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TECH. NOTE
AERO. 2811

ROYAL AIRCRAFT ESTABLISHMENT

(FARNBOROUGH)

TECHNICAL NOTE No. AERO. 2811

8 ft. x 6 ft. TRANSONIC WIND TUNNEL TESTS ON A 0.7 SCALE MODEL OF A 6½ in. UNGUIDED ROCKET

by

D. J. Kettle

FEBRUARY, 1962

MINISTRY OF AVIATION

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ROYAL AIRCRAFT ESTABLISHMENT

(FARNBOROUGH)

8' × 6' TRANSONIC WIND TUNNEL TESTS ON A 0.7 SCALE MODEL OF A $6\frac{1}{2}$" UNGUIDED ROCKET

by

D. J. Kettle

R.A.E. Ref: Aero H/5202

SUMMARY

Measurements of normal force and pitching moment have been made on a 0.7 scale model of a $6\frac{1}{2}$" unguided rocket at Mach numbers from 0.4 to 1.24 in the 8' × 6' transonic tunnel at Farnborough. The results are analysed to show the movement of centre of pressure on the rocket and the effect of modifications to the nose and tail, designed to improve the stability. The results show that none of the modifications was successful in preventing a sudden forward movement of the centre of pressure at a Mach number of 0.95, although the movement was reduced by a bourrelet fitted to the tail.

LIST OF CONTENTS

TABLE

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (CONTD)

1 INTRODUCTION

At the request of the A.R.D.E., transonic wind tunnel tests were made of a 0.7 scale model of a $6\frac{1}{2}$" unguided rocket. In particular it was required to investigate the movement of the centre of pressure with Mach number in the range $M = 0.4$ to 1.24, and the effect of modifications designed to improve the stability of the rocket. Two types of nose spike were tested, each with and without a bourrelet attached to the tail of the rocket; these modifications were intended to maintain a rearward position of centre of pressure as far as possible while having certain practical advantages of storing and launching compared with the more usual arrangement of tail fins.

In this note the results of normal force and pitching moment measurements on four configurations of the rocket are discussed.

2 DESCRIPTION OF MODEL AND TESTS

The model, which was made to 0.7 scale, was manufactured from magnesium alloy. The various arrangements tested are shown in Fig.1, the basic body being the same in all cases. Two types of nose spike were tested which were identical apart from a difference in the angle of the conical portion as indicated. Each was tested with and without a base plate (bourrelet) attached to the rear end of the rocket. A normal force and pitching moment strain gauge balance was incorporated in a sting which supported the model internally from the rear.

The tests were made over a range of incidences from $-2\frac{1}{2}^{\circ}$ to 10° and a range of Mach numbers from 0.4 to 1.24 at a Reynolds Number of 2×10^{6} per foot. The tests were made in the R.A.E. 8' × 6' transonic tunnel during May 1959.

3 PRESENTATION OF RESULTS

Figs.2 to 5 show normal force plotted against incidence over the test Mach number range. Normal force (C_z) is positive downwards and ($-C_z$) has been plotted so as to give positive normal force at positive incidence. The pitching moments, shown in Figs.6 to 9, were measured about a point 3.16 diameters aft of the nose of the spike and are positive in the nose-up direction; stability is therefore denoted by negative pitching moments at positive incidences and vice versa. The forces and moments have been non-dimensionalised by using as reference area and length, the model maximum cross-sectional area (0.1129 sq ft) and maximum diameter, excluding bourrelet, (0.379 ft) respectively. The model incidences have been corrected for pitch of the tunnel stream and for deflection of the sting under load. It will be noted however that the curves in Figs.2 to 5 still have a small non-zero value of C_z at the origin, possibly due to model misalignment. The position of the centre of pressure is shown plotted in Figs.10 to 13 against ($-C_z$) and in order to avoid the errors arising at very small values of C_m and C_z, the centre of pressure position at zero normal force has been obtained by measuring the slope of the pitching moment curves for that case only.

In accordance with present procedure in the 8' × 6' transonic tunnel, no corrections have been applied to the results on account of tunnel constraint effects. While these are largely unknown for such a bluff shape as the present model, they would not be expected to be very significant except in the speed range just about $M = 1$ where reflections of the bow shock from the tunnel walls, strike the model.

4 DISCUSSION OF RESULTS

4.1 Normal force

Each of the four configurations tested appears to have similar normal force characteristics as shown by Figs.2 to 5. At incidences below about 5° the curves are linear at all Mach numbers and for incidences between about 5° and 10° there is a gradual increase of normal force slope. A further feature shown in broken line in Figs.3 and 4 for example, is the small step in the curves which occurs at progressively higher incidences and Mach numbers above 0.95. It is suggested that the flow, which at low incidences and Mach numbers consists essentially of vortices shed from each side of the rocket, reattaches at higher incidences and Mach numbers by means of a supersonic expansion terminated by a shock. The step in the normal force curves would thus appear to occur at the point of reattachment. The effect is also discernible in the pitching moment curves and is referred to in the next paragraph. Fig.6 shows values of normal force slope plotted against Mach number for the four configurations tested. The curves show a rise in the value of $dC_z/d\alpha$ at a Mach number of about 0.9 to a value which is roughly constant at supersonic speeds. The general differences between the four curves are probably not significant.

4.2 Pitching moment

The main feature shown by Figs.7 to 10 is the rapid change in pitching moment slope at $M = 0.95$. The change was so abrupt that two completely different pitching moment curves were obtained at the same speed, the stable one when the speed was approached carefully from below and the unstable one when it was approached carefully from above. In a typical case (30° nose spike and bourrelet, Fig.10) the unstable pitching moment curve at $M = 0.95$ joins the stable curve at $(-C_z) = 0.2$ and this is a feature of many of the results at higher Mach numbers. As far as can be judged the increase of stability is always accompanied by an increase of lift. This was referred to in para. 4.1 where it was suggested that the increase of lift (and stability) might be linked with flow reattachment aft of the bluff nose. The supersonic expansion region would be terminated by a shock and give a better pressure recovery towards the rear of the body. This would reduce the lift at the rear of the body and hence give a nose-up pitching moment. Figs.11 to 14 show the corresponding movements of centre of pressure for each of the four configurations. In all cases the centre of pressure is aft of the C.G. for Mach numbers up to 0.9 but is seen to move slowly forward with incidence; this result is in general agreement with the results of Ref.1. For Mach numbers of 0.95 and above, the centre of pressure is forward of the C.G., the change occurring abruptly at $M = 0.95$.

Fig.15 shows the movement of the centre of pressure with Mach number at zero incidence and indicates the slight advantage of the 30° nose spike at subsonic speeds compared with the 10° nose spike. The main advantage shown appears to be that due to adding the bourrelet (with both 10° and 30° nose spikes) which gives a centre of pressure position about 1 calibre further aft compared with no bourrelet.

5 CONCLUSIONS

The main conclusions to be drawn from the results are summarised as follows:

(i) None of the modifications tested was successful in preventing a sudden forward movement of the centre of pressure occurring at a Mach number of 0.95 and zero incidence.

(ii) At Mach numbers up to 0.9 the centre of pressure is aft of the C.G. in all cases at zero incidence.

(iii) Compared with the nose spike, the bourrelet shows to better advantage in reducing the forward movement of centre of pressure at speeds above M = 0.95.

REFERENCE

No.	Author(s)	Title, etc.
1	Potter, J.L., Shapiro, N.M., Murphree, W.D.	Normal force distributions on right circular cylinders in subsonic and supersonic flows. U.S.A. Ordnance Missile Lab. Report 2R4F, P.60022. December, 1954.

ATTACHED:-

Table 1
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TABLE 1

Principal details of model

Scale:- 0.7 full scale

Rocket length with nose spike (10° and 30°)	28 in.
Rocket length with nose spike and bourrelet	29.05 in.
Length of nose spike (including conical portion)	5.0 in.
Maximum diameter of body ($\equiv$ 1 calibre)	4.55 in.
Diameter of bourrelet	5.01 in.
Pitching moment reference axis aft of nose	14.38 in. ($\equiv$ 3.16 calibres)

FIG. 1

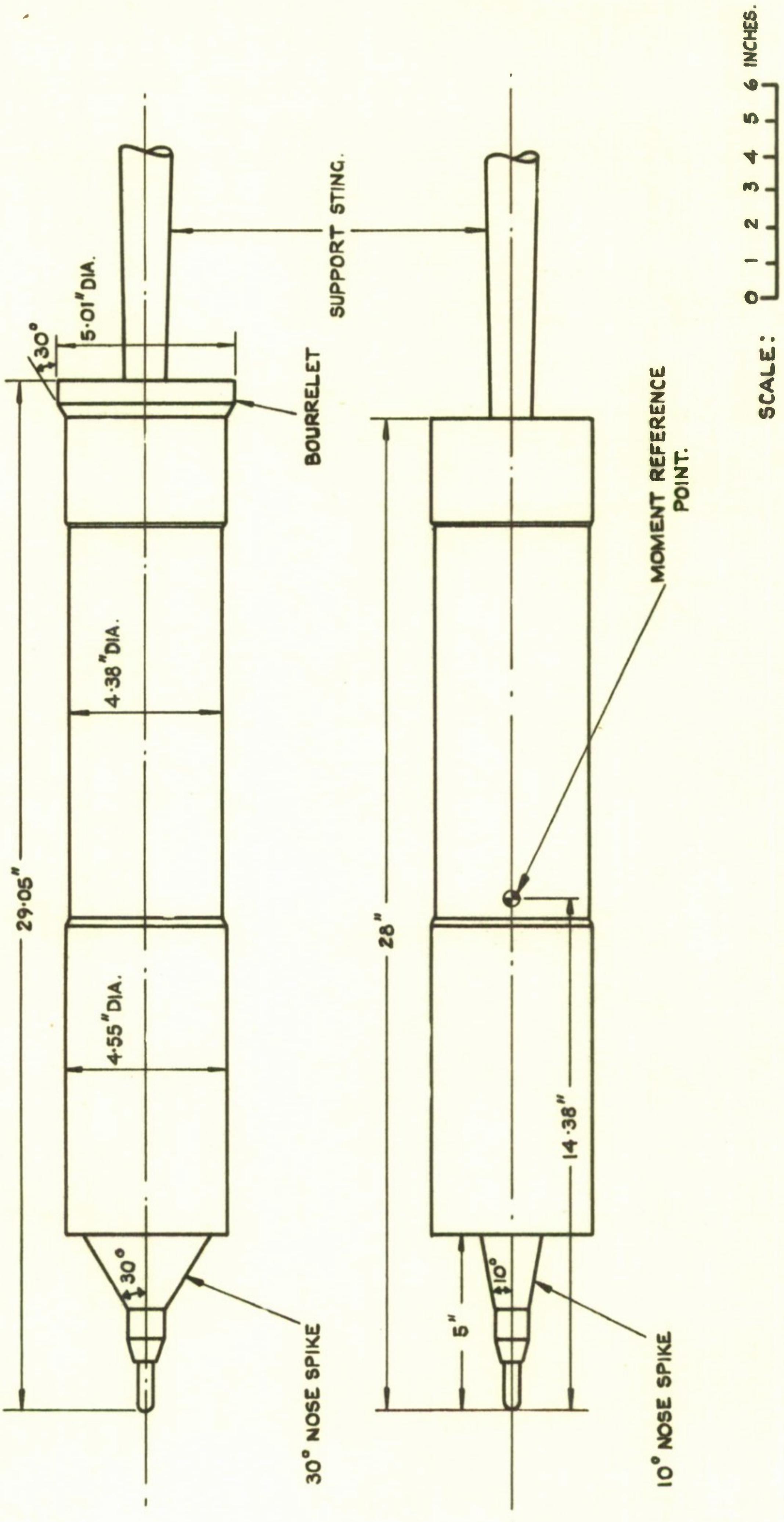

FIG. 1. GENERAL ARRANGEMENT OF MODEL.

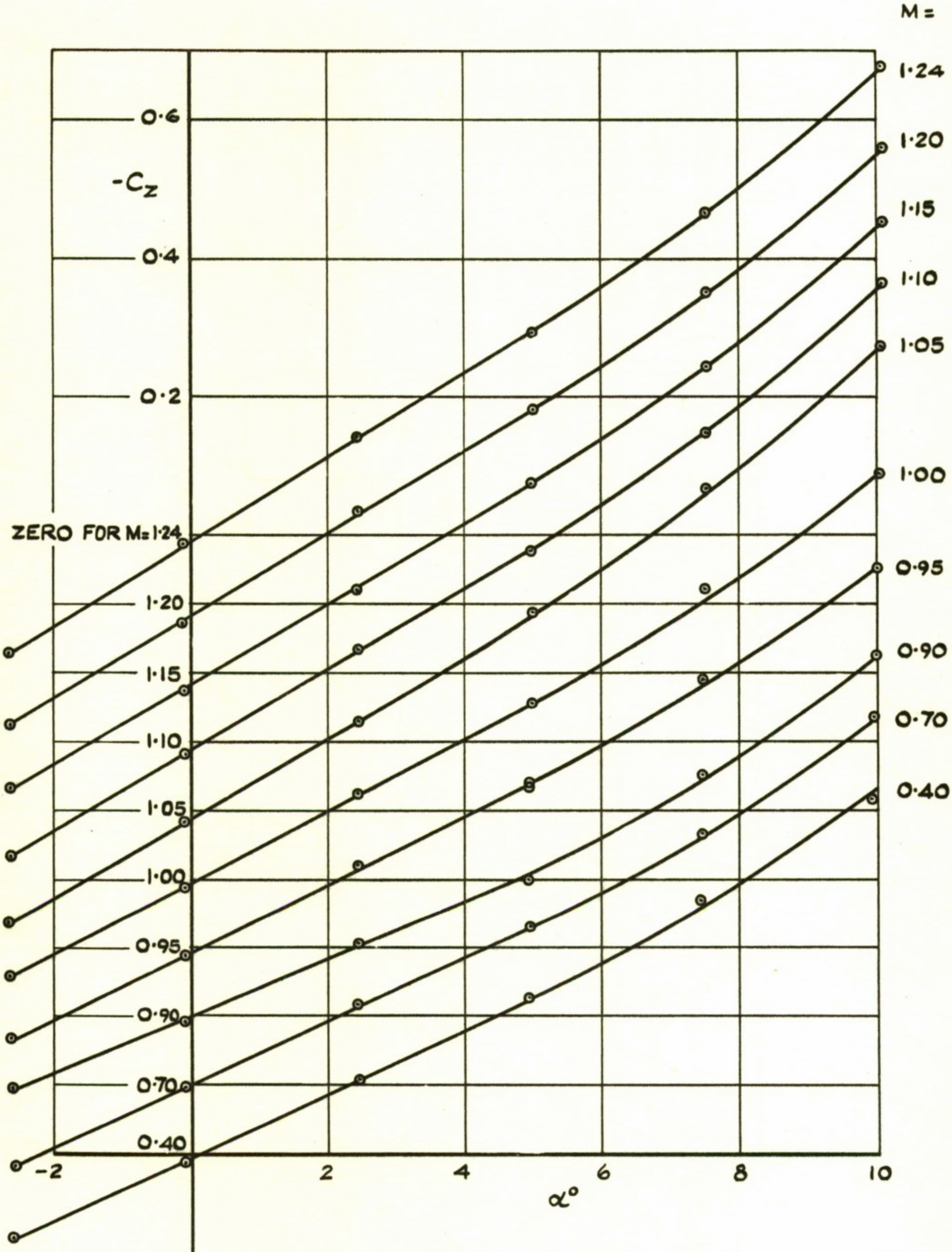

FIG. 2. $-C_z$ VS α AT VARIOUS MACH NUMBERS

BODY + 30° NOSE SPIKE

42005.S.

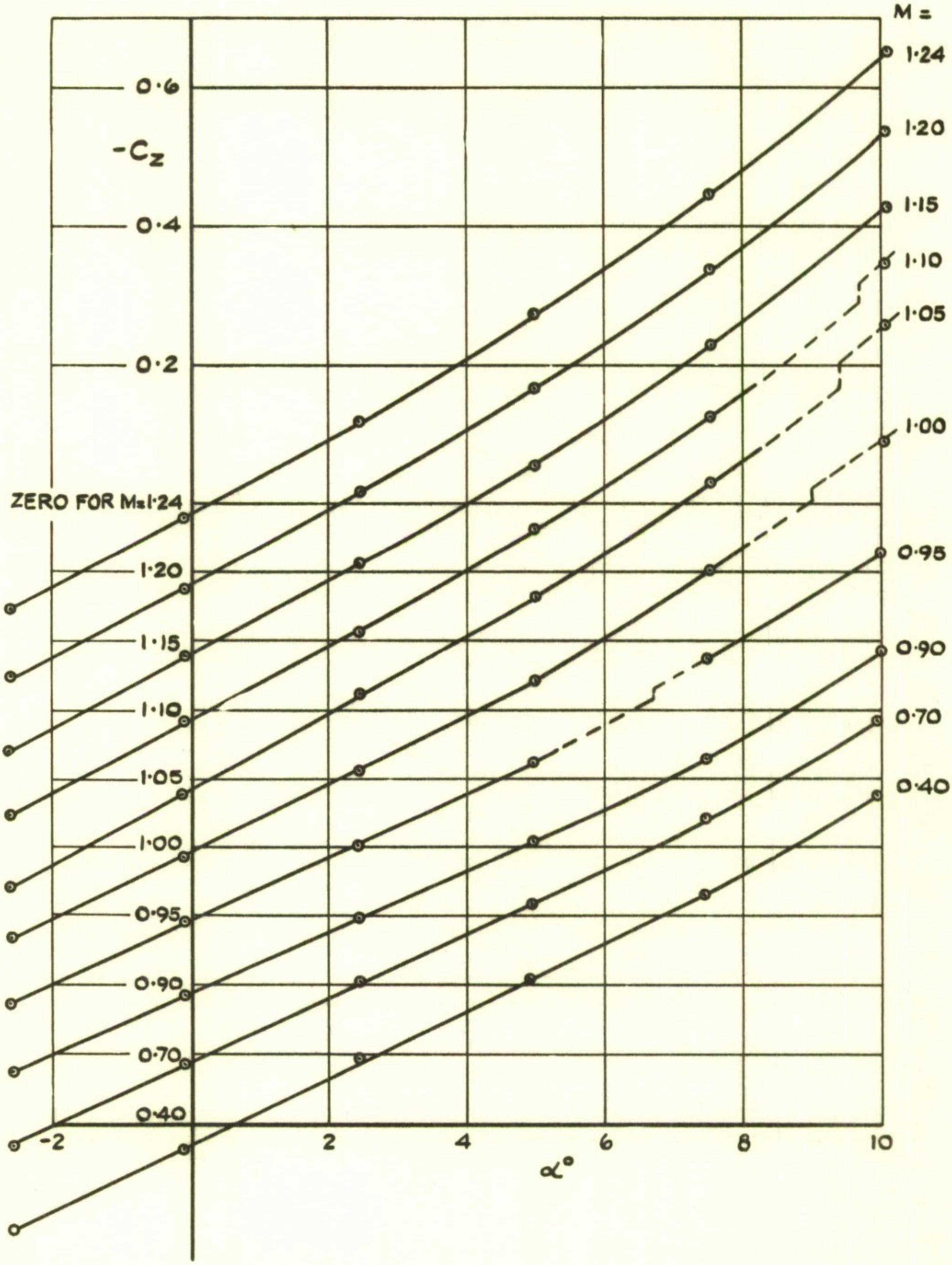

FIG. 3. $-C_z$ vs α AT VARIOUS MACH NUMBERS

BODY + 10° NOSE SPIKE

FIG. 4

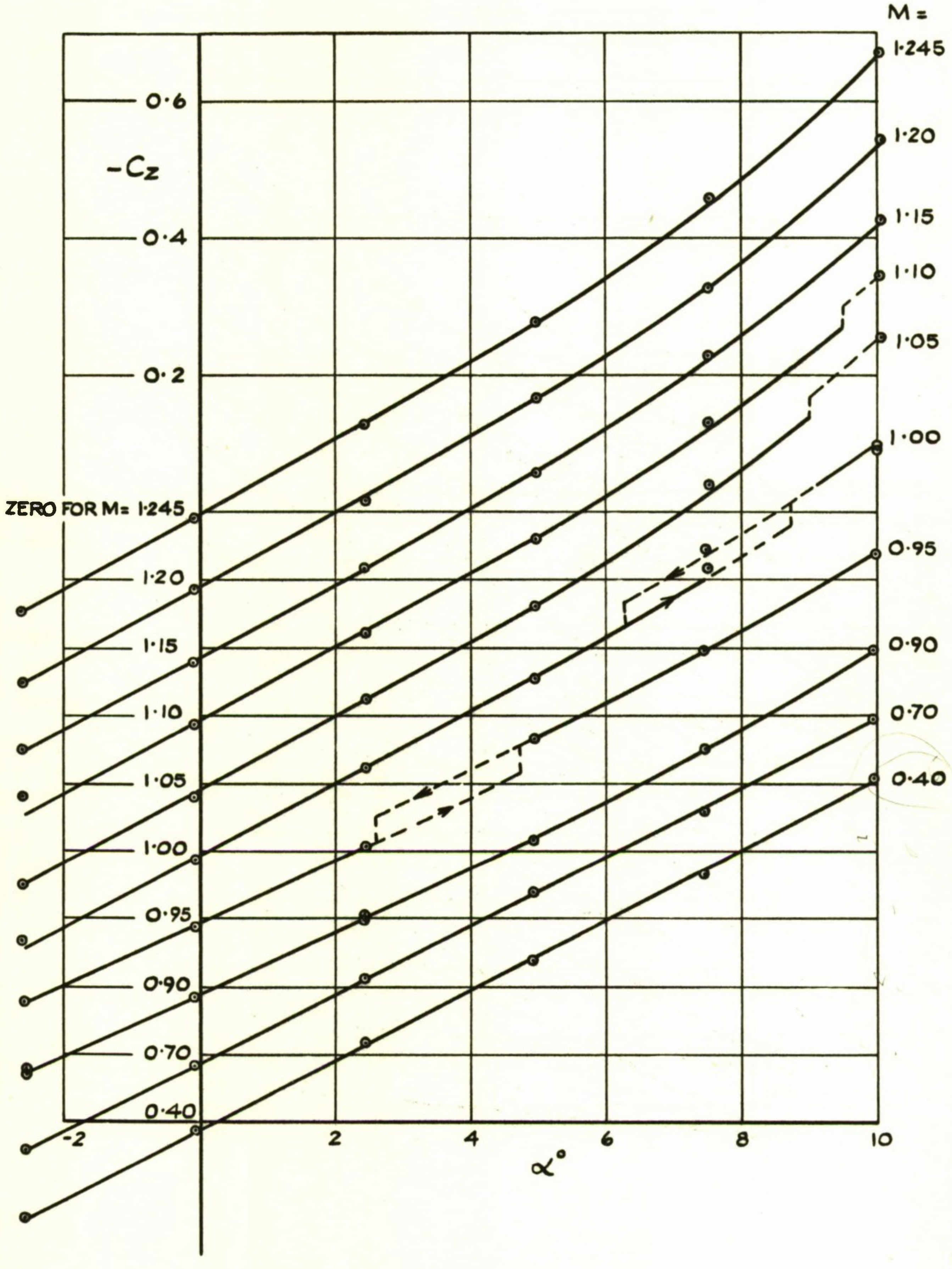

FIG. 4. $-C_z$ vs α AT VARIOUS MACH NUMBERS

BODY + 10° NOSE SPIKE + BOURRELET.

42007. S.

FIG. 5

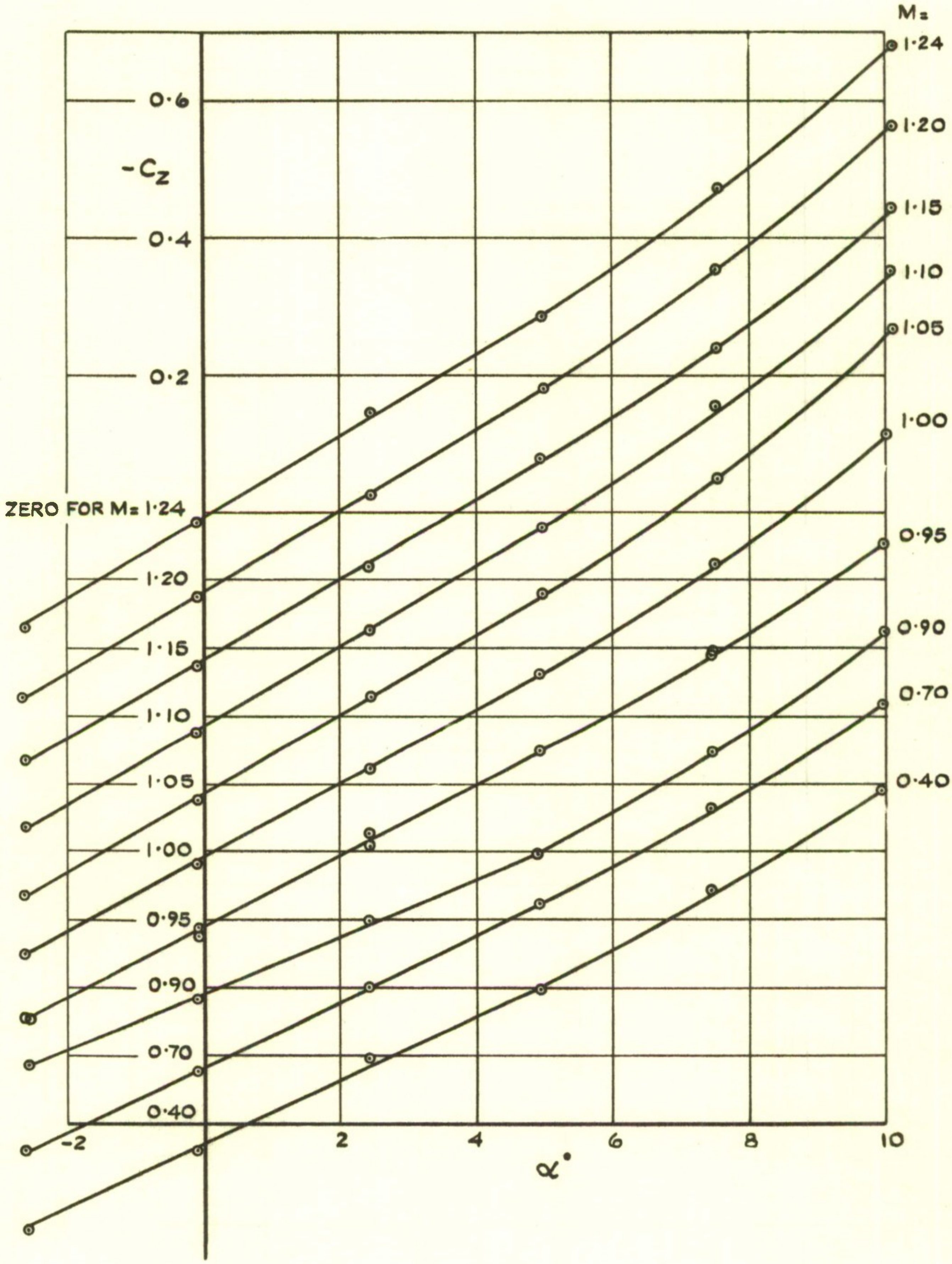

FIG. 5. $-C_z$ vs α AT VARIOUS MACH NUMBERS

BODY + 30° NOSE SPIKE + BOURRELET.

FIG. 6.

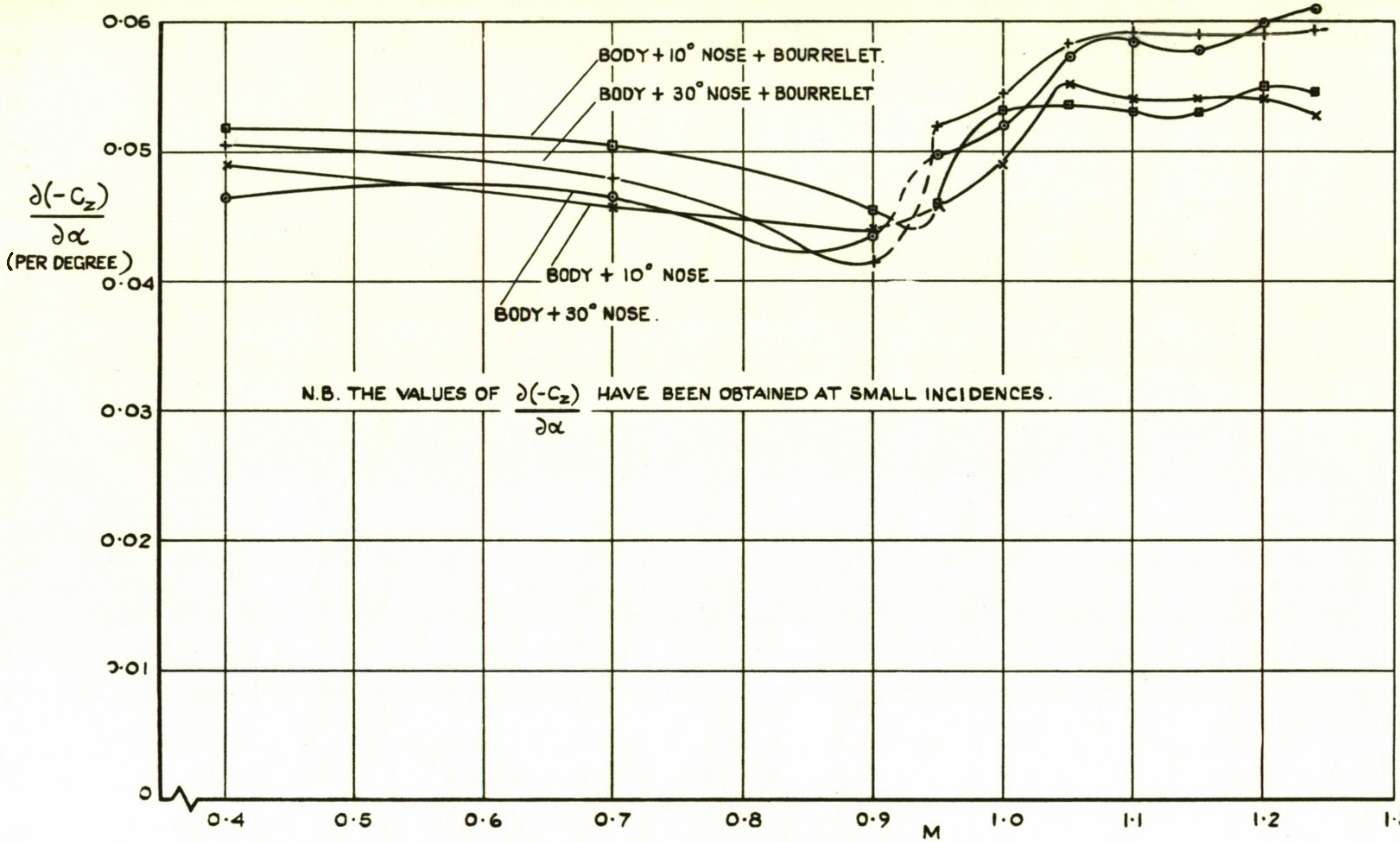

FIG. 6. NORMAL FORCE SLOPE vs. MACH NUMBER-COMPARISON OF CONFIGURATIONS.

FIG. 7

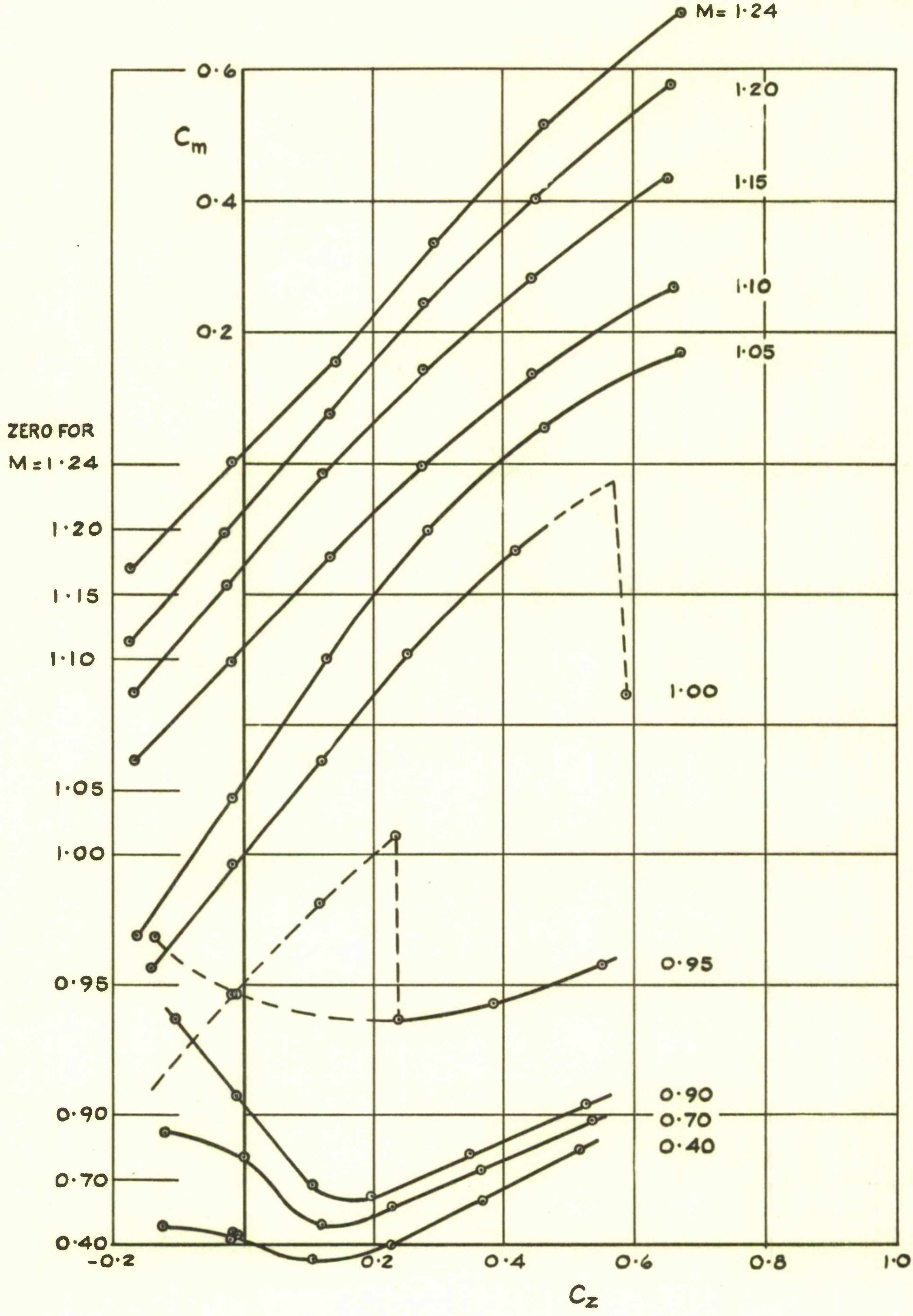

FIG. 7. C_m VS. C_z AT VARIOUS MACH NUMBERS

BODY + 30° NOSE SPIKE.

FIG. 8.

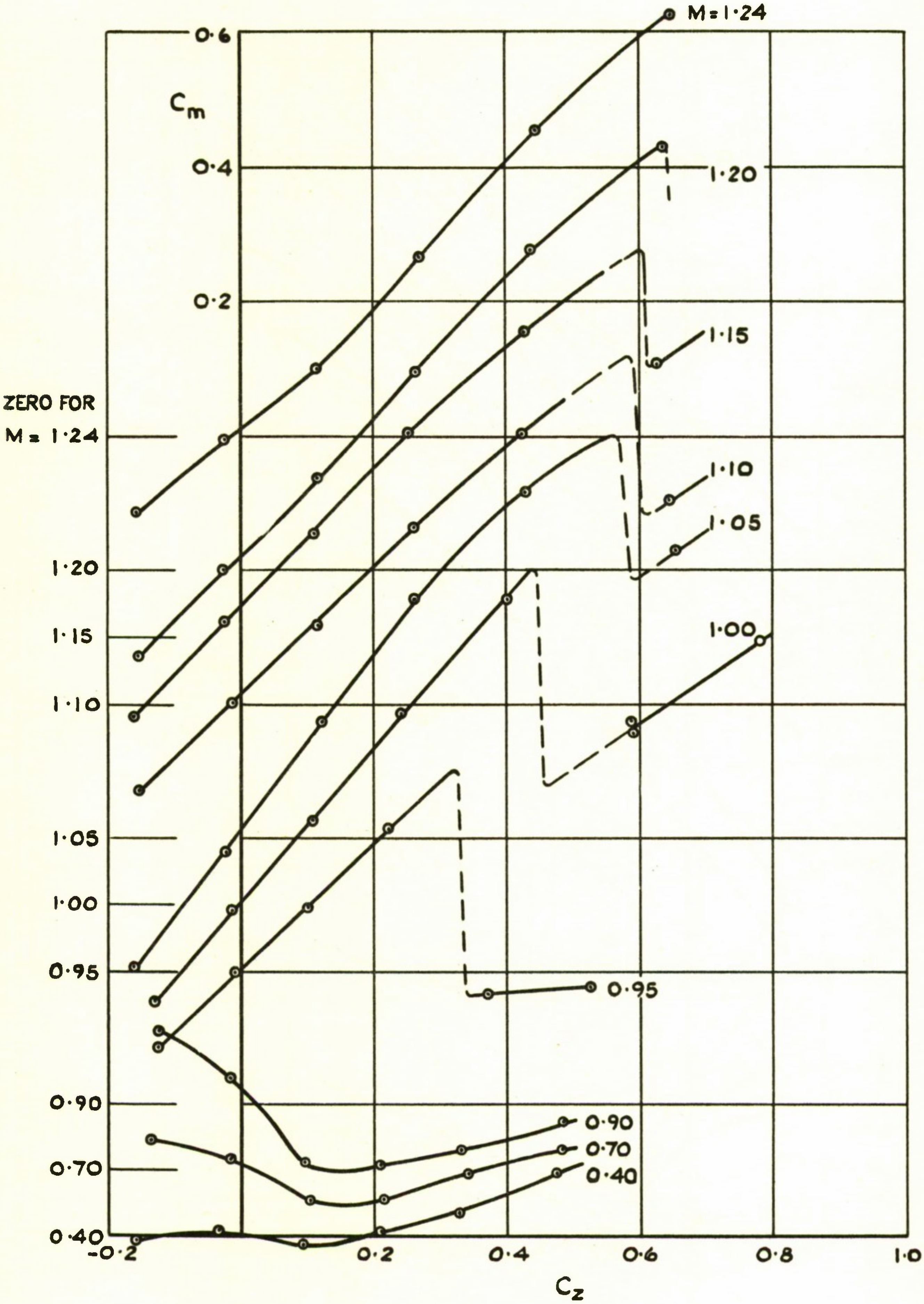

FIG. 8. C_m vs C_z AT VARIOUS MACH NUMBERS

BODY + 10° NOSE SPIKE.

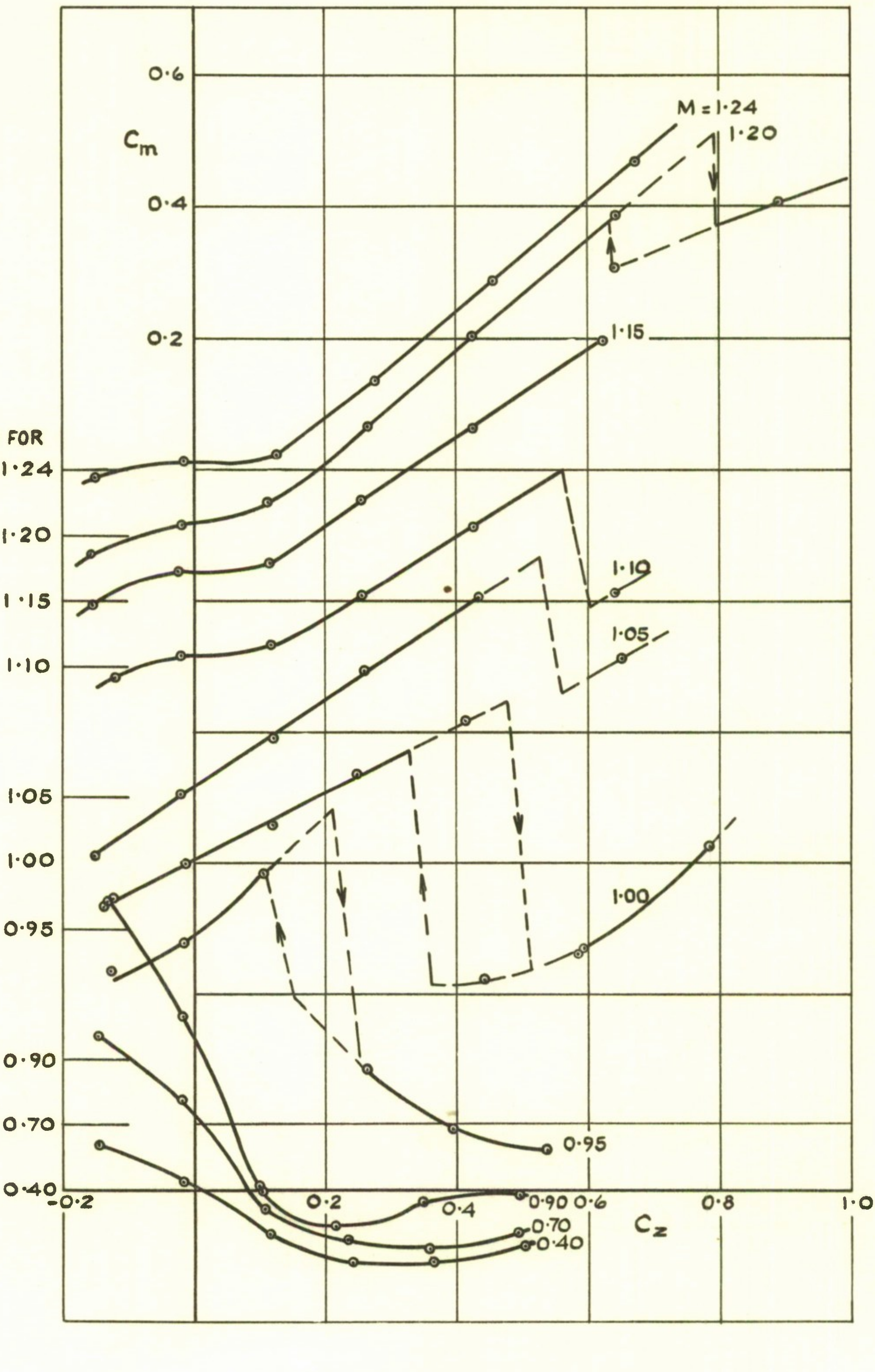

FIG. 9. C_m VS. C_z AT VARIOUS MACH NUMBERS

BODY + 10° NOSE SPIKE + BOURRELET.

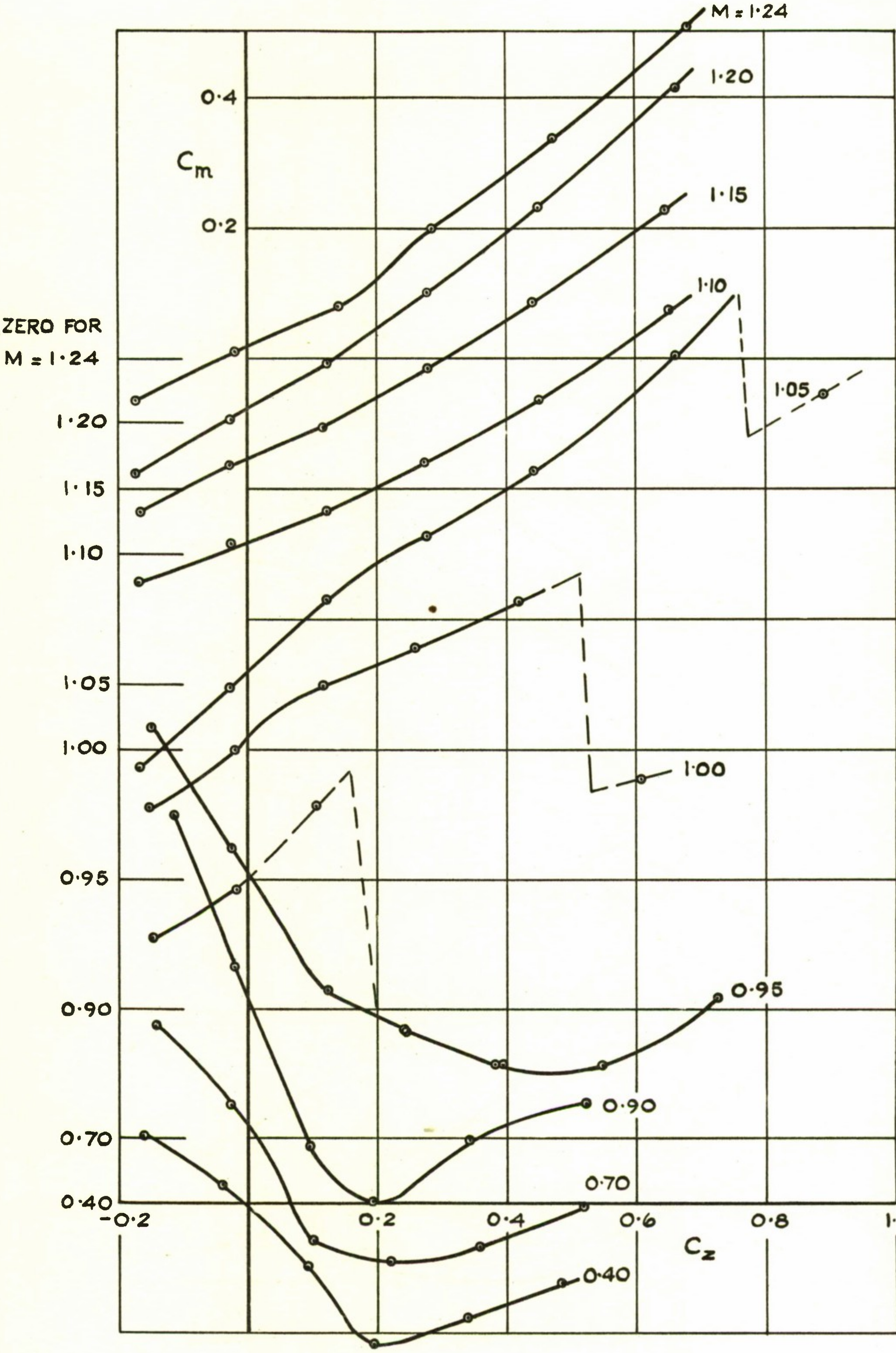

FIG. 10 C_m VS. C_z AT VARIOUS MACH NUMBERS

BODY + 30° NOSE SPIKE + BOURRELET.

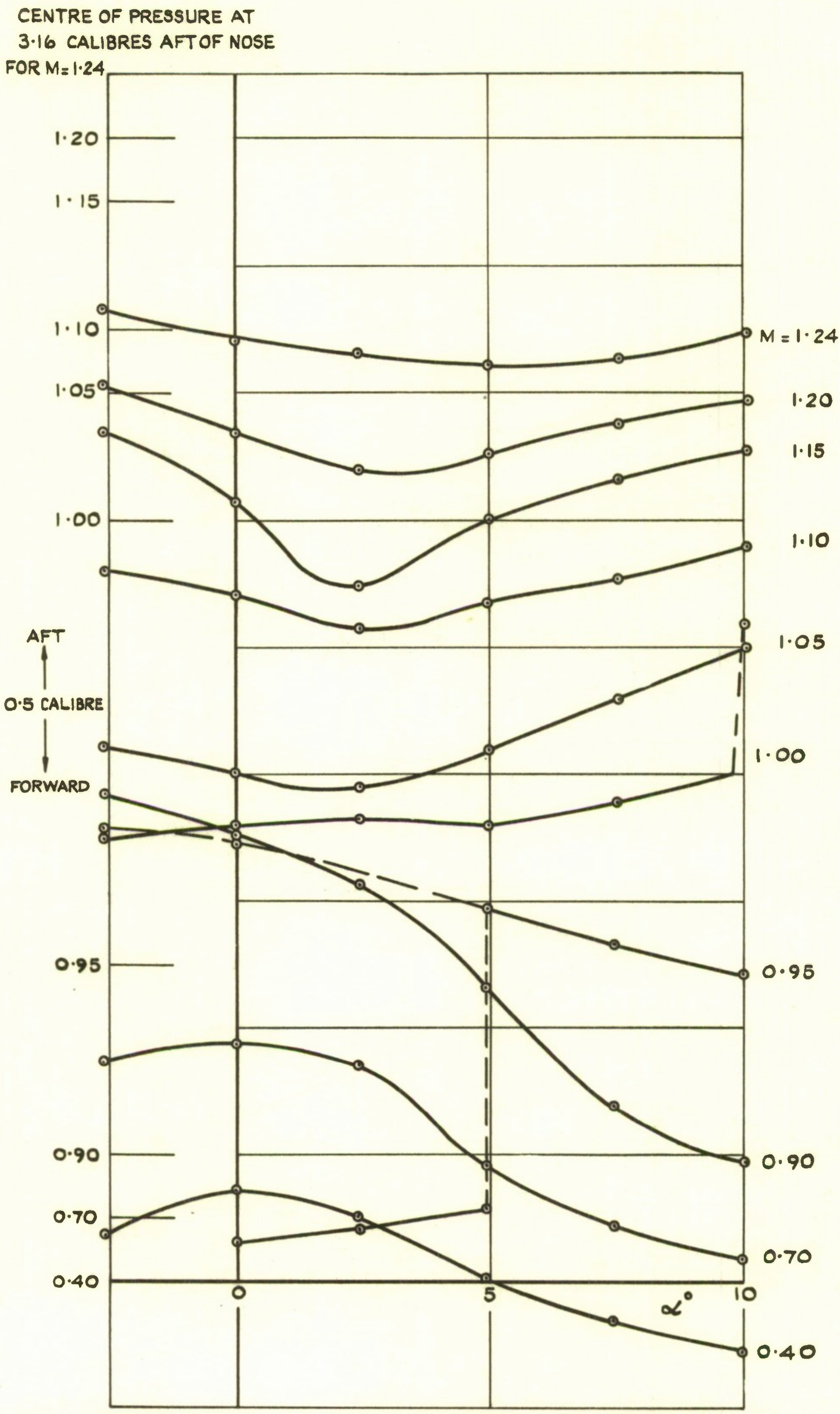

FIG. 11. POSITION OF CENTRE OF PRESSURE vs. α
BODY + 30° NOSE SPIKE.

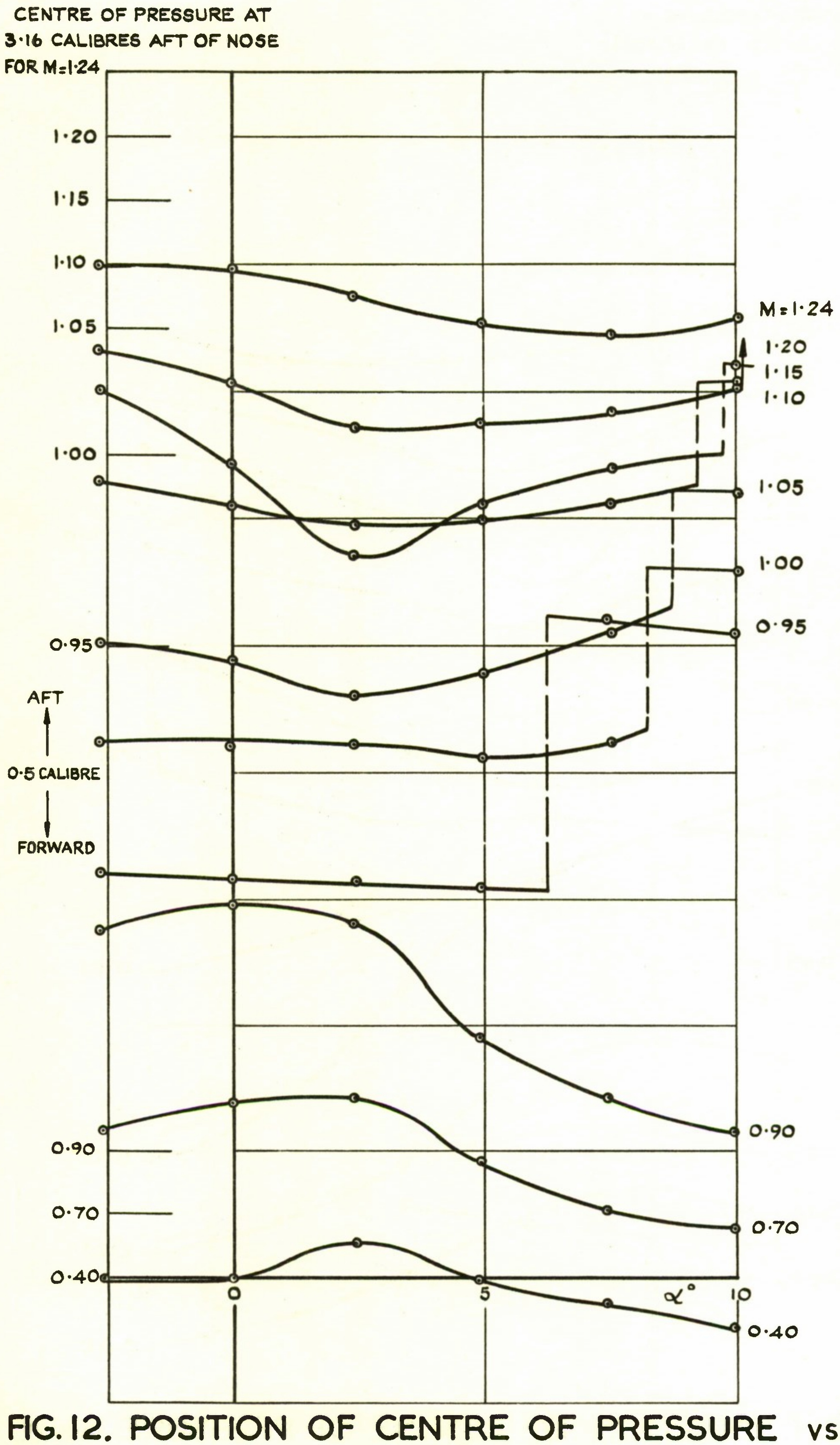

FIG. 12. POSITION OF CENTRE OF PRESSURE vs. α

BODY + 10° NOSE SPIKE.

FIG. 13.

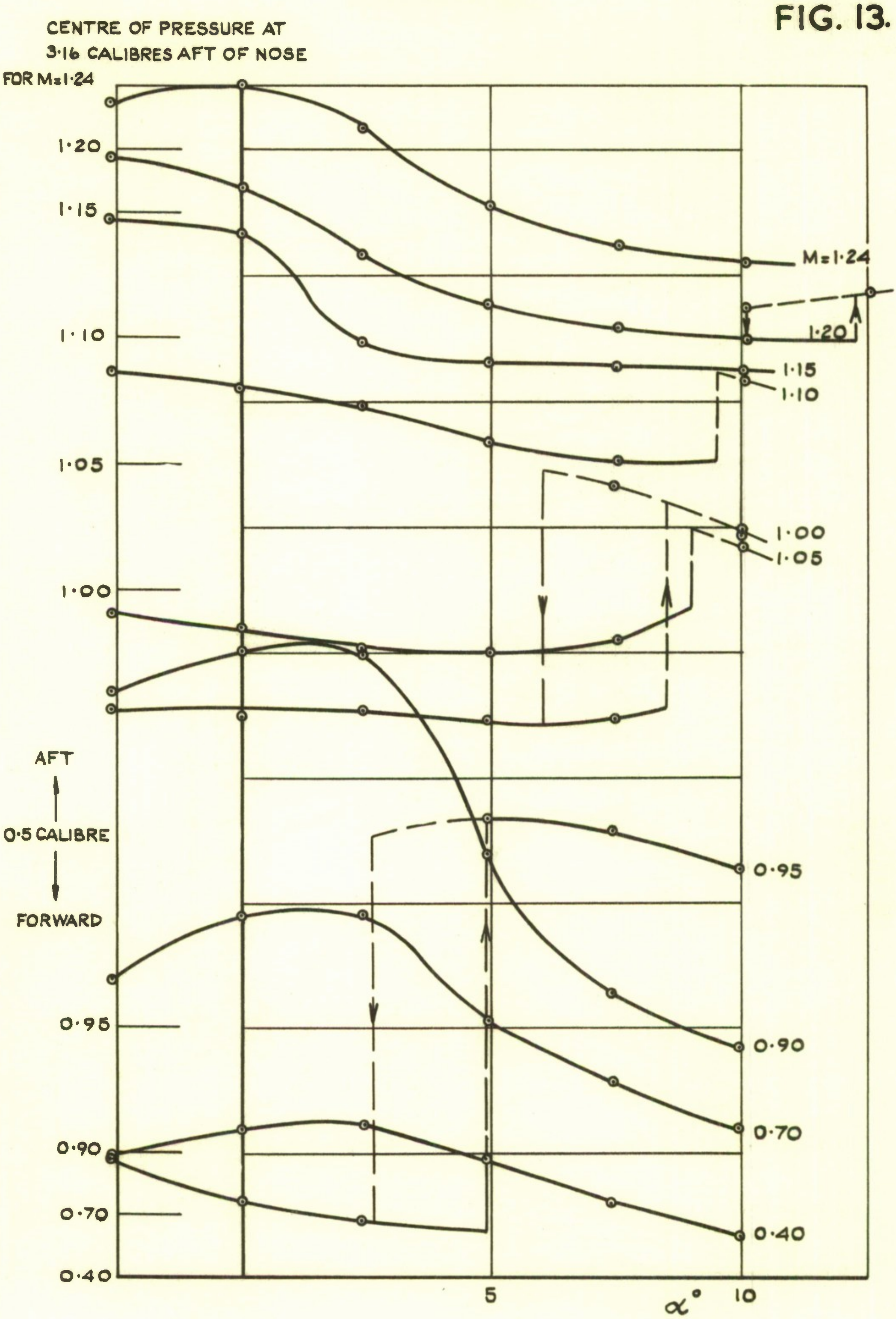

FIG. 13. POSITION OF CENTRE OF PRESSURE vs. α

BODY + 10° NOSE SPIKE + BOURRELET.

FIG. 14.

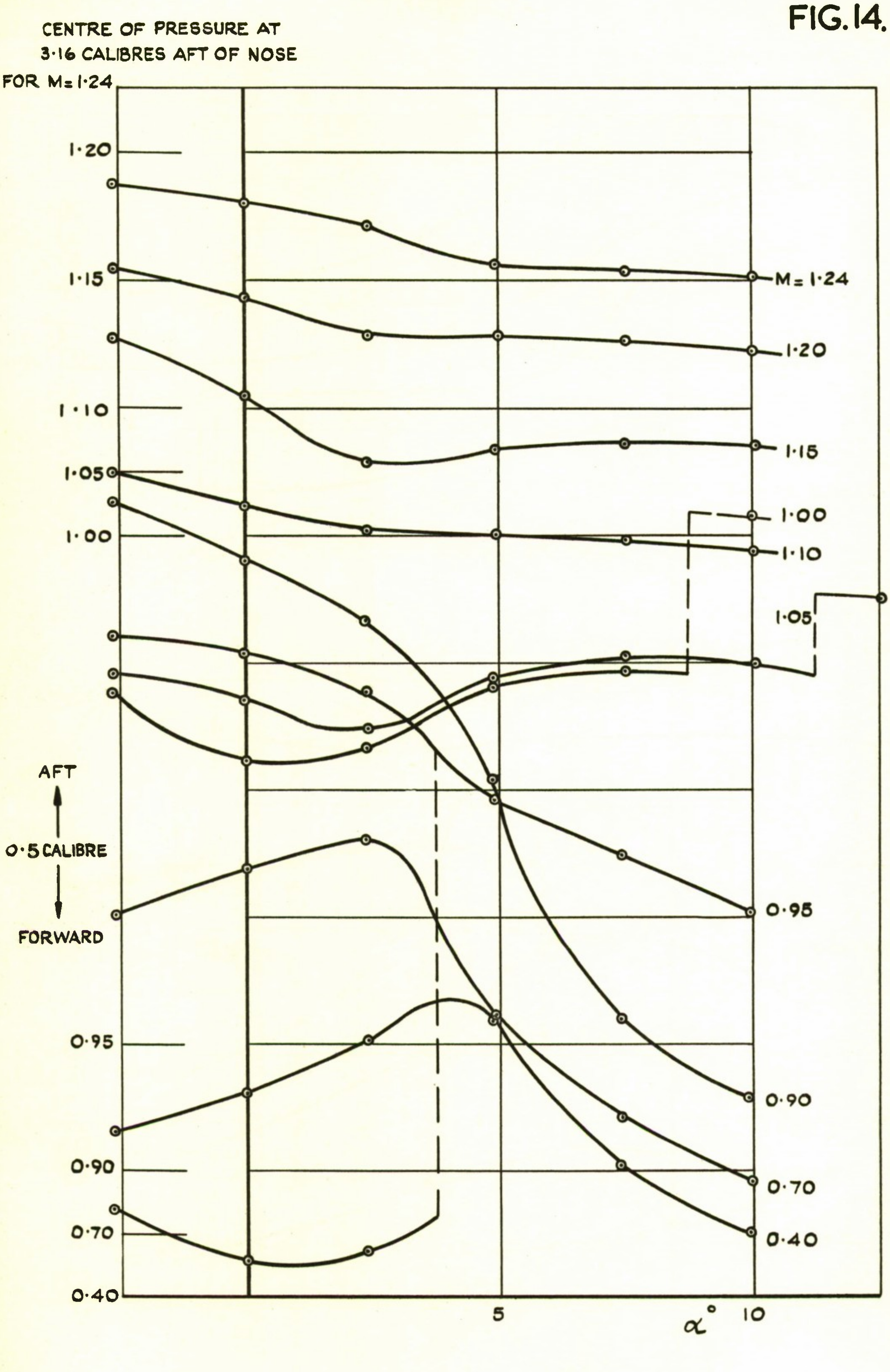

FIG. 14. POSITION OF CENTRE OF PRESSURE vs. α

BODY + 30° NOSE SPIKE + BOURRELET.

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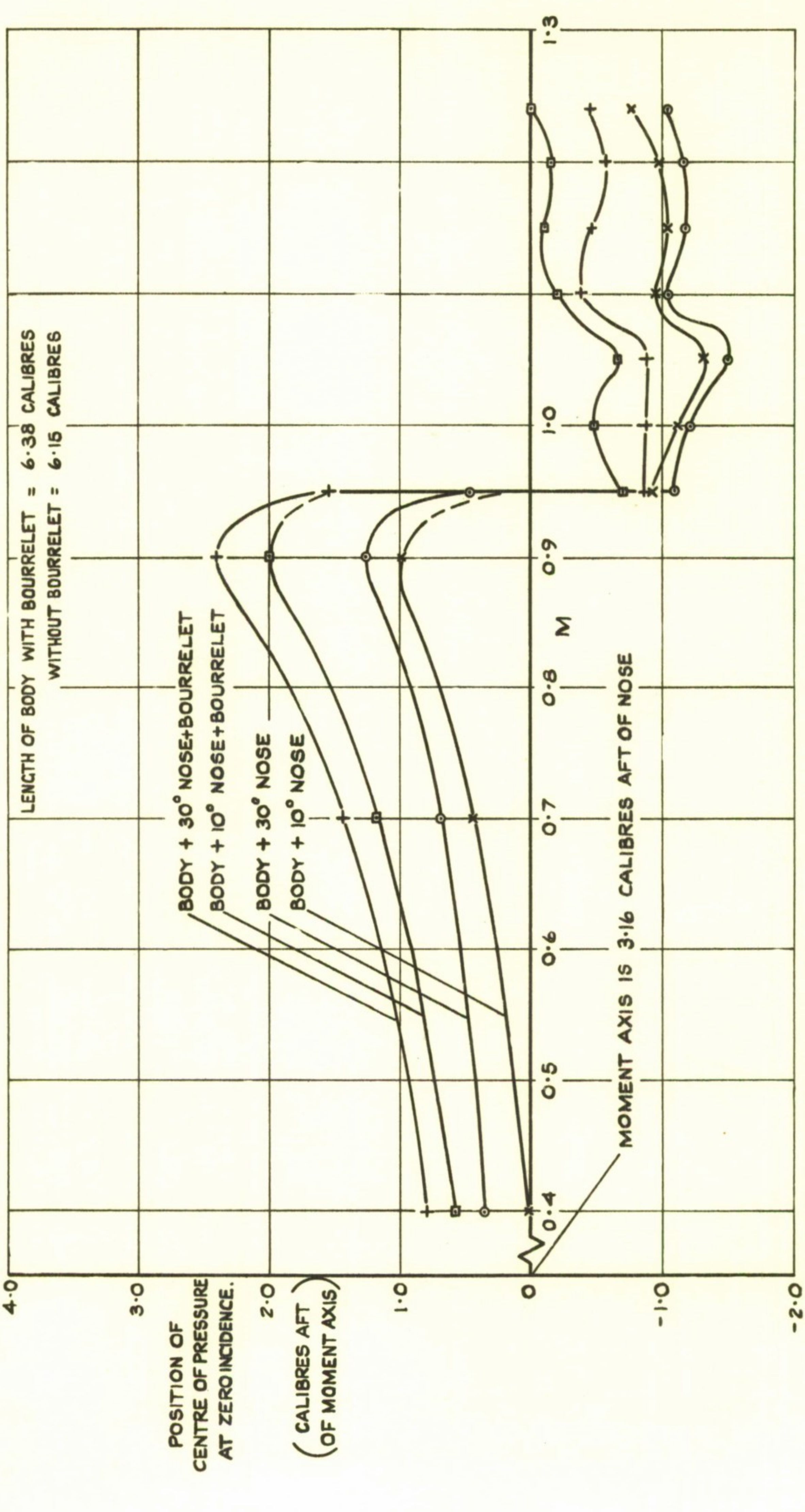

FIG. 15. CENTRE OF PRESSURE POSITION vs. MACH. NUMBER - COMPARISON OF CONFIGURATION.

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