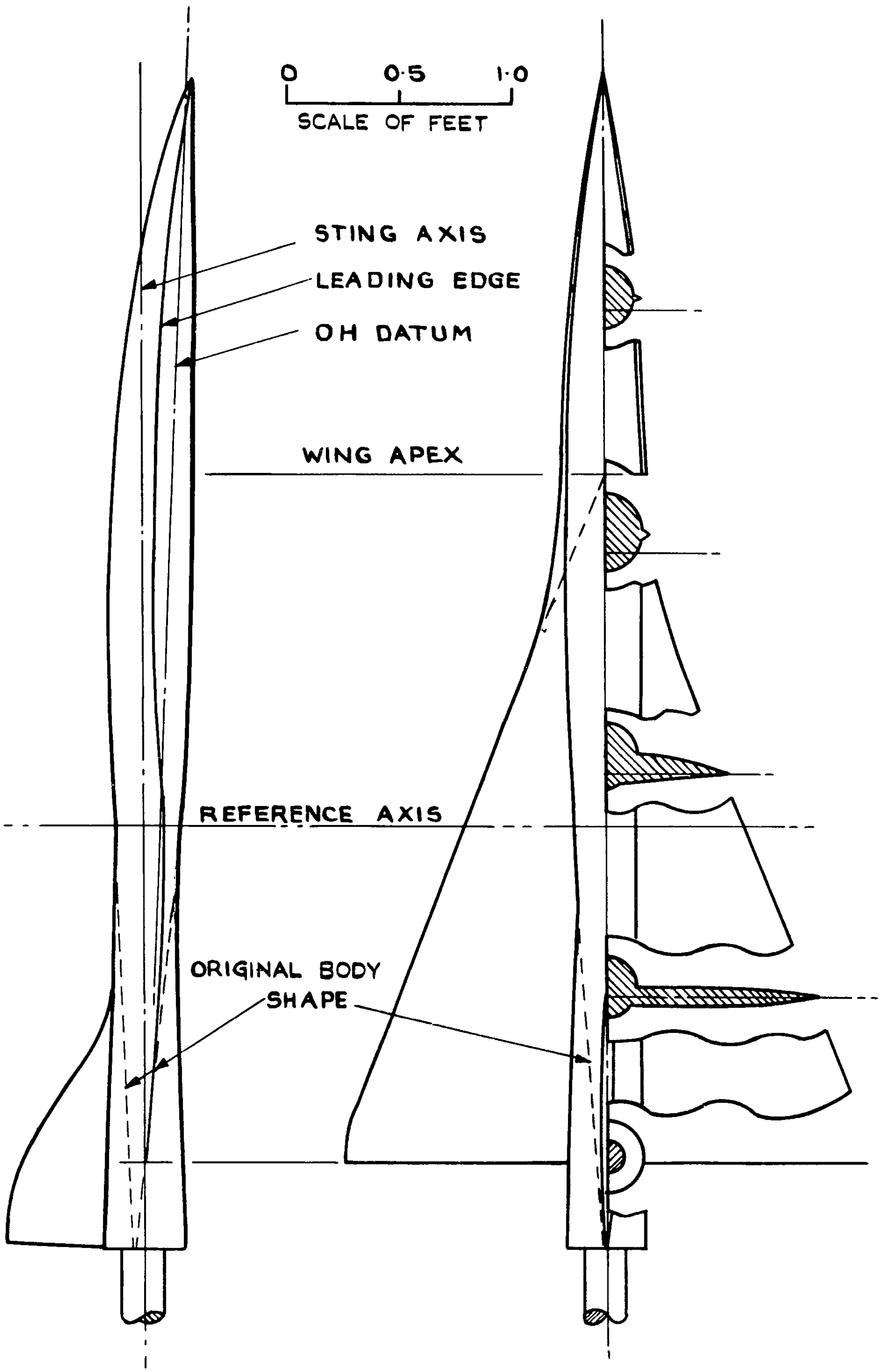


FIG. 2 BRISTOL TYPE 198 MODEL

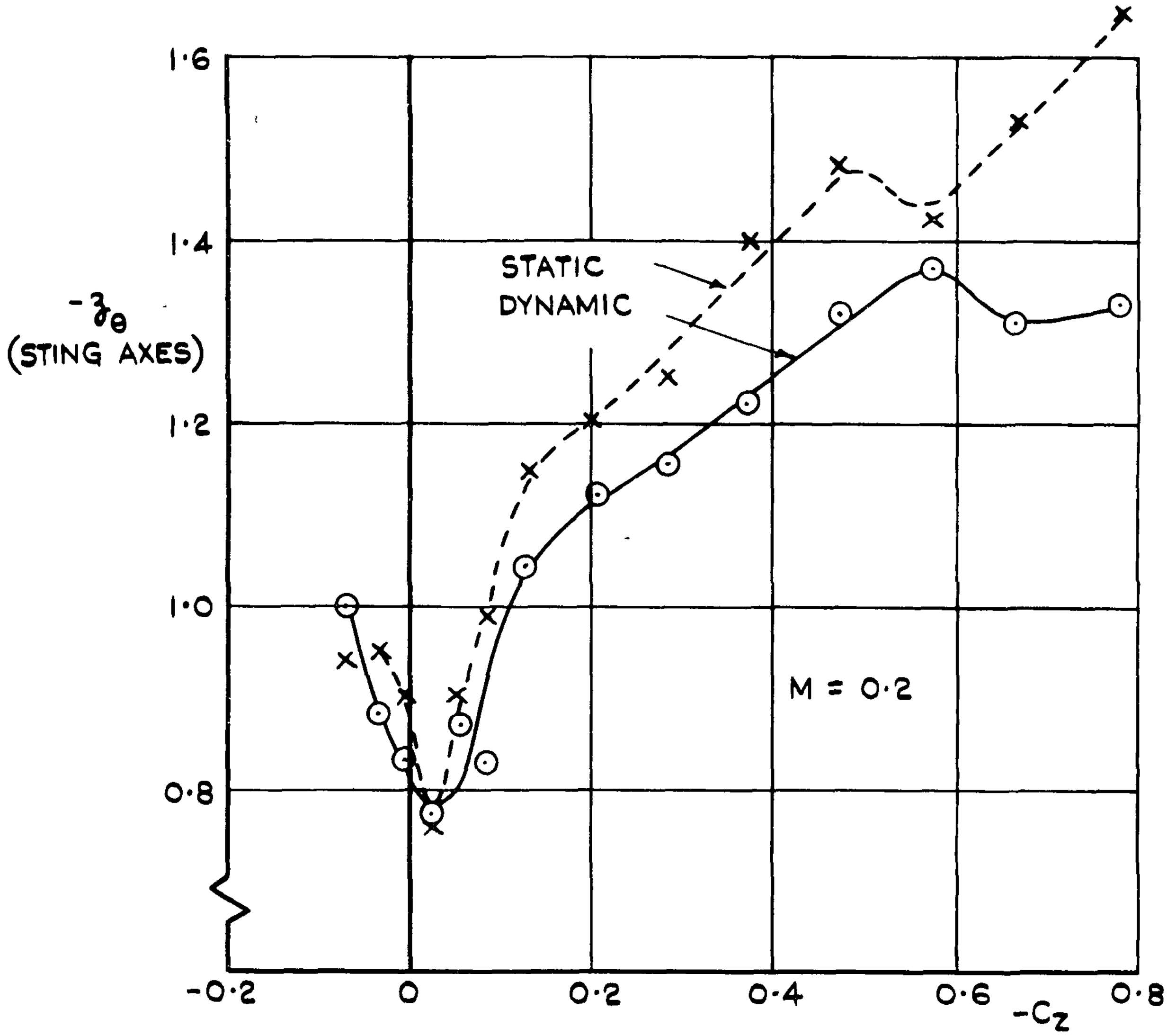


FIG.3 CROSS DERIVATIVE, $-z_\theta$. M=0·2

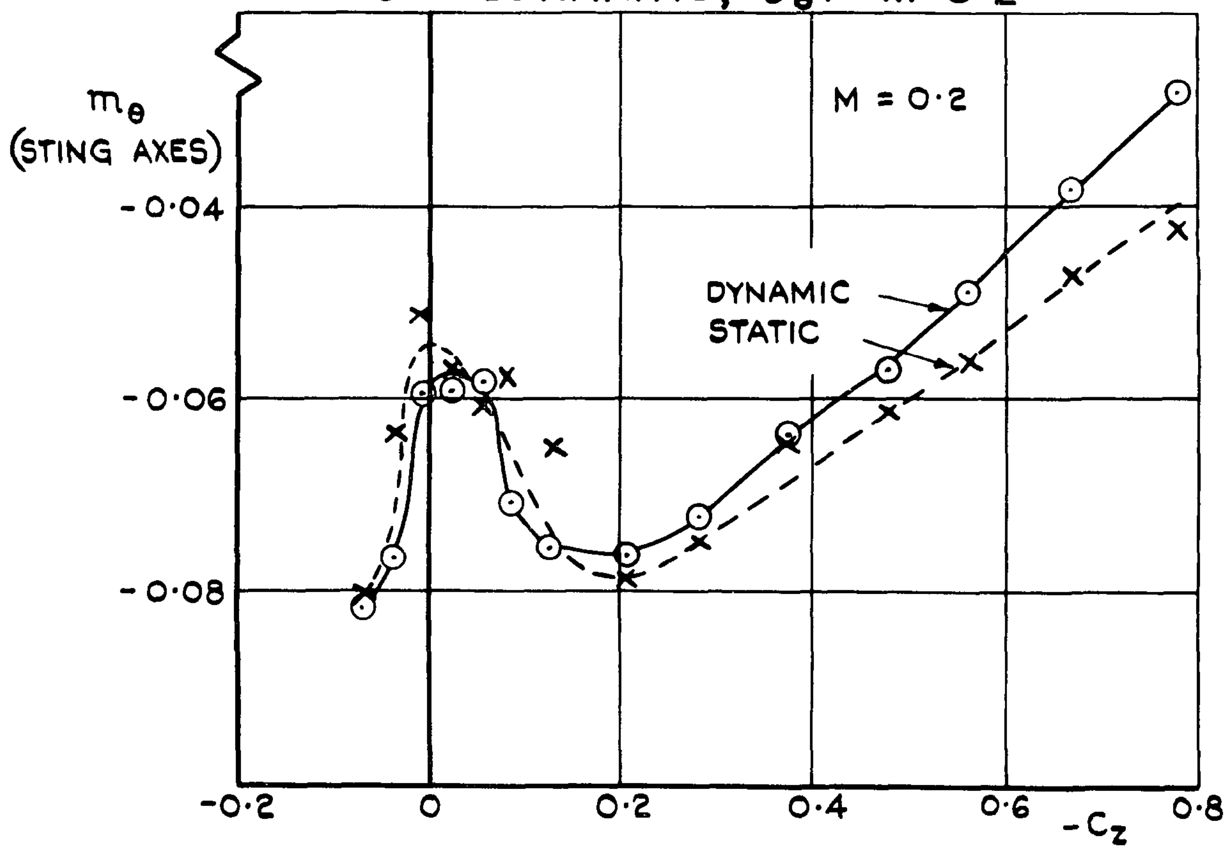


FIG.4 STABILITY IN PITCH, m_θ. M=0·2

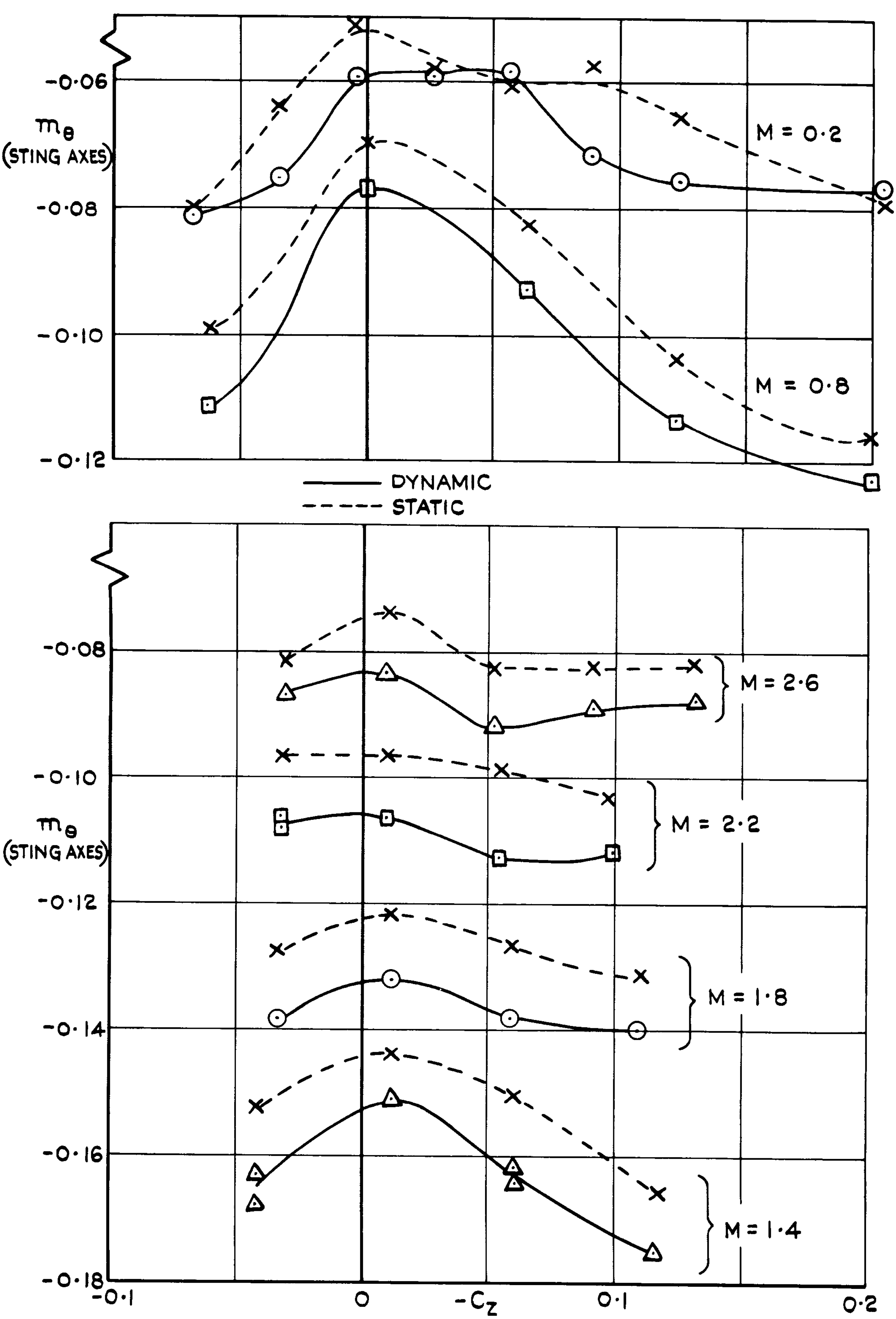


FIG. 5 STABILITY IN PITCH, m_θ

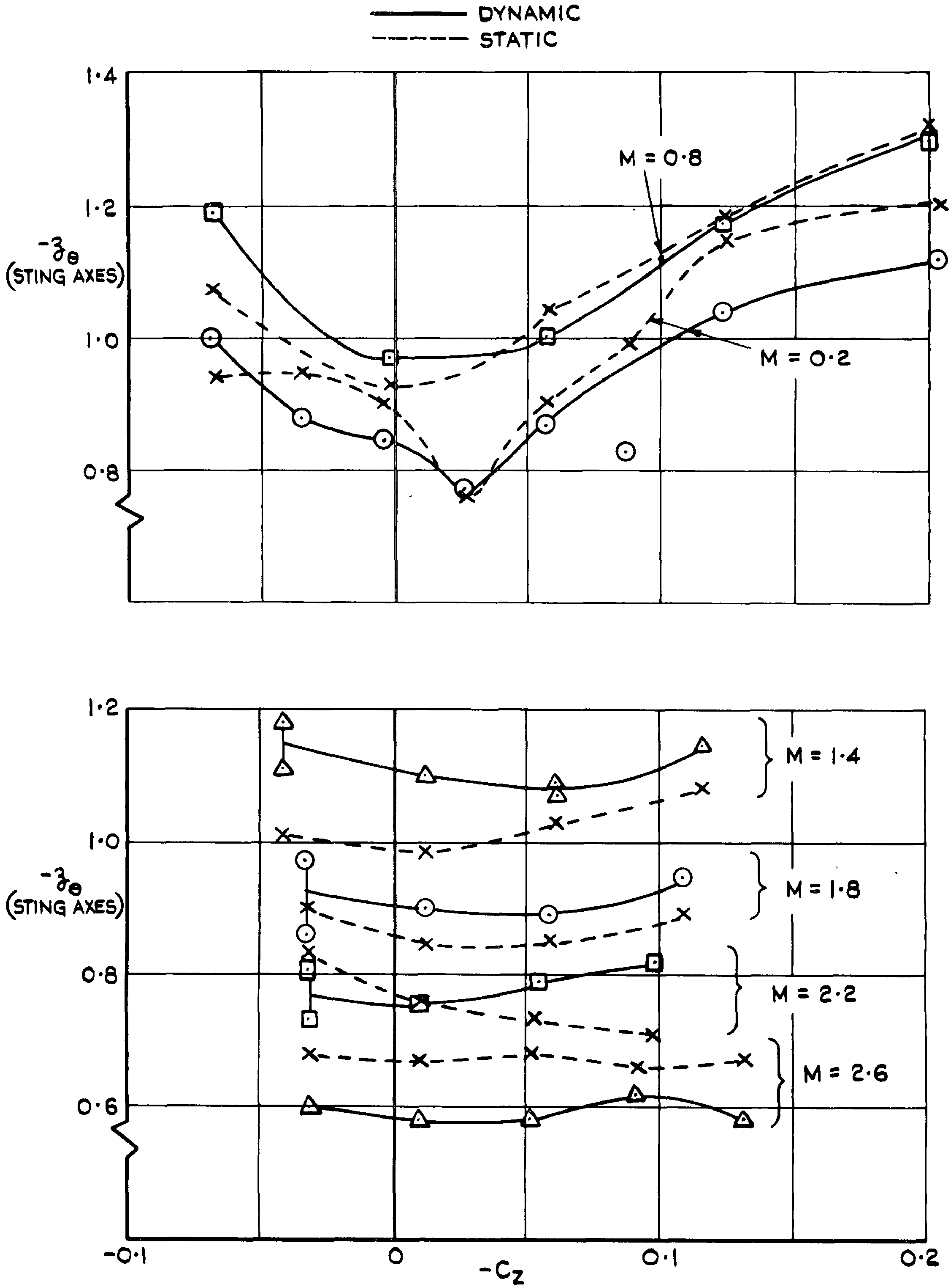


FIG.6 CROSS DERIVATIVE, $-z_\theta$

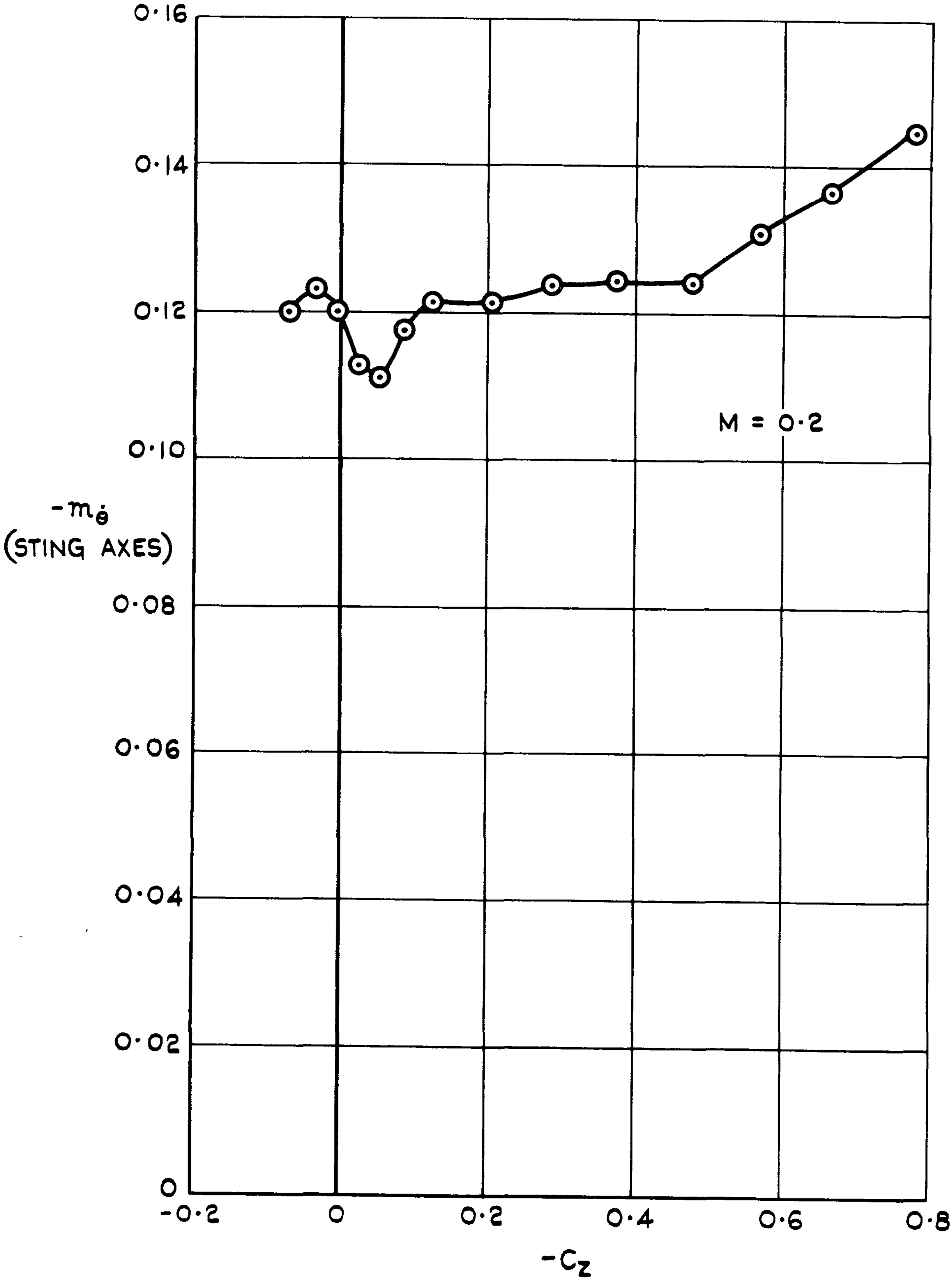


FIG. 7 DAMPING IN PITCH, $-m_{\dot{\theta}}$. M=0·2

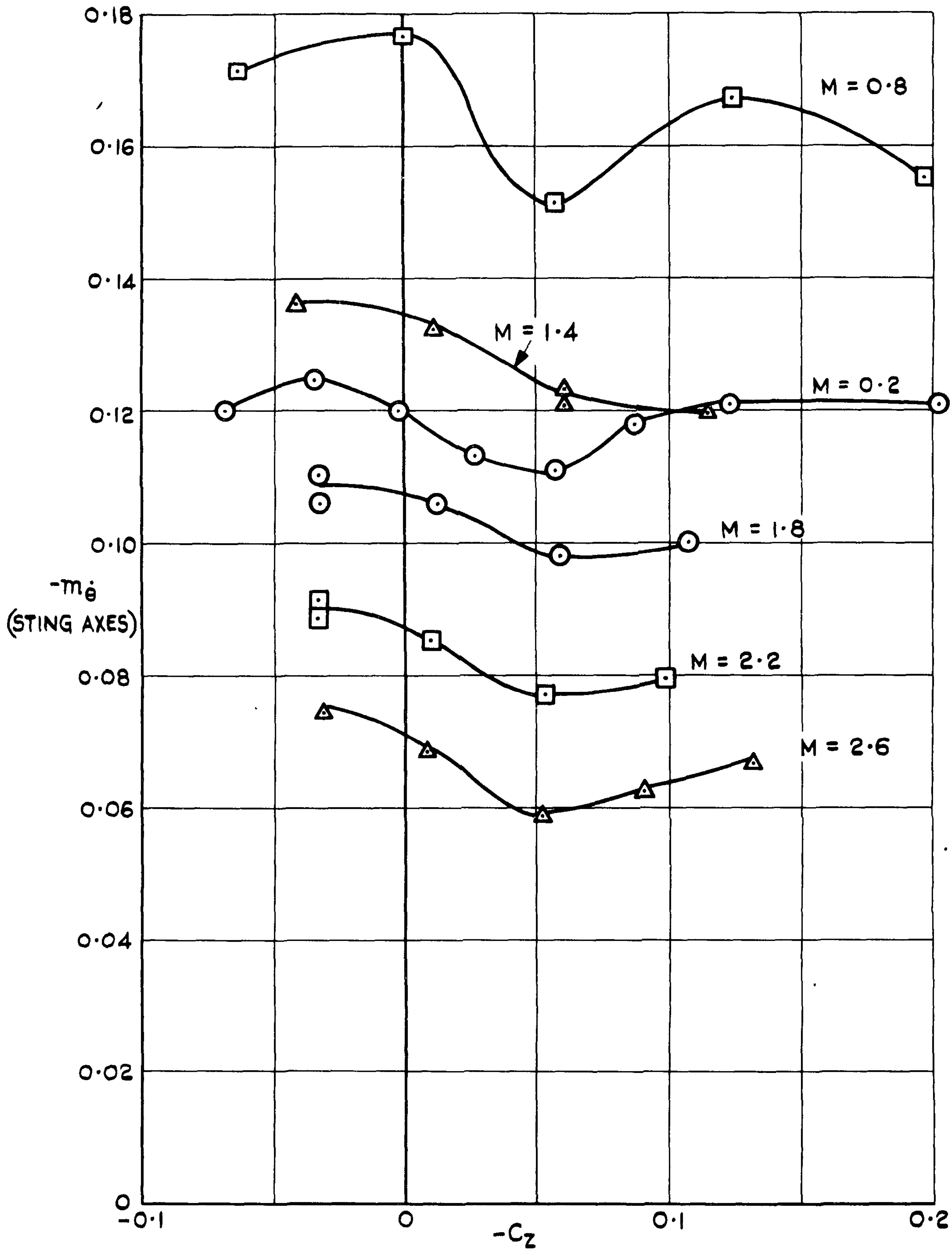


FIG. 8 DAMPING IN PITCH, $-m_{\dot{\theta}}$

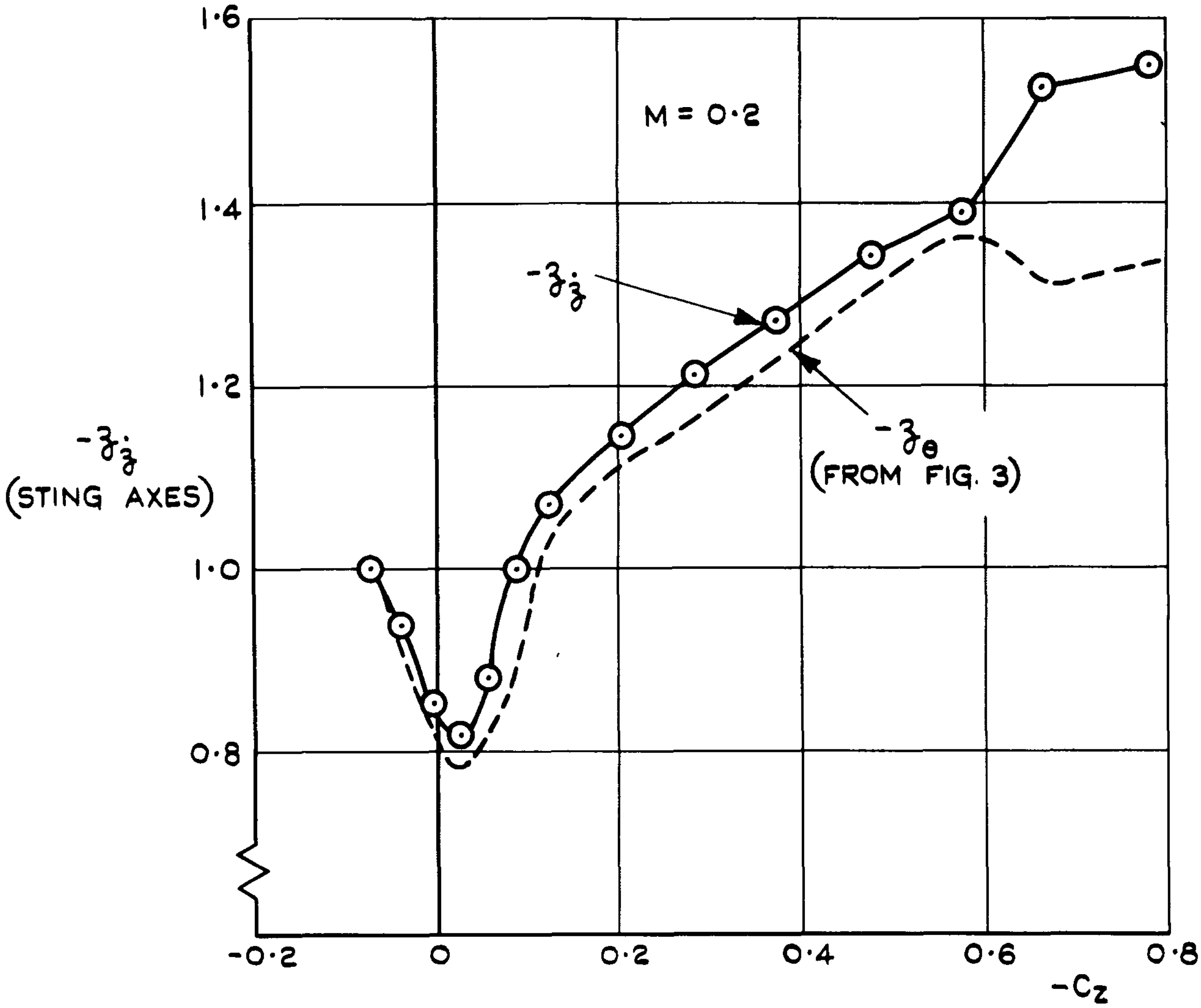


FIG. 9 DAMPING IN HEAVE, $-z_{\dot{z}}$. M=0·2

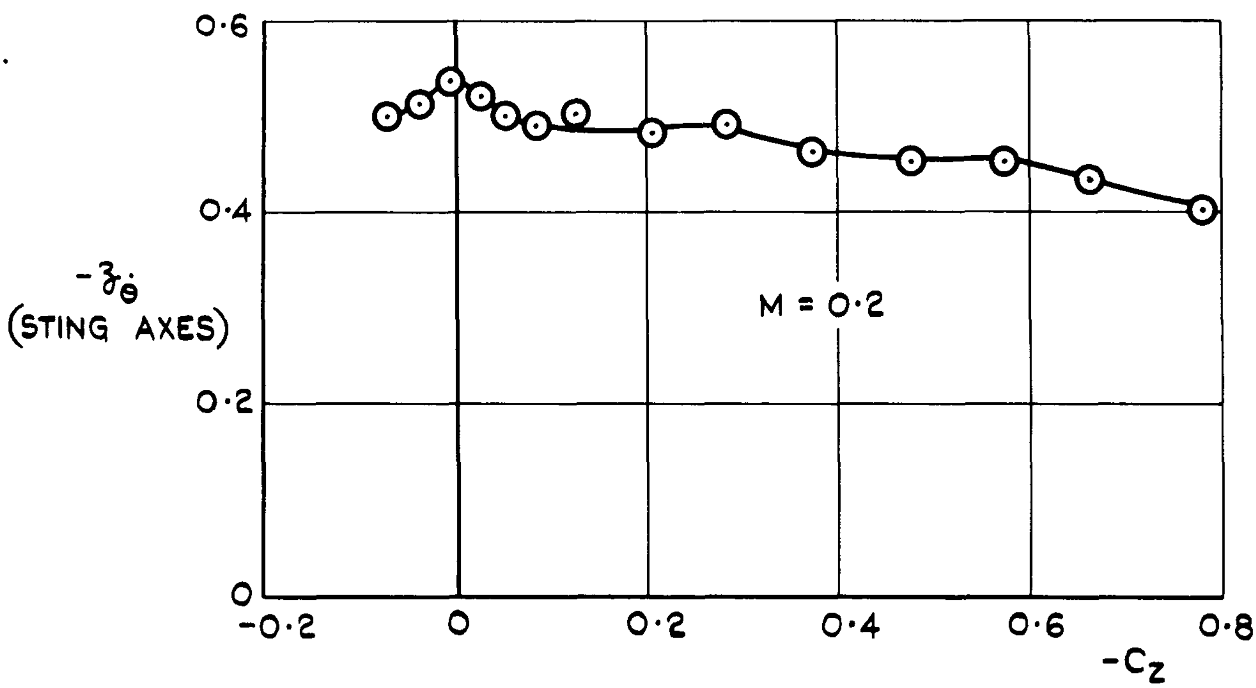


FIG. 10 CROSS DERIVATIVE, $-z_{\dot{\theta}}$. M=0·2

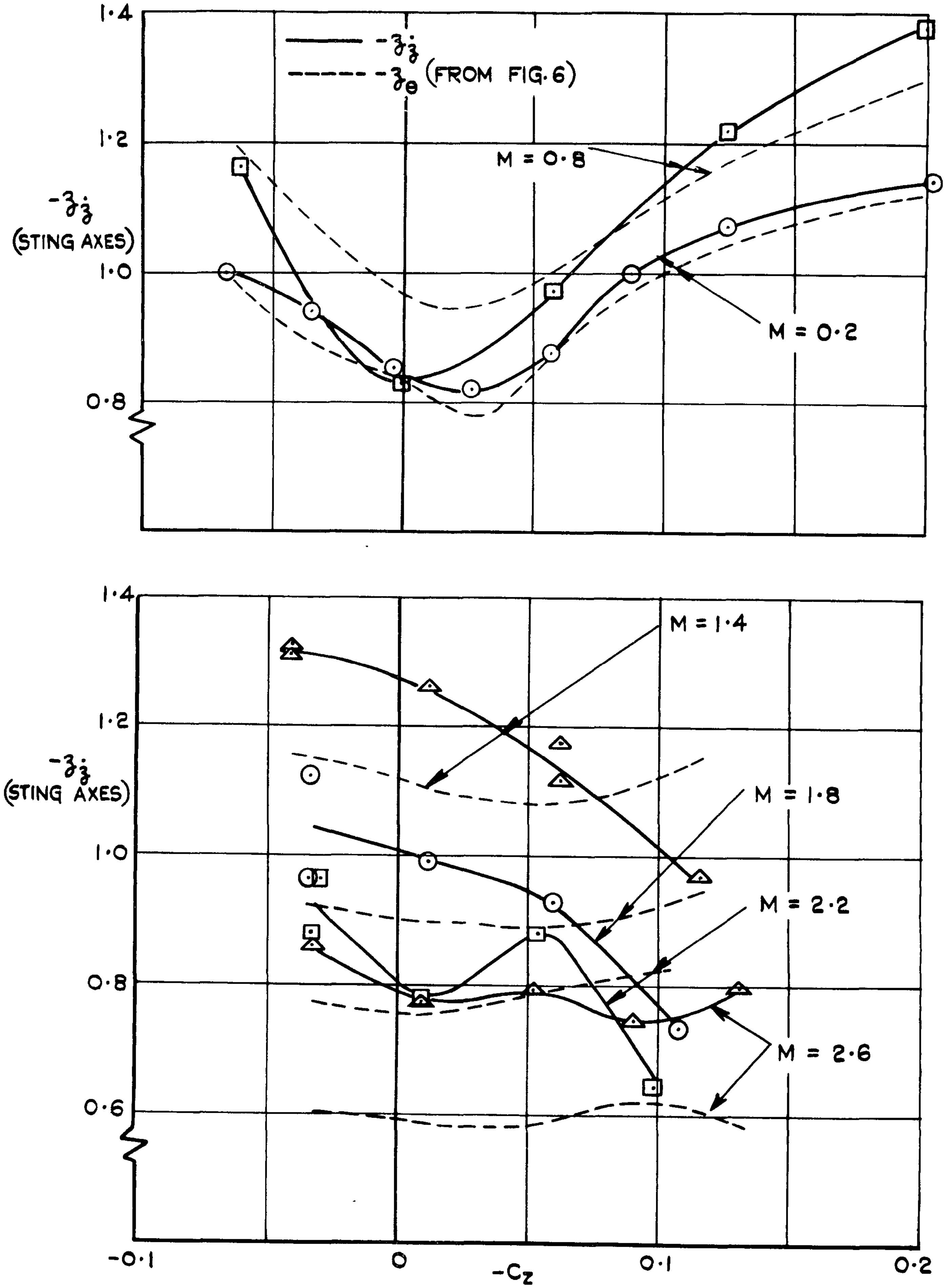


FIG.11 DAMPING IN HEAVE, $-z_{\dot z}$

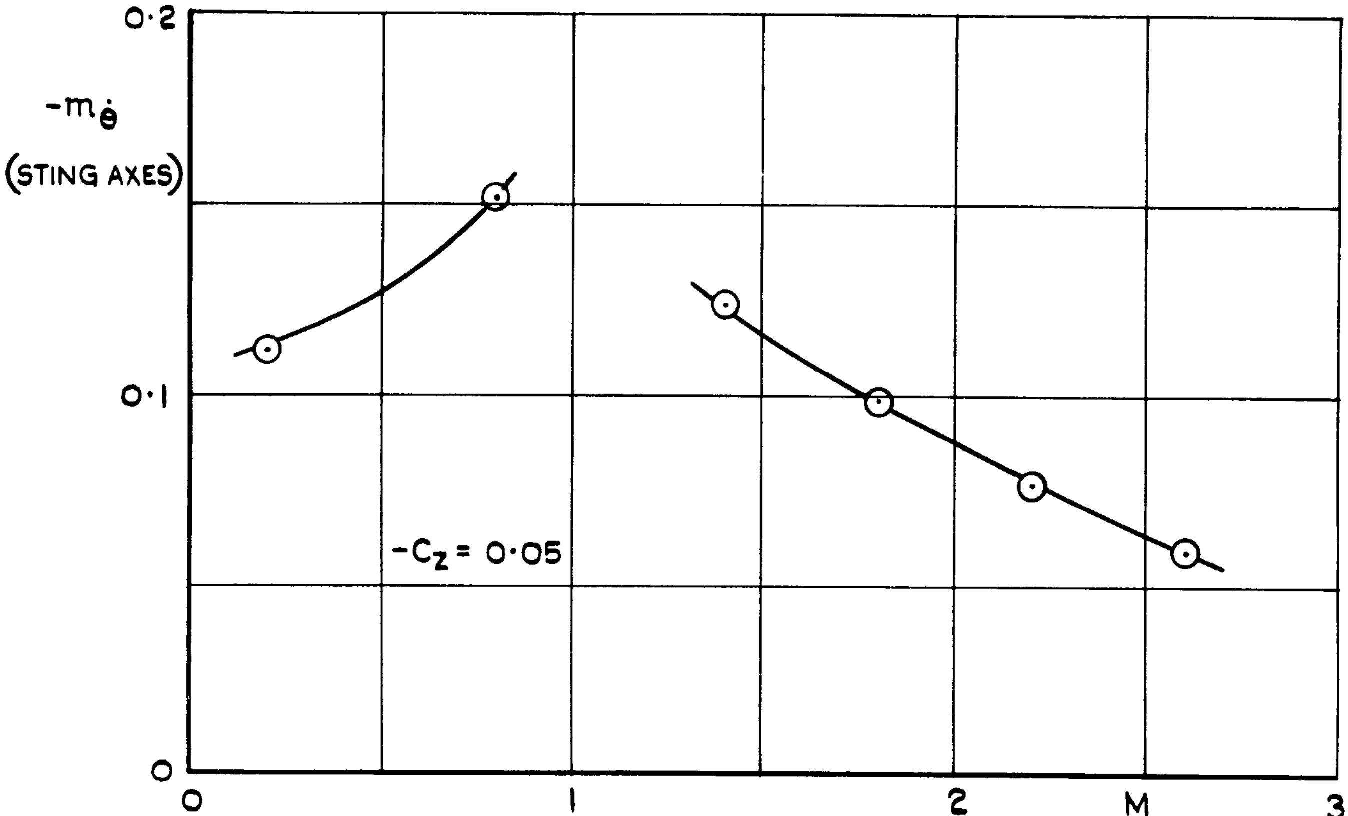


FIG. 12 DAMPING IN PITCH, $-m_{\dot\theta}$. VARIATION WITH MACH NUMBER

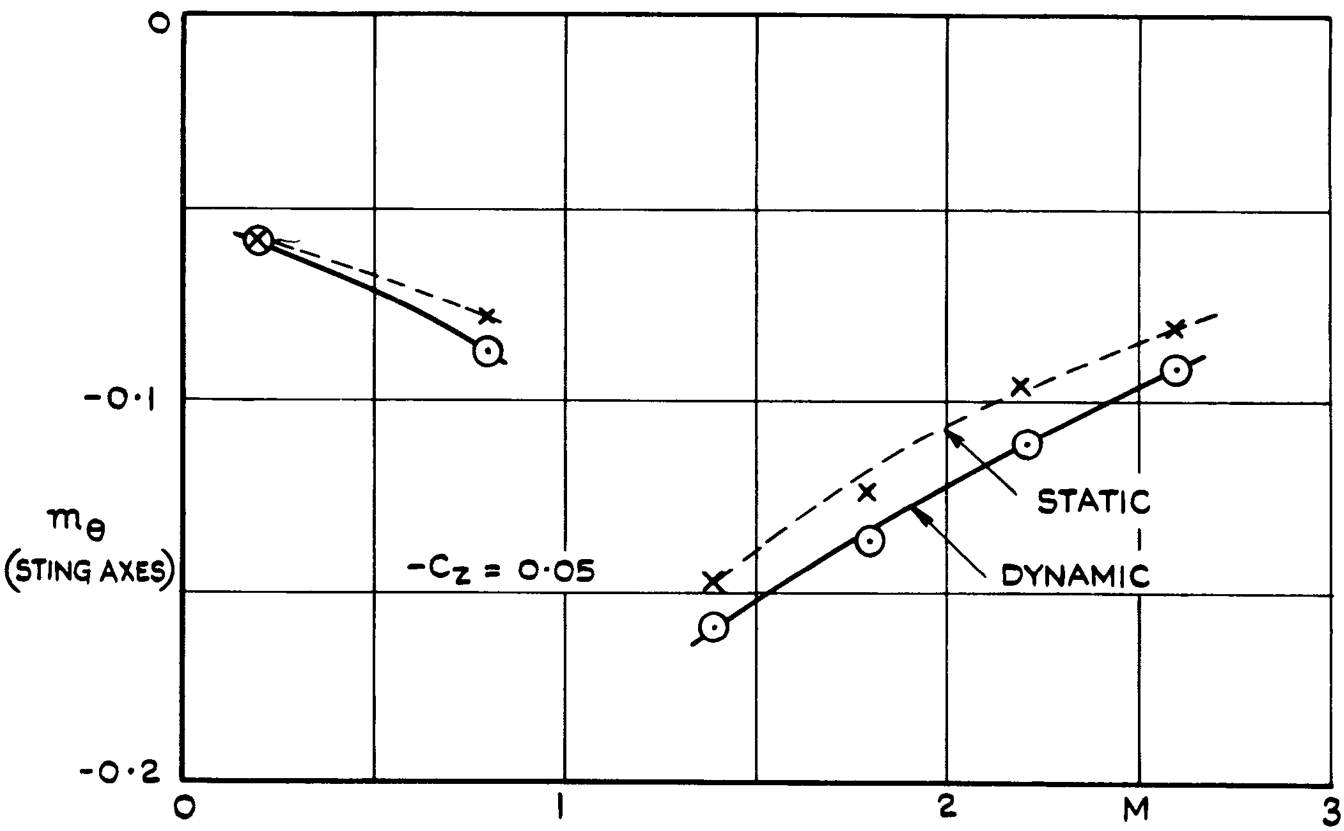


FIG. 13 STABILITY IN PITCH, m_θ. VARIATION WITH MACH NUMBER

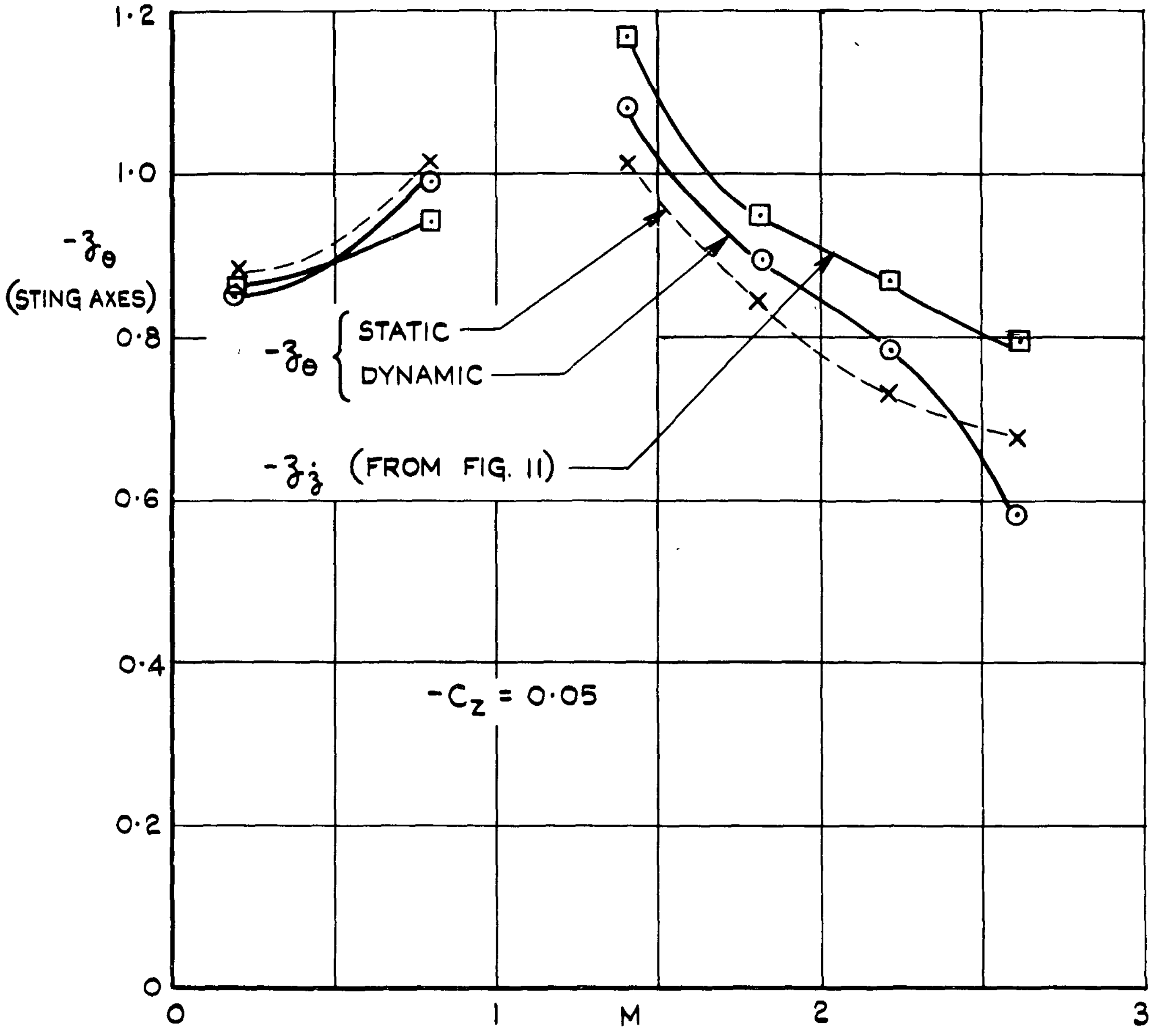


FIG. 14. CROSS DERIVATIVE, $-z_\theta$. VARIATION WITH MACH NUMBER

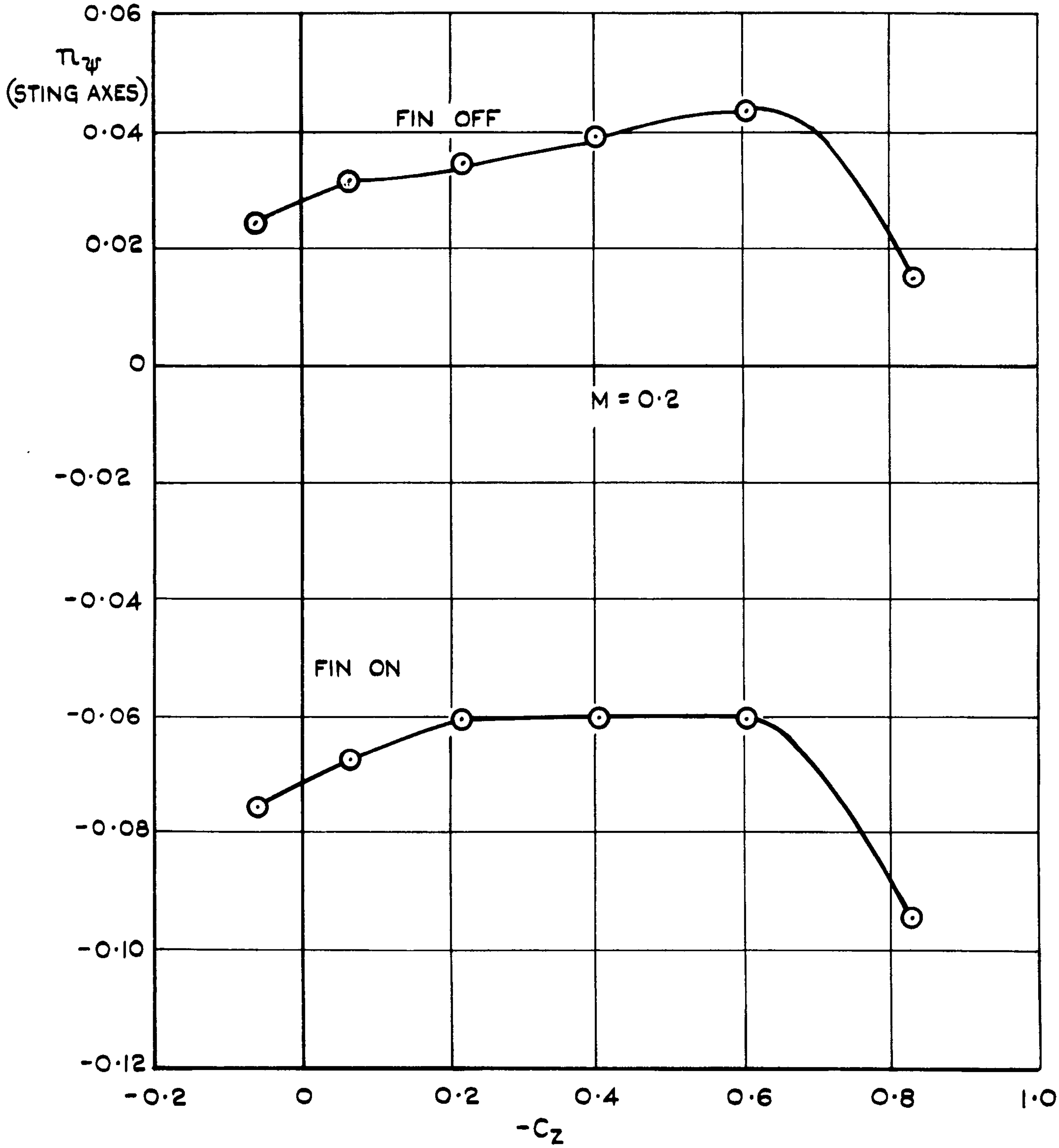


FIG. 15 STABILITY IN YAW, n_ψ. M = 0·2

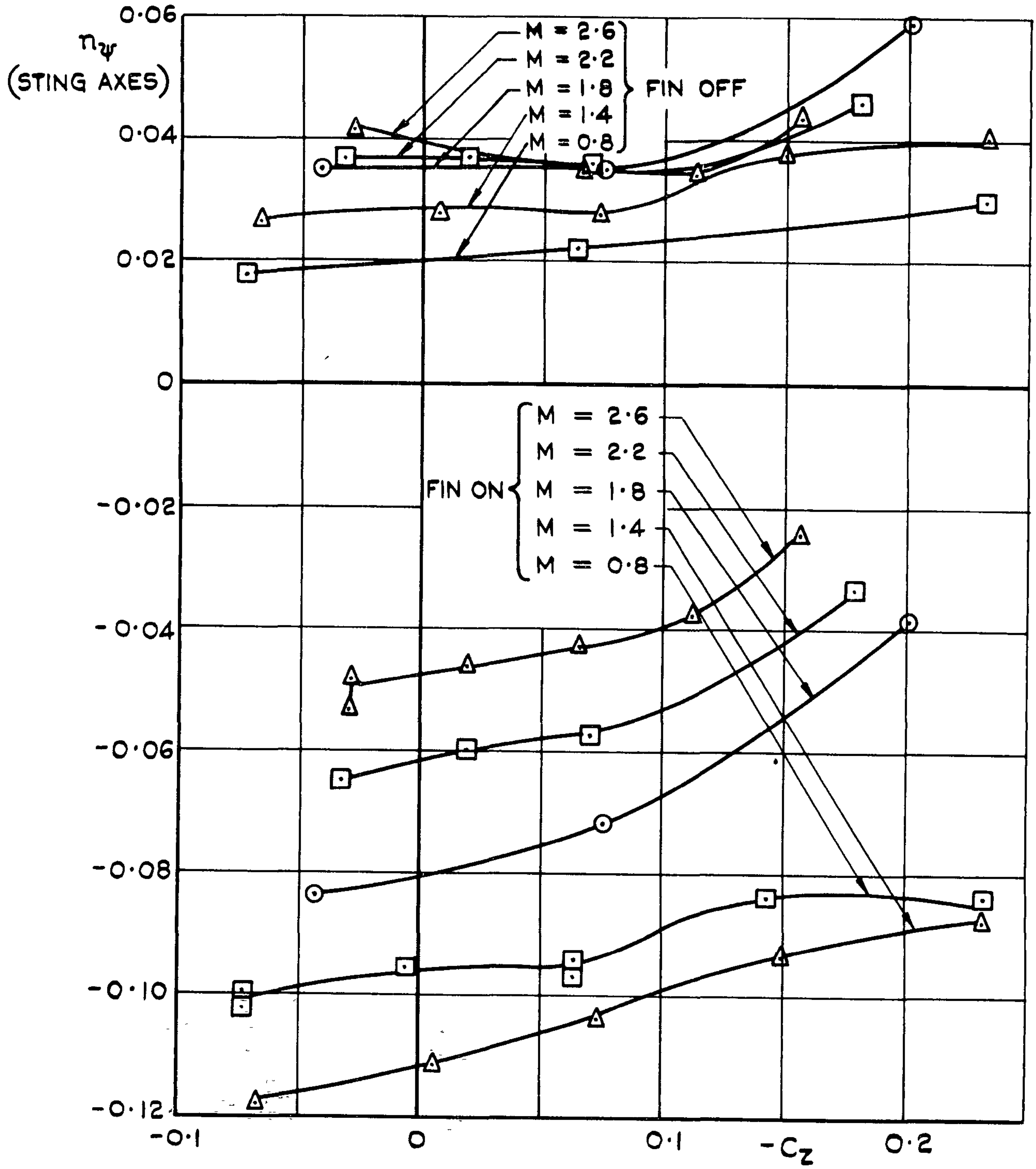


FIG. 16 STABILITY IN YAW, n_ψ

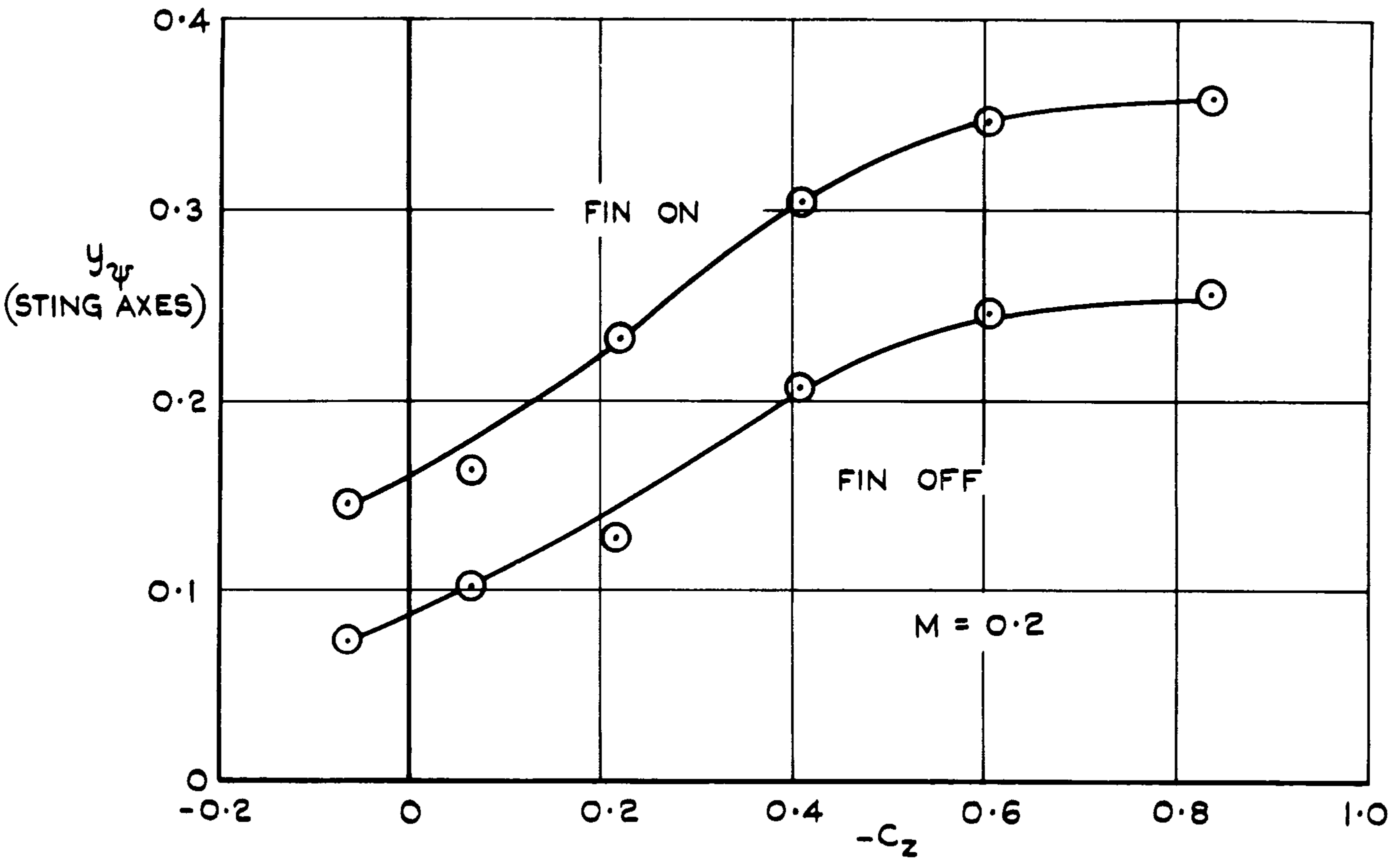


FIG. 17 CROSS DERIVATIVE, y_{ψ}. M = 0·2

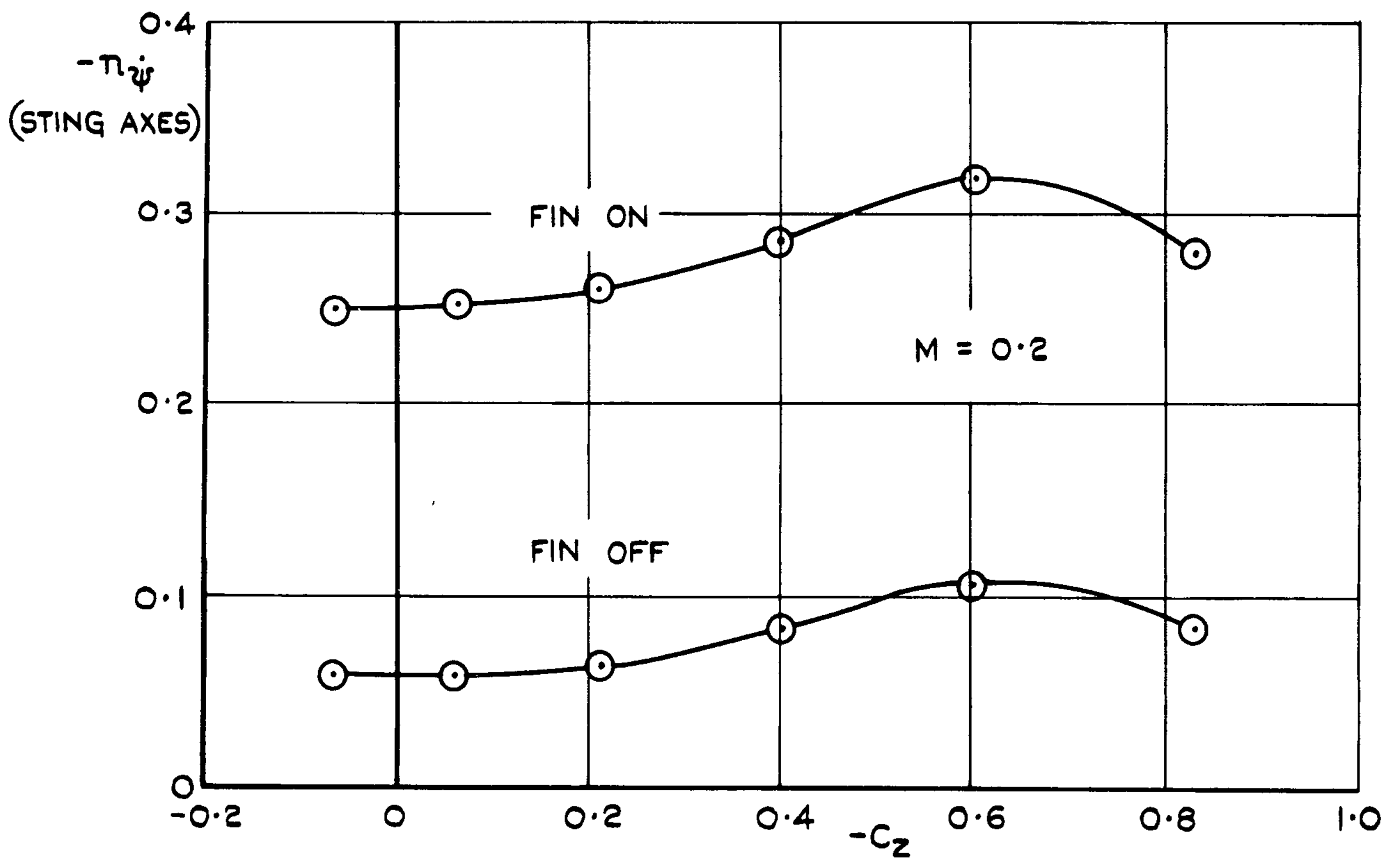


FIG. 18 DAMPING IN YAW, $-n_{\dot{\psi}}$. M = 0·2

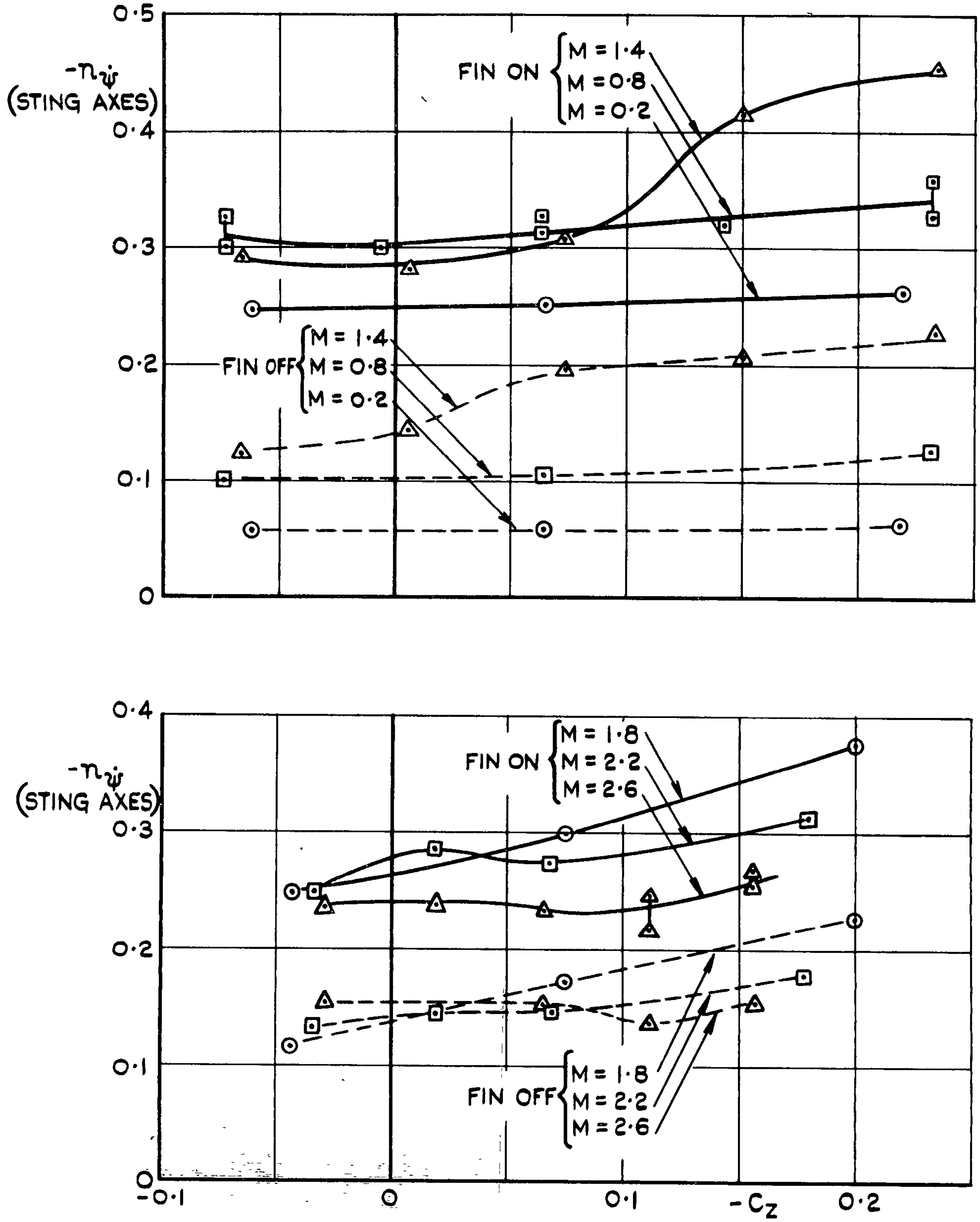
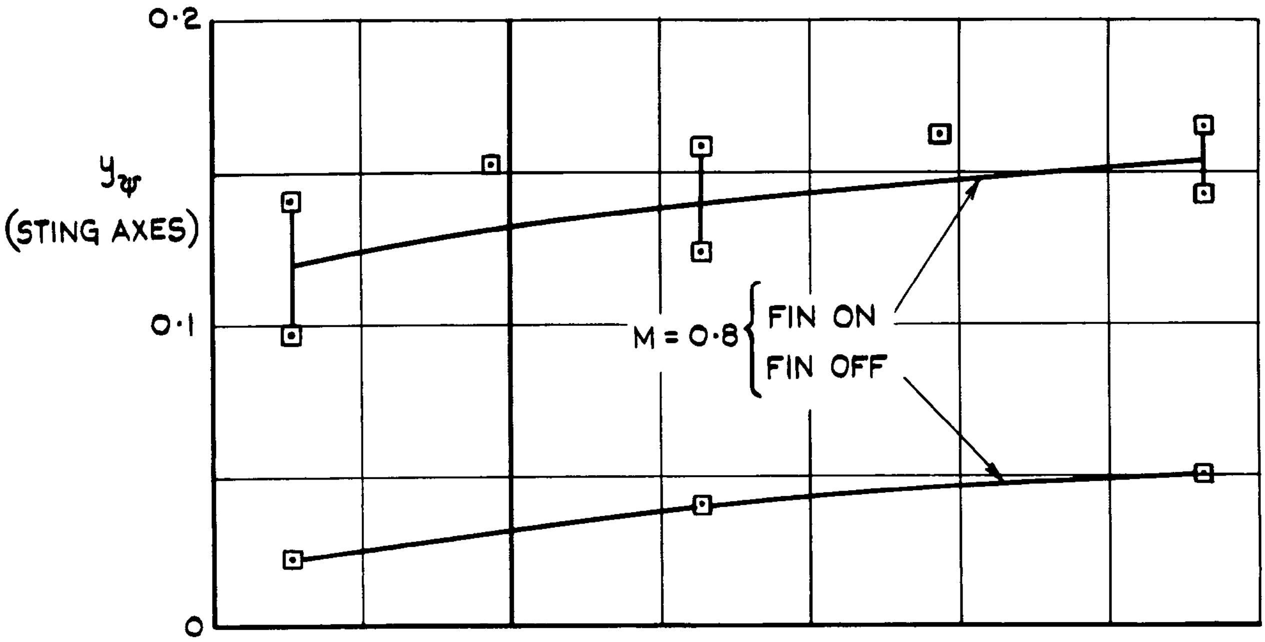


FIG. 19 DAMPING IN YAW, $-n_{\dot\psi}$



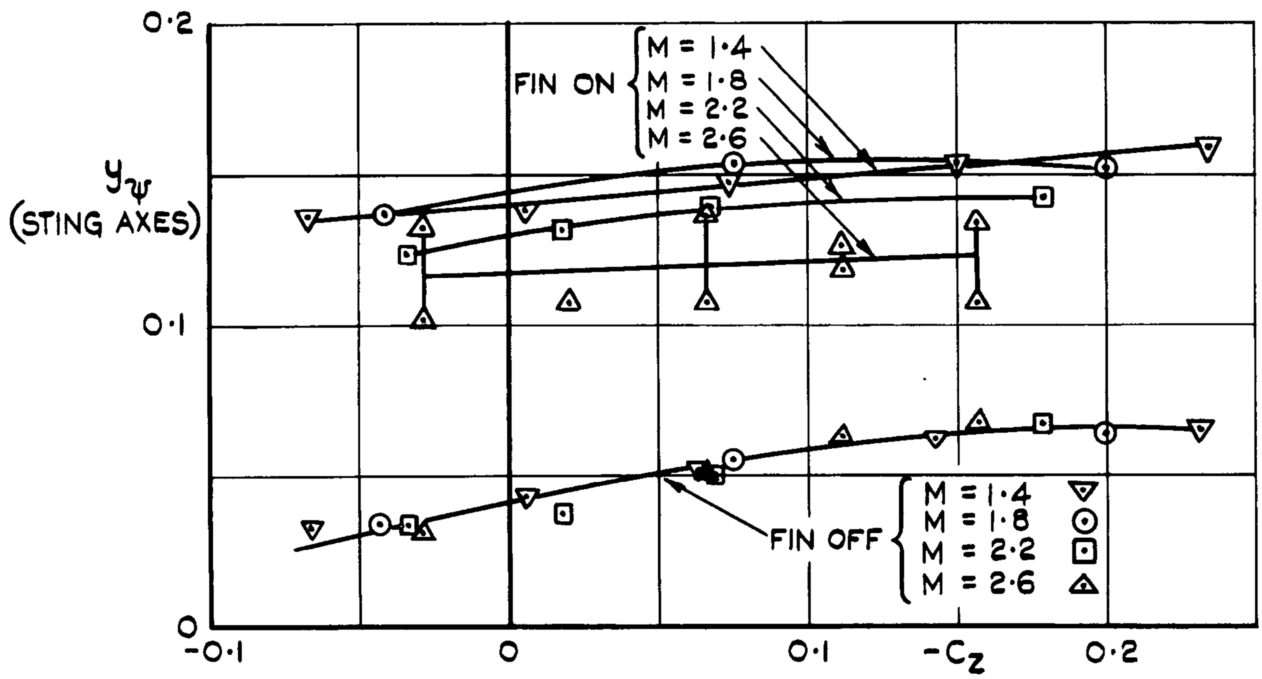


FIG 20 CROSS DERIVATIVE, y_ψ

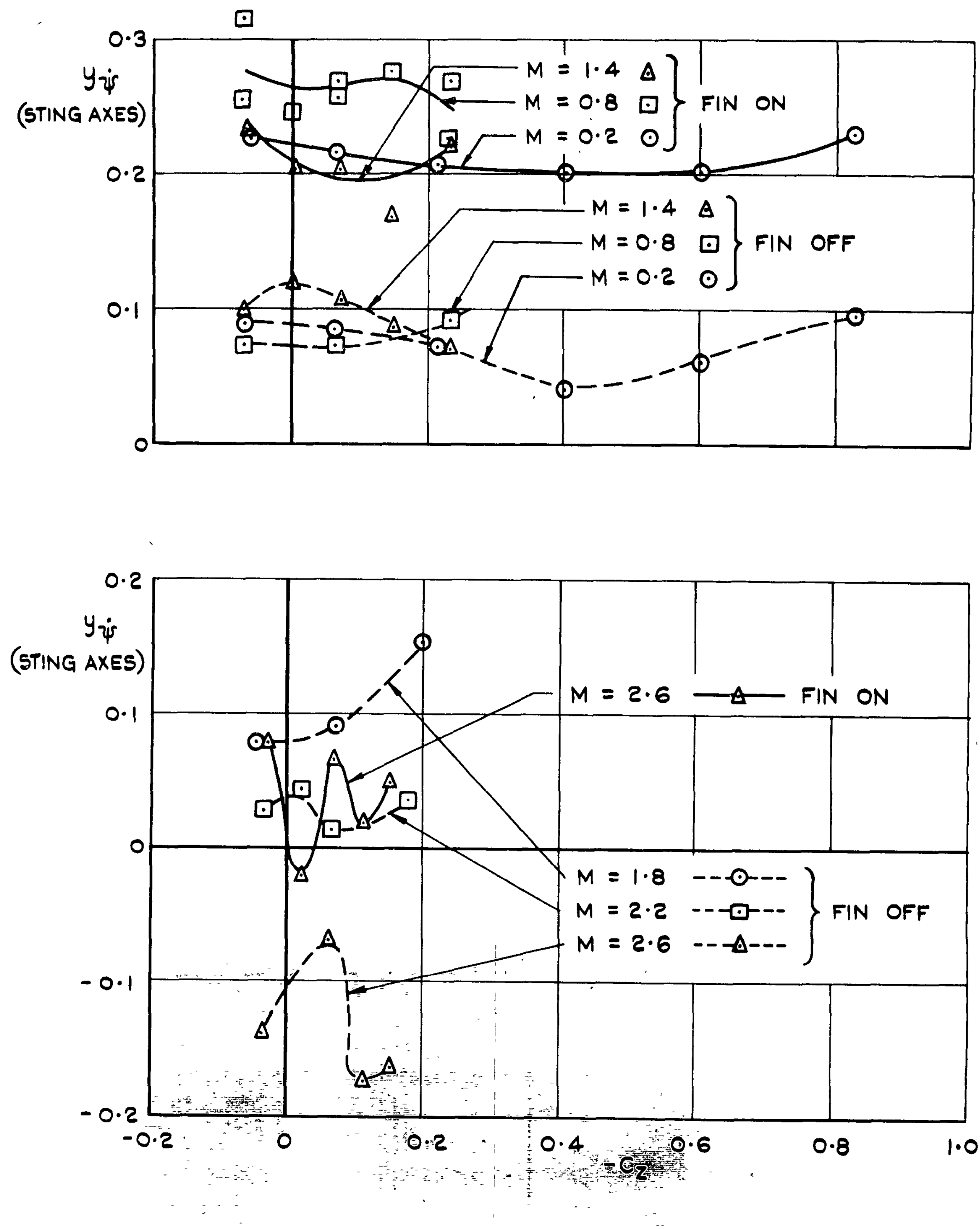


FIG. 21 CROSS DERIVATIVE, $y_{\dot\psi}$

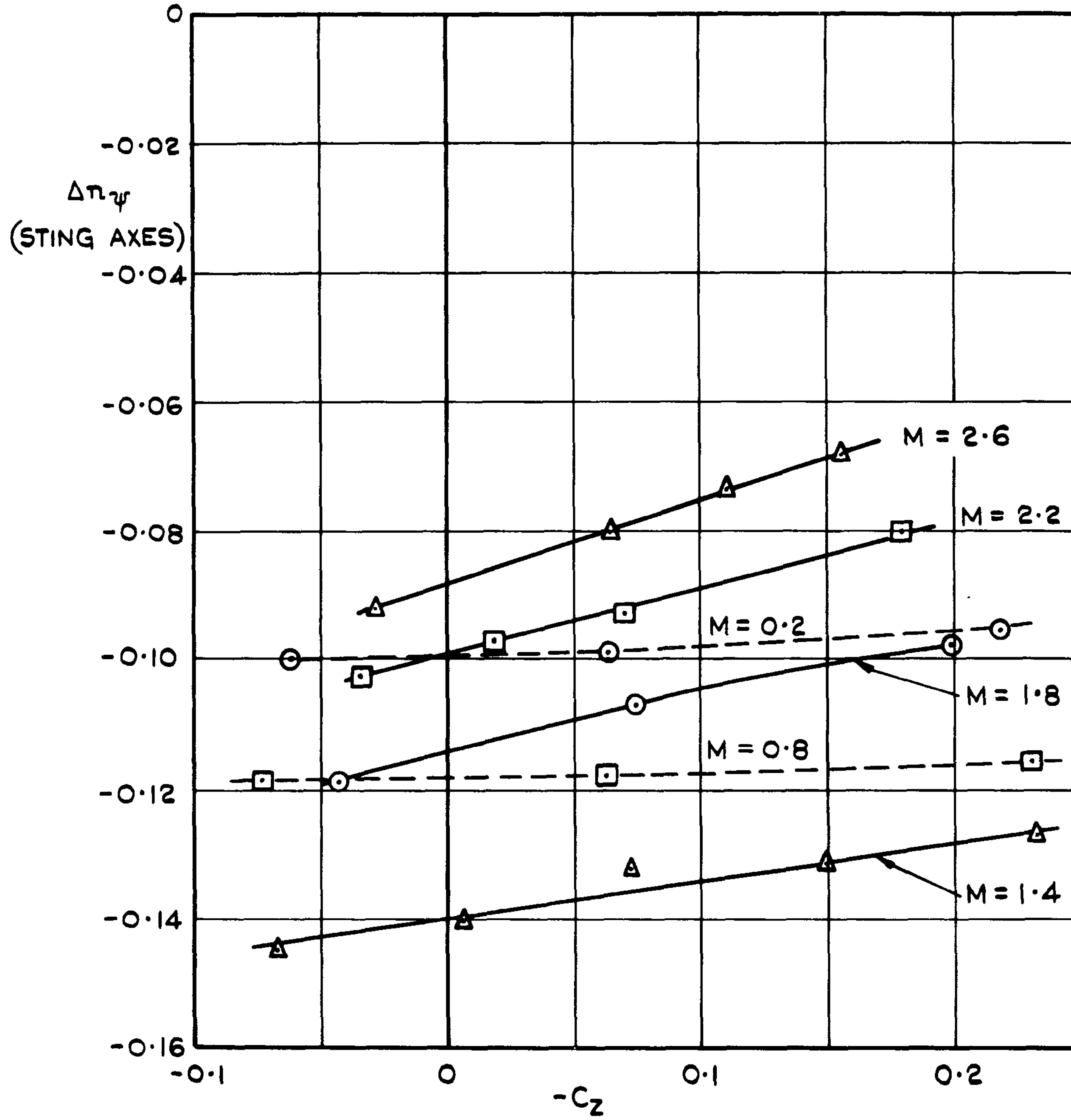


FIG. 22 STABILITY IN YAW.
FIN CONTRIBUTION, Δn_{ψ}

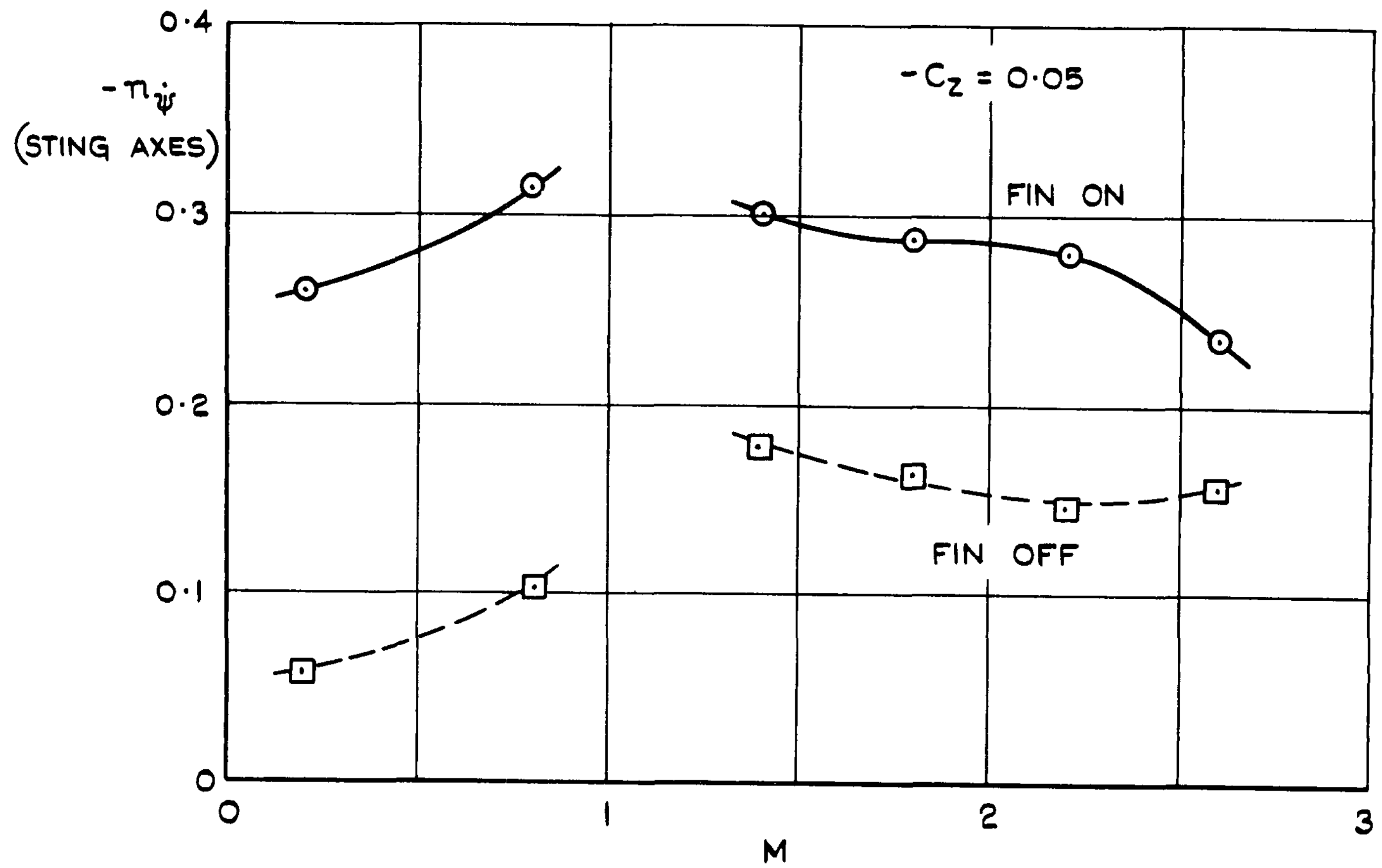


FIG. 23 DAMPING IN YAW, $-n_{\dot\psi}$. VARIATION WITH MACH NUMBER

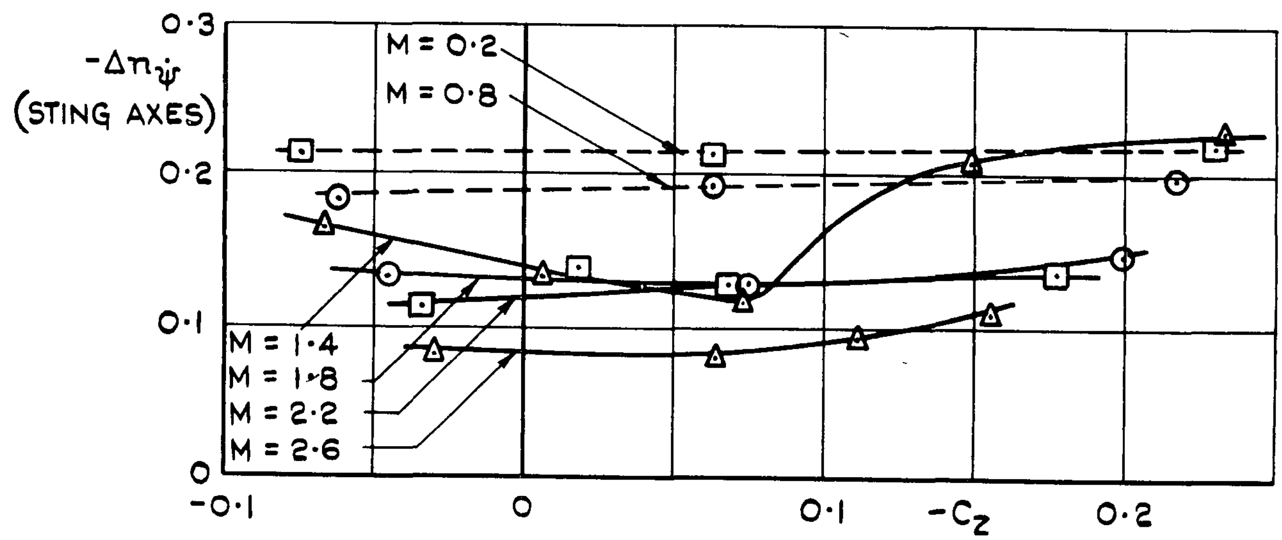


FIG. 24 DAMPING IN YAW. FIN CONTRIBUTION, $-\Delta n_{\dot\psi}$

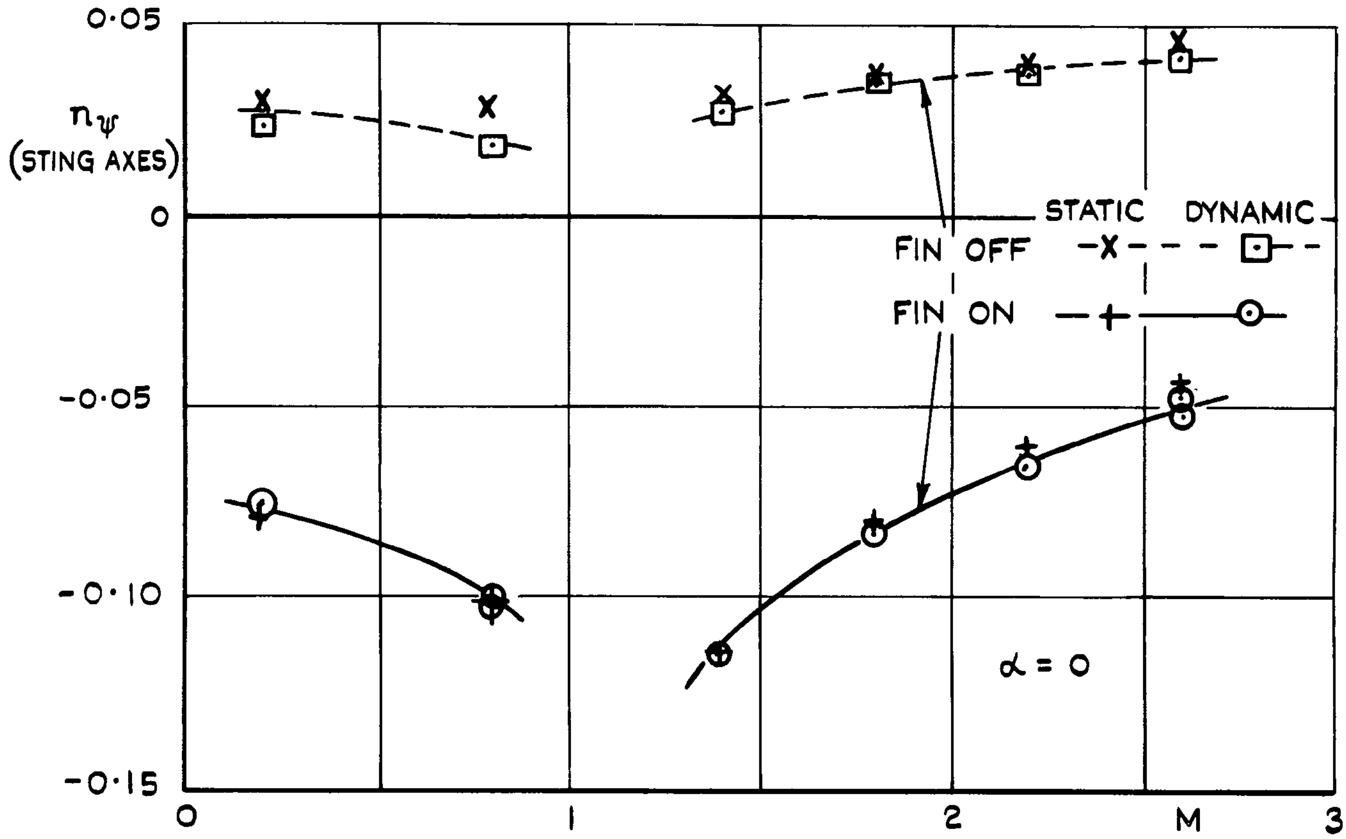


FIG. 25 STABILITY IN YAW, n_ψ. VARIATION WITH MACH NUMBER

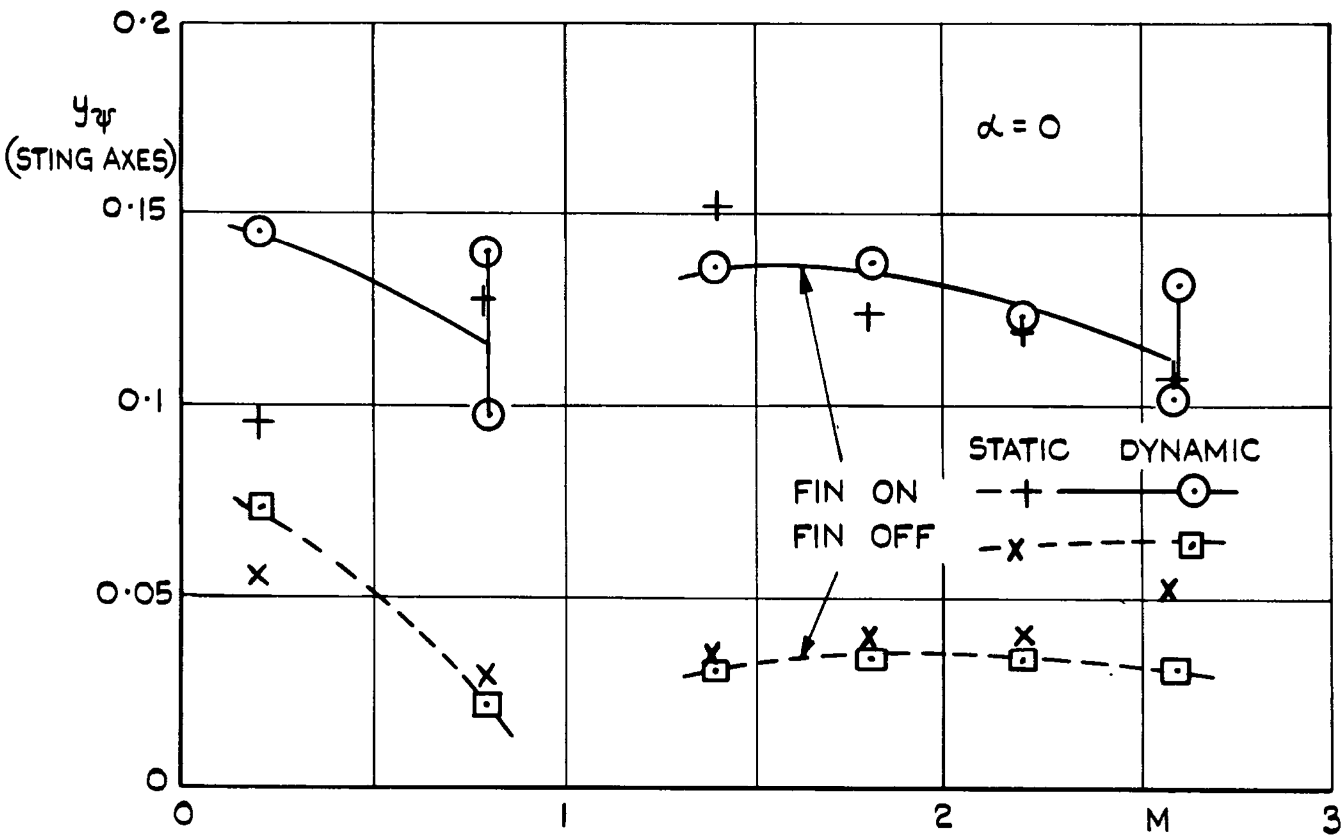


FIG. 26 CROSS DERIVATIVE, y_ψ. VARIATION WITH MACH NUMBER

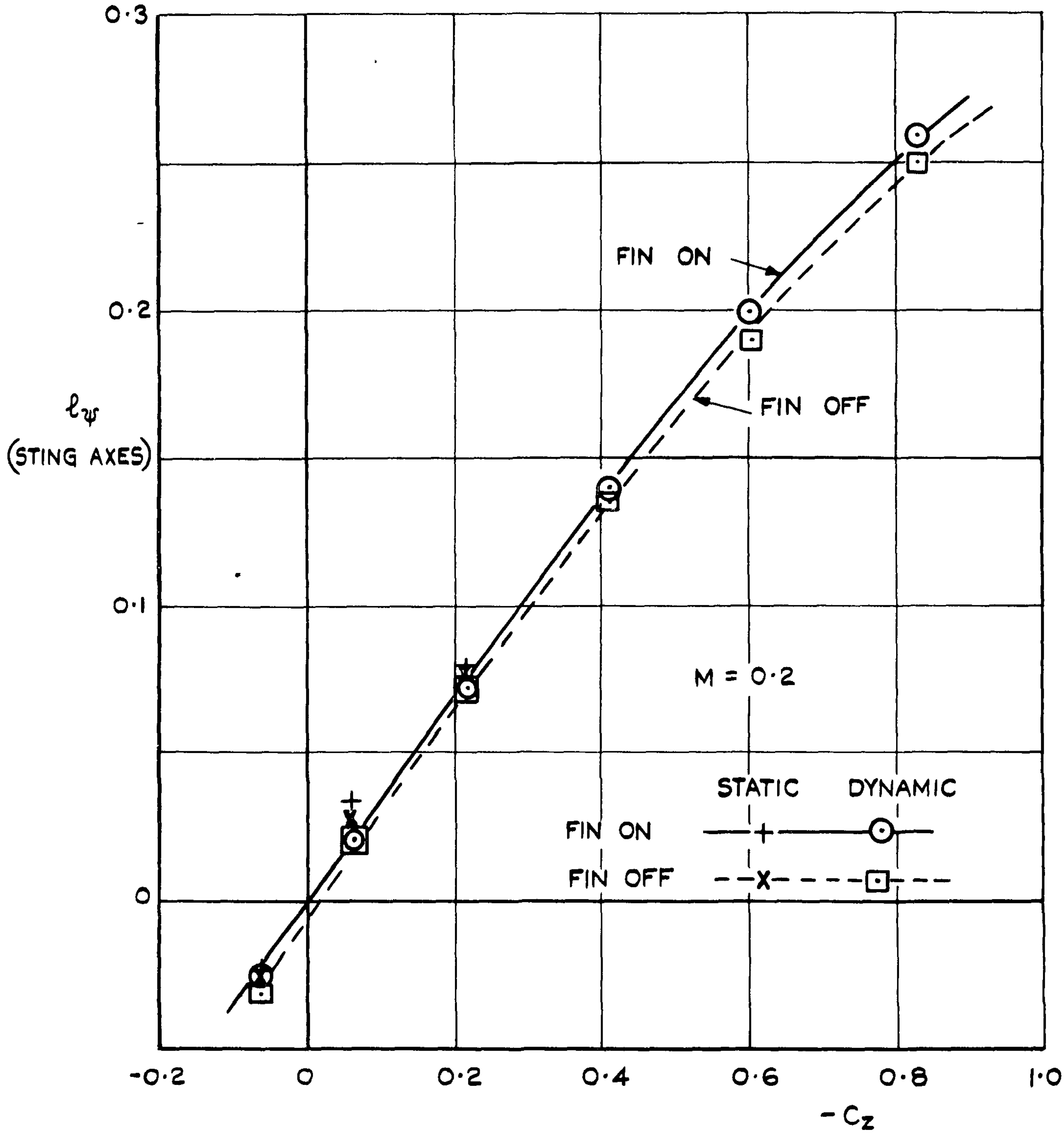


FIG. 27 CROSS DERIVATIVE, ℓ_ψ. M=0·2

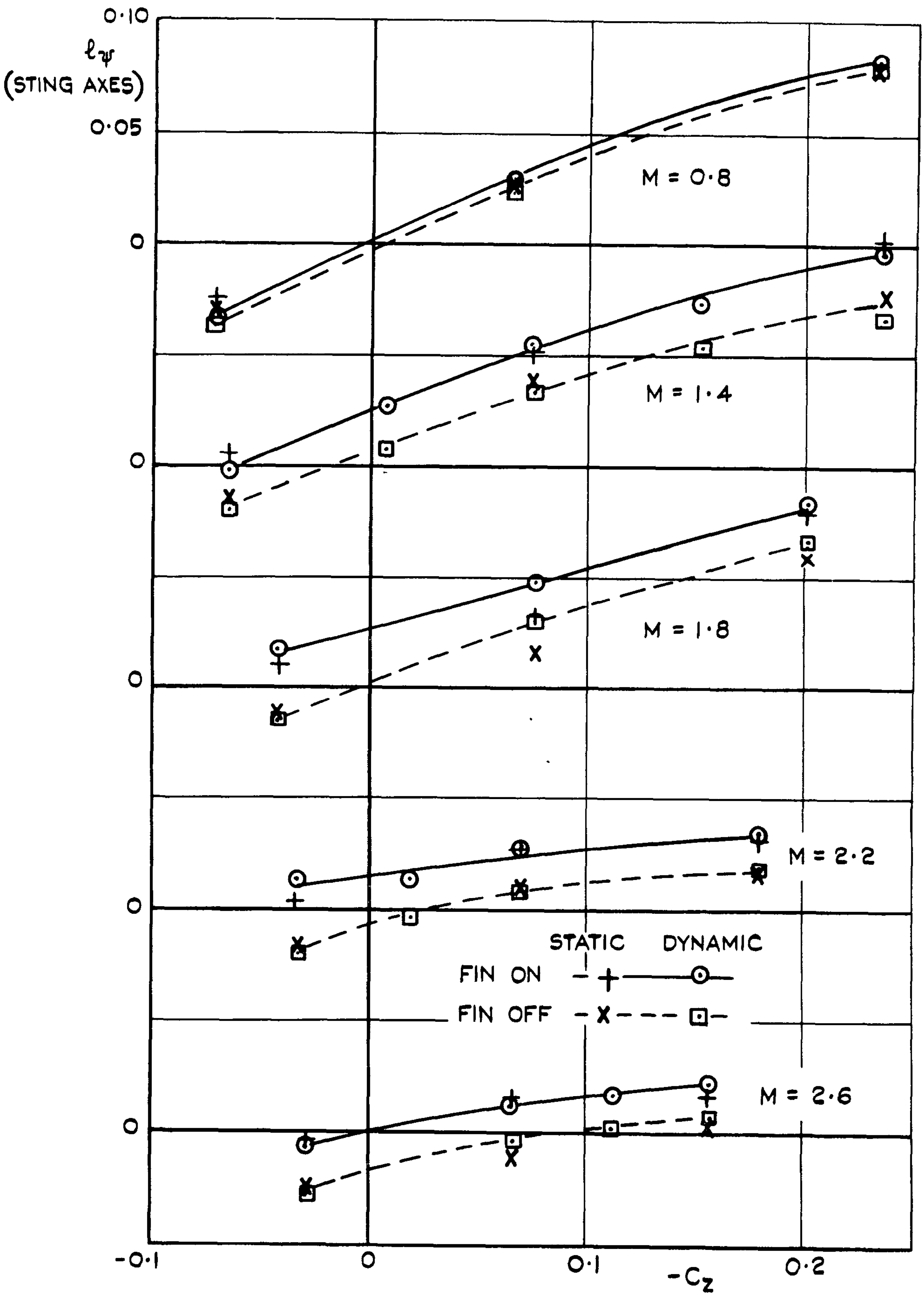


FIG. 28 CROSS DERIVATIVE, ℓ_ψ

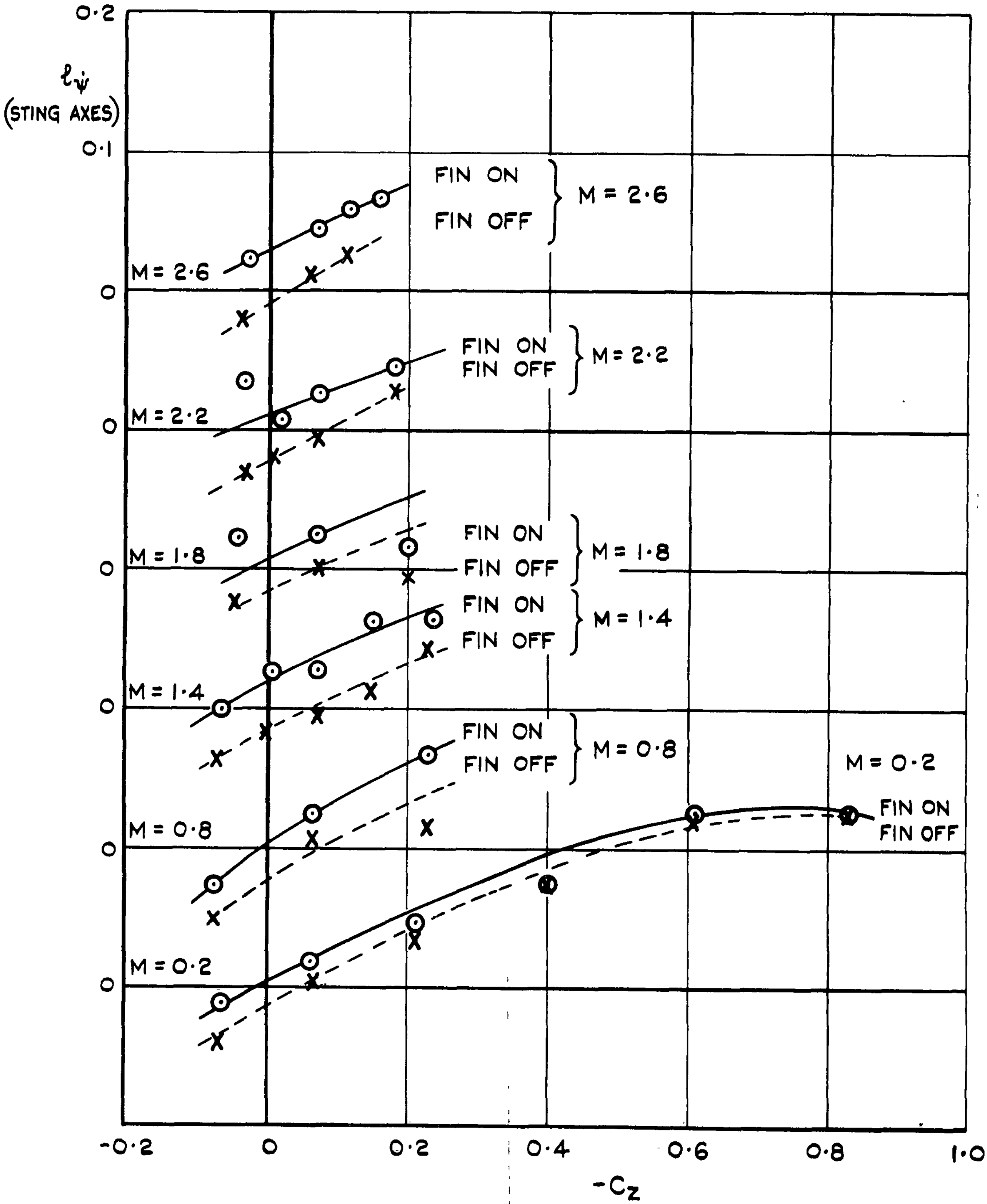


FIG. 29 CROSS DERIVATIVE $\ell_{\dot\psi}$

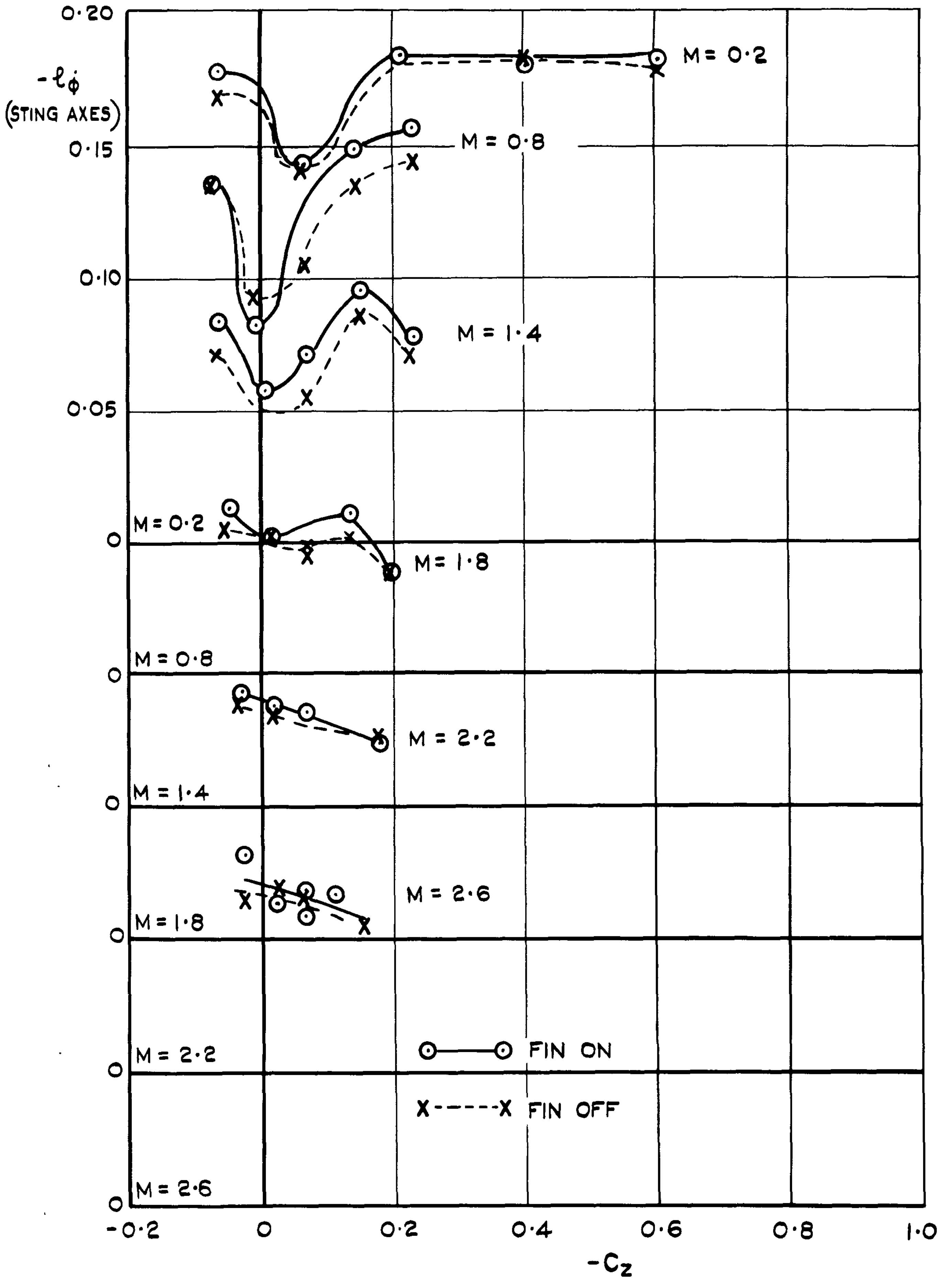


FIG. 30 DAMPING IN ROLL, $-\ell_{\dot{\phi}}$

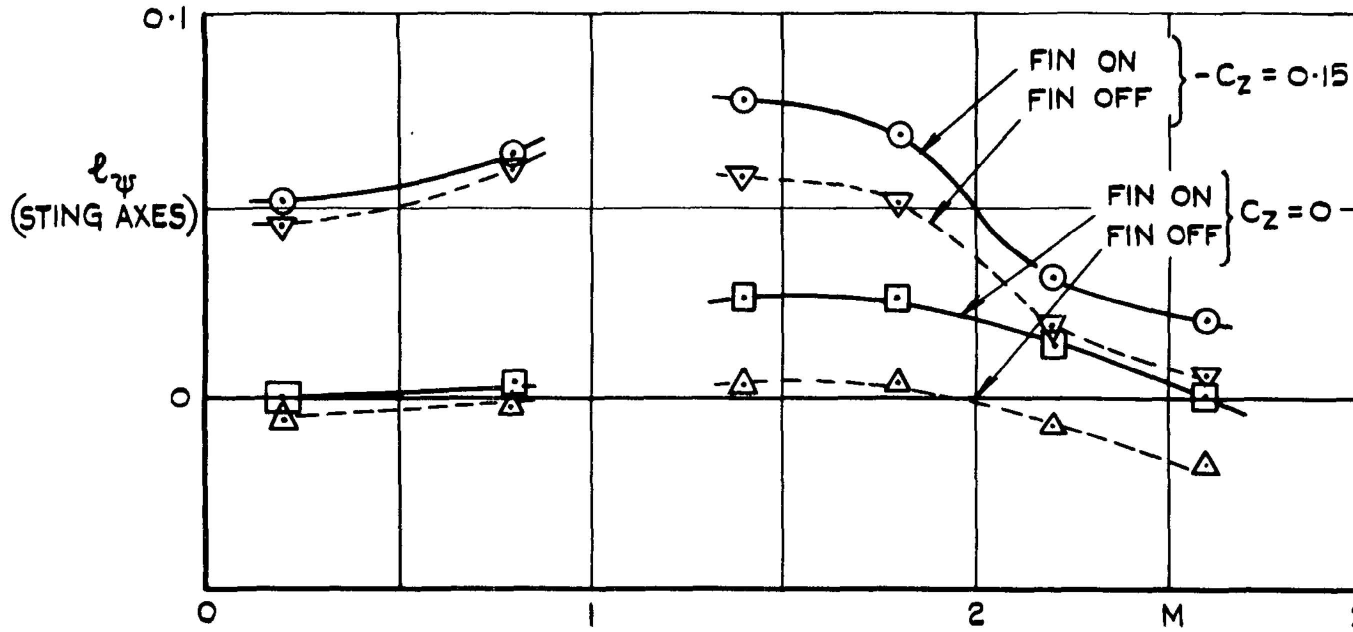


FIG. 31 CROSS DERIVATIVE, ℓ_ψ. VARIATION WITH MACH NUMBER

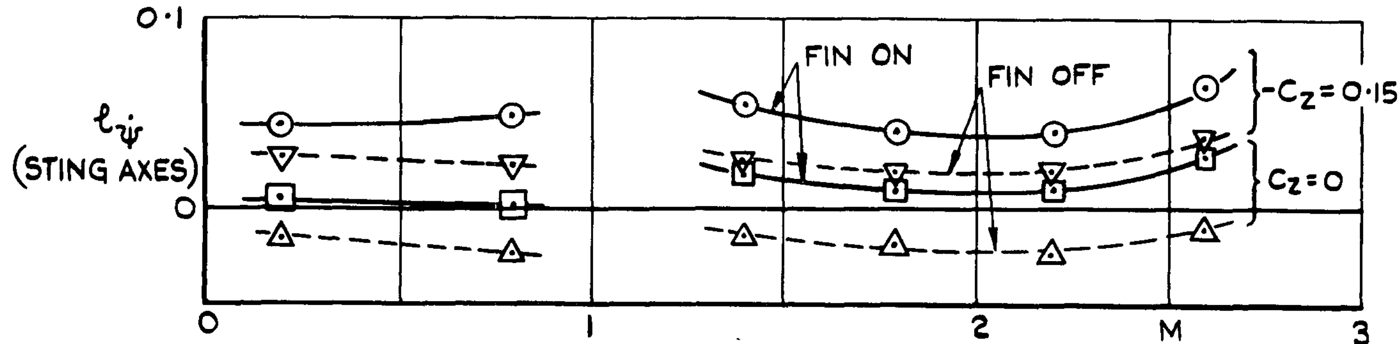


FIG. 32 CROSS DERIVATIVE, $\ell_{\dot\psi}$. VARIATION WITH MACH NUMBER

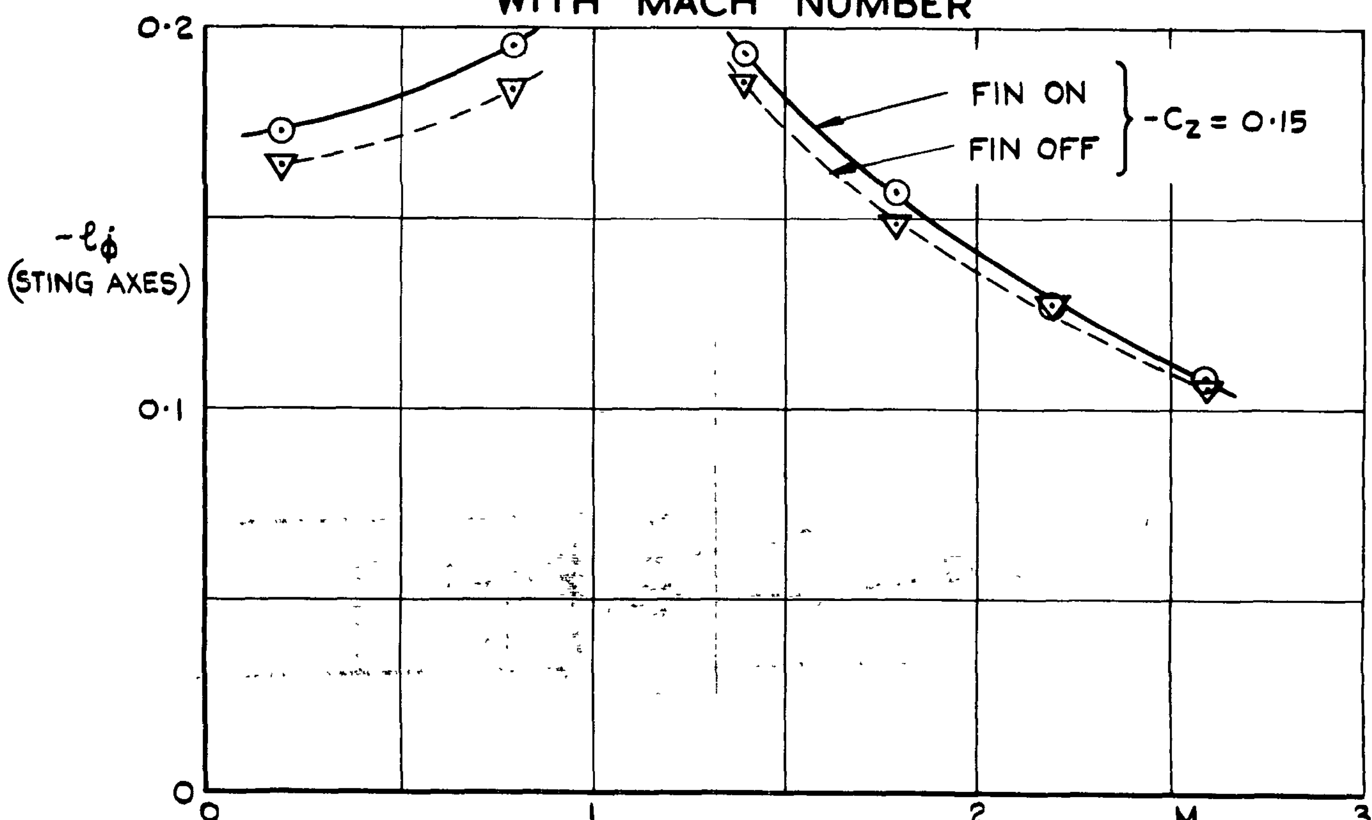


FIG.33 DAMPING IN ROLL, $-\ell_{\dot\phi}$. VARIATION WITH MACH NUMBER

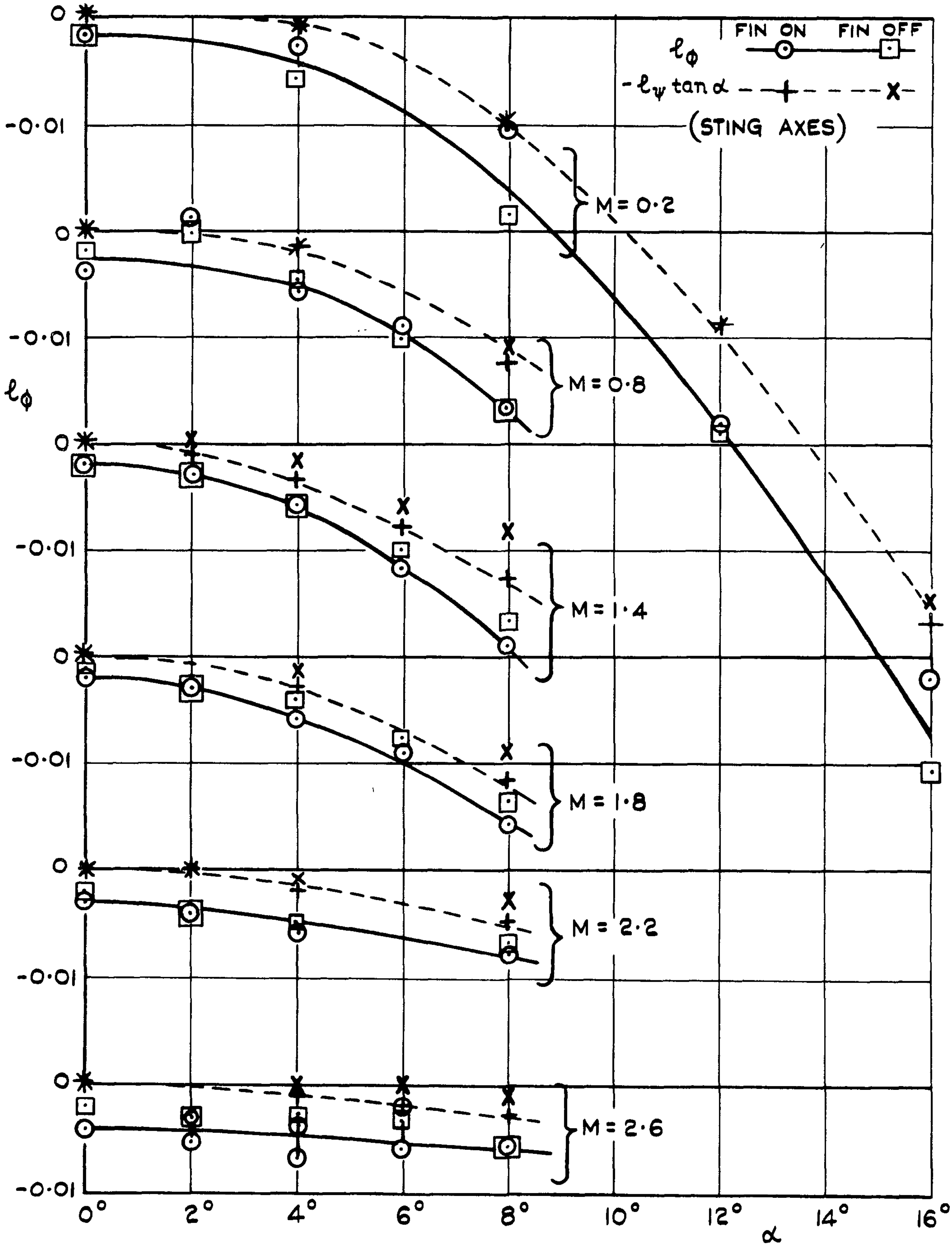


FIG. 34 COMPARISON OF ℓ_ϕ AND ℓ_ψ tan α

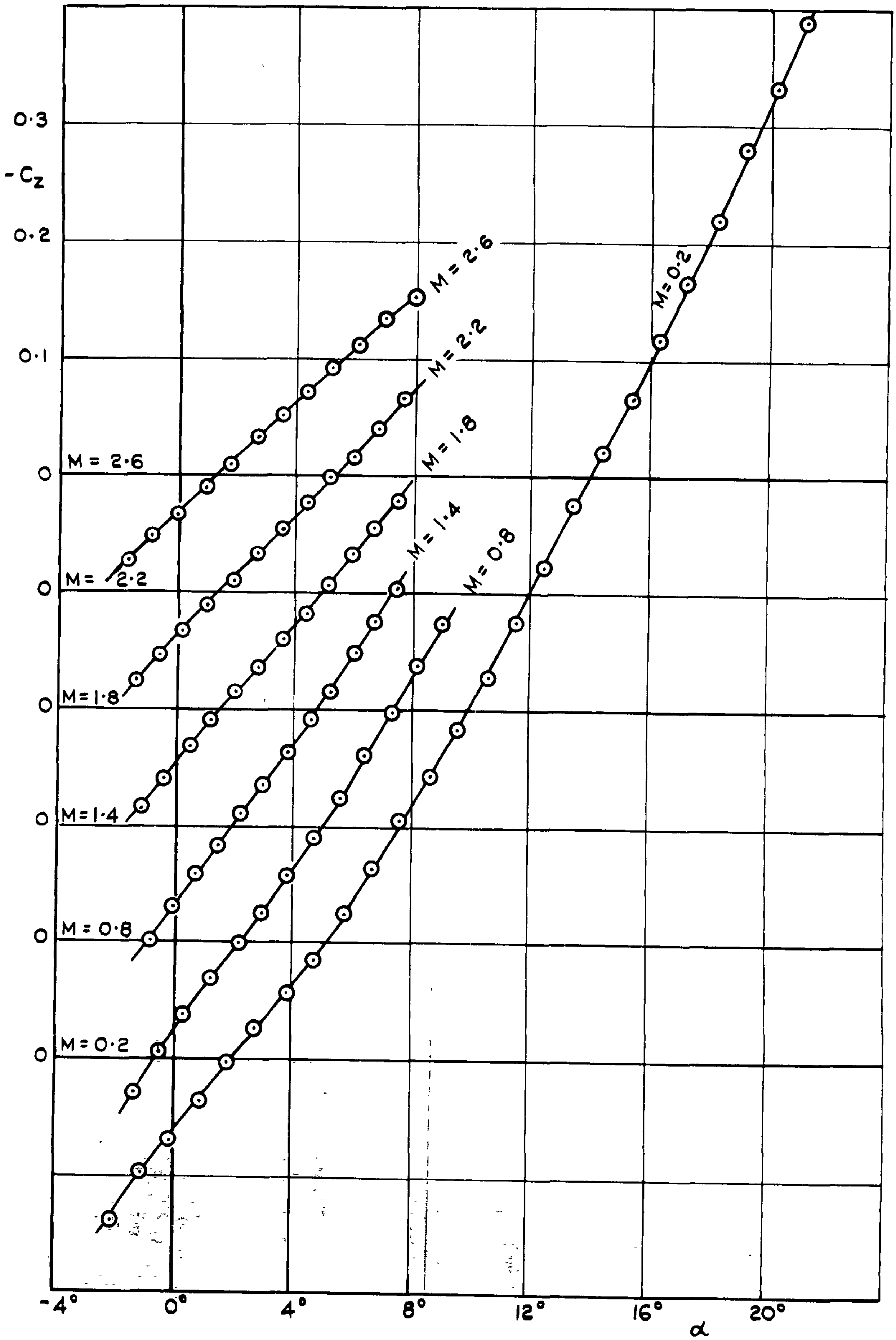


FIG. 35 STATIC NORMAL FORCE, -C_Z

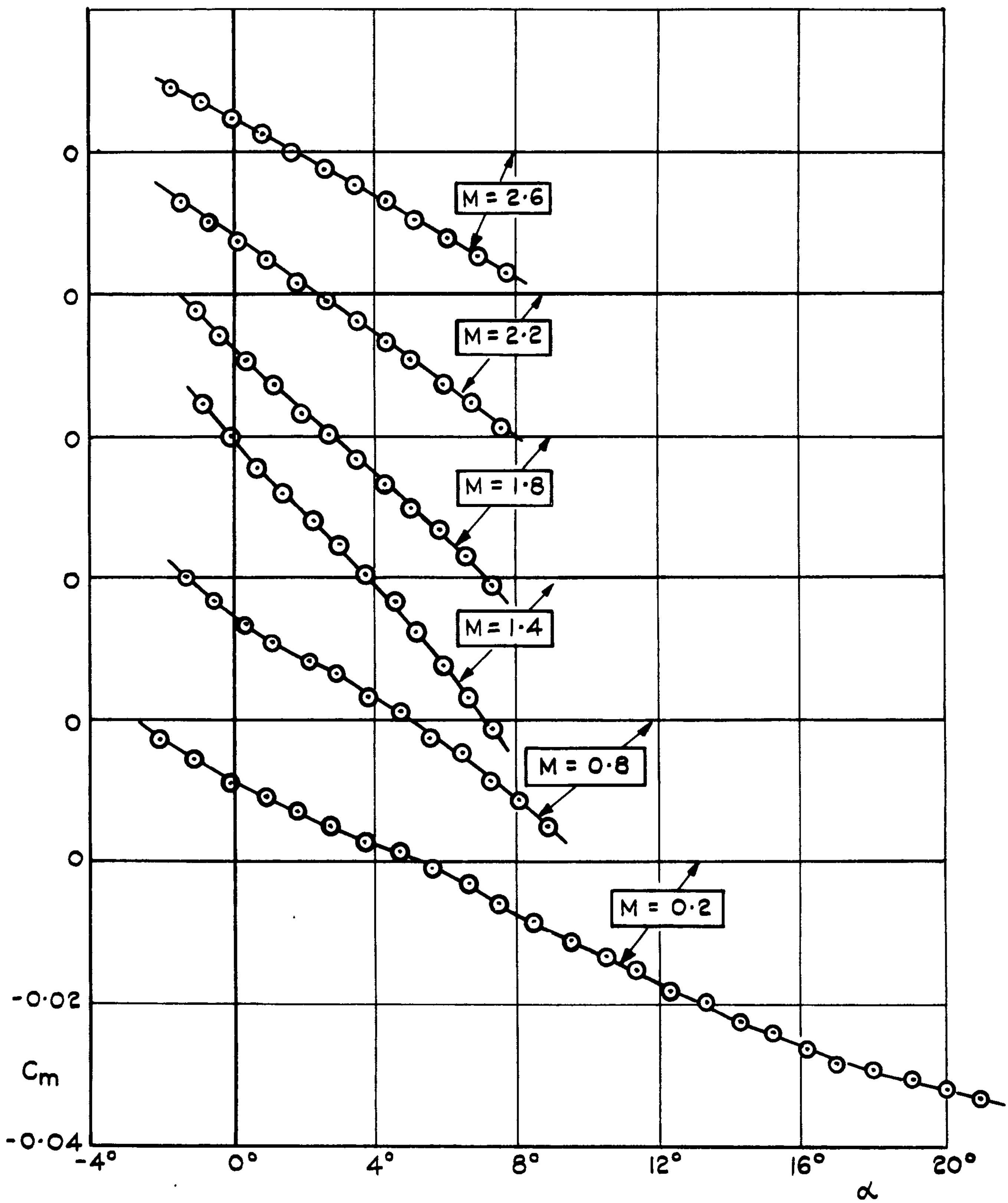


FIG. 36 STATIC PITCHING MOMENT, C_m

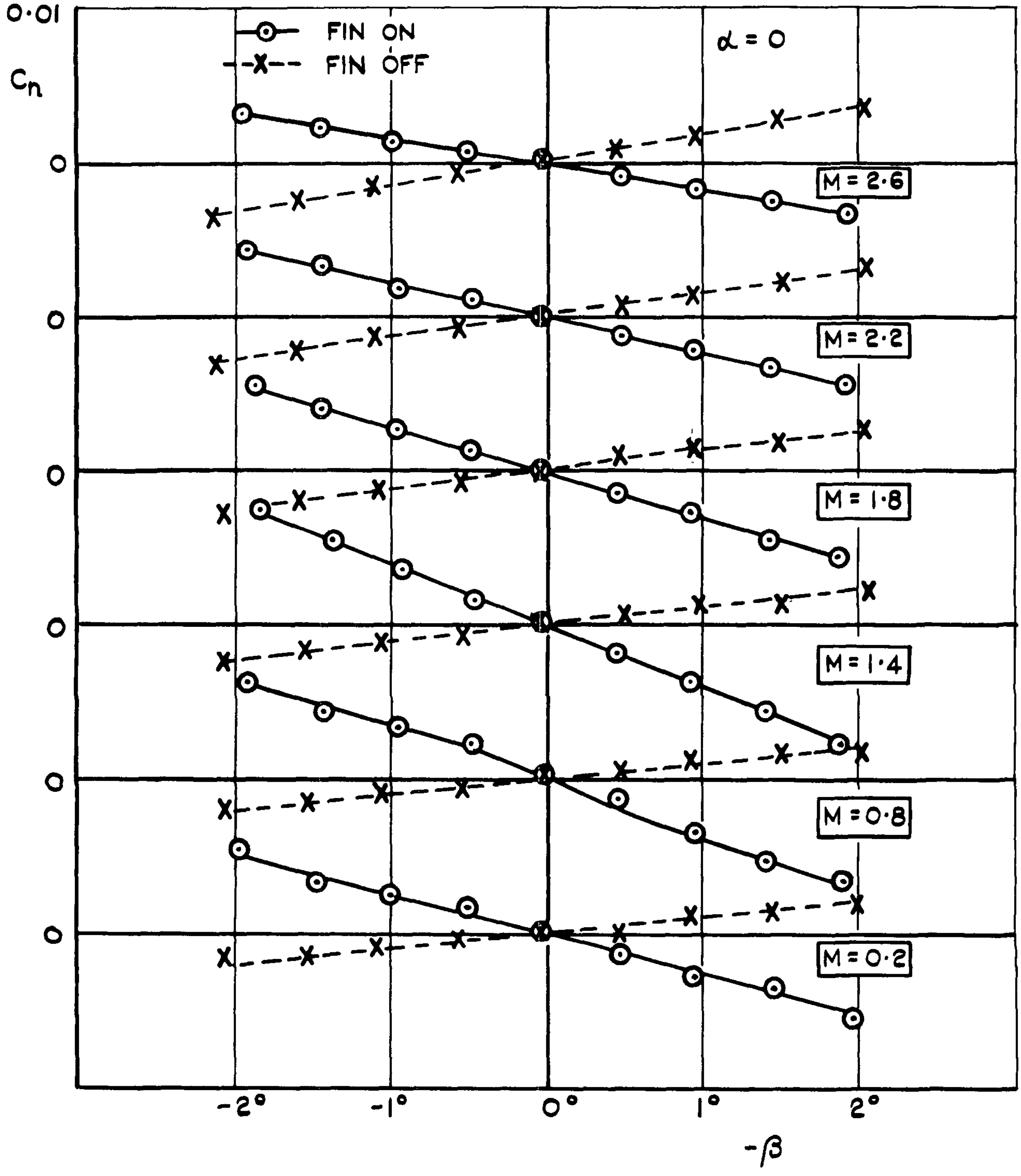


FIG. 37 STATIC YAWING MOMENT, C_n

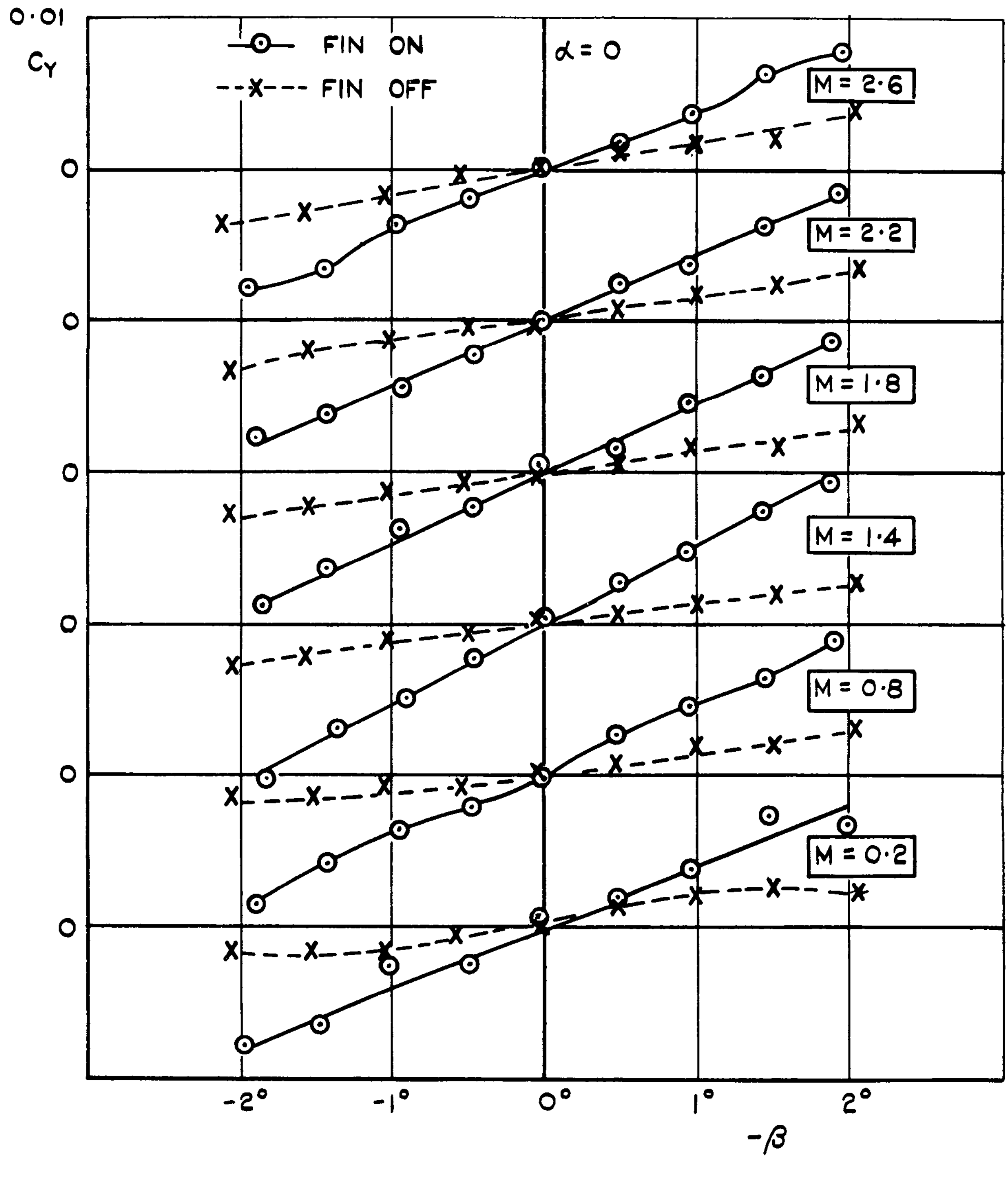


FIG. 38 STATIC SIDE FORCE, C_Y

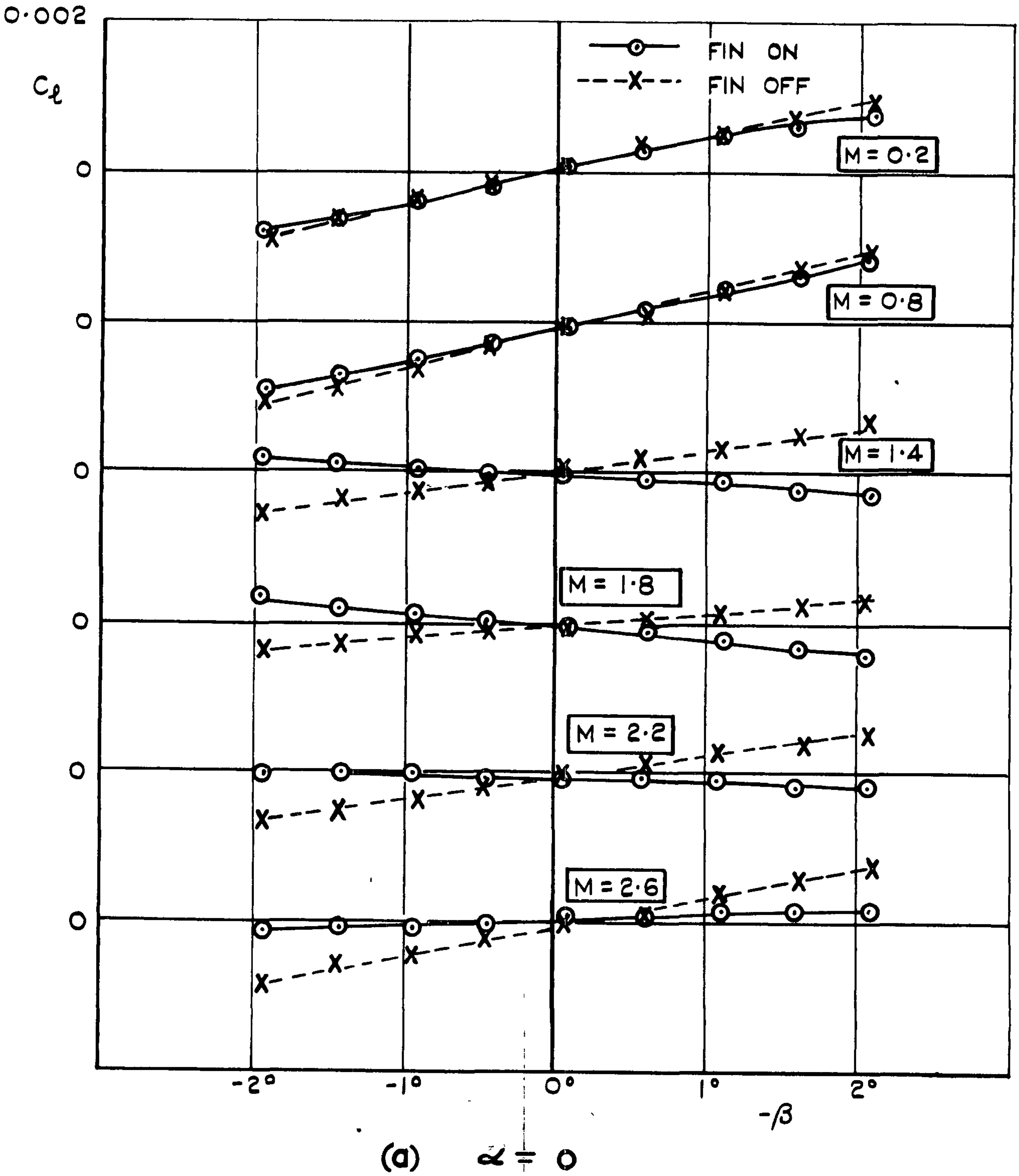
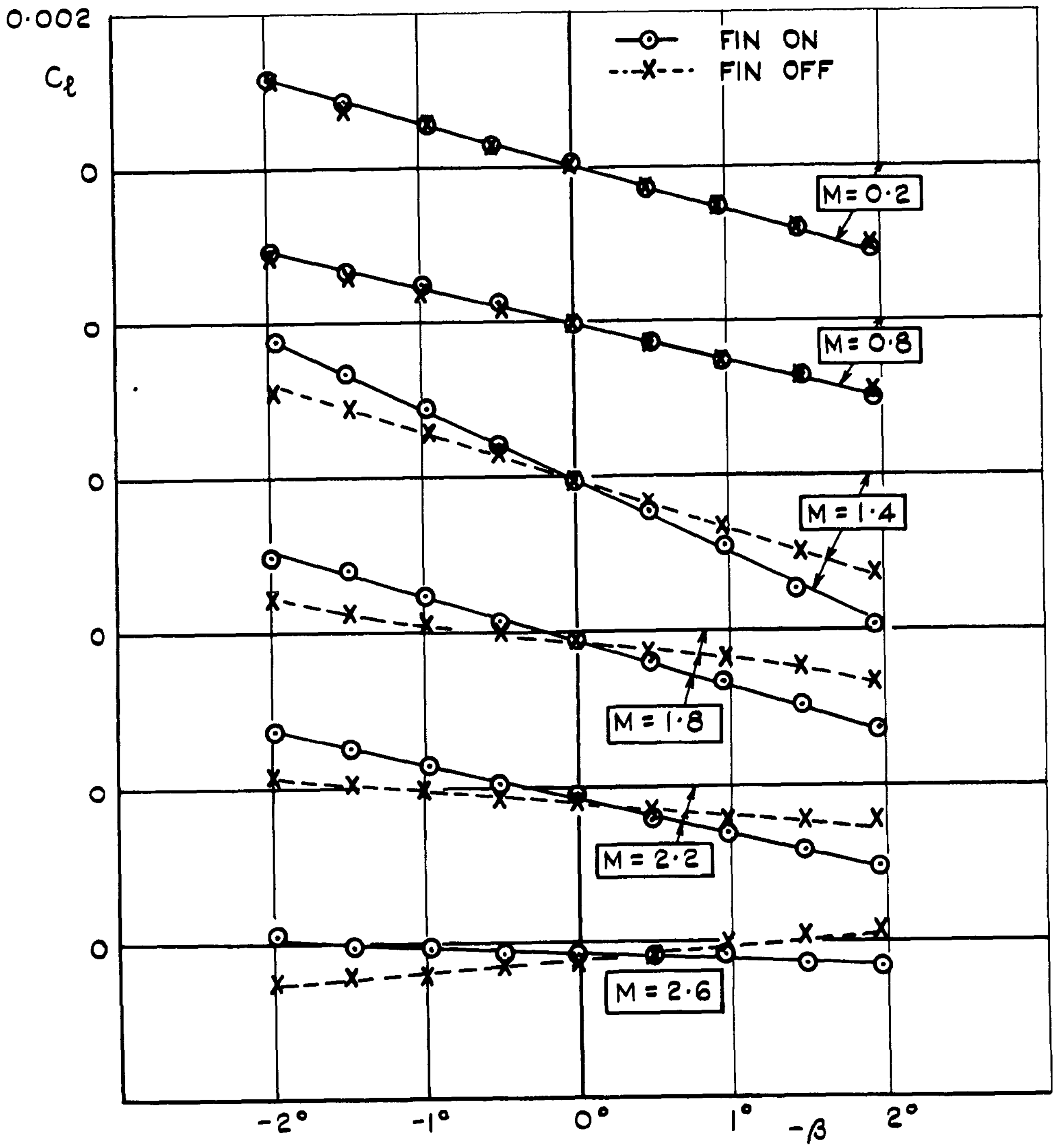


FIG.39(a) STATIC ROLLING MOMENT, C_ℓ



(b) $\alpha = 4°$

FIG. 39(b) STATIC ROLLING MOMENT, C_ℓ

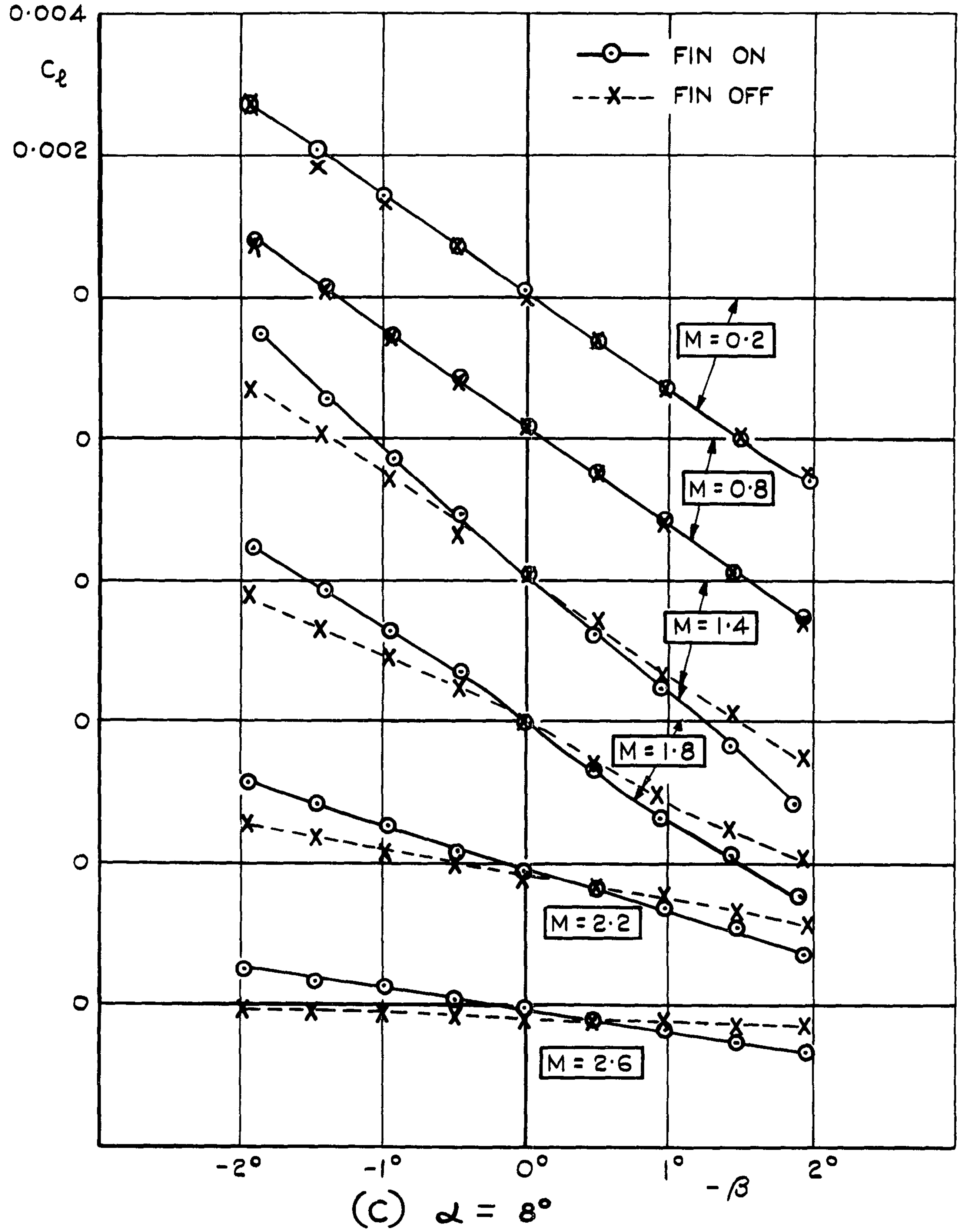


FIG.39(c) STATIC ROLLING MOMENT, C_ℓ

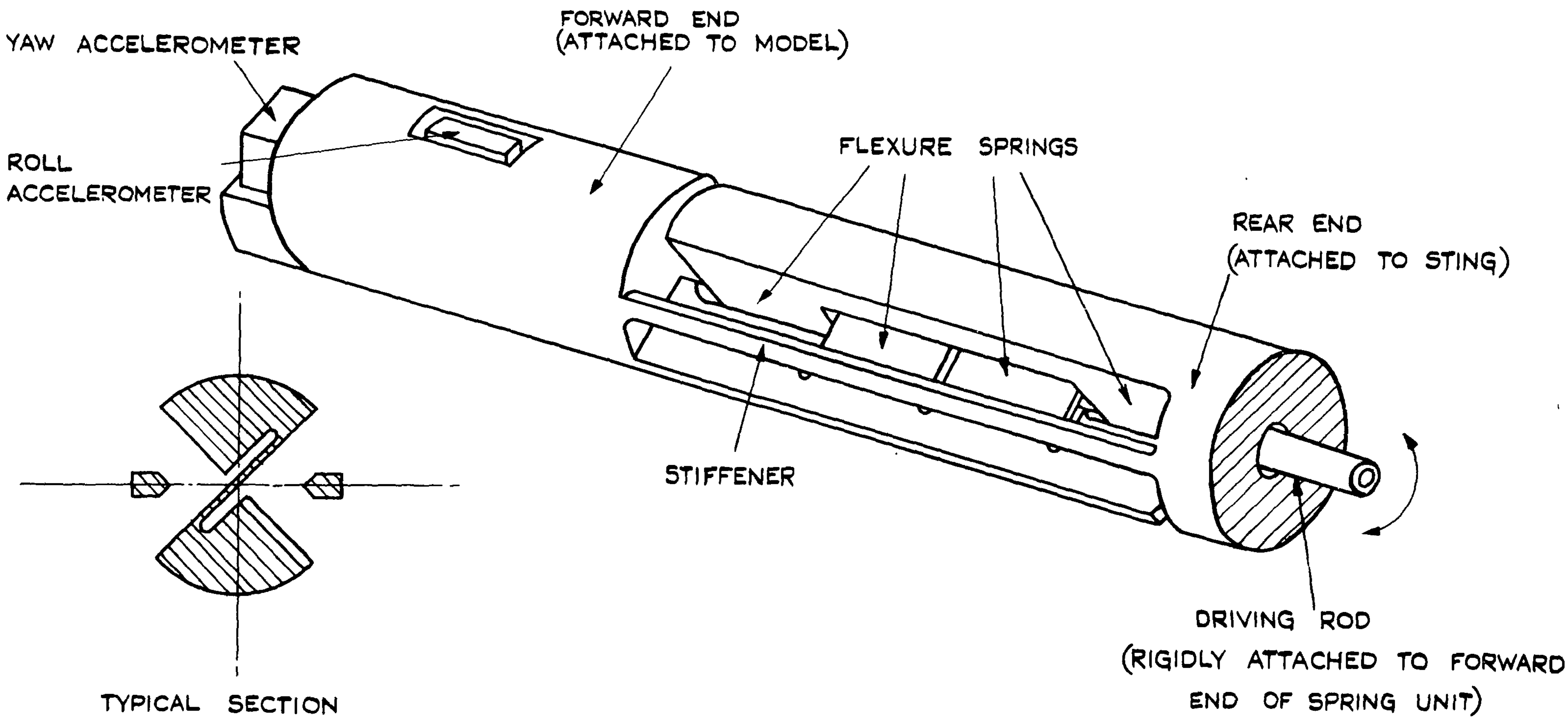


FIG. 40 ROLL SPRING UNIT

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J. S. Thompson
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MEASUREMENTS OF OSCILLATORY DERIVATIVES AT MACH NUMBERS UP TO 2.6 ON A MODEL OF A SUPERSONIC TRANSPORT DESIGN STUDY (BRISTOL TYPE 198)

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