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Wind Tunnel Tests on a 1/12th Scale Model of the Bristol Type 188 Research Aircraft with Rectangular, Wedge Intakes at Mach Numbers from 2.0 to 2.7

by

T. A. Cook, B.Sc.

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WIND TUNNEL TESTS ON A 1/12TH SCALE MODEL OF THE BRISTOL TYPE 188 RESEARCH AIRCRAFT WITH RECTANGULAR, WEDGE INTAKES AT MACH NUMBERS FROM 2.0 TO 2.7

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SUMMARY

A 1/12th scale model of the Bristol Type 188 research aircraft with modified intakes has been tested in the 8 ft × 8 ft wind tunnel at R.A.E., Bedford, at Mach numbers of 2.00, 2.20, 2.40 and 2.70. The tests were made to investigate the effects of rectangular, wedge intakes on the model by comparing the results with those of previous tests[1,2] in which the model had axi-symmetric conical centrebody intakes. The comparison shows the effects of the new intakes on longitudinal and lateral stability, drag and tailplane power, the most important of these being a forward shift of approximately 10% $\bar{c}$ in aerodynamic centre and a reduction of directional stability.

Replaces A.R.C. 25 028.

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1 INTRODUCTION

It was suggested, as part of the flight development programme for the Bristol Type 188 research aircraft, that consideration should be given to one aircraft fitted with rectangular, variable-wedge intakes. The aircraft was designed with circular intakes having conical centrebodies, offering a speed capacity of up to about Mach 2. With the suggested rectangular intakes it was hoped that it should be possible to reach a Mach number of about 2·75, the wedge angle and throat area on the intake being variable.

As is apparent from Fig.1, the new intakes extend some distance ahead of the original, conical centrebody intakes and consequently could be expected to have significant effects on the aerodynamic characteristics of the aircraft. The purpose of the tests described in this note was to determine these effects using a 1/12th scale model previously tested with conical centrebody intakes[1,2]. Tests were made at Mach numbers of 2.00, 2.20, 2.40 and 2.70 (for direct comparison with the results of Ref.2) in the 8 ft × 8 ft wind tunnel at R.A.E., Bedford.

2 THE MODEL

The model tested was a 1/12th scale reproduction of the full-scale design mounted on a twin-sting support system (Figs.1 and 2). The principal dimensions of the model and other details are listed in Table 1. Fig.1 includes a comparison between the rectangular intakes of the present tests and the conical centrebody intakes of previous tests.

A full description of the model and balance arrangement is given in Ref.1. For the purpose of the present tests the original, circular nacelle cowlings and centrebodies were replaced by rectangular intakes with wedge angle and throat area appropriate to a Mach number of 2.75, i.e. the design condition. Externally the rectangular intake faired into the circular section of the engine nacelle aft of the intake (as on the full-scale design): internally, aft of the throat, the nacelle duct was designed to give a smooth change of cross-sectional area. The layout of a nacelle duct is shown in Fig.3.

3 THE TESTS

The tests were made in the 8 ft × 8 ft high speed wind tunnel at R.A.E., Bedford, at Mach numbers of 2.00, 2.20, 2.40 and 2.70. At M = 2.00, 2.20 and 2.40, the Reynolds number of the tests was 2.5×10^6, based on standard mean chord, but at M = 2.70 available tunnel power limited the Reynolds number to 2.1×10^6.

Three model configurations were tested, viz. the complete model with tailplane settings of -4° and -10° relative to the nacelle datum lines* and the model with tailplane and fin removed. (Aileron and rudder angles were zero for all tests.) The effects of the wedge intakes on overall stability, trim and tailplane power could thus be determined.

*The configuration with a tailplane setting of -10° was not tested at M = 2.20.

The ranges of nominal angles of incidence and sideslip covered are given in the following table:

α^{o}	β^{o}
-4	0, ±2
-2	0, ±2
0	0, ±1, ±2, ±4, ±6
+2	0, ±2
+4	0, ±1, ±2, ±4, ±6
+6	0, ±2
+8	0, ±1, ±2, ±4, ±6
+10	0, ±2
+12	0, ±2
+14	0

The model was tested both right way up and inverted, and the results were meaned to make some allowance for the effects of tunnel flow deflections at the position of the model.

The position of boundary layer transition was fixed using bands of distributed roughness, formed by sprinkling carborundum particles on to a very thin base of Araldite. Grade 100 carborundum powder was used which had a maximum particle height of about 0.008 in. above the model surface. Locations and widths of the roughness bands are included in the model details listed in Table 1. The efficacy of the roughness bands in promoting boundary layer transition on the wings was checked during the tests described in Ref.2 using the azobenzene technique.

The moment reference point of the model was at 18% of the standard mean chord, in the plane of the nacelle datum lines. Pitching moment coefficients have been based on $\bar{c}$. Angles of incidence and sideslip were derived using the tangent and sine definitions respectively and corrected for balance and sting distortion under load: the angles of incidence quoted are those of the nacelle datum lines. Axial force measurements were corrected for the difference between static pressure measured at the axial force units of the twin balances and free-stream static pressure. Correction to axial force was also made for the internal drag of the nacelles, though it should be noted that these corrections were based on a duct calibration with the conical centrebody intakes fitted. In all cases, this correction was found to be negligible compared with the accuracy of axial force measurement.

A further possible source of error lies in the fact that the intakes appeared to be spilling during the present tests. This is evident from the measurement of mass flow using pitot and static pressure measurements near each duct exit. Values of the mass flow ratio A_o/A_{EN}, where A_o is the upstream cross-sectional area of the stream-tube swallowed by each nacelle and A_{EN} is the projected frontal area of the intake at zero incidence and sideslip, are shown in Fig.4 for a few different model attitudes. The plots represent mean values for the port and starboard ducts. At M = 2.75, the design Mach number of the intakes on the model, there is over 20% spillage. The schlieren photographs of Fig.5 support this conclusion qualitatively at M = 2.00, where there is most spillage.

The accuracy of the tests was assumed to be the same as that for the tests of Ref.2. Errors were estimated to be as follows:-

C_L	:	±0.003	$\pm 0.004\ C_L$
C_Y	:	±0.002	$\pm 0.002\ C_Y$
C_D	:	±0.007	$\pm 0.007\ C_Y$
C_m	:	±0.0005	$\pm 0.003\ C_m$
C_ℓ	:	±0.0007	$\pm 0.004\ C_\ell$
C_n	:	±0.0007	$\pm 0.007\ C_n$

Resolution errors in angles of incidence and sideslip were ±0.01°: tunnel flow deflections were less than about 0.2° over the model (this effect has been corrected for as far as possible).

4 PRESENTATION AND DISCUSSION OF RESULTS

Results of the tests are presented graphically in Figs.6 to 22. In all these figures, a comparison is made between the results of the present tests and those of corresponding tests made with conical centrebody intakes[2]: thus the figures show the effects of substituting the wedge intakes for the conical centrebody intakes. Only the direct effects of this substitution are discussed since the overall aerodynamics of the model have already been fully discussed in Ref.2.

4.1 Lift and pitching moment

Lift-curves are plotted in Figs.6, 7 and 8, and pitching moments in Fig.9. Lift-curve slopes at zero incidence and longitudinal stability slopes at zero lift are shown in Figs.10 and 11 respectively. The effects of the wedge intakes on tailplane power and the mean angle of downwash at the position of the tailplane are shown in Figs.12 and 13 respectively. The present tests included tailplane settings of -4° and -10° only, whereas the results quoted in Ref.2 for the model with conical centrebody intakes were obtained by averaging the results from three tailplane settings, viz. -4°, -10°, -14°. Tailplane power and downwash angles for the tests with the conical centrebody intakes have therefore been re-calculated using the results for settings of -4° and -10° only, to give a more accurate comparison in Figs.12 and 13. (In the tests of Ref.2, curves of pitching moment against tailplane setting were found to be non-linear.)

The most significant effects of the wedge intakes are those on pitching moment (Fig.9) and longitudinal stability (Fig.11). The change of intake results in a shift forward of aerodynamic centre position of roughly 0.1 $\bar{c}$, this shift being approximately constant with Mach number. The difference in pitching moment (Fig.9) is maximum at high values of C_L becoming zero at a lift coefficient of about -0.2 to -0.4. The shift in aerodynamic centre position is to be expected from the increased lifting area provided by the wedge intakes (Fig.1), in particular the forward extension of the upper lip. The situation is, however, complicated by intake spillage (which is most likely to have been below the intake), and also because some pitching moment is generated by vertical changes in momentum of the air swallowed by the intake (this latter effect produces no resultant lift).

Flow complications are more evident in lift effects on the model, particularly with the tailplane and fin off. The extension forward of the intakes, which result in the centre of pressure movement mentioned above, might be expected to produce an overall increase of lift-curve slope, but, as is shown in Fig.10, this is only apparent above M = 2.20. At M = 2.00 the wedge intakes result in a loss of lift-curve slope, probably as an effect of spillage air aft of the intakes. Since spillage increases with decreasing Mach number it will have most influence on the external aerodynamics at the low Mach number end of the test range. A similar explanation would apply to lift effect at zero incidence. At M = 2.70 there is a positive lift increment due to the wedge intakes (Figs.6-8), which decreases with decreasing Mach number.

Figs.12 and 13 show the influence of the wedge intakes on the tailplane. In general (Fig.12) the new intakes result in increased tailplane power, though implying that the opposite will be the case at Mach numbers below 2.00. Downwash results at M = 2.00 (Fig.13) show that, when the tailplane is entirely in the downwash field aft of the wing, there is an almost constant increase in mean downwash angle of about 0.3°, due to the wedge intakes. This appears to be true at other Mach numbers also, though these variations are complicated by the fact that part or all of the tailplane is forward of the wing trailing edge shock wave with consequently large flow variations over the tailplane chord.

4.2 Lateral derivatives

Variations of the lateral derivatives n_v, y_v and ℓ_v with model incidence are shown in Figs.14, 16 and 17 respectively.

Fig.14 shows a loss of n_v at all Mach numbers and incidences with the wedge intakes present. Most of this effect is a result of the additional side area forward of the moment reference point, as is seen from the tailplane and fin off results. There is in addition, however, some effect of the intakes on fin effectiveness (Fig.15). Fin effectiveness, Δn_v, has been defined as the increase in n_v of the model when the fin and tailplane, (the latter at a setting of -4°), are added to the model, without change of incidence. At M = 2.00, the wedge intakes cause a small decrease in fin effectiveness at most incidences, while at M = 2.70 they cause an increase in fin effectiveness.

The effect of the wedge intakes on y_v, (Fig.16), is not so consistent as that on n_v. At $M = 2.70$ there is a general loss of $-y_v$, but at other Mach numbers the effect on y_v is irregular. The effect on ℓ_v is similar, (Fig.17), there being no consistent differences.

4.3 Drag

Drag coefficients are plotted against lift coefficients in Figs.18, 19 and 20.

Parabolae of the form

$$C_D = C_{D_o} + \frac{K}{\pi A}\left(C_L - C_{L_o}\right)^2$$

have been fitted to the curves, where C_{D_o} is the minimum drag coefficient, C_{L_o} is the value of the lift coefficient at which $C_D = C_{D_o}$, K is the induced drag factor and A the aspect ratio of the wing. The values of C_{L_o}, averaged over the Mach number range, were as follows:

Configuration	$\eta = -4^o$	$\eta = -10^o$	Tailplane and fin off
Conical centrebody intakes	-0.004	-0.009	+0.006
Wedge intakes	0	-0.004	+0.004

Values of C_{D_o} and K are plotted in Figs.21 and 22 respectively.

The model with wedge intakes has a higher minimum drag than the model with conical centrebody intakes. The difference, however, decreases with increasing Mach number. The large possible error in drag (section 3) should be borne in mind in comparing drag results for the two intake configurations. A discussion of the effects of these errors is included in the discussion on drag in Ref.2: in particular, it should be noted that the estimated error in the difference between the drags of any two configurations is ±0.004, and that the minimum drag coefficients obtained from Ref.2, and reproduced in Fig.21, have been smoothed with the results for Mach numbers below 2.00 (Ref.1), and do not agree with the minima of the curves for the model with conical centrebody intakes shown in Figs.18 to 20. As explained in Ref.2, the error in the differences in drag is due mainly to hysteresis in the measurement of axial force, which, though constant for each configuration, is indeterminate.

Fig.22 shows that the model with wedge intakes has lower induced drag factors than the model with conical centrebody intakes. This is most probably a result of the redistributed lift of the model: the effect is similar to the reduction in induced drag due to adding the tailplane (and fin) to the model.

5 CONCLUSIONS

Results of tests on a 1/12th scale model of the Bristol Type 188 at Mach numbers from 2.00 to 2.70 with rectangular, wedge intakes have been compared with the results of Ref.2 describing similar tests with conical centrebody intakes. The comparison has shown:-

(1) Effects on lift are small. For the complete model, above M = 2.00, there is a small gain in lift and lift-curve slope at zero incidence, both of which increase with increasing Mach number.

(2) There are large changes in pitching moment due to a shift forward in aerodynamic centre position of about 10% of $\bar{c}$. Small effects on tailplane power and downwash were also observed.

(3) There is an overall reduction of directional stability due to the increase in forward side area and small changes in fin effectiveness. Irregular changes in y_v and ℓ_v occur.

(4) While there is a general increase in minimum drag coefficient due to substituting the wedge intakes for the conical centrebody intakes, there is a substantial reduction in induced drag factor.

LIST OF SYMBOLS

A	aspect ratio of nominal wing planform
b	wing span
$\bar{c}$	standard mean chord of nominal wing
S	gross area of nominal wing planform
q	free-stream dynamic pressure
M	free-stream Mach number
C_L	lift coefficient = lift force/qS
C_Y	side force coefficient = side force/qS
C_D	drag coefficient = drag force/qS
C_m	pitching moment coefficient = pitching moment/$qS\bar{c}$

LIST OF SYMBOLS (CONTD)

C_ℓ	rolling moment coefficient = rolling moment/qSb
C_n	yawing moment coefficient = yawing moment/q S b
α	angle of incidence of nacelle centre lines
β	angle of sideslip
η	tailplane angle relative to nacelle centre lines
ε	downwash angle relative to the free-stream direction
y_v	side force due to sideslip = $\frac{1}{2}\frac{\partial C_Y}{\partial \beta}$, β in radians
n_v	yawing moment due to sideslip = $\frac{\partial C_n}{\partial \beta}$, β in radians
ℓ_v	rolling moment due to sideslip = $\frac{\partial C_\ell}{\partial \beta}$, β in radians
C_{D_o}	minimum drag coefficient
C_{L_o}	lift coefficient corresponding to $C_D = C_{D_o}$
K	induced drag factor = $\pi A \frac{\partial C_D}{\partial \left(C_L - C_{L_o}\right)^2}$

LIST OF REFERENCES

Ref. No.	Author	Title, etc.
1	Taylor, C.R. Cook, T.A.	Supersonic wind tunnel tests on a 1/12th scale model of the Bristol Type 188 research aircraft; Part I; M = 1.4 to 2.0. A.R.C. 23 278. April, 1961.
2	Cook, T.A.	Supersonic wind tunnel tests on a 1/12th scale model of the Bristol Type 188 research aircraft. Part II; M = 2.0 to 2.7. A.R.C. 23 748. September, 1961.

TABLE 1

Principal details of the model

Scale:	1/12th
Wing:	
Area, S	2.75 sq ft
Span, b	2.924 ft
Aspect ratio, A	3.108
Standard mean chord, $\bar{c}$	0.941 ft
Aerodynamic mean chord, $\bar{\bar{c}}$	1.025 ft
Distance of leading edge of $\bar{\bar{c}}$ aft of leading edge of inboard wing	0.143 ft
Dihedral	0
Wing-body (wing-nacelle) angle	2°
Sweepback of leading edge:-	
Inboard of nacelles	0
Outboard of nacelles	38°
Aileron horn	65°
Sweep-forward of trailing edge	5°
Section (excluding aileron horns)	Biconvex, circular arc with sharp leading edge; t/c = 4%; maximum thickness at 55% on inboard wing and 51% on outboard wing.
Section (aileron horns)	Faired from above section to 8% R.A.E. 104 section at the tip.
Gap between wing and aileron horn	0.008 in.
Fuselage:	
Length	5.917 ft
Fin:	
Area	0.528 sq ft
Sweepback of leading edge	64°
Section	Modified R.A.E. 104 section with constant maximum thickness, t/c = 4% at tip.

TABLE 1 (CONTD)

Tailplane:	
Area	0.484 sq ft
Span	1.292 ft
Aspect ratio	3.4
Root chord	0.5 ft
Tip chord	0.25 ft
Section	4.5% circular arc
Height of tailplane pivot above nacelle datum lines	0.682 ft
Distance of pivot aft of moment reference point	2.418 ft
Nacelles:	
Distance of nacelle centre-lines outboard of fuselage centre-line	0.625 ft
Roughness bands:	
Wings; band width	5% of chord
position of forward edge	$2\frac{1}{2}$% of chord
Aileron horns; band width	0.25 in.
position of forward edge	0.25 in. aft of leading edge
Fuselage; band width	0.5 in.
position of forward edge	1.0 in. aft of nose
Fin; band width	0.5 in.
position of forward edge	at leading edge
Tailplane; band width	0.5 in.
position of forward edge	0.25 in. aft of leading edge
Nacelles; band width	0.5 in.
position of forward edge	0.25 in. aft of lip (external surfaces only).

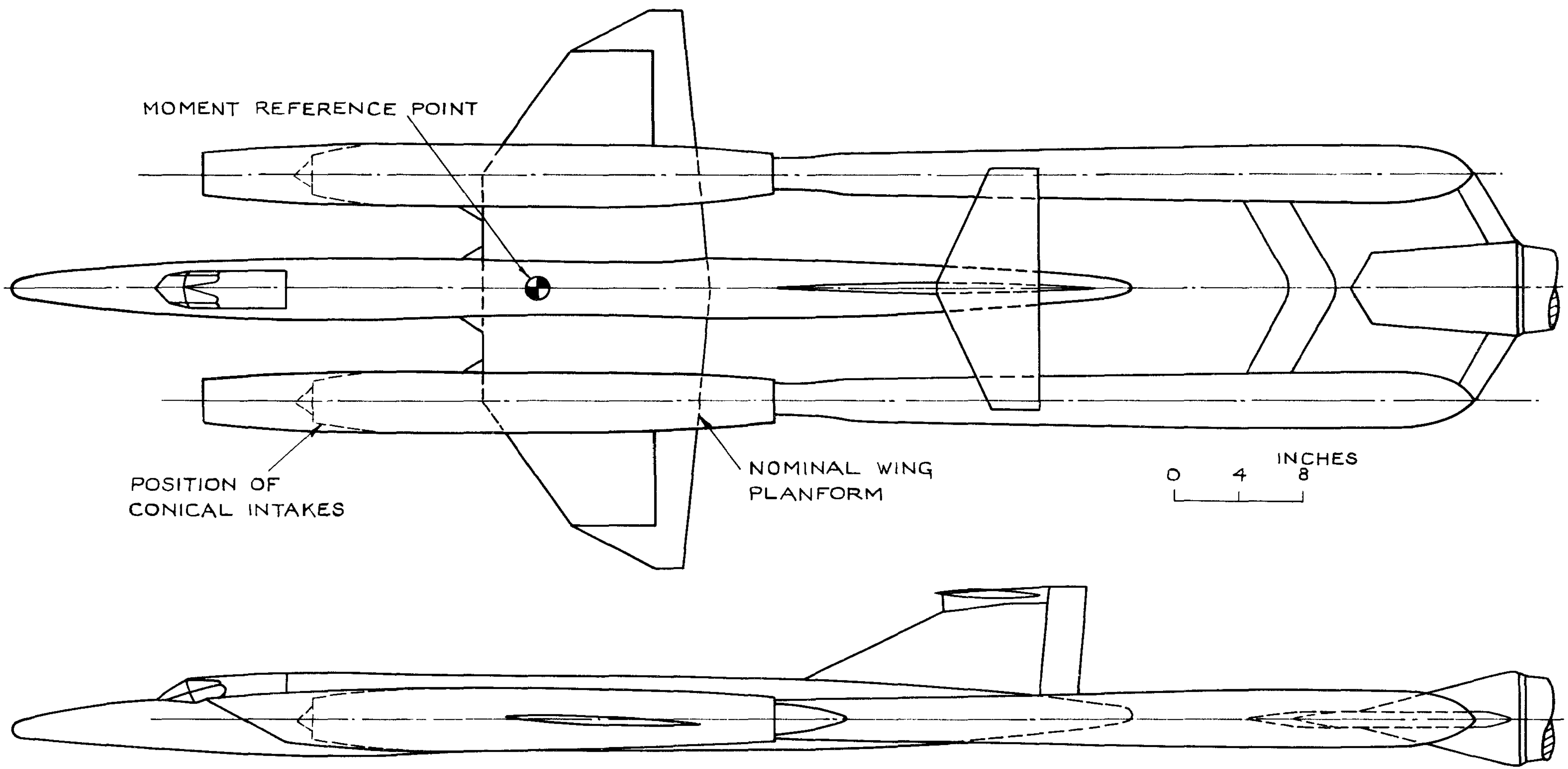


FIG.1. GENERAL ARRANGEMENT OF MODEL AND SUPPORT SYSTEM.

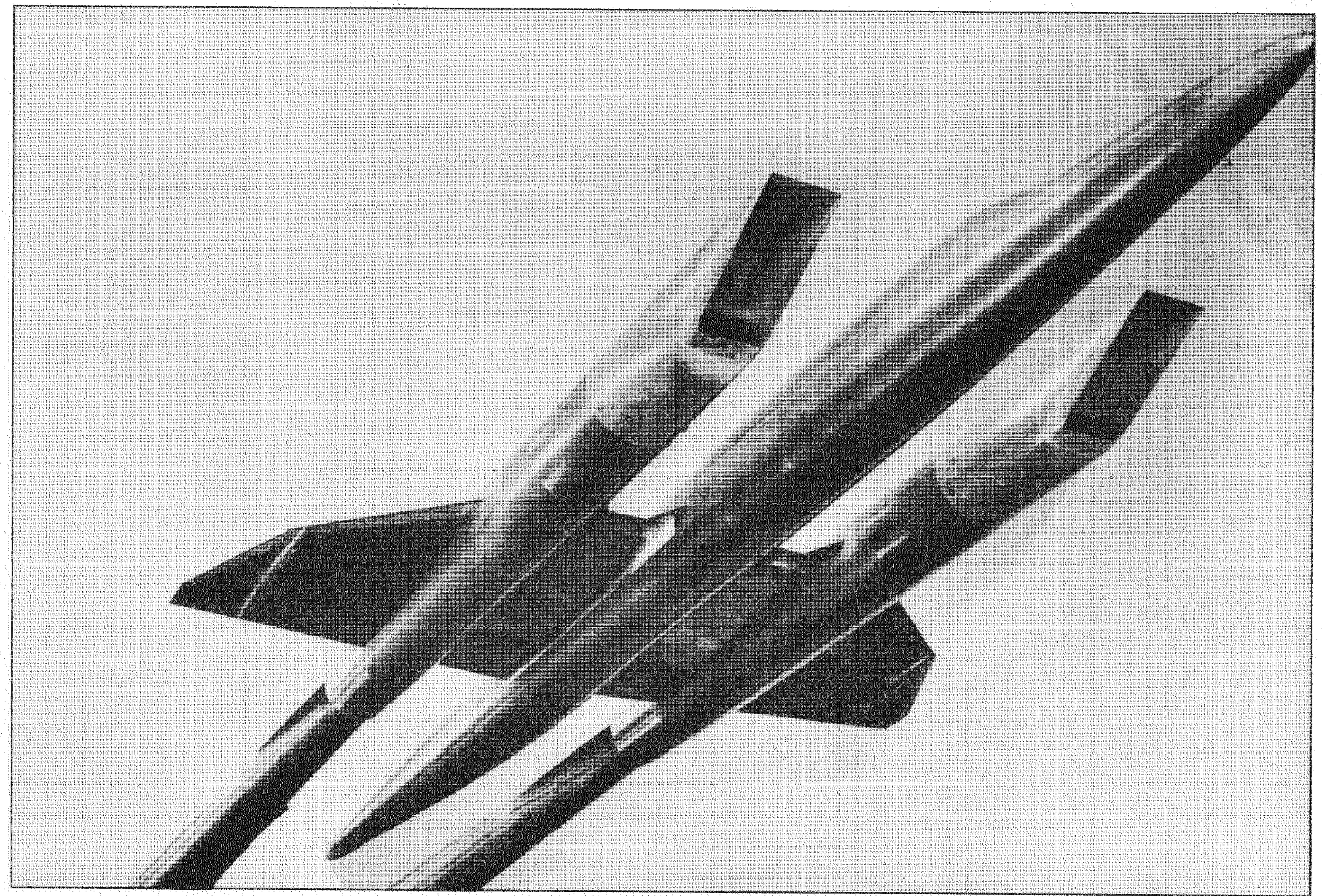


FIG.2. MODEL MOUNTED ON STING SUPPORTS

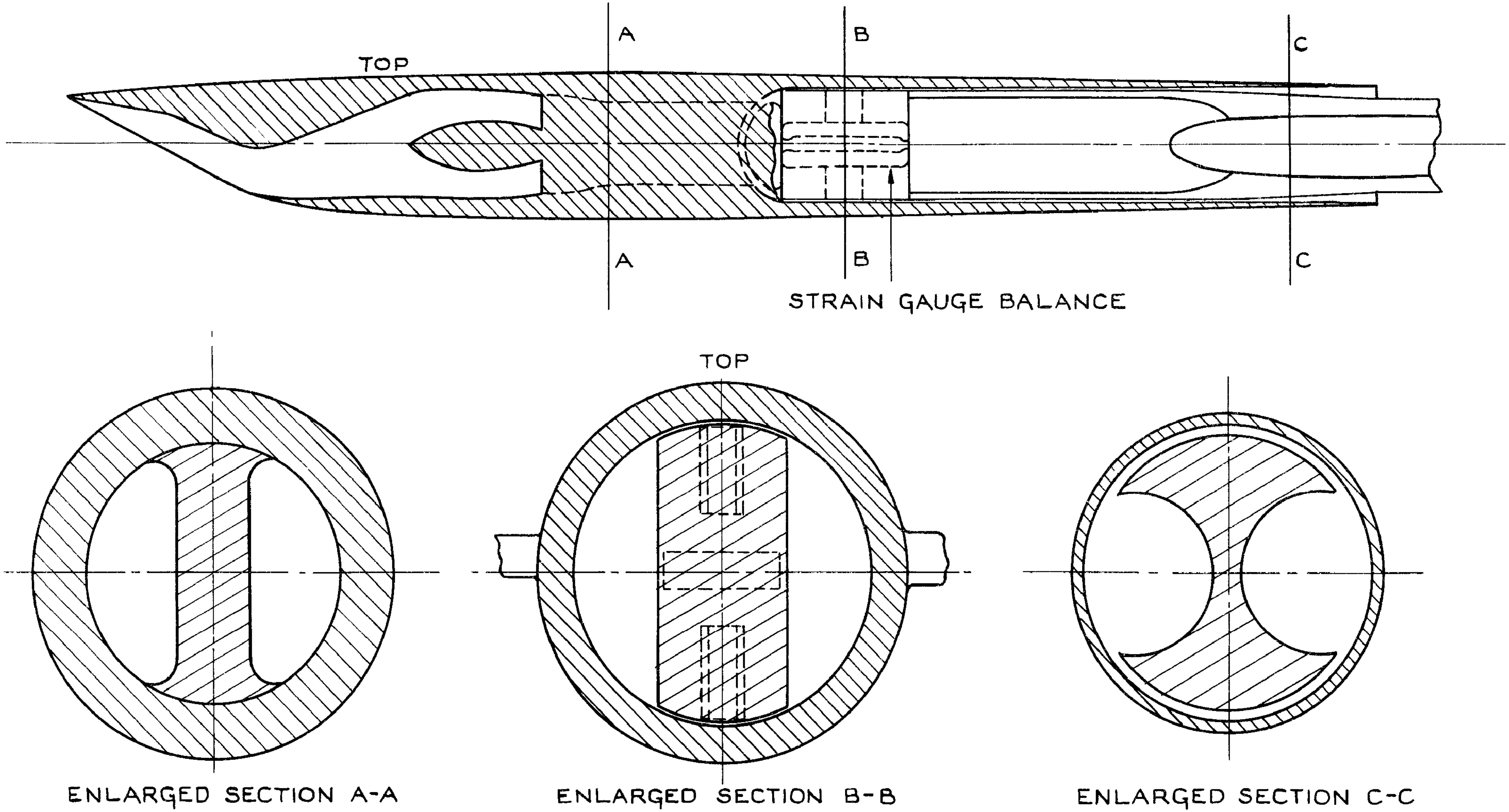


FIG. 3. GENERAL ARRANGEMENT OF NACELLE.

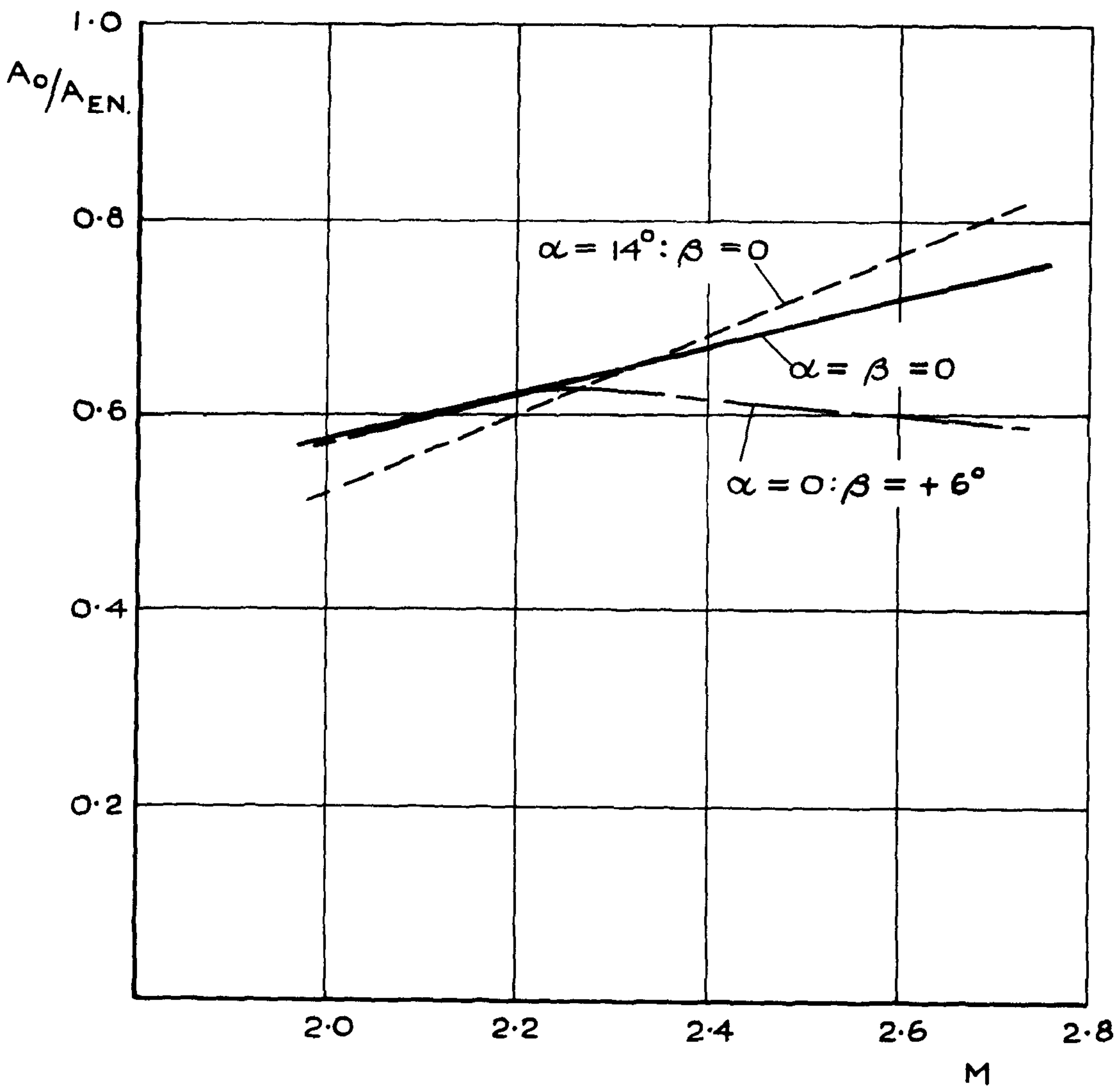
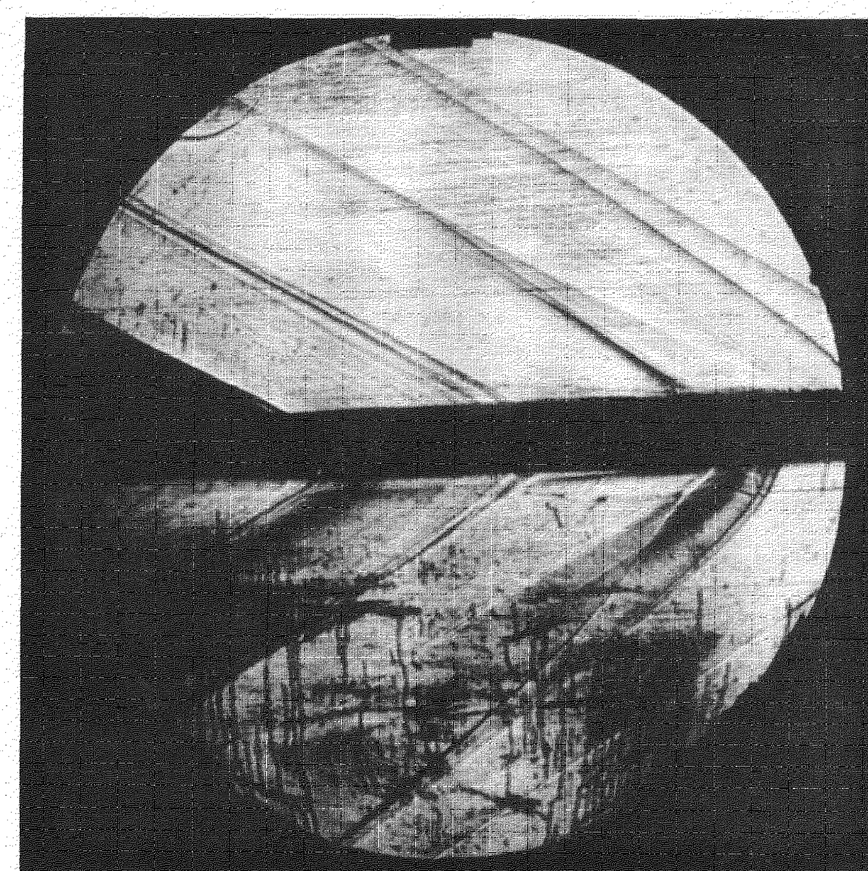
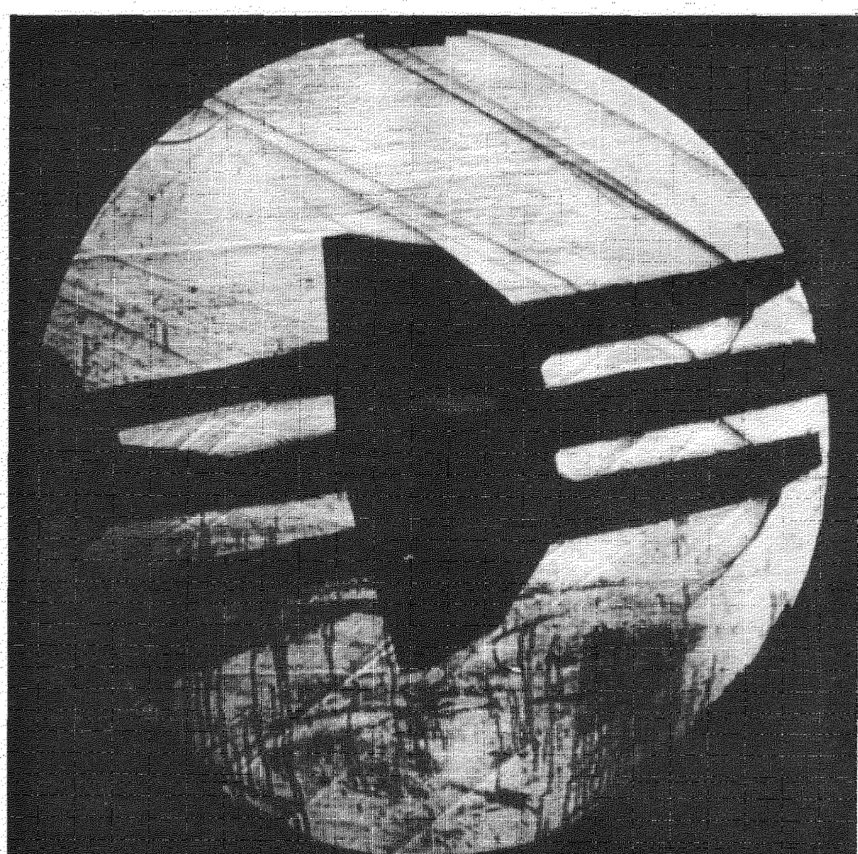


FIG.4. MEAN DUCT MASS FLOW.



(a) $\alpha = 0 : \beta = 0$



(b) $\alpha = +4^\circ : \beta = +6^\circ$

FIG.5. SCHLIEREN PHOTOGRAPHS AT M = 2·00

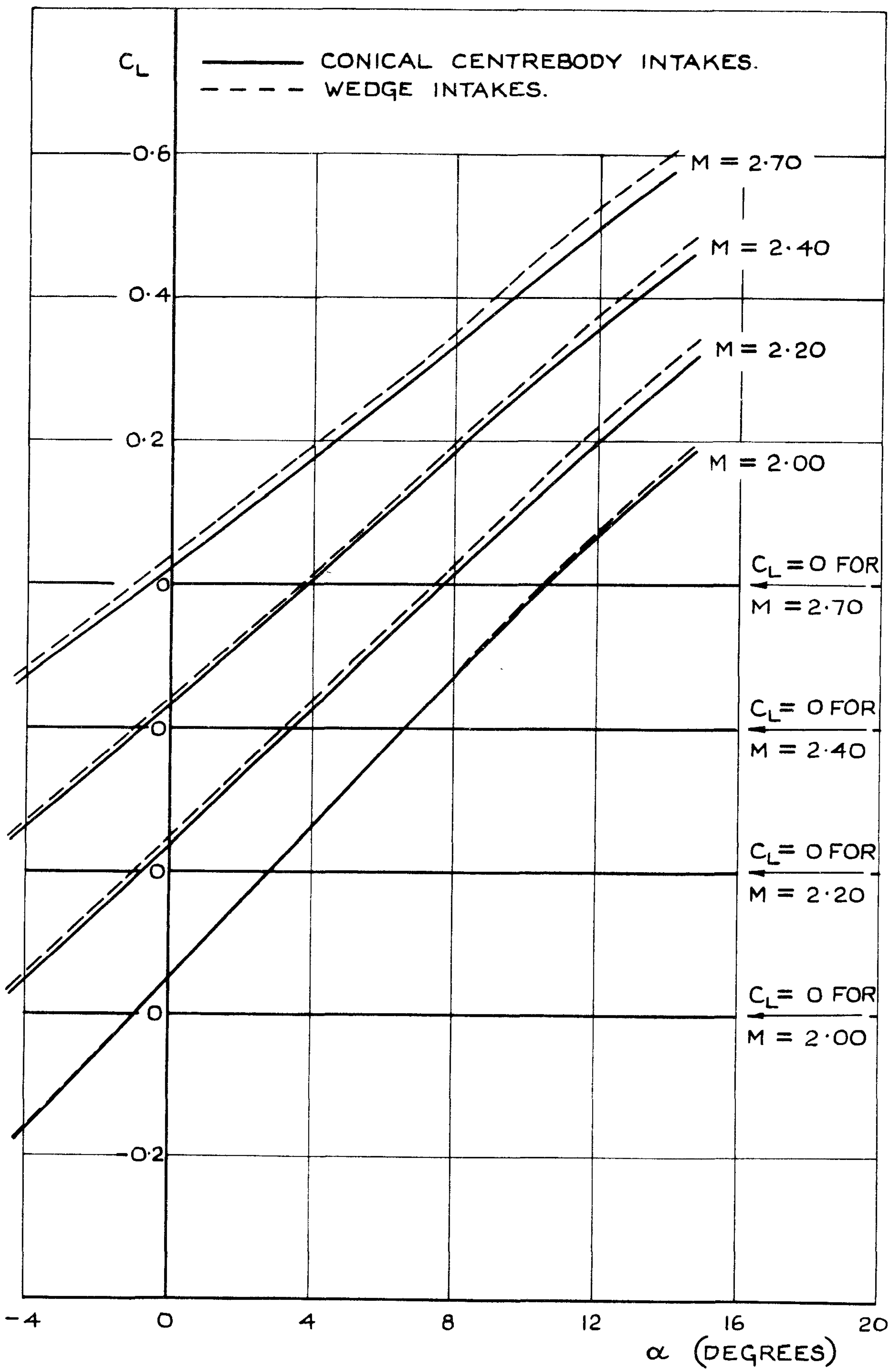


FIG. 6. VARIATION OF C_L WITH α: $\eta = -4°$.

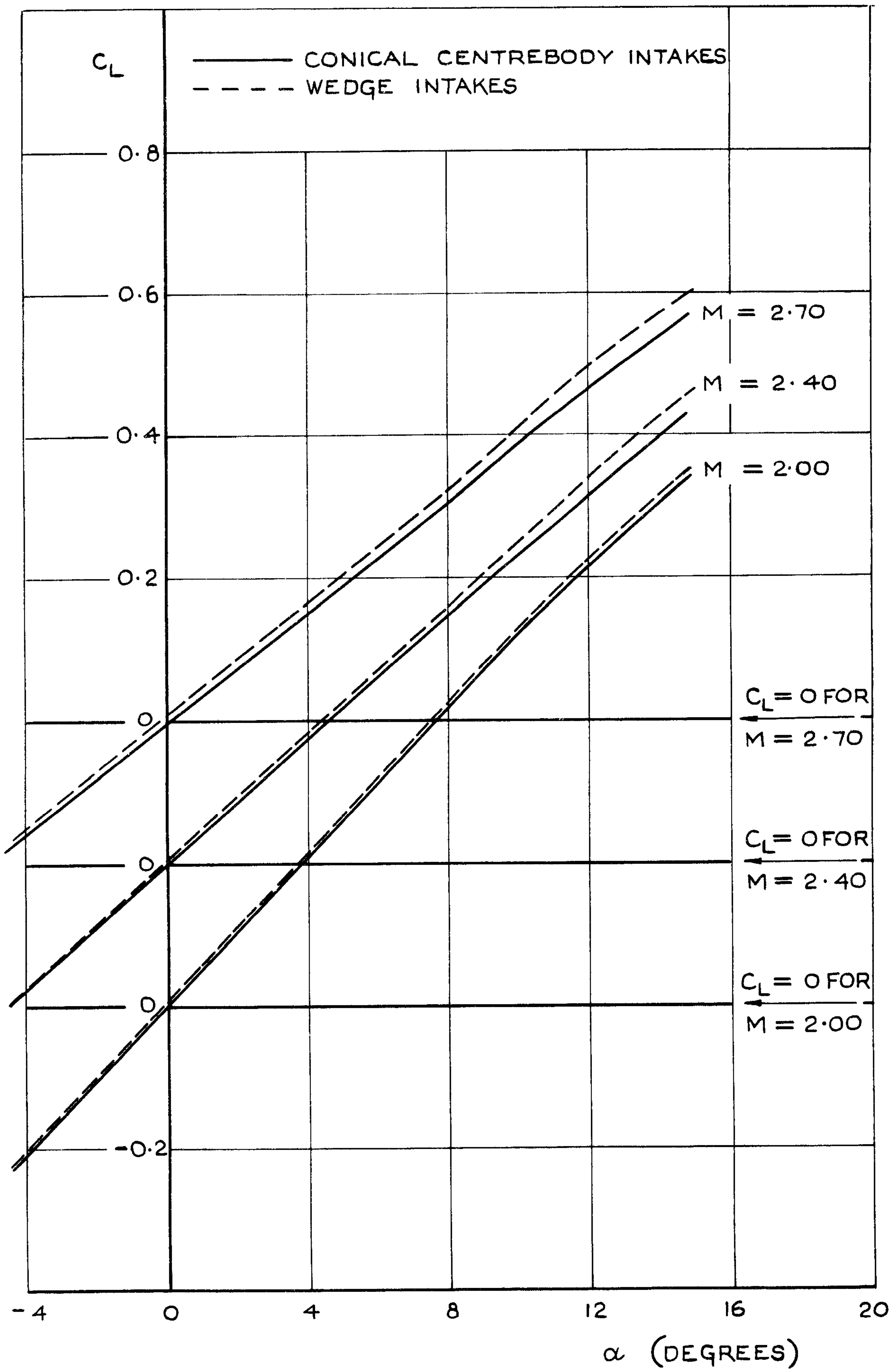


FIG.7. VARIATION OF C_L WITH α: $\eta = -10°$.

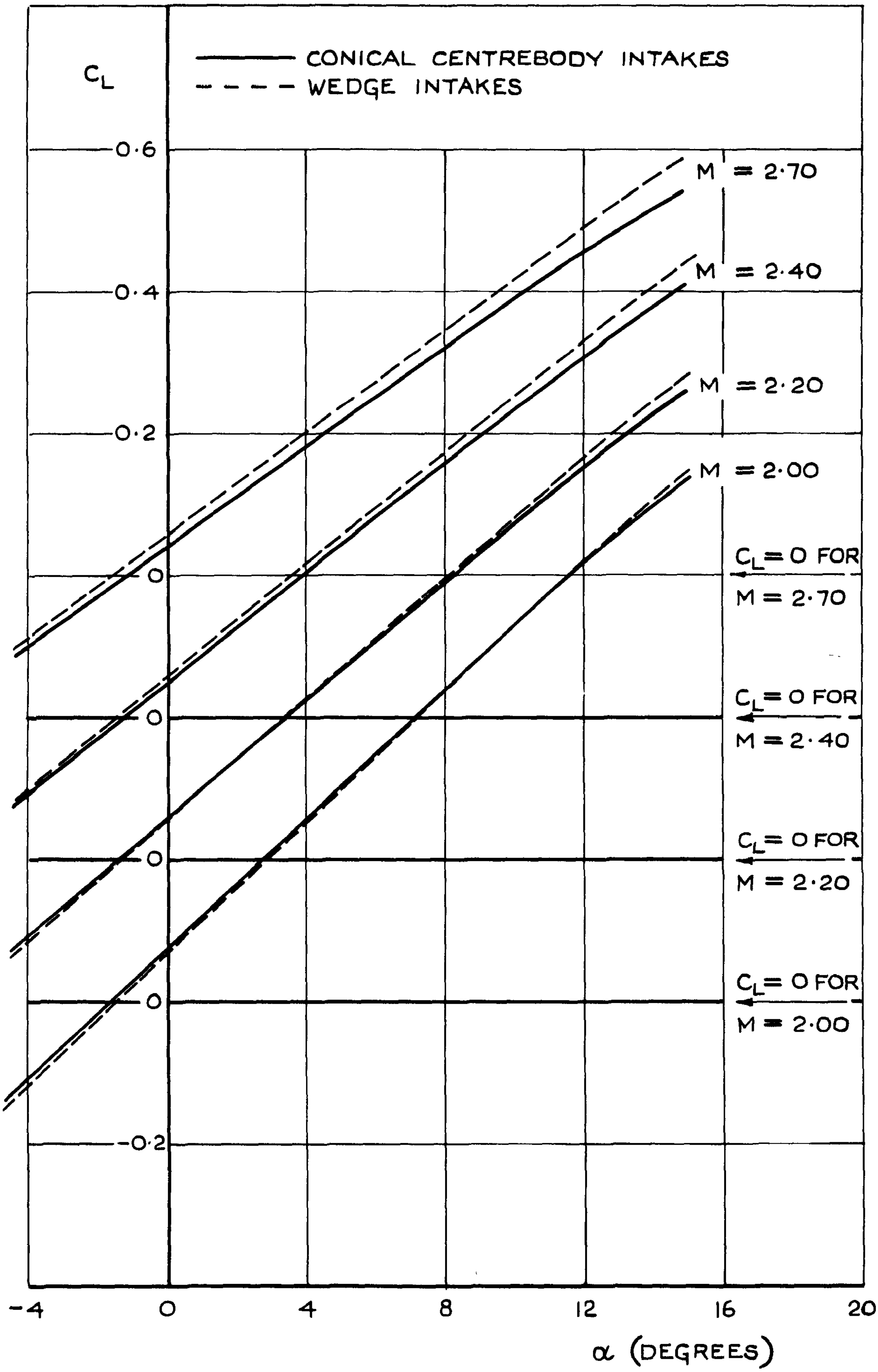
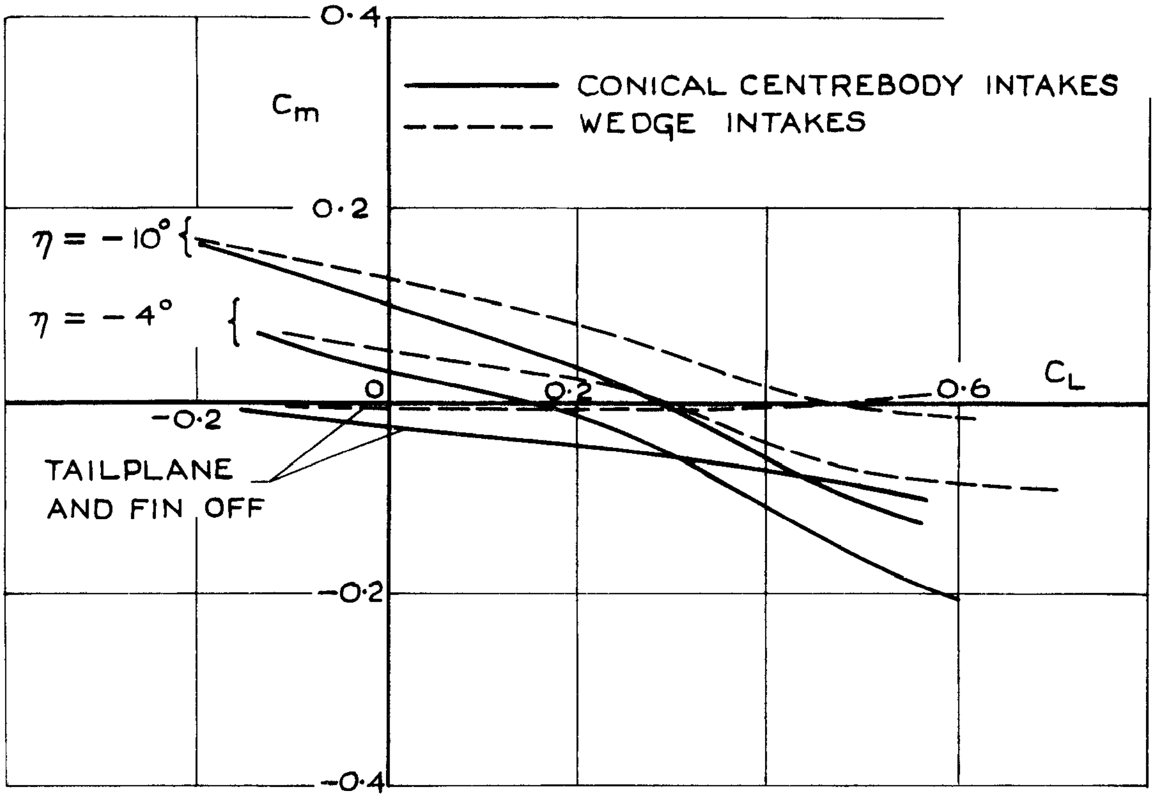
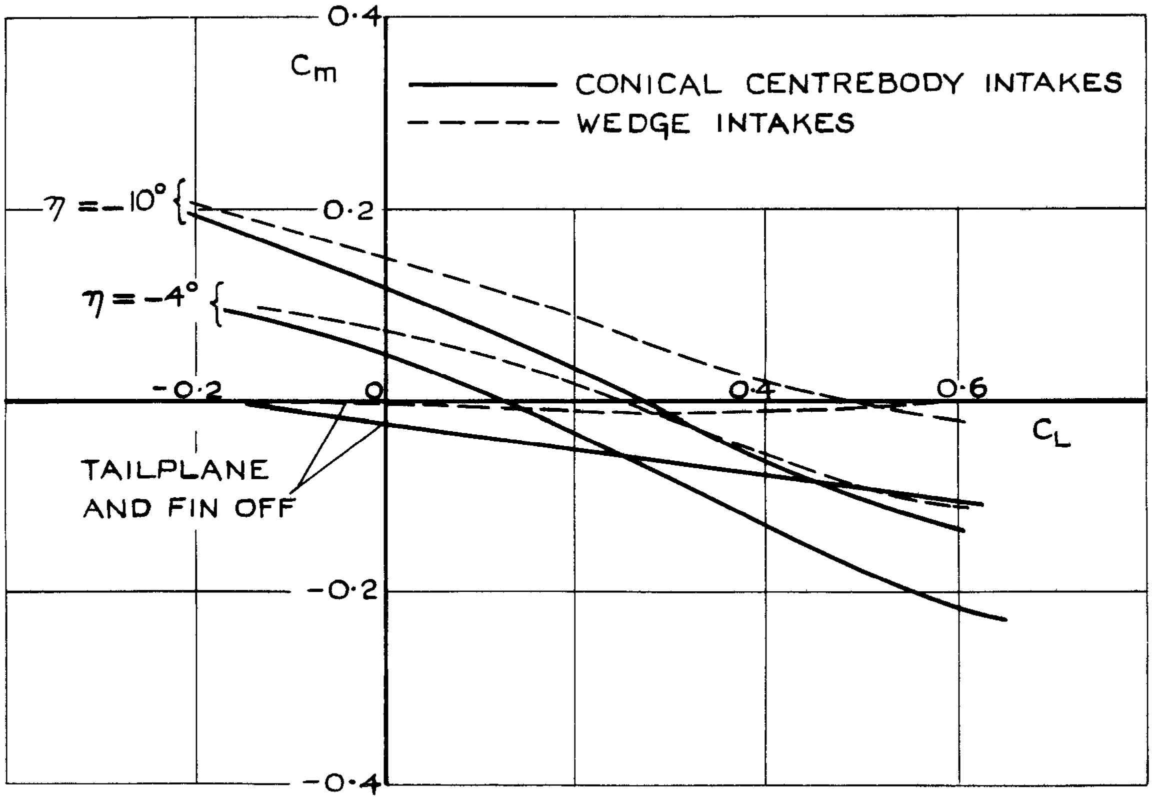


FIG.8. VARIATION OF C_L WITH α: TAILPLANE AND FIN OFF.

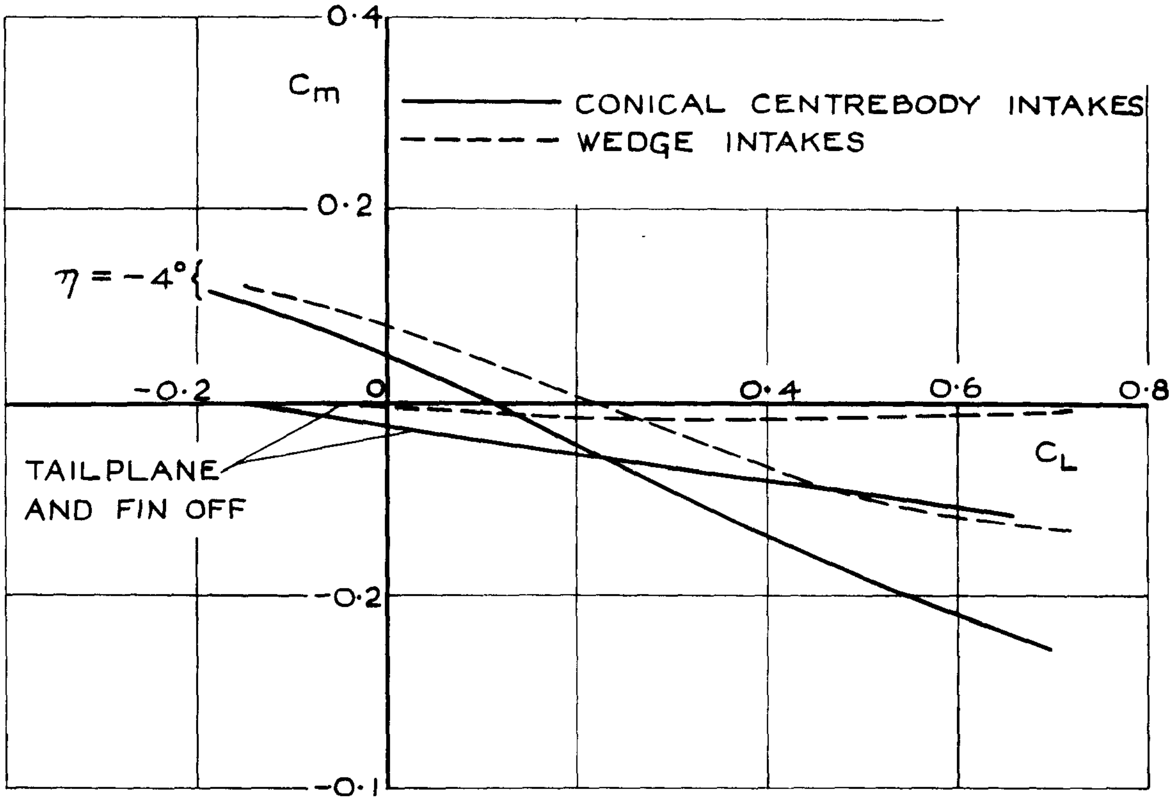


(a) M = 2·70

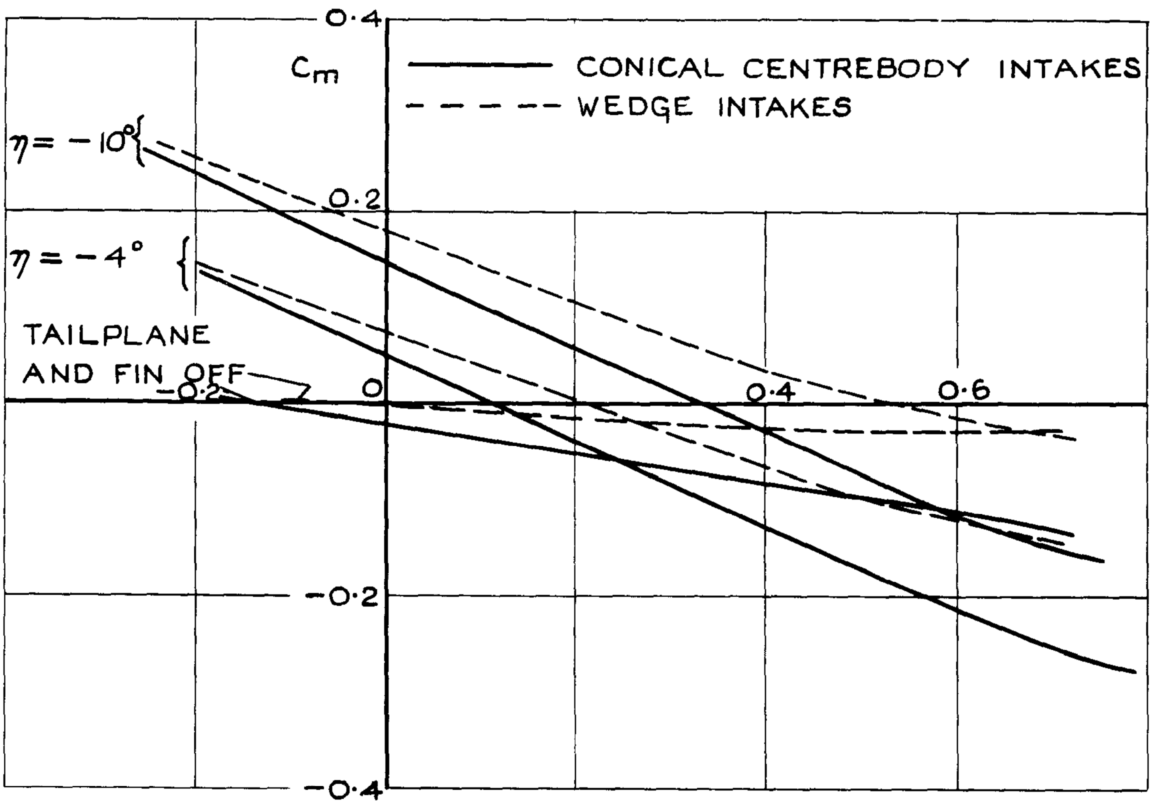


(b) M = 2·40

FIG. 9. VARIATION OF C_m WITH C_L.



(c) M = 2·20



(d) M = 2·00

FIG. 9. (CONTD) VARIATION OF C_m WITH C_L.

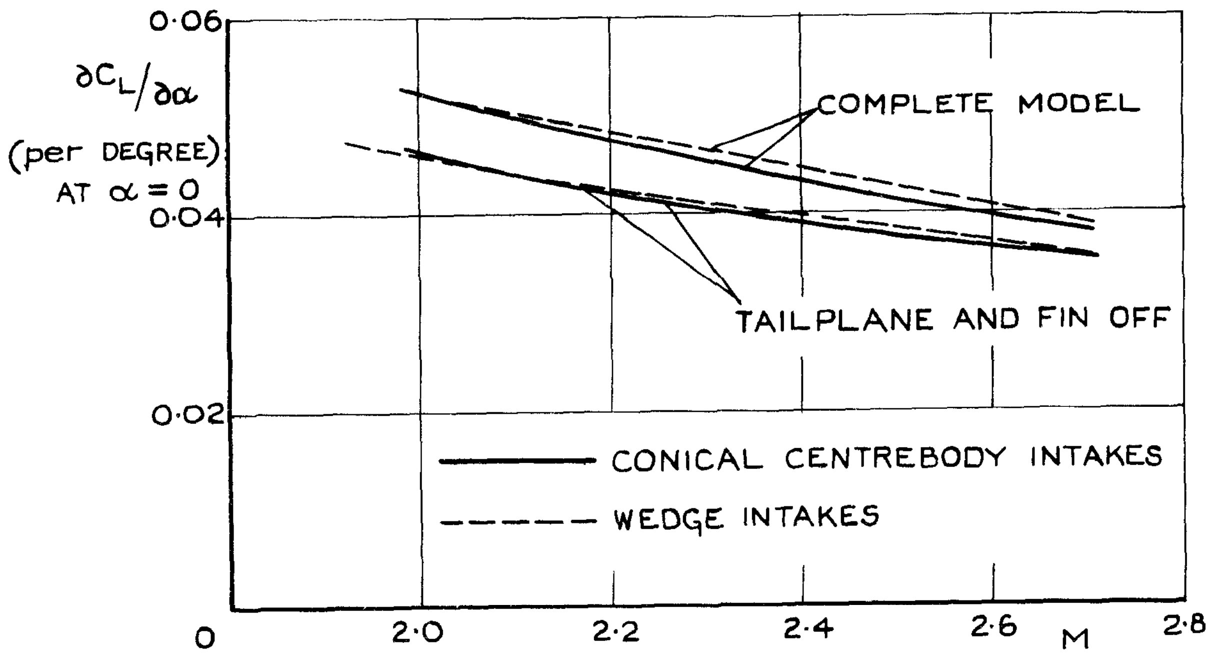


FIG.10. LIFT-CURVE SLOPES AT ZERO INCIDENCE.

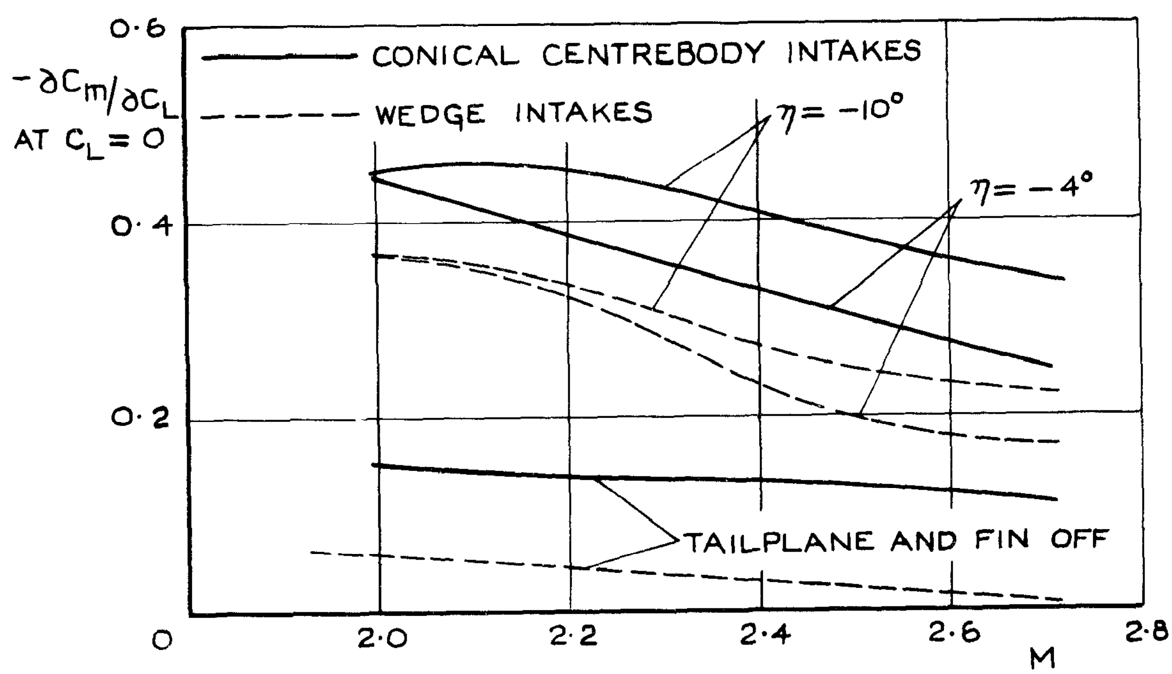


FIG.11. LONGITUDINAL STABILITY SLOPES AT ZERO LIFT.

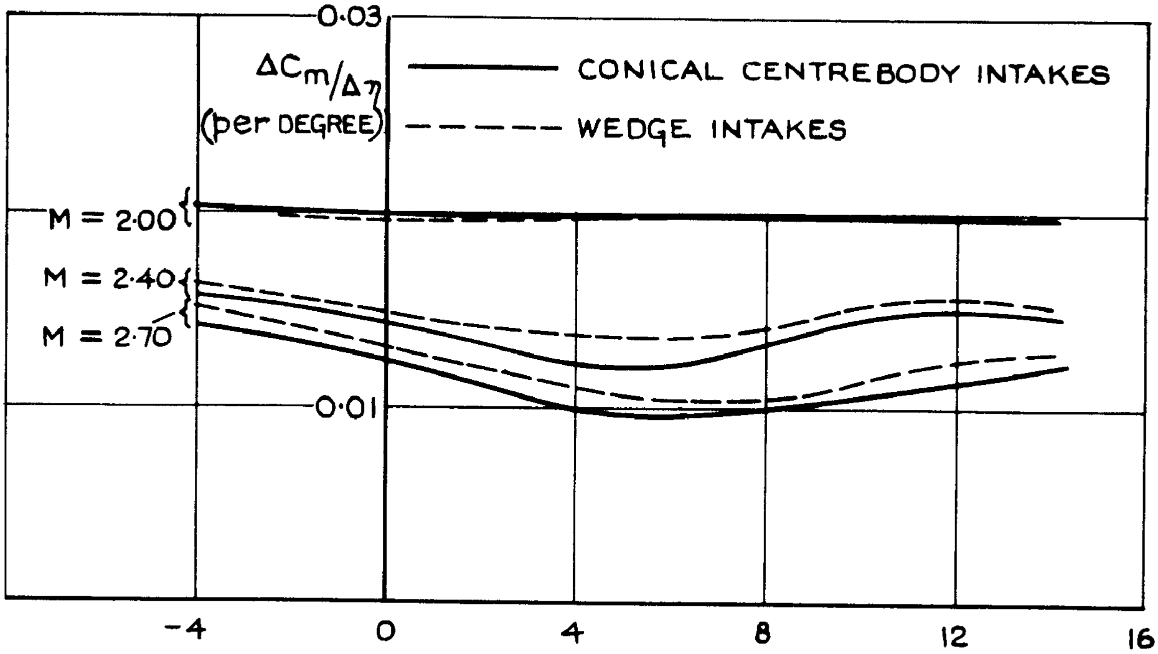


FIG.12. TAILPLANE POWER AT CONSTANT MACH NUMBER.

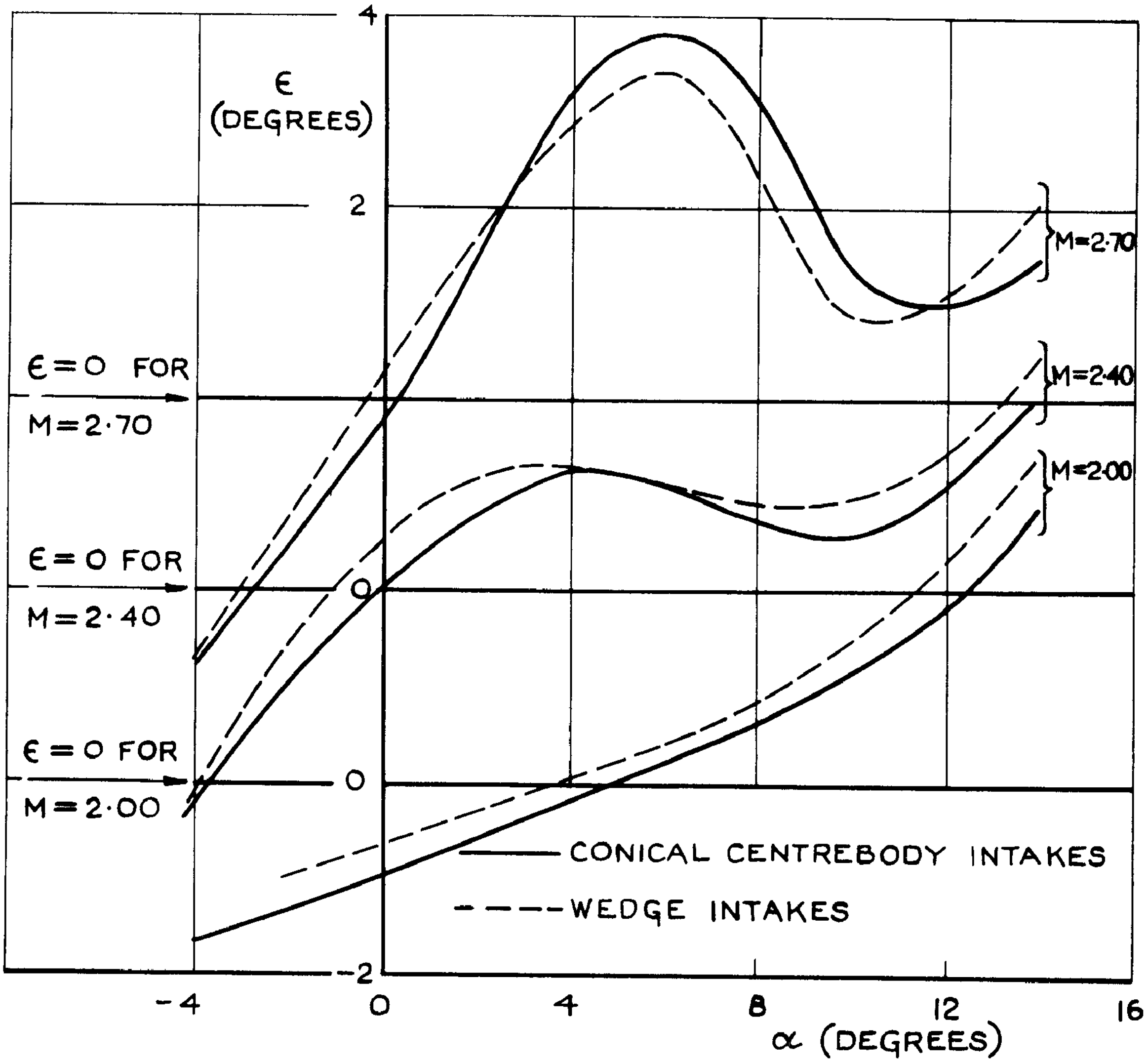


FIG.13. MEAN ANGLE OF DOWNWASH AT POSITION OF TAILPLANE.

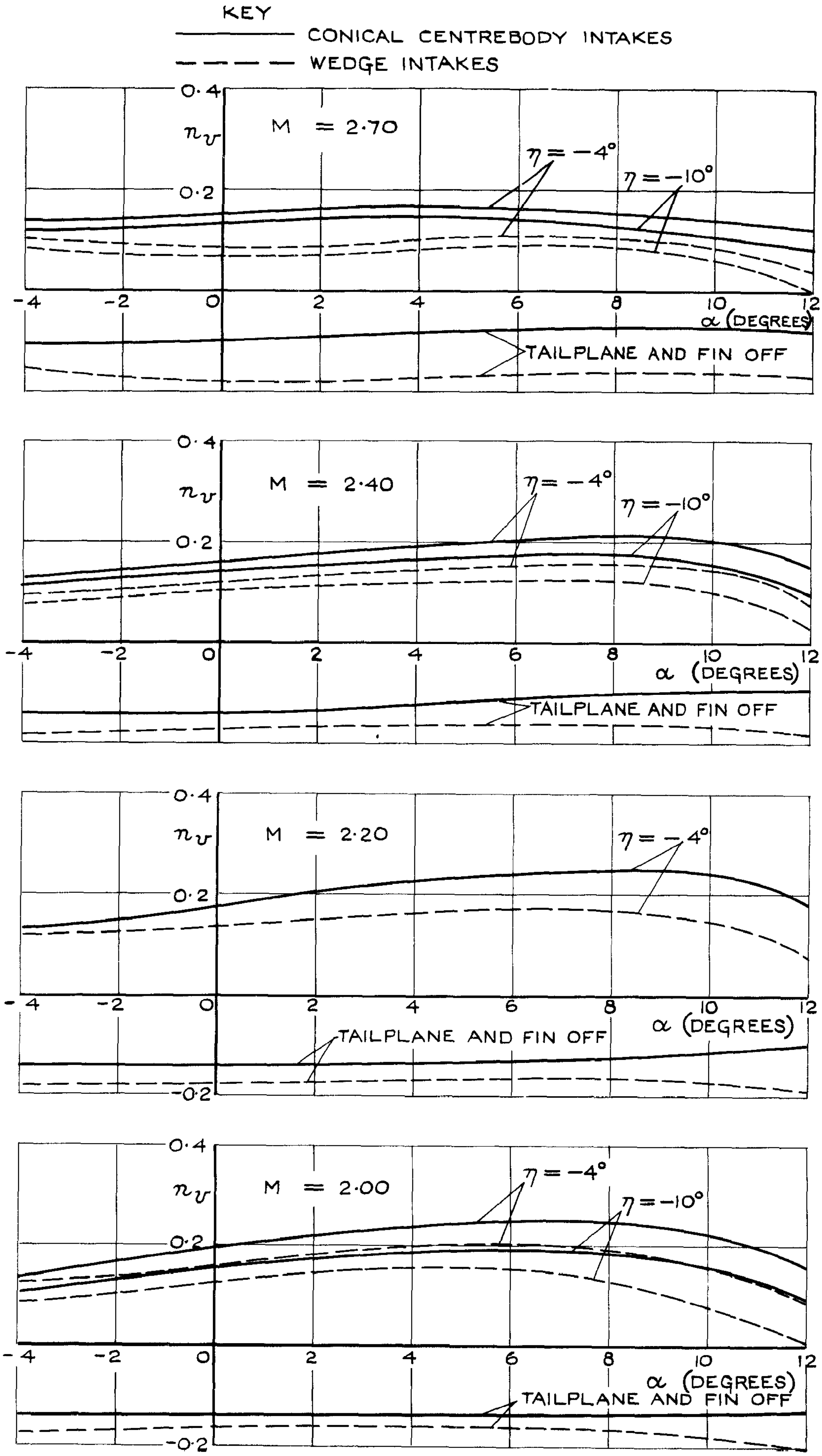


FIG.14. VARIATION OF n_v WITH INCIDENCE.

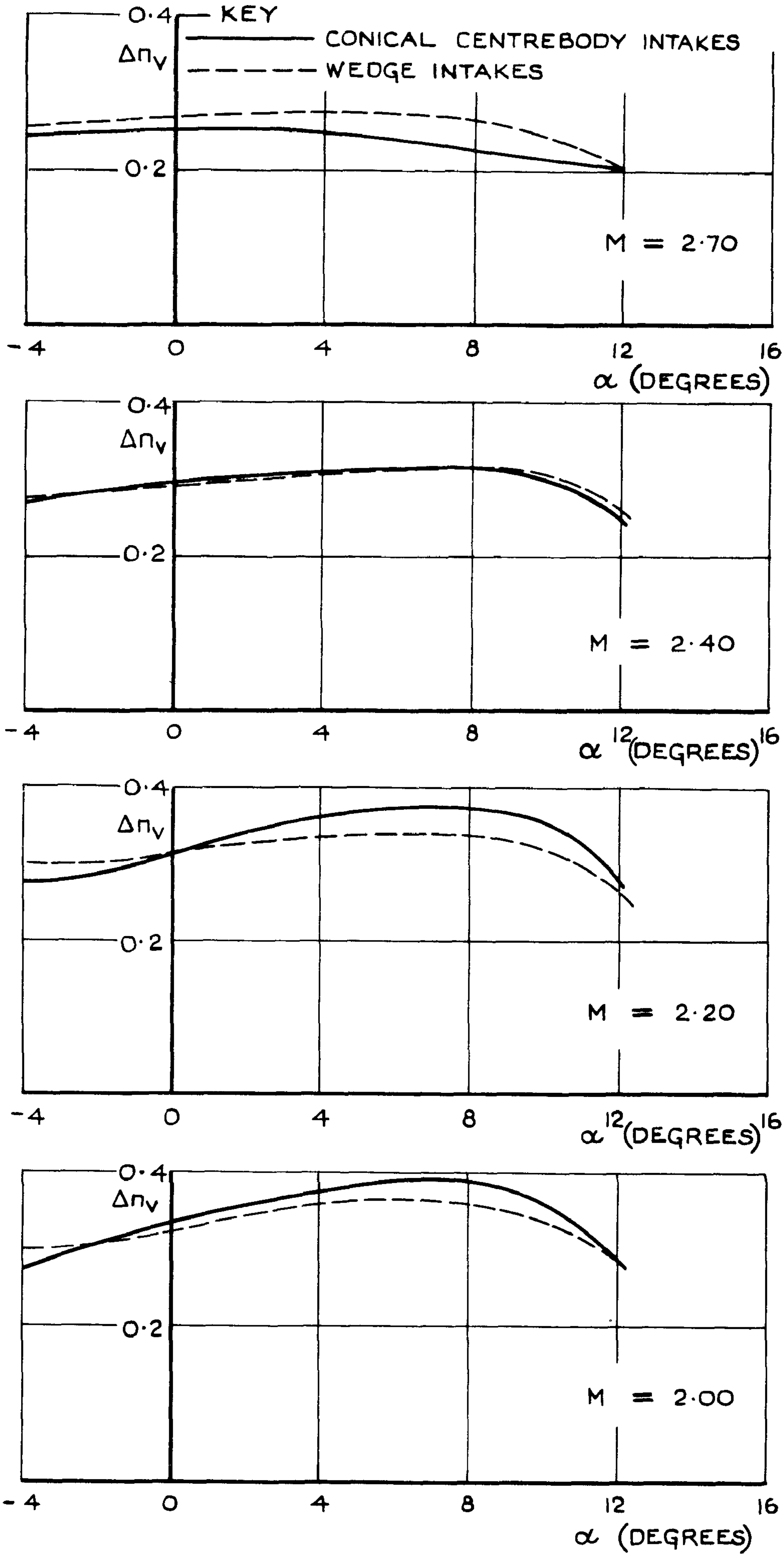


FIG. 15. VARIATION OF FIN EFFECTIVENESS (Δn_V) WITH INCIDENCE : $\eta = -4°$.

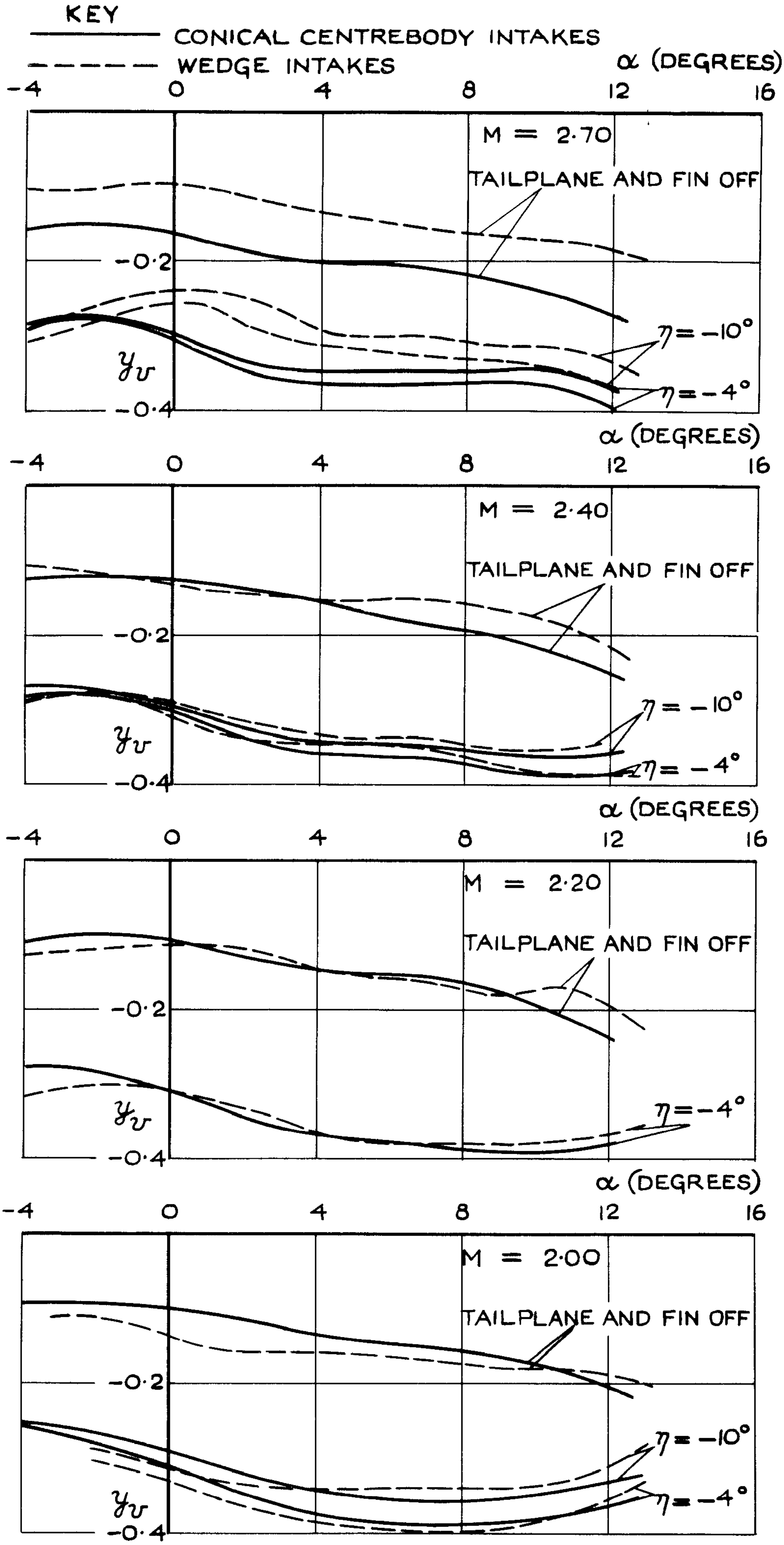


FIG. 16. VARIATION OF y_v WITH INCIDENCE.

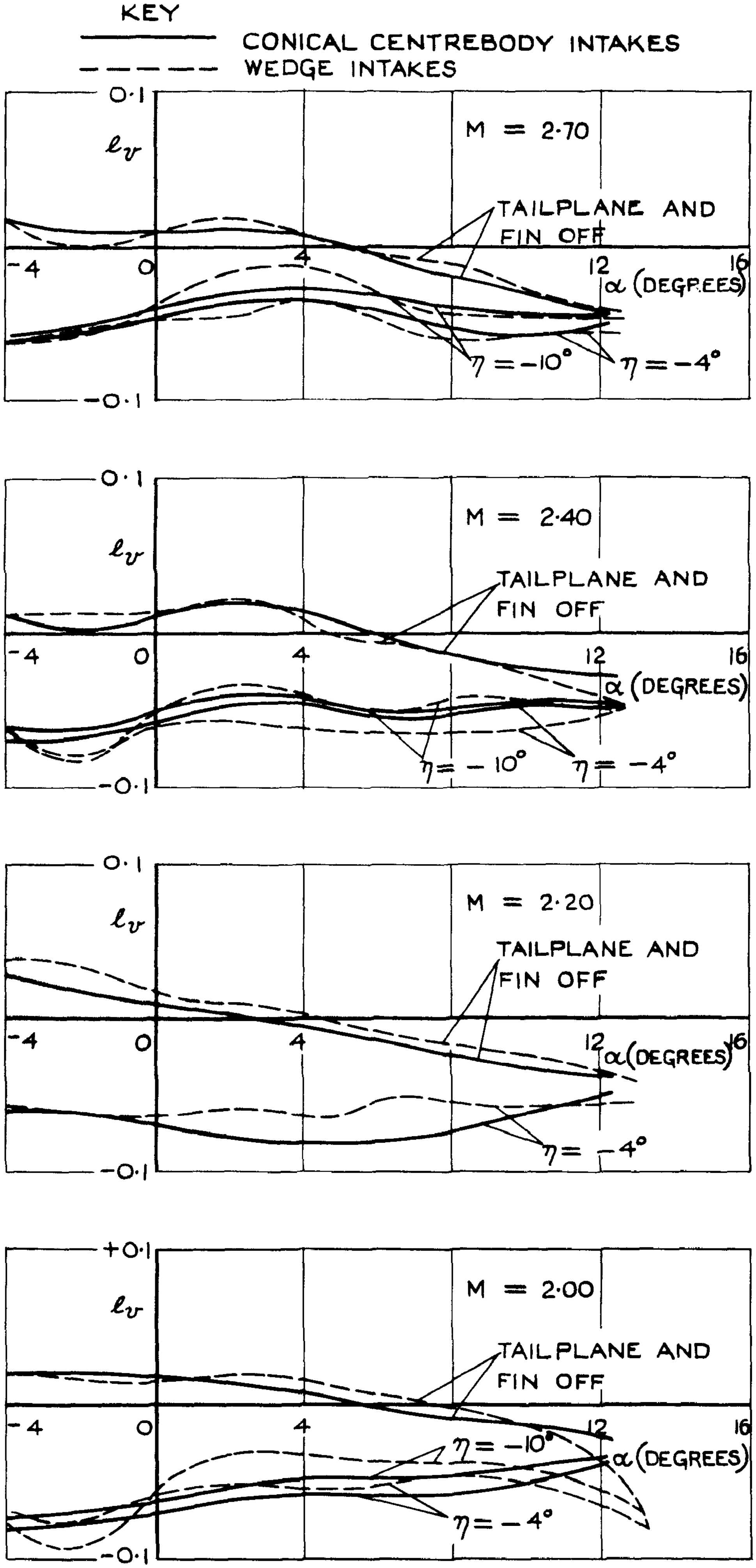


FIG. 17. VARIATION OF l_v WITH INCIDENCE.

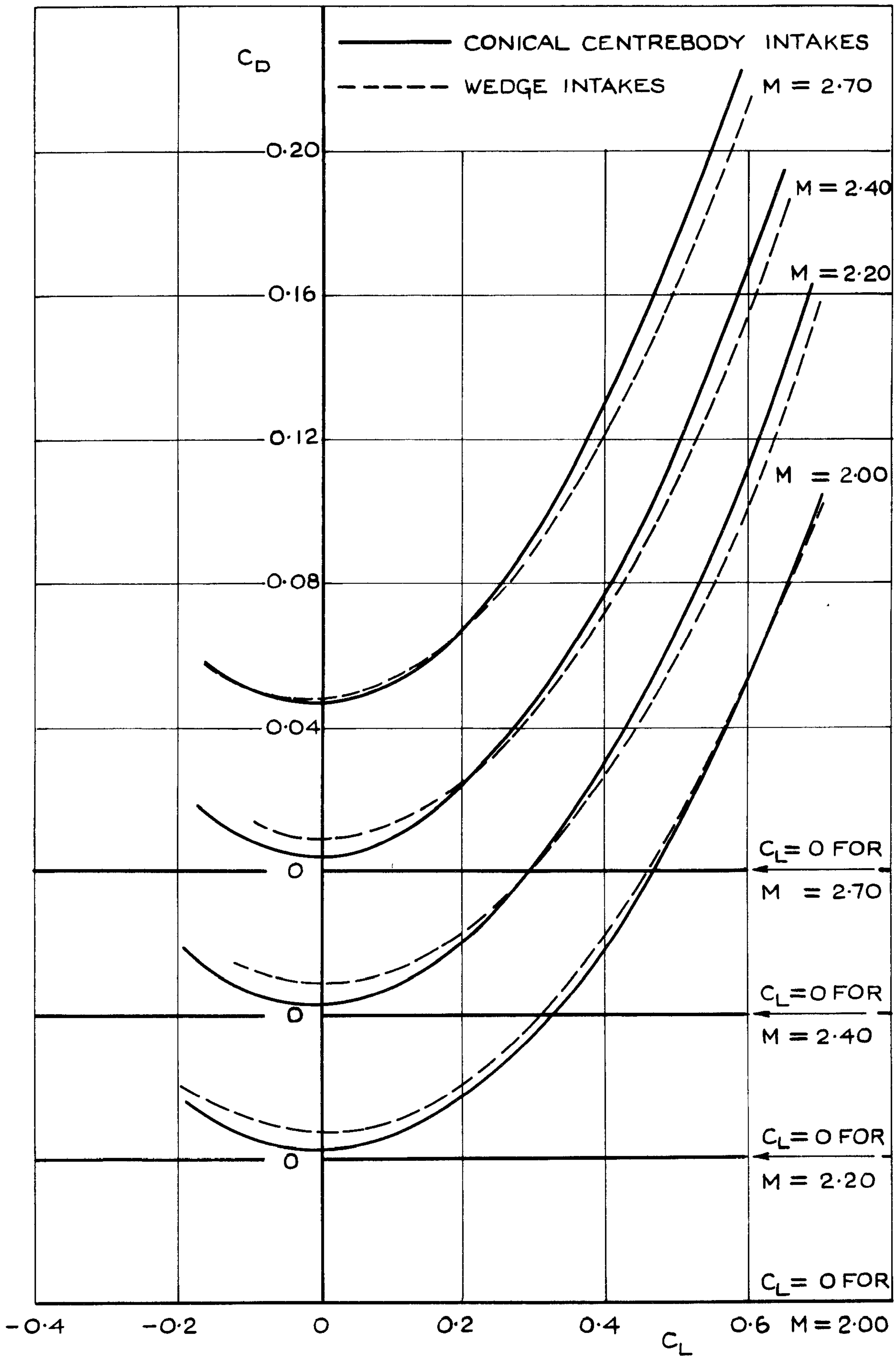


FIG. 18. VARIATION OF C_D WITH C_L: $\eta = -4°$.

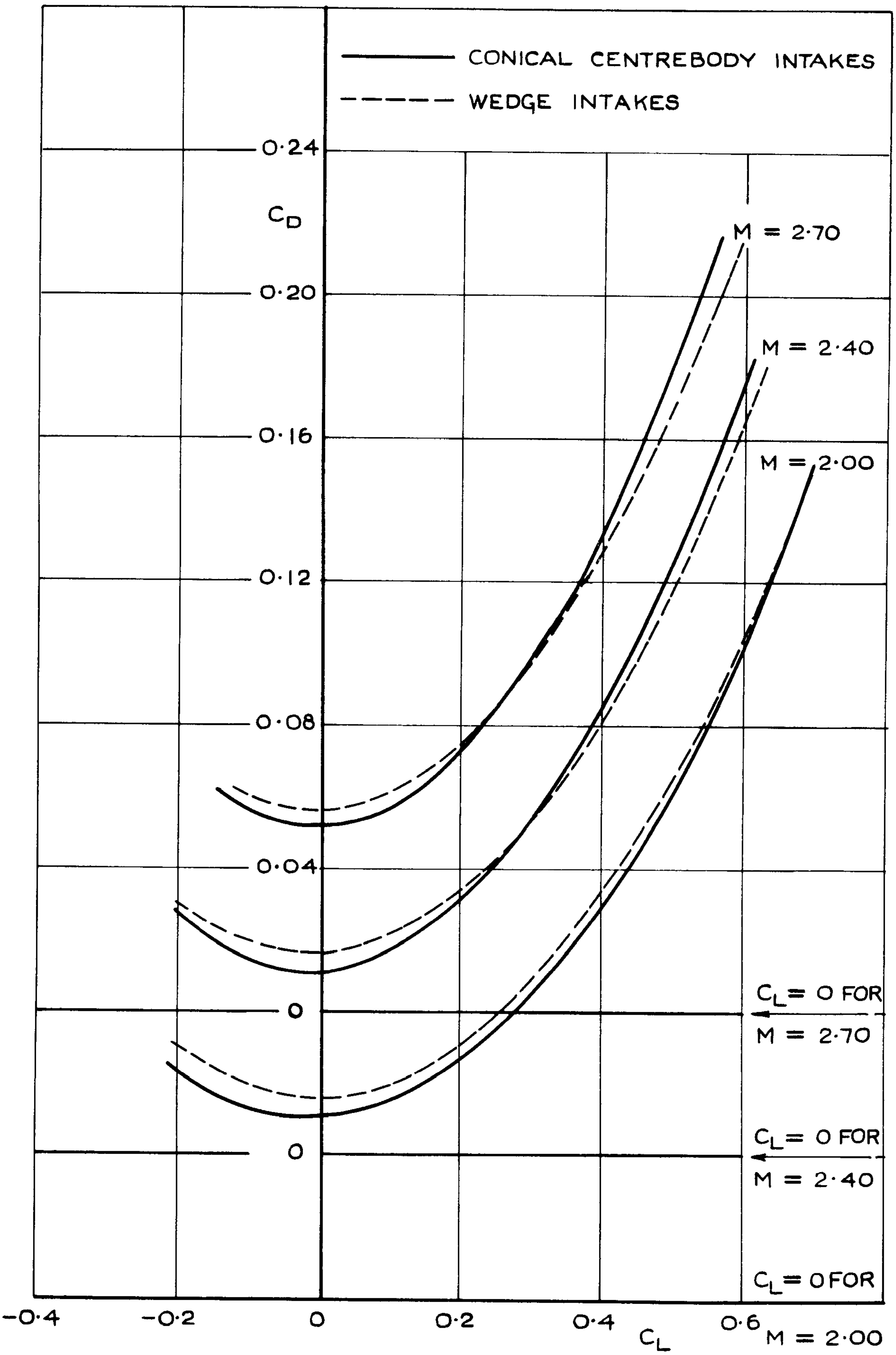


FIG. 19. VARIATION OF C_D WITH C_L: $\eta = -10°$.

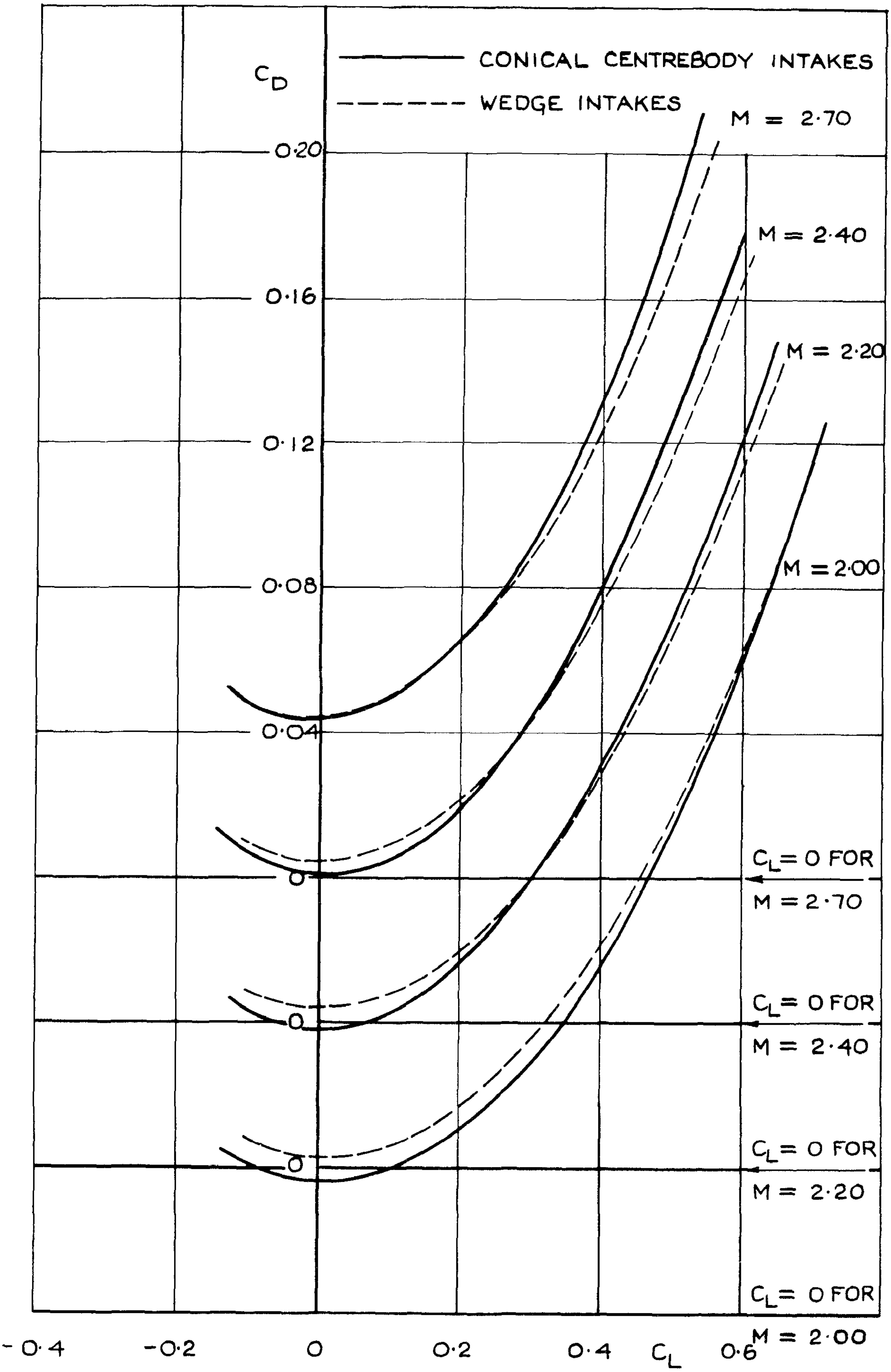


FIG.20. VARIATION OF C_D WITH C_L: TAILPLANE AND FIN OFF.

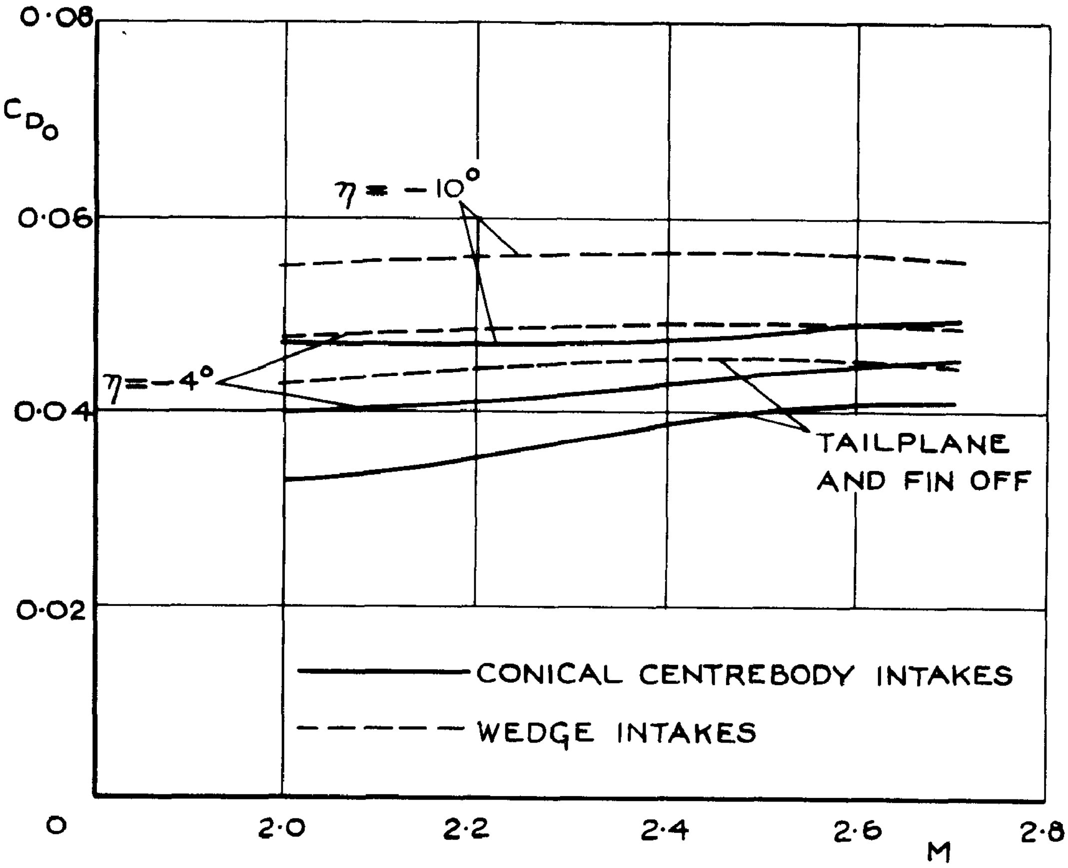


FIG. 21. VARIATION OF MINIMUM DRAG COEFFICIENT WITH MACH NUMBER.

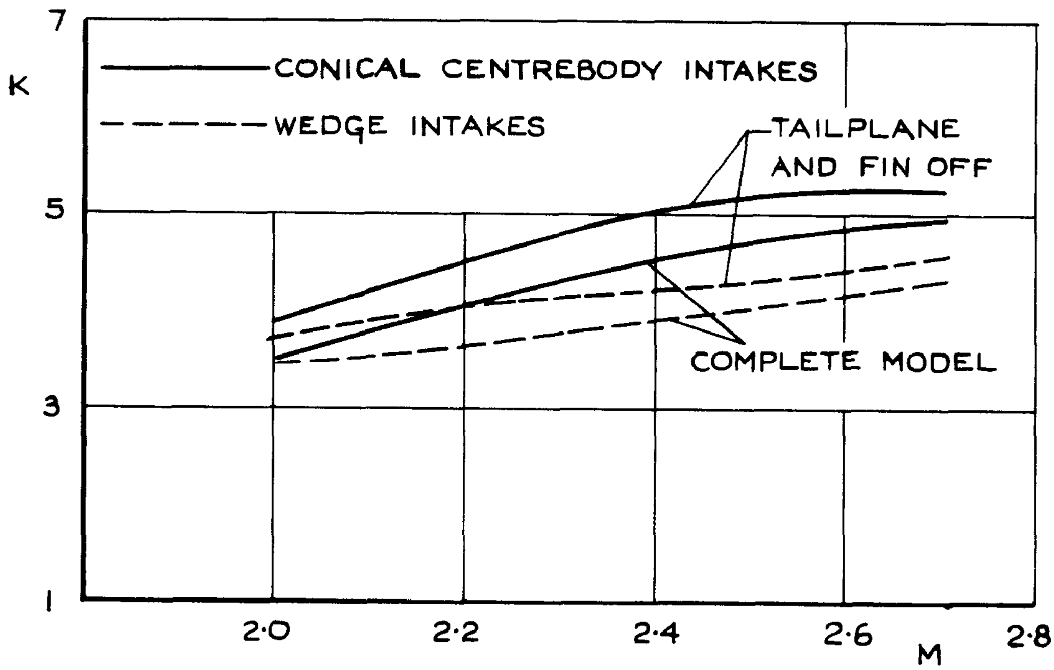


FIG. 22. VARIATION OF INDUCED DRAG FACTOR WITH MACH NUMBER.

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WIND TUNNEL TESTS ON A 1/12TH SCALE MODEL OF THE BRISTOL TYPE 188 RESEARCH AIRCRAFT WITH RECTANGULAR, WEDGE INTAKES AT MACH NUMBERS FROM 2.0 TO 2.7.

Cook, T. A. April, 1963.

A 1/12th scale model of the Bristol Type 188 research aircraft with modified intakes has been tested in the 8 ft x 8 ft wind tunnel at R.A.E., Bedford, at Mach numbers of 2.00, 2.20, 2.40 and 2.70. The tests were made to investigate the effects of rectangular, wedge intakes on the model by comparing the results with those of previous tests[1,2] in which the model had axi-symmetric conical centrebody intakes. The comparison shows the effects of the new intakes on longitudinal and lateral stability, drag and tailplane power, the most important of these being a forward shift of approximately 10% $\bar{c}$ in aerodynamic centre and a reduction of directional stability.

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