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DEFENCE RESEARCH CENTRE SALISBURY
SOUTH AUSTRALIA

TECHNICAL REPORT

WSRL-0327-TR

WIND TUNNEL TESTS ON A TUBE-LAUNCHED MISSILE CONFIGURATION WITH A DEFLECTABLE NOSE CONTROL AND A NOVEL WRAP-AROUND FIN STABILISER

K.D. THOMSON

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K.D. Thomson

SUMMARY

Experiments have been conducted in the Mach number range 0.80 to 2.00 on a tube-launched missile configuration with a deflectable nose control and a wrap-around fin stabiliser having six fins disposed in a symmetrical triform arrangement. The results show that the control effectiveness increases markedly with Mach number. Trim curves are non-linear at subsonic speeds and approach linearity at supersonic Mach numbers.

The results have been applied to a small hypothetical missile configuration and indicate that the nose control is powerful enough to provide a terminal control capability. For the case considered, in subsonic flight the missile must fly on a near-ballistic trajectory. However, in supersonic flight the control is powerful enough to permit horizontal flight above M = 1.5 while retaining a sufficient reserve to provide a terminal correction capability. Detailed control system assessments have not been made.

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1. INTRODUCTION

In reference 1 a proposal was made for a missile control concept in which a portion of the missile nose could be deflected, similar to the drooped nose of the Concorde aircraft, but being able to deflect in any plane. It was suggested that such a control may in some circumstances be preferable to the canard control systems frequently used on terminally corrected missiles. Wind tunnel experiments at both subsonic and supersonic speeds were conducted on a long slender cylindrical body with a blunted ogival nose, a portion of which could be deflected through angles up to 28°. The results of these experiments indicated that the deflectable nose produced increments in body normal force and pitching moment, and that the control, although exhibiting non-linear behaviour, showed promise for the terminal correction of missiles. The configuration tested did not have stabilising fins and it was conjectured in reference 1 that interference between the nose and a rear-mounted stabiliser may be less than that which occurs between canard controls and rear-mounted fins. On this basis, the wind tunnel results were used in a preliminary assessment which indicated that the deflectable nose control system would be effective in controlling a long slender missile with rear stabilising surfaces.

In the present investigation a finned missile configuration suitable for tube launching was tested in order to determine whether the favourable predictions in reference 1 could be confirmed. A symmetrical wrap-around finned configuration (figure 1) of the type originally defined in reference 2 was selected. The particular six finned arrangement chosen has been tested in wind tunnel experiments(ref.3). The type of wrap-around fin selected for the experiment is particularly appropriate for use with a deflectable nose control. The conventional wrap-around fin configuration (in end view like a swastika but with curved arms) induces large rolling moments, causing a missile to spin rapidly in one direction at subsonic speeds and rapidly in the opposite direction at supersonic speeds. Control of a missile with this type of stabiliser would require de-spinning of the nose, a requirement difficult to satisfy and expensive to achieve. In contrast, the symmetrical wrap-around fin produces negligible rolling moments at small angles of attack, and a deflectable nose control should not require nose de-spinning.

Wind tunnel tests were conducted at both subsonic and supersonic speeds in the 380 mm x 380 mm wind tunnel S-1 at WSRL. A record of these experiments is contained in this report.

Simplistic calculations are then made to determine under what circumstances the control system could be expected to provide effective terminal control for a representative small missile.

2. MODEL AND TEST PROCEDURE

The model body (figure 1) was a 25 mm diameter (d) tangent ogive-cylinder having a 3d ogival nose shortened by spherical nose blunting, and a cylindrical afterbody, giving an overall length of 10 d. The nose was fitted with a spherical joint and an internal worm and wheel mechanism which enabled the front 1.205 d of the nose to be deflected in one direction through angles between 0° and 28°. A six-finned symmetrical wrap-around fin unit with triform symmetry was attached to the rear of the body and could be mounted with one pair of fins on the top (designated Fins 1) or two pairs on top (designated Fins 2). The Fins 1 configuration is shown in figure 1. The Fins 2 configuration is obtained by rotating the fin arrangement through 180° around the body. A four component strain gauge balance was mounted within the body and measured normal force and pitching moment, side force and yawing moment.

The front section of the model body of length 4.5 diameters was the same as that tested in reference 1. The body boundary layer manipulators were unaltered and there is no doubt that they were as effective as they were shown to be in reference 1, since the Reynolds number range was $1.6 \times 10^5 \leqslant R_d \leqslant 2.4 \times 10^5$, compared with $1.6 \times 10^5 \leqslant R_d \leqslant 1.7 \times 10^5$ for the tests reported in reference 1.

All experiments were carried out at zero roll angle, the control being deflected in the vertical plane as shown in figure 1.

3. RESULTS

The wind tunnel programme covered the following range of parameters:

Mach No.	Nose Angle (°)	Pitch Angle (°)	Remarks
0.80,0.95,1.40, 2.00	0,4,8,16,25	0(1)13	Both Fins 1 and Fins 2 configurations

Although four-component tests were conducted, the measured side forces and yawing moments were very small and are not presented in this report. The results reported cover normal force and pitching moment measurements (figures 2 and 3) and their increments due to control deflection (figures 4 and 5). For convenience, the pitching moment reference station was taken to be the nose-cylinder junction 2.705 d from the nose.

Force and moment coefficients (figures 2 and 3) are accurate to within 1% of full scale. However, further errors could occur in the derivation of force and moment increments (figures 4 and 5) which were determined by graphical interpolation and differencing; the maximum error in $|\Delta C_Z|$ is believed to be 0.05 and in $|\Delta C_m|$, 0.20. No experimental points have been marked in the figures in order to minimise congestion.

4. DISCUSSION

Figure 2 shows that the normal force curves for zero control angle are very nearly independent of fin orientation. Deflection of the nose produces only a small increment in C_Z, particularly at subsonic speeds, but the increment becomes larger as Mach number increases. The control effectiveness is non-linear with respect to both control angle and incidence, the incidence-dependence being particularly noticeable at subsonic speeds. However, as Mach number increases to supersonic values incidence-dependence decreases markedly and at $M = 2.00$ the dependence has just about disappeared, as shown by the nearly parallel normal force curves for each control angle in figure 2(d).

At zero control angle the pitching moment characteristic is dependent to a small extent upon fin orientation (figure 3) only for angles of incidence greater than about 3°, Fins 2 configuration producing a generally slightly steeper pitching moment curve. Deflection of the nose produces a significant and orderly increment in C_m. As for normal force, the control effectiveness with respect to pitching moment is non-linear, with variations in both control angle and incidence, and the remarks relating to normal force also hold for pitching moment.

Figures 4 and 5 show increments in normal force and pitching moment coefficient. In view of the relatively large errors possible in $|\Delta C_Z|$ and $|\Delta C_m|$, these graphs should be interpreted as indicating trends rather than providing definitive data on control effectiveness. Nevertheless, the major characteristics of the control can be determined, namely, their ineffectiveness for small control angles and the trend towards linearity at increasing supersonic Mach numbers. Since $|\Delta C_Z|$ is virtually independent of Fins 1 or Fins 2 configurations, figure 4 displays Fins 1 results only. In contrast, there is a small but significant effect on ΔC_m due to fin orientation, and figure 5 contains both Fins 1 and Fins 2 results. Because of the magnitude of errors in ΔC_m the confusing performance of the control indicated in figure 5(b) at $M = 0.95$ for Fins 1 at $\delta < 15°$, may not be borne out in practice. However, because of the control ineffectiveness in this region, resolution of this doubt is not likely to be an important issue. The differences in performance with fin orientation in figure 5(b) and also in figure 5(d) are believed to be generally correct.

In reference 1 it was conjectured that the deflectable nose *might not* have one of the defects of canard controls. In particular, it is well known that a large proportion of the downwash produced by a lifting canard control is removed from the flow by stabilising or lifting surfaces mounted downstream. The result is that the increment in normal force produced by canards is countered to a significant extent by a normal force decrement on the downstream surfaces, so that canards produce mainly a pitching moment increment. It was argued in reference 1 that there may be a net normal force *gain as well* as a pitching moment increment by using a deflectable nose control, since the downwash is concentrated more in the lee of the body than it is for canards, and is therefore further away from the stabilising fins. Figure 6 has been prepared in order to test this supposition. Neglecting the effect of differences in length between the body tested in reference 1 and that in the present test (10.705 d compared with 10 d) the ratio has been determined of normal force increment with and without fins, namely $\Delta C_Z/\Delta C_{Z_{NF}}$, for a control deflected through 25°. Figure 6 shows this ratio plotted against Mach number for several different angles of incidence and it is seen that for incidences less than 10°, typically one half to three quarters of the ΔC_Z generated by control deflection is removed by the presence of the fins.

The greatest loss occurs at subsonic speeds. For larger incidences the proportion decreases, probably because of the progressive control downwash movement into the lee of the body with increasing incidence. The deflectable nose therefore has the same defect as canard controls.

5. APPLICATION TO HYPOTHETICAL MISSILE

In order to determine whether a deflectable nose control could have a useful practical application some simplistic calculations have been carried out on a configuration representative of a typical small missile. The configuration in figure 1 was chosen, with a missile diameter of 150 mm; the missile mass was assumed to be 90 kg. The wind tunnel tests enabled the centre of pressure position to be calculated over the Mach number range of the tests, the mean position for incidences less than 4° being 6.89 d when $\delta = 0°$, and 6.40 d for $\delta = 25°$. The furthest forward centre of pressure position was 6.32 d for $\delta = 25°$ at $M = 2.00$. In order to conform with standard missile practice a centre of gravity position was selected such that the minimum static margin was about 1 d; the centre of gravity was therefore selected to be 5.30 d from the nose.

Calculated trim curves are given in figure 7. Although the controls exhibit non-linear behaviour they nevertheless are orderly. Their effectiveness increases markedly with Mach number up to at least M = 2.00. Wind tunnel experiments would be worthwhile to determine whether this trend continues at higher supersonic speeds. Over the speed range covered, the trimmed incidences and normal force coefficients are not large and therefore the missile would not be very agile, and would probably be limited to a terminal correction role.

In order to obtain an indication of the agility, it is assumed that the missile has a target acquisition range of 4 km. At the instant of target acquisition the control is deflected through 25° and the missile flies at constant speed and with constant lateral acceleration to the target. The cross-range it can achieve in the last 4 km of flight is given in figure 8. The cross-range could also be interpreted as the radius of the circle which the missile must fly through at a distance of 4 km from the target in order to have the possibility of hitting a stationary target. This provides an indication of the maximum dispersion which the missile can have at the instant of target acquisition. Also shown in figure 8 is the maximum (constant) speed a target could have while still being vulnerable to attack from the missile (ie, cross-range divided by flight time for the last 4 km of trajectory). Figure 8 shows that the cross-range or 4 km circle radius increases approximately linearly with Mach number from about 0.3 km at M = 0.80 to 1.2 km at M = 2.00. The speed curve shows that if the missile flies at the speed of sound it will be able to follow a target moving at up to 40 m/s, which is greater than the speed of most land and sea vehicles, except under very exceptional circumstances. At M = 2.00 a target speeding at up to 200 m/s is vulnerable. If travelling at $M < 1.15$ the missile would have to fly on a near-ballistic trajectory, but if travelling at greater than M = 1.15 the control would permit it to fly in level flight. Therefore, it is likely that a missile flying at a moderately low supersonic Mach number ($M \approx 1.5$ say) would be capable of level flight, and also have sufficient reserve control power to manoeuvre towards moving ground or sea targets.

It is concluded therefore that a tube launched missile of the type being considered could, by use of a deflectable nose control system, be used in a terminal correction role against moving ground or sea targets.

It is contended that it may be possible for a missile of the type shown in figure 1 to be flown over somewhat longer distances than could a missile with a conventional (swastika form) wrap-around fin stabiliser, without large dispersions developing. As mentioned in Section 1, a feature of the conventional wrap-around fin stabiliser is that it develops large rolling moments of different sign at subsonic and supersonic speeds. Such a missile when accelerating from launch to supersonic speed would roll in one direction at subsonic speeds and then slow down and roll in the other direction at supersonic speeds. The roll and pitch frequencies would become identical at least three times and at each conjunction the missile would suffer a dynamic roll-pitch interaction, with an associated growth in dispersion. In contrast, a missile of the form shown in figure 1 would in principle avoid these regions of dynamic instability because at small incidence no rolling moments are generated by the symmetrical fin configuration. In a real situation it would probably be necessary to have some way of spinning the missile during the initial boost phase in order to minimise launch dispersion, and this would introduce one source of dynamic roll-pitch interaction.

6. FINAL COMMENTS

It appears that a deflectable nose could be used to control a tube launched missile with a symmetrical wrap-around fin stabiliser. The control is non-linear and is not very powerful, but the deflection of a larger proportion of the nose would be expected to increase its power. The control effectiveness increases with Mach number up to $M = 2.00$ and extrapolation indicates that a further increase might be expected at higher Mach numbers. Based on simple calculations relating to one small hypothetical missile it is concluded that the control is likely to provide adequate agility for the terminal correction of a missile used against land and sea vehicles, particularly if the missile flies supersonically. For subsonic flight speeds the terminal correction is limited to that required by a missile flying on a near-ballistic trajectory, but for flight at $M \geqslant 1.5$ approximately, it appears that the control would permit the missile to fly horizontally and still have sufficient reserve power to provide terminal correction.

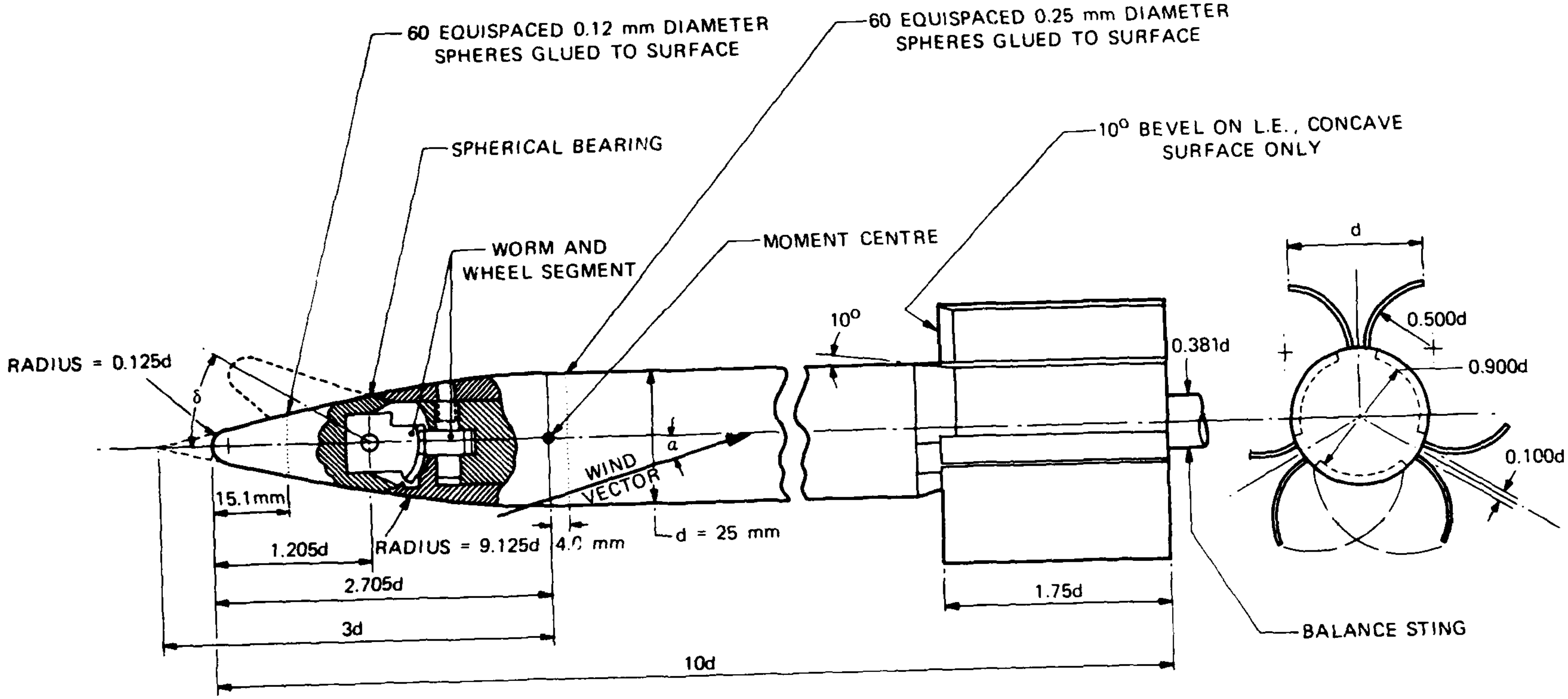
The symmetry of the stabiliser permits the avoidance of areas of dynamic roll-pitch interaction and consequently small dispersions in trajectory may be achievable. Hence it may be possible to use the configuration over greater ranges than are achieved by missiles stabilised by conventional wrap-around fins.

NOTATION

C_m	pitching moment coefficient = M/qSd
C_Z	normal force coefficient = Z/qS
$C_{Z_{NF}}$	normal force coefficient, no fins
$C_{Z_{trim}}$	normal force coefficient at trim
M	pitching moment coefficient; also Mach number
R_d	Reynolds number = $V\,d/\nu$
S	reference area = $\pi d^2/4$
V	missile speed
Z	normal force
d	body diameter
q	dynamic pressure
α	angle of incidence
α_{trim}	angle of incidence at trim
δ	control angle
ν	kinematic viscosity

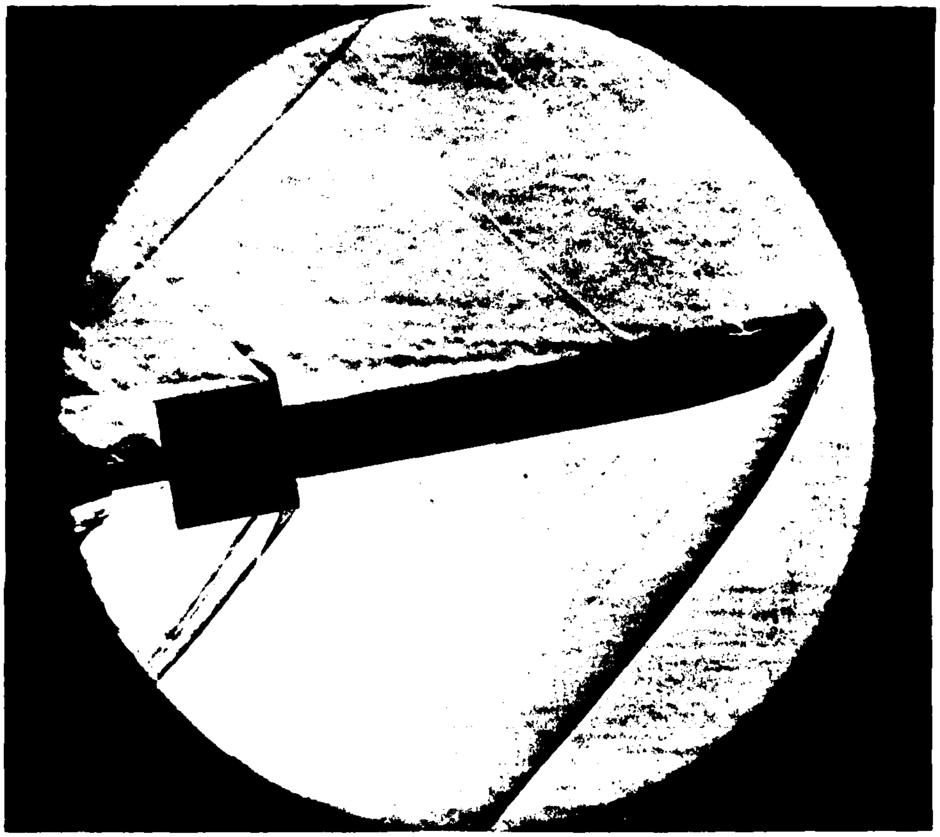
REFERENCES

No.	Author	Title
1	Thomson, K.D.	"The use of a deflectable nose on a missile as a control device". WSRL-0211-TR, 1981
2	Robinson, M.L. and Fenton, C.E.	"Static aerodynamic characteristics of a wrap-around fin configuration with small rolling moments at low incidence". WRE-TN-527 (WR&D), 1971
3	Robinson, M.L. and Fenton, C.E.	"Static aerodynamic characteristics of a projectile configuration with six wrap-around fins". (Unpublished)



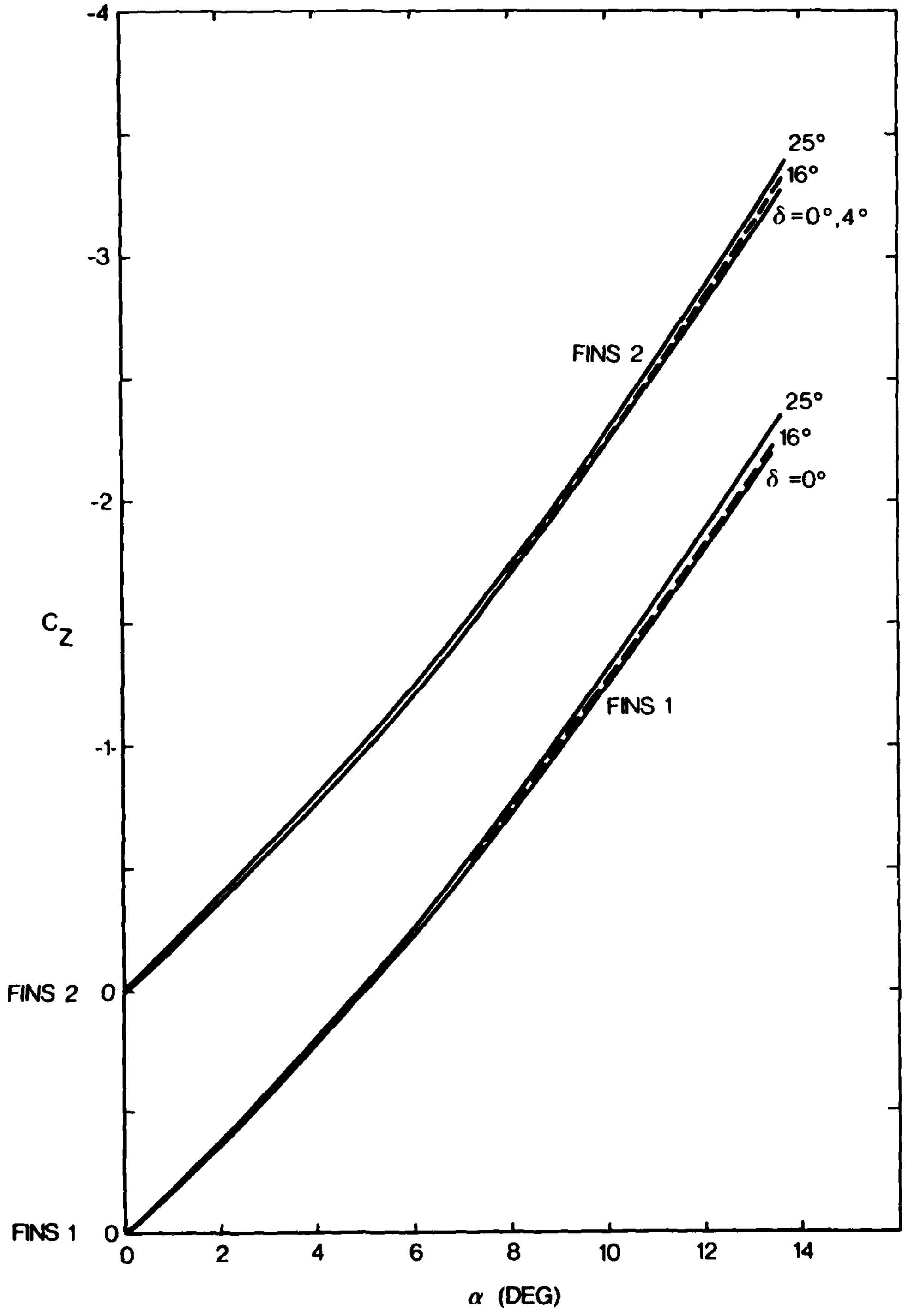
(a) Model geometry

Figure 1. Details of wind tunnel model



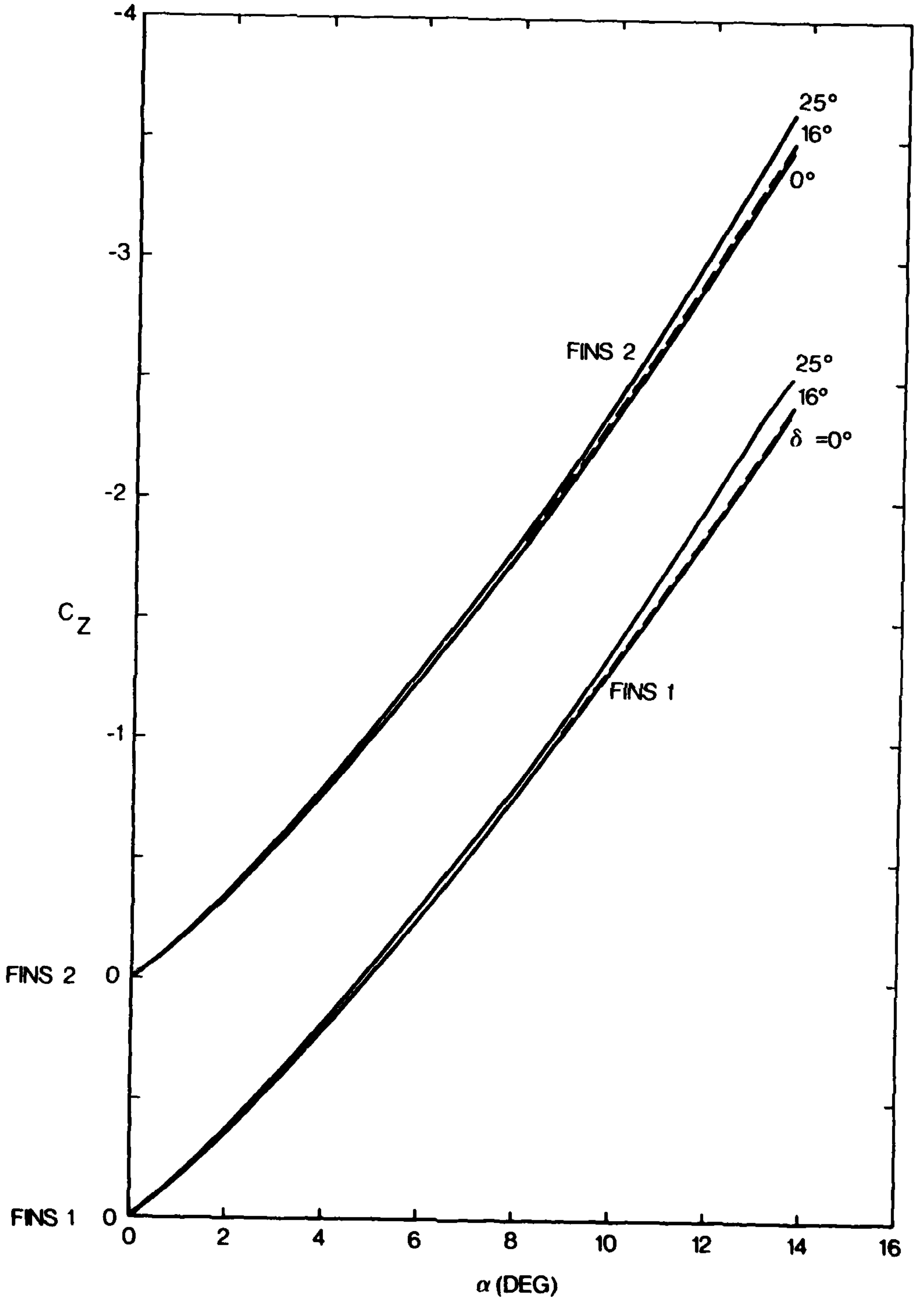
(b) Schlieren photograph $M = 1.40$, $\alpha = 10^{\circ}$, $\delta = 25^{\circ}$

Figure 1(Contd.).



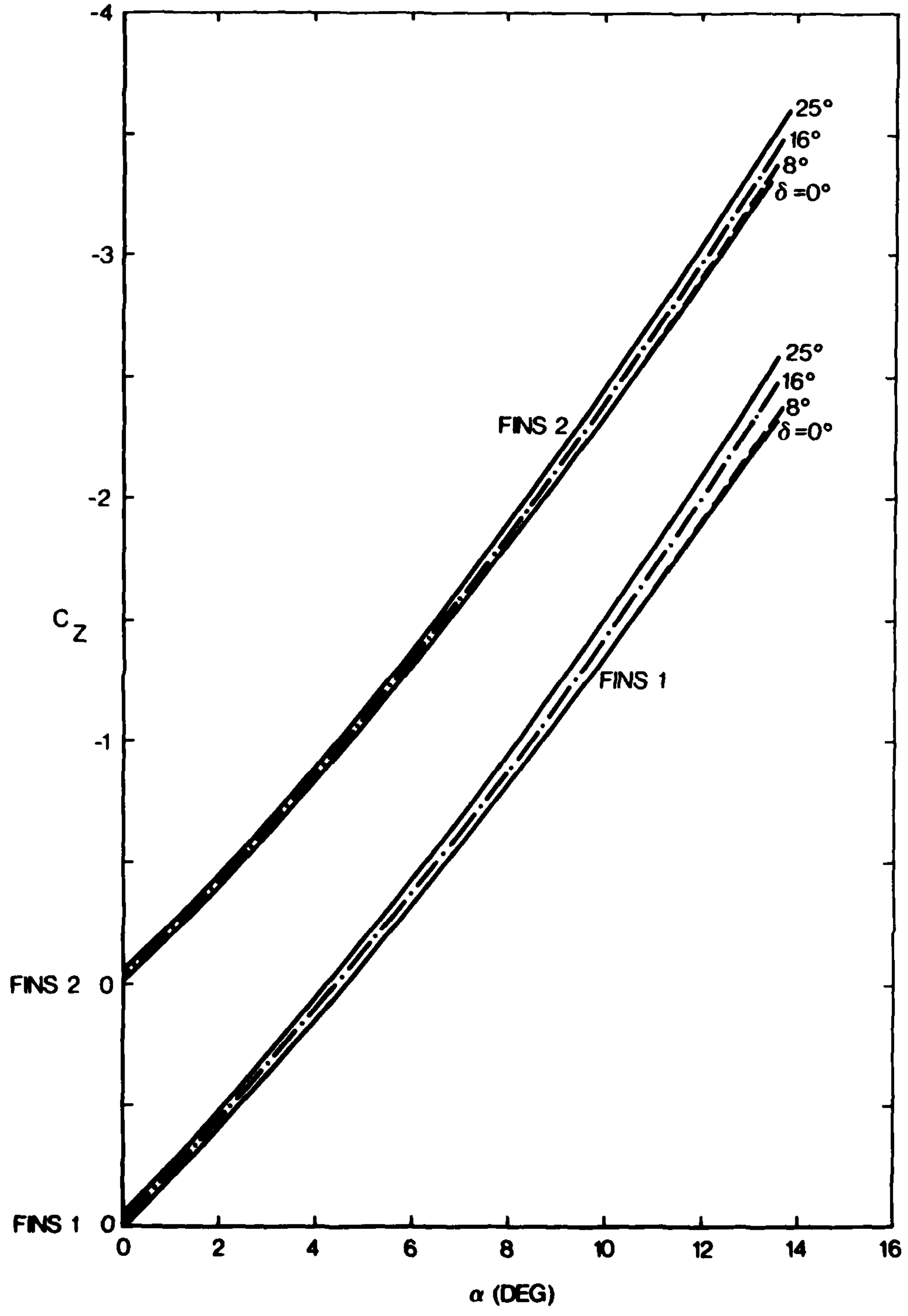
(a) M = 0.80

Figure 2. Normal force characteristics



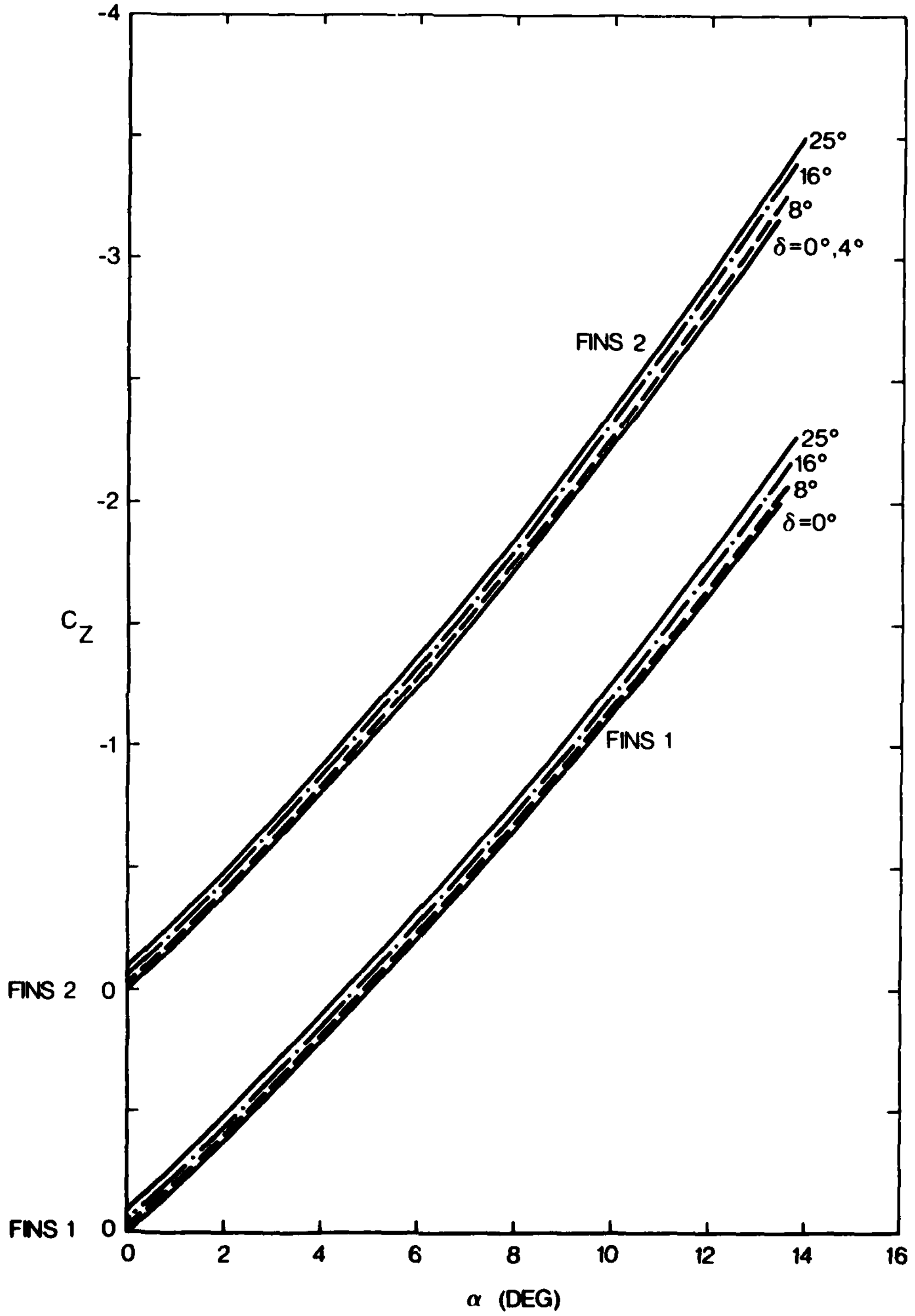
(b) M = 0.95

Figure 2(Contd.).



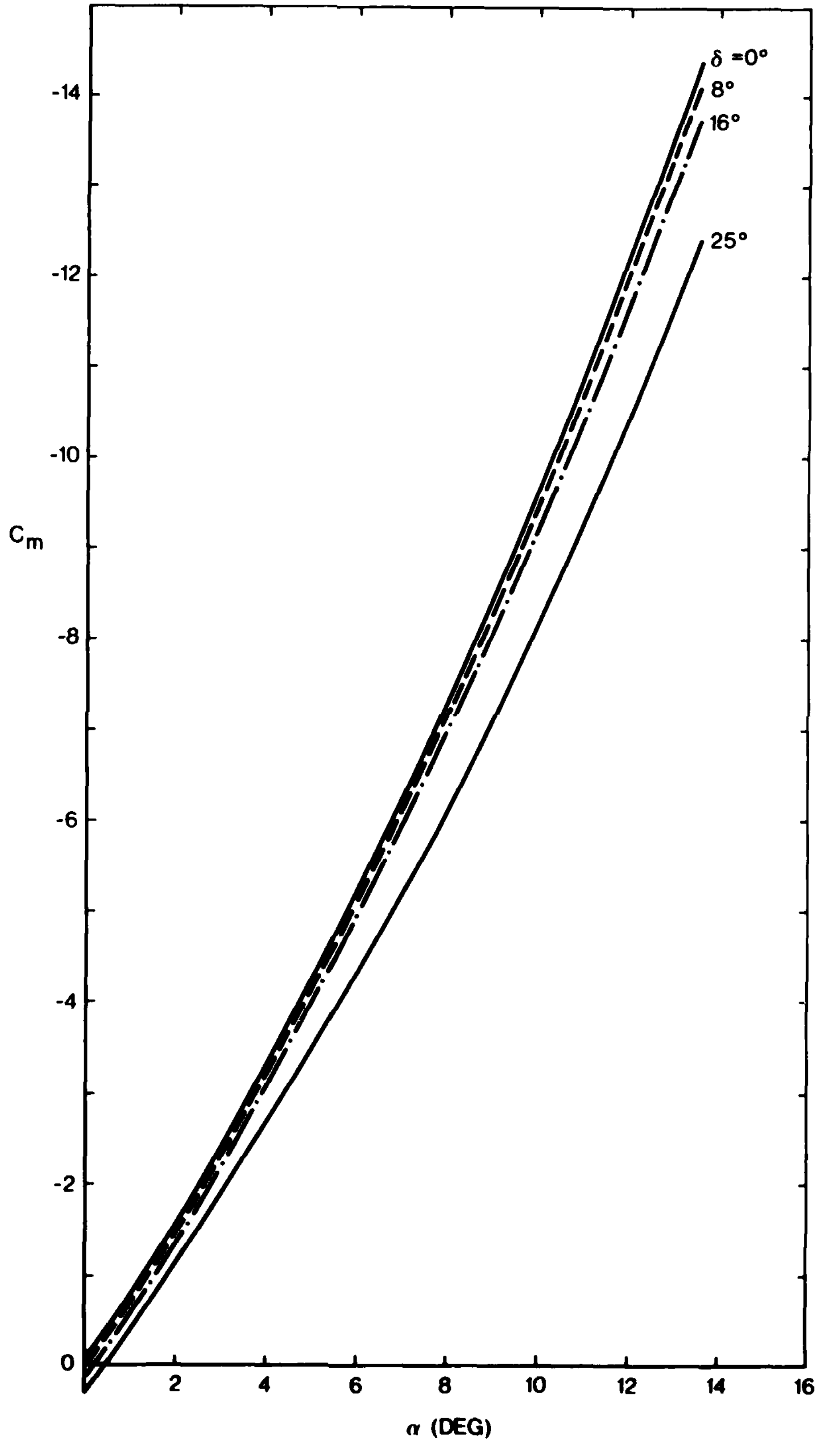
(c) M = 1.40

Figure 2(Contd.).



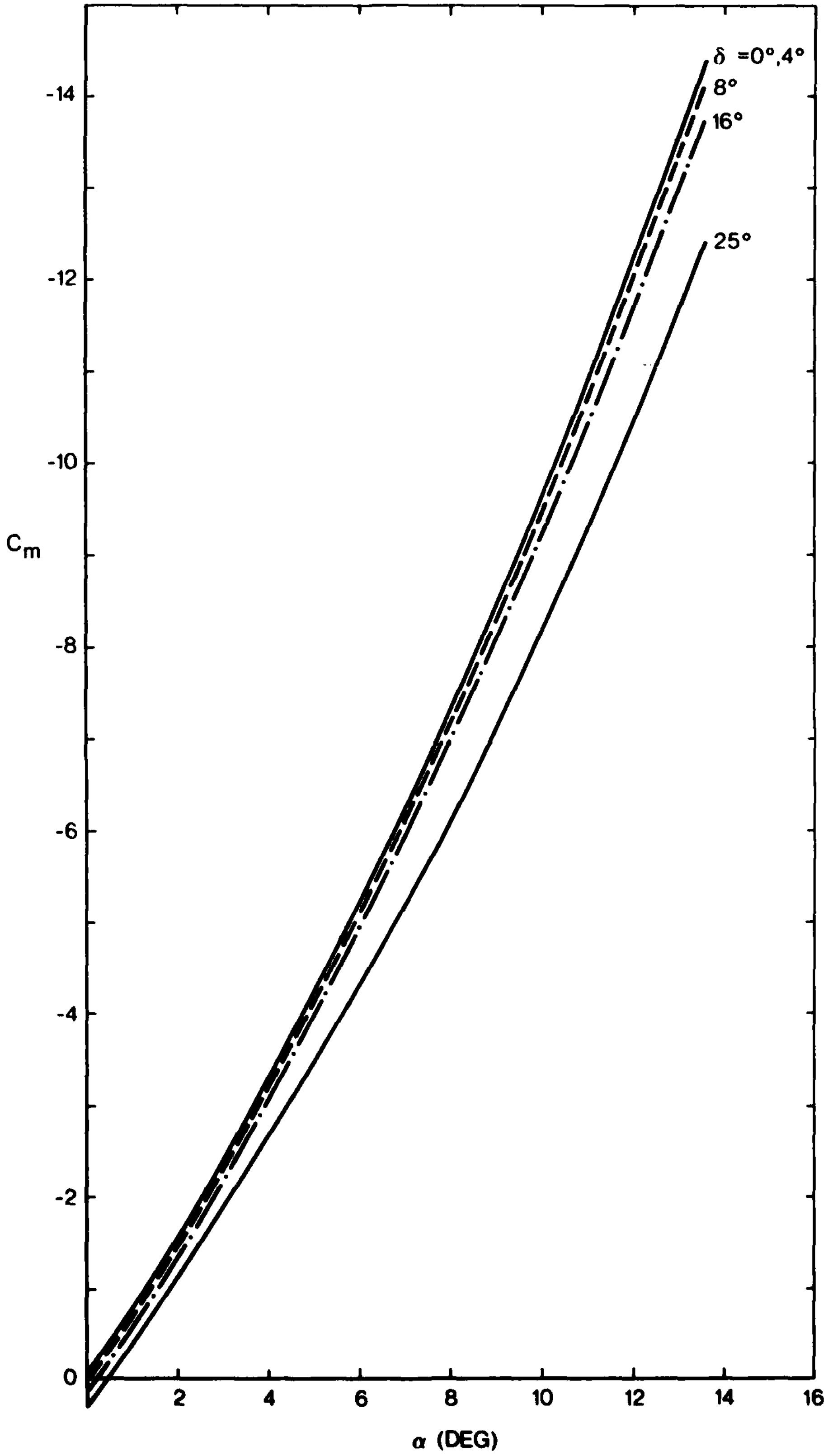
(d) M = 2.00

Figure 2(Contd.).



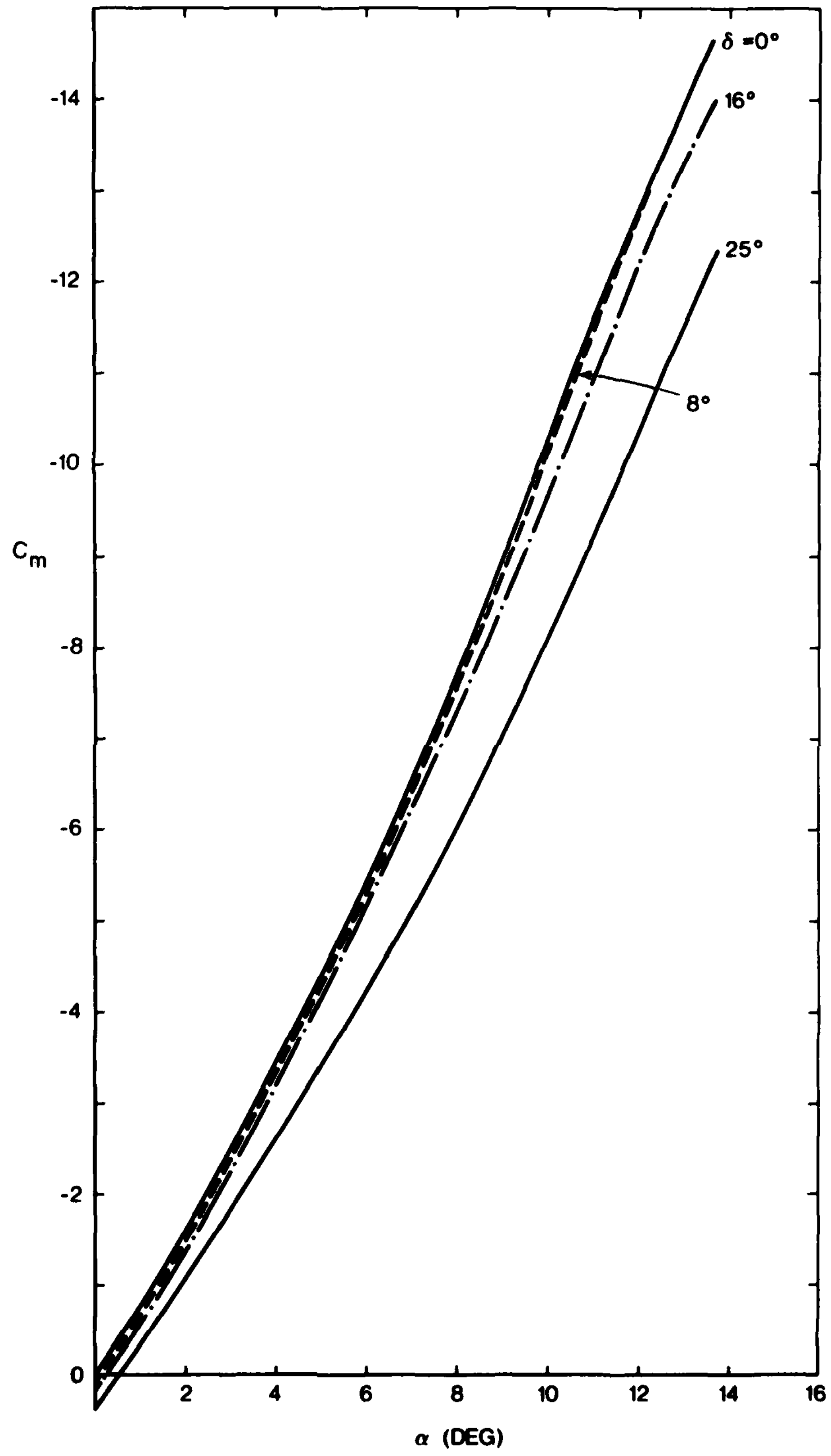
(a) M = 0.80, FINS 1

Figure 3. Pitching moment characteristics



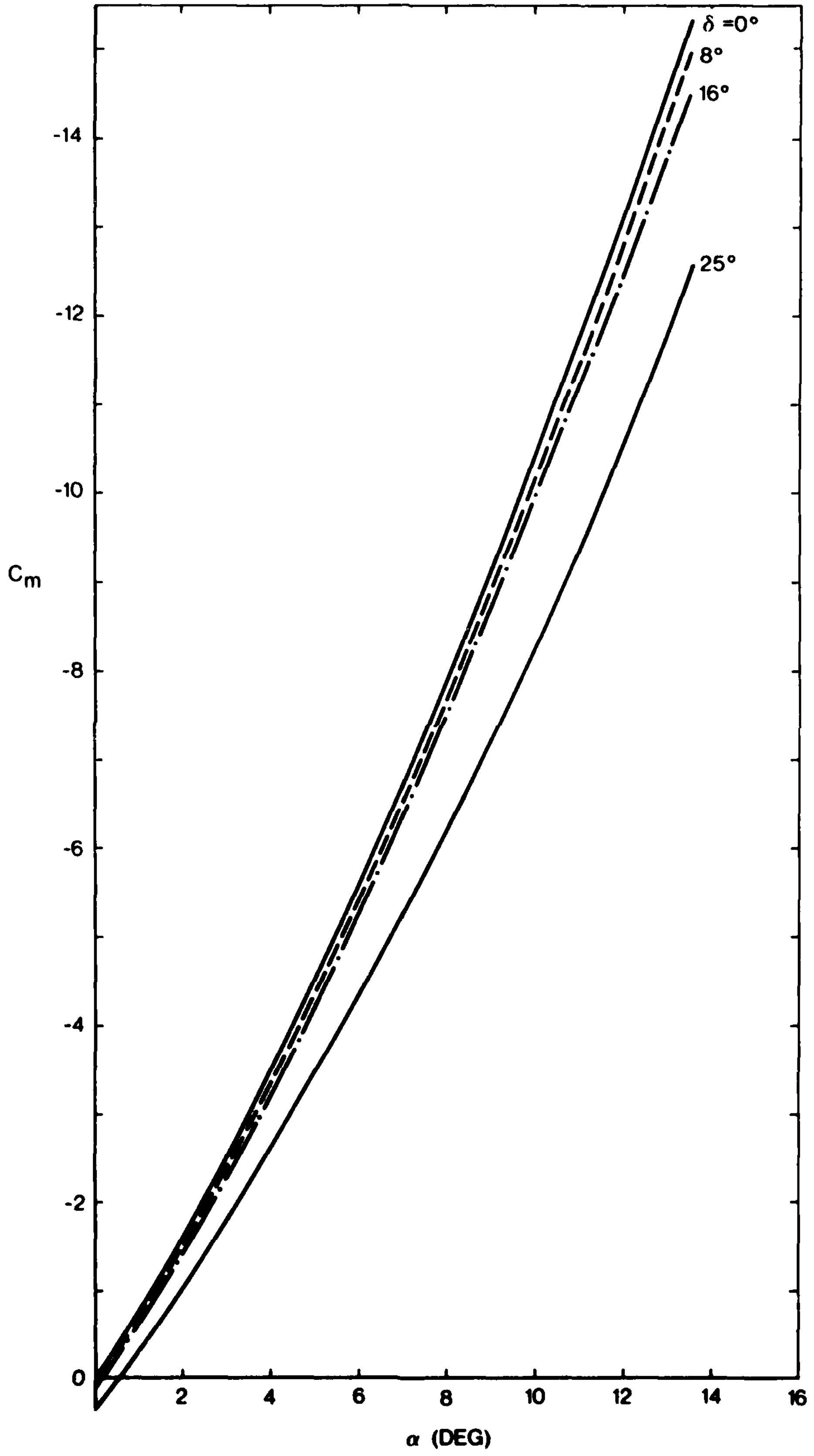
(b) M = 0.80, FINS 2

Figure 3(Contd.).



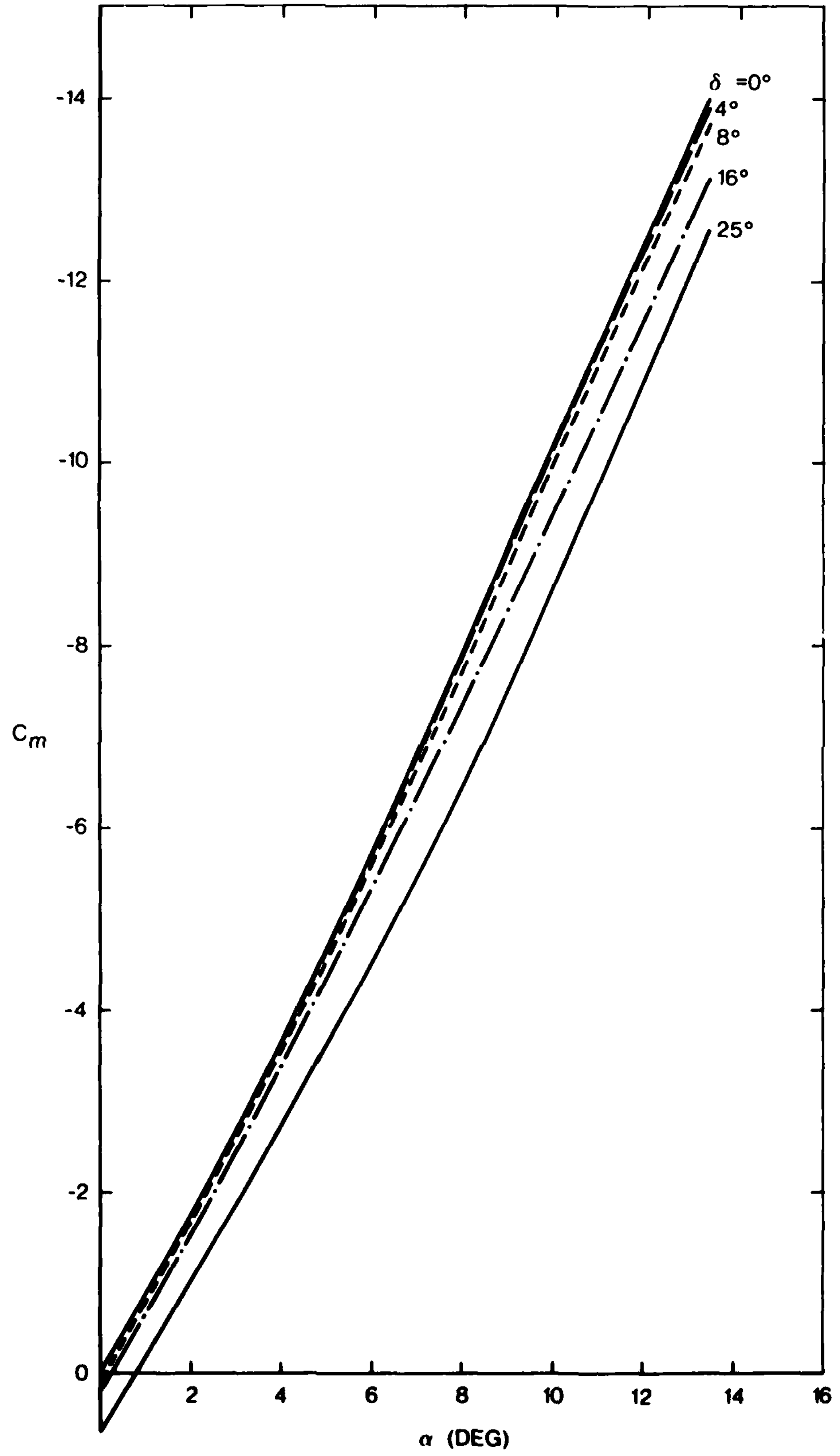
(c) M = 0.95, FINS 1

Figure 3(Contd.).



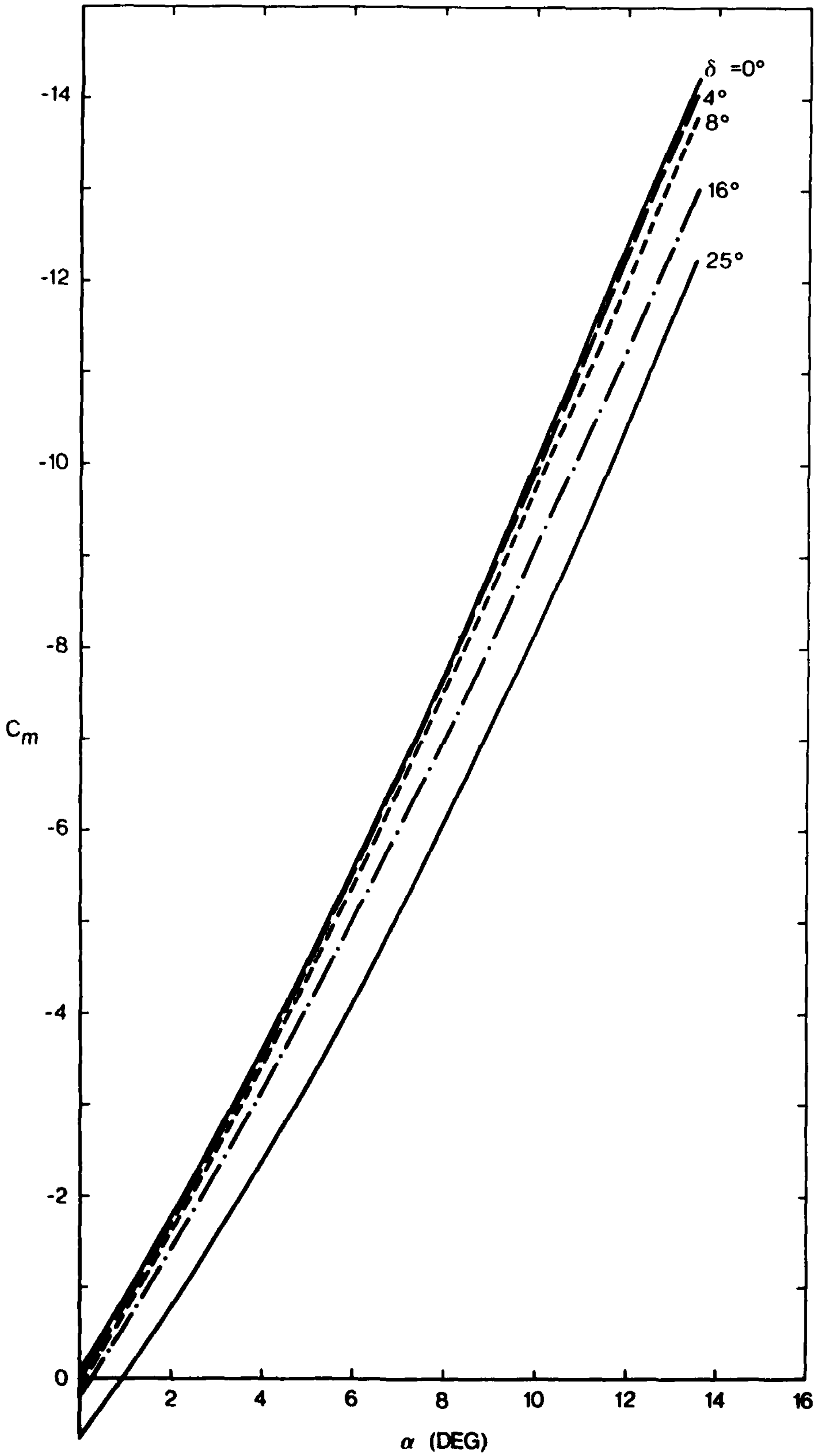
(d) M = 0.95, FINS 2

Figure 3(Contd.).



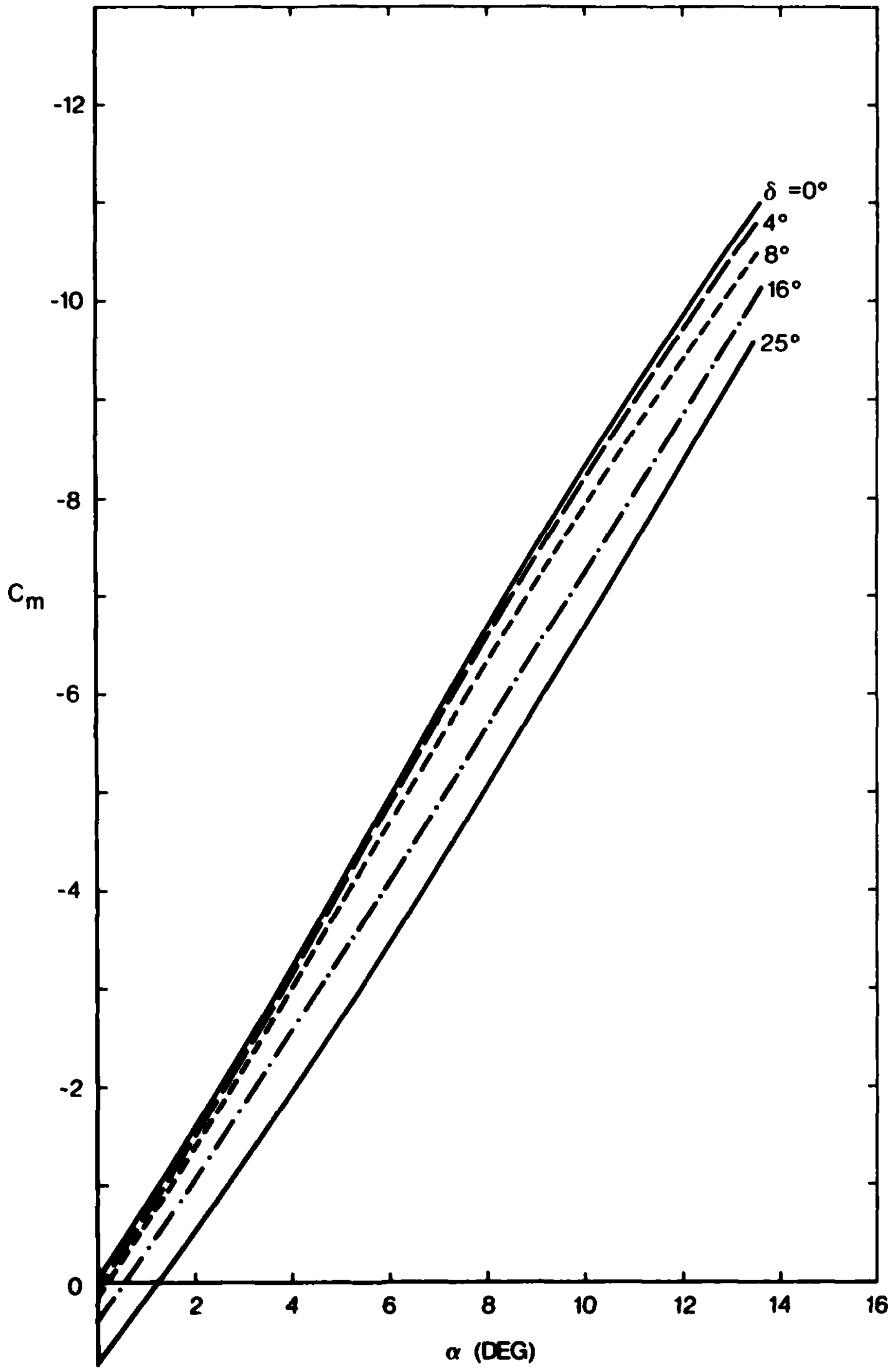
(e) M = 1.40, FINS 1

Figure 3(Contd.).



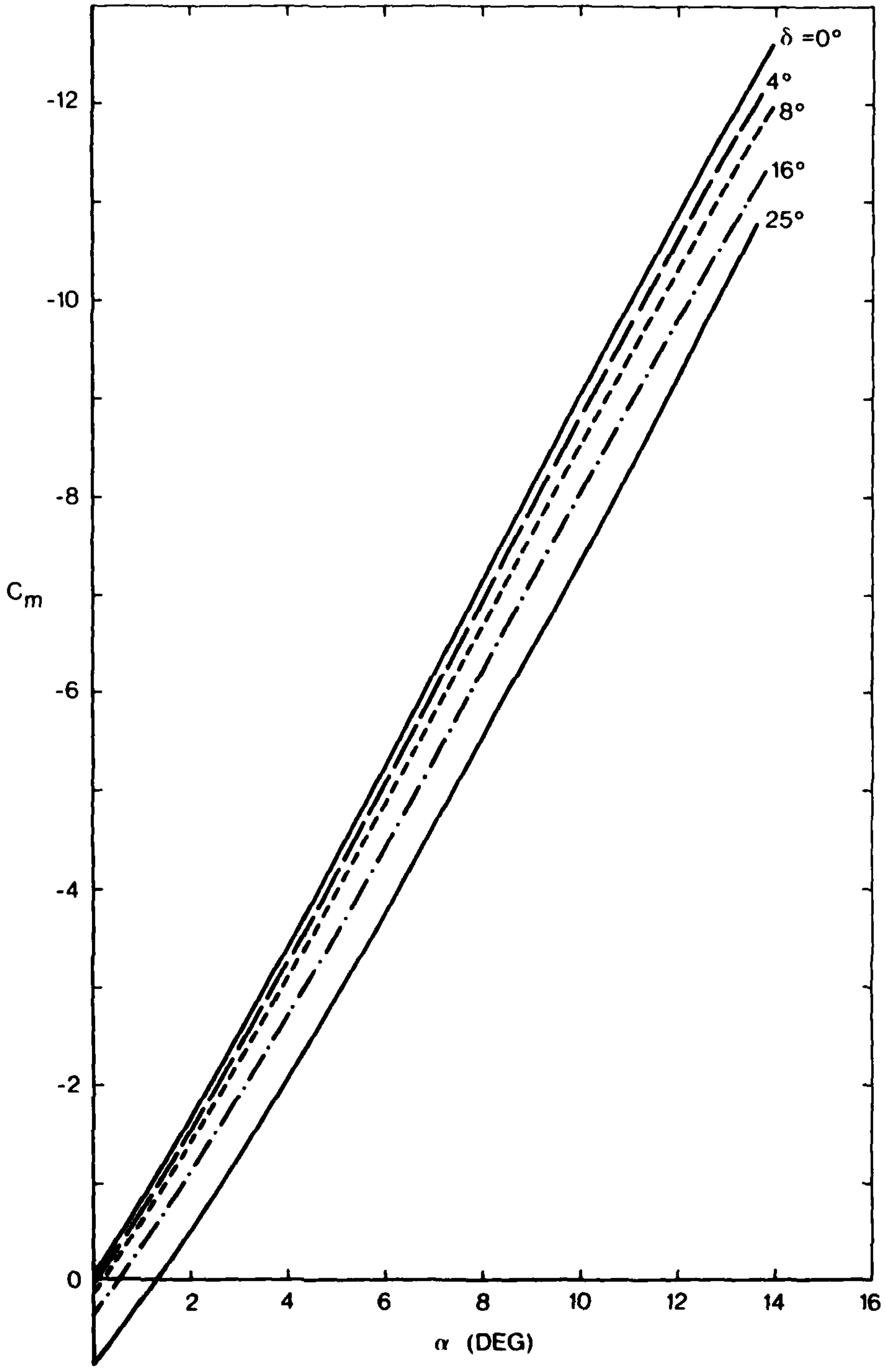
(f) M = 1.40, FINS 2

Figure 3(Contd.).



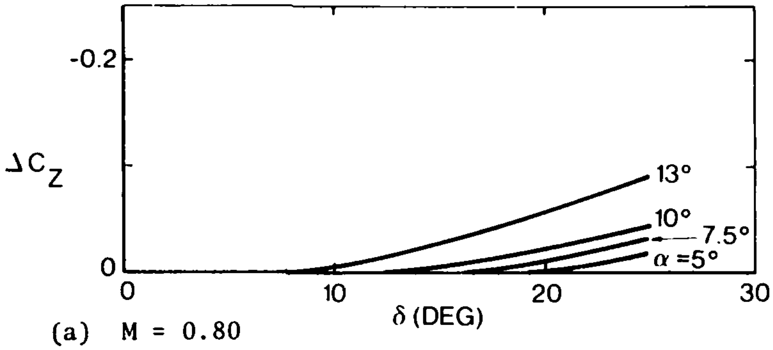
(g) M = 2.00, FINS 1

Figure 3(Contd.).

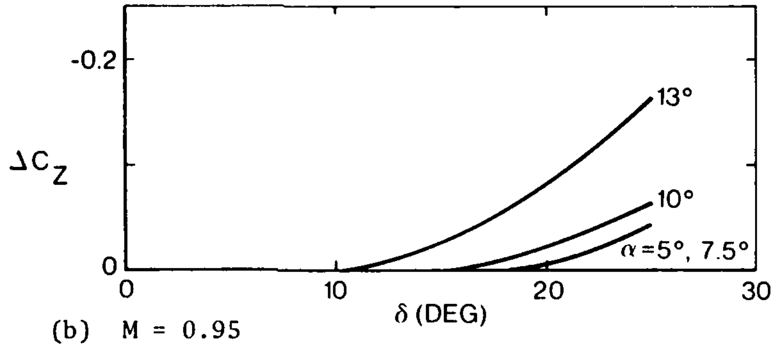


(h) M = 2.00, FINS 2

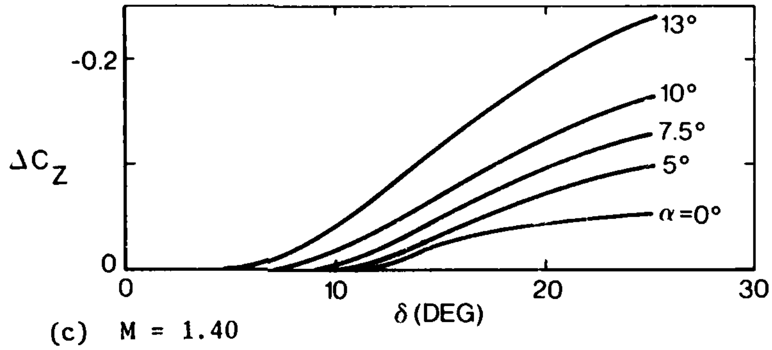
Figure 3(Contd.).



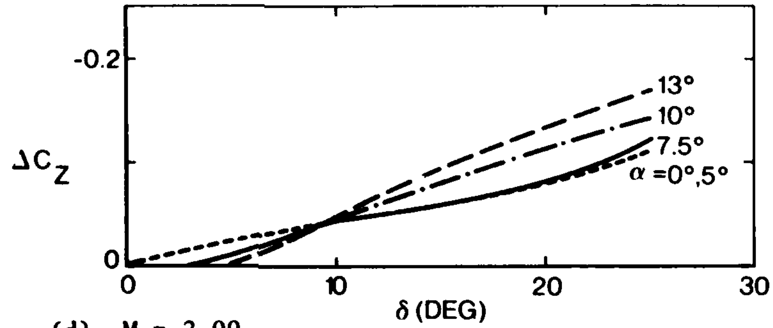
(a) M = 0.80



(b) M = 0.95



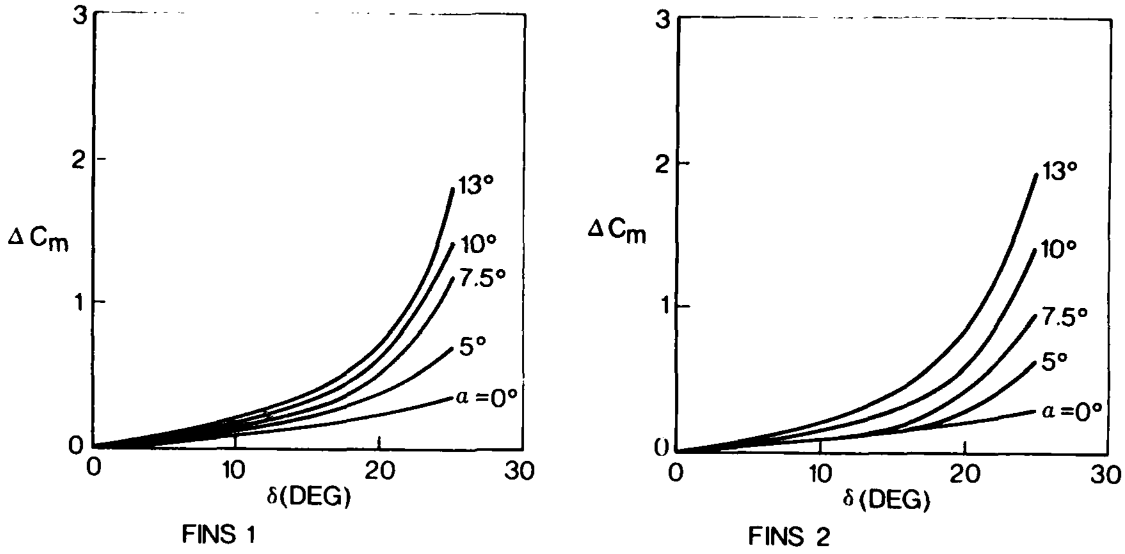
(c) M = 1.40



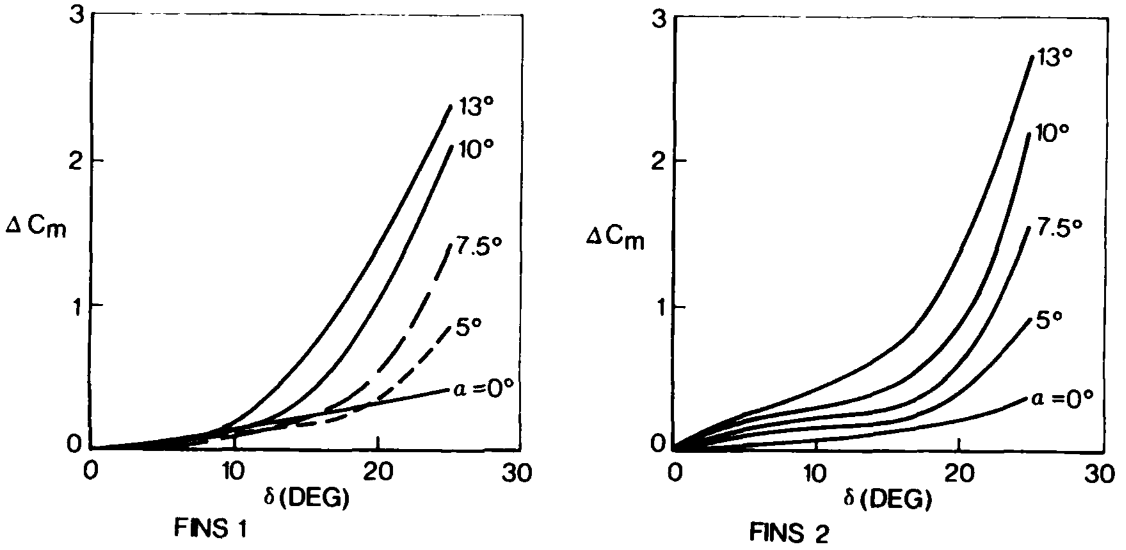
(d) M = 2.00

FINS 1

Figure 4. Increment in normal force coefficient due to control deflection.

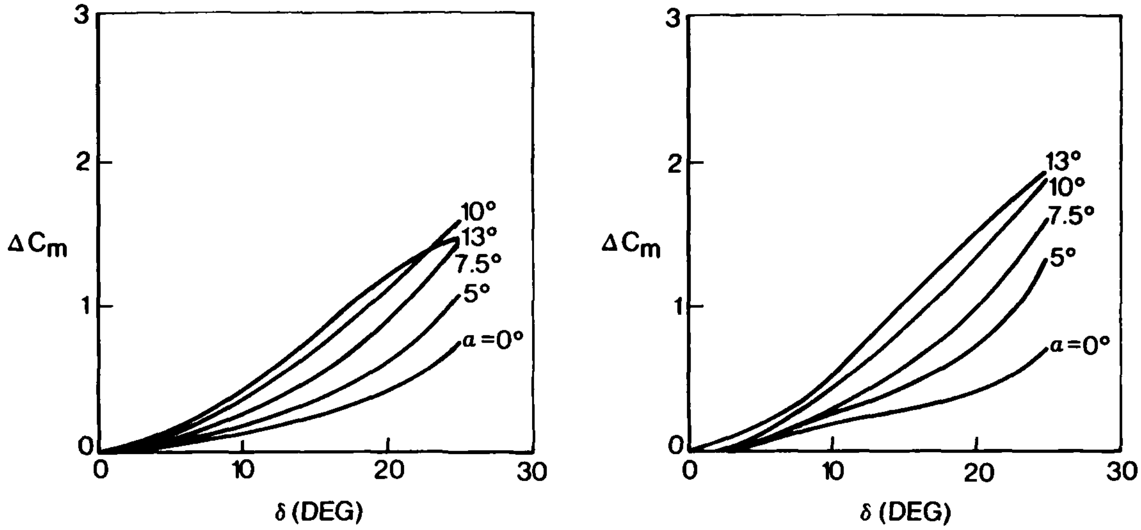


(a) M = 0.80



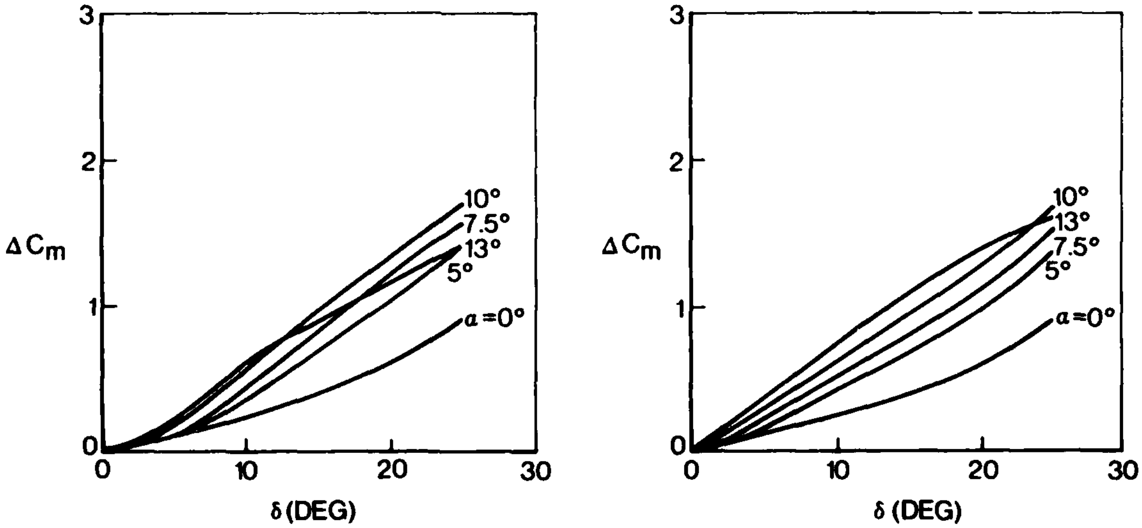
(b) M = 0.95

Figure 5. Increment in pitching moment coefficient due to control deflection



FINS 1 FINS 2

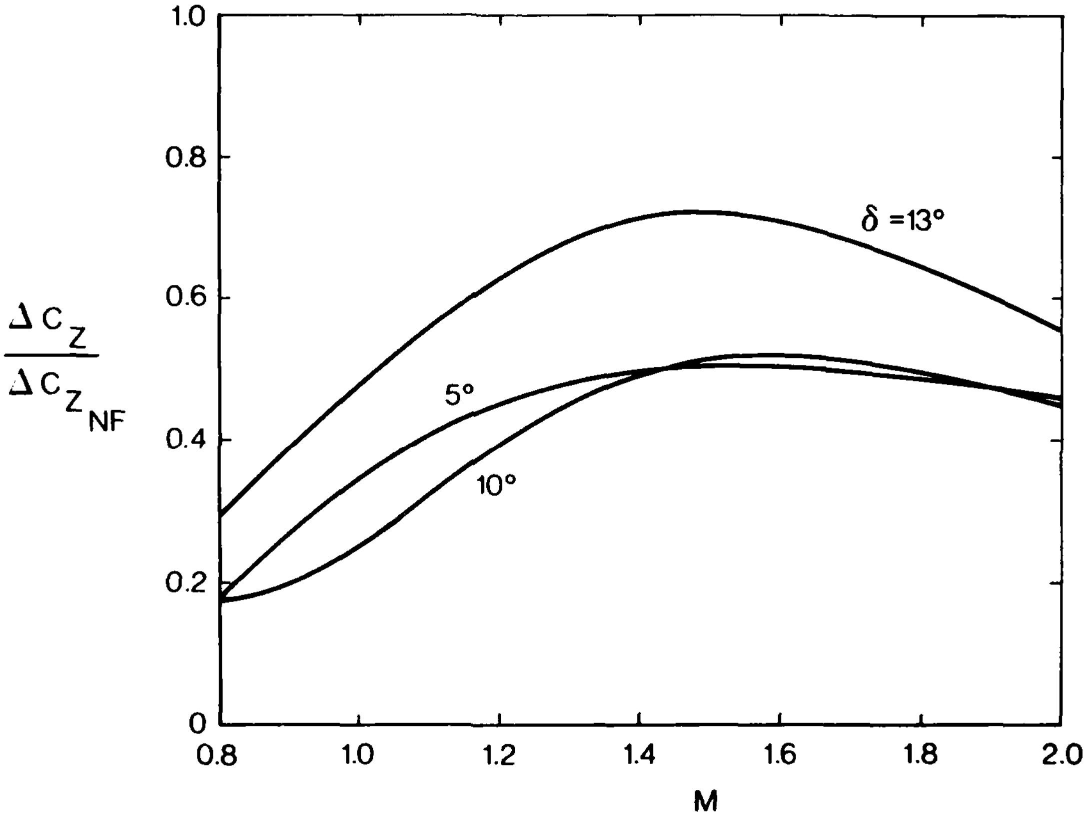
(c) M = 1.40



FINS 1 FINS 2

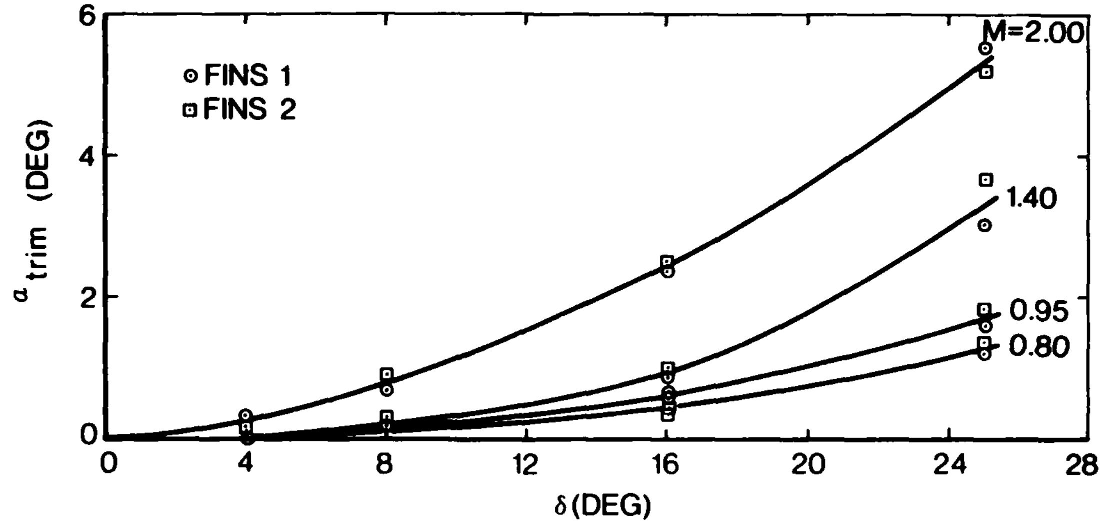
(d) M = 2.00

Figure 5(Contd.).

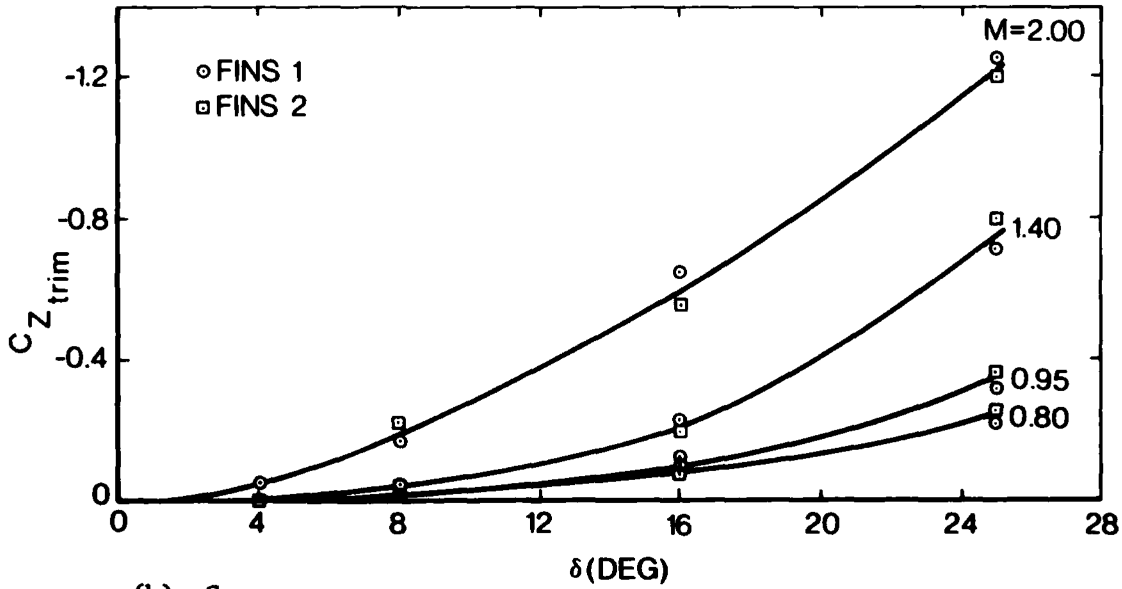


δ = 25°

Figure 6. Effect of stabilising fins on normal force increment due to deflection of nose control



(a) a_{trim}



(b) $C_{Z_{trim}}$

Figure 7. Trim curves for missile configuration with CG 5.30 diameters behind nose

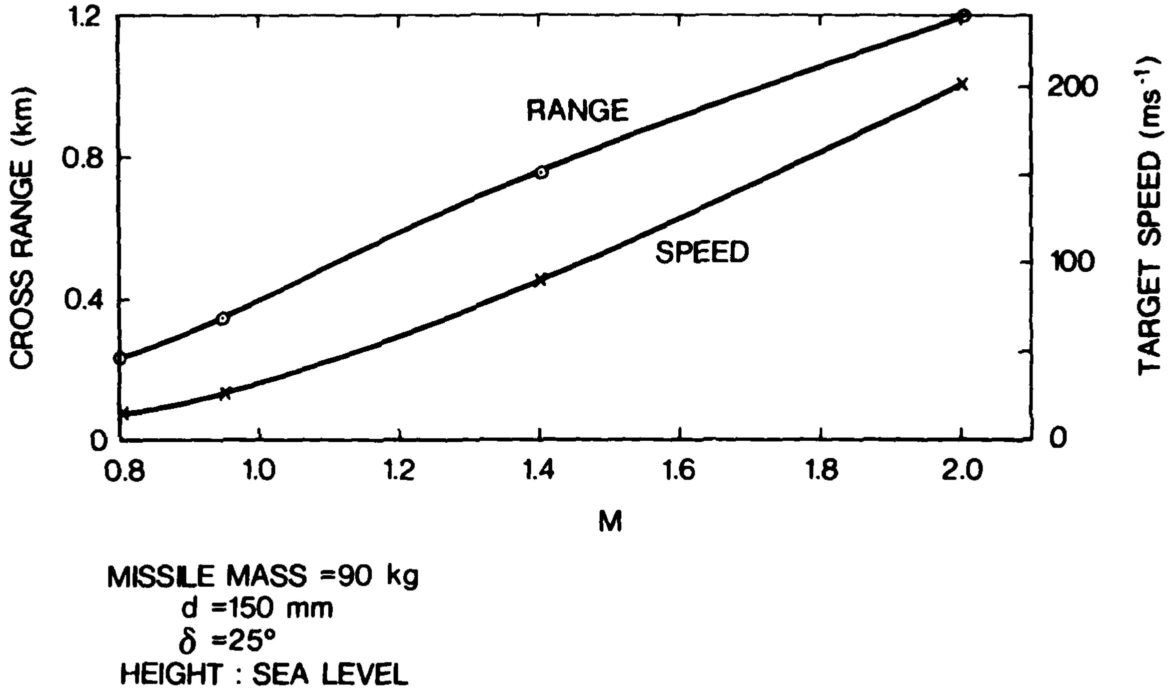


Figure 8. Maximum cross range and limiting target speed for hypothetical missile with full control applied 4 km from target

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Experiments have been conducted in the Mach number range 0.80 to 2.00 on a tube-launched missile configuration with a deflectable nose control and a wrap-around fin stabiliser having six fins disposed in a symmetrical triform arrangement. The results show that the control effectiveness increases markedly with Mach number. Trim curves are non-linear at subsonic speeds and approach linearity at supersonic Mach numbers.

The results have been applied to a small hypothetical missile configuration and indicate that the nose control is powerful enough to provide a terminal control capability. For the case considered, in subsonic flight the missile must fly on a near-ballistic trajectory. However, in supersonic flight the control is powerful enough to permit horizontal flight above M = 1.5 while retaining a sufficient reserve to provide a terminal correction capability. Detailed control system assessments have not been made.

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