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Low-Speed Wind-Tunnel Investigation of the Roll Stability of a 1/5 Scale Model of the Short SC 1 at Large Sideslip

by

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LOW-SPEED WIND-TUNNEL INVESTIGATION OF THE ROLL STABILITY OF A 1/5 SCALE MODEL OF THE SHORT SC 1 AT LARGE SIDESLIP

by

W. J. G. Trebble, B.Sc.

SUMMARY

In order to facilitate the study of the roll stability of V/STOL aircraft at large angles of sideslip, low speed wind-tunnel tests have been made on a 1/5 scale model of the Short SC 1. The results show that very large rolling moments can be produced if roll and sideslip are present together because of the lateral movement of the wing centre of pressure. This rolling problem is aggravated by a loss in aileron power as sideslip angle is increased.

Recovery is feasible by turning into wind (reducing sideslip) and thus reducing the rolling moments to an acceptable level.

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*Replaces R.A.E. Technical Report 67104 - A.R.C. 29420

CONTENTS

1 INTRODUCTION

During the course of the test flying of V/STOL aircraft the control characteristics in jet-borne flight can conveniently be investigated by following prescribed ground paths such as the perimeter tracks around airfields. This naturally involves flying at low forward speeds which could well be of the same order as the natural wind speed and thus large sideslip angles may occur during some parts of the circuit. Under these circumstances, pilots flying the Short SC 1 research aircraft have found that when they have banked the aircraft to follow a corner in the prescribed ground path the aircraft has continued to roll beyond the intended angle of bank and there is also a severe loss of aileron effectiveness. Fortunately, it has always been found that full control could be regained by taking off the sideslip and this course of action has so far proved successful on each occasion that the phenomenon has been encountered. However, in view of the uncertain origin and the hazardous nature of this behaviour, investigation at model scale was desirable and a $^1/_5$ scale model of the Short SC 1 was constructed for low-speed wind-tunnel testing. Consideration of the available evidence suggested that the rolling at large sideslip might arise from:-

(i) aerodynamic shielding of the 'rearward' wing by the body at large sideslip angles, a view supported by the fact that the Short SC 1 appeared to be more prone to the trouble than any other aircraft;

(ii) interference between the lifting-jet efflux and the mainstream flow;

(iii) interference arising from the flow into the intake.

Consequently the model was built so that each of these possibilities might be investigated though the main part of the present investigation was to be concerned with the first possibility.

2 MODEL DETAILS

A $^1/_5$ scale model of the Short SC 1 (Figs.1 and 2) was constructed mainly from wood although duralumin was used for the main spar and blowing box (Fig.3). Normal aerodynamic controls (elevators, ailerons and rudder) could be deflected but no provision was made for puffer controls or their housings. A detachable fin and dorsal were incorporated so that fin effect could be studied. The propulsion engine duct was represented only in so far as free air flow was allowed through it and, for simplicity, the four lifting engines were simulated by a single 4 inch diameter nozzle. No attempt was made at this stage to represent the intake flow.

For the unblown tests the model was mounted erect on a single cylindrical rotating strut (Figs.1 and 3). This strut was shielded from air loads by an aerofoil shaped fairing though the upper 2.5 inches of the strut was left exposed to the air stream; this fairing remained along wind as the strut rotated. It had originally been intended to use a 2 inch diameter strut (Fig.3) for all testing of the unblown model but the failure of a weld necessitated a change over to the larger hollow compressed air supply strut (3.25 inches O.D.) for most of the programme. These struts are henceforth referred to as the small and large strut respectively and their size relative to the model can be appreciated from Fig.1. Naturally, for the configurations with efflux represented, the model was mounted inverted on the larger strut (Fig.4). Internal spacers having angles between their top and bottom surfaces of 0°, 5°, 10° and 20° could be inserted between the model and the top of the strut. Judicious rotation of this spacer in azimuth relative to the model allowed the selection of a prescribed set of angles of pitch and roll. The angular position of the model was assumed to be derived by first pitching through an angle ϑ (positive nose up) then rolling through an angle ϕ about the body major axis (positive with port wing up) and finally sideslipping through an angle β about the gravitational vertical axis (positive when anticlockwise viewed from above). The six component balances remained stationary throughout but the forces and moments were subsequently converted to body axes with the moment centre taken on the wing chordline at the fore and aft position of the centre of the lifting jets; i.e. at 0.557 c_o (113.72 inches full scale behind the wing apex).

3 EXPERIMENTAL TECHNIQUES

3.1 Test details

The majority of the tests were made in the No.2 $11\frac{1}{2} \times 8\frac{1}{2}$ ft wind tunnel at R.A.E. (Farnborough) during April 1965 at a wind speed of 100 ft/sec following an initial Reynolds number investigation (Fig.6) which showed that there appeared to be little scale effect between 100 ft/sec and 200 ft/sec. For the blown model, the appropriate velocity ratios could not be achieved at speeds above 100 ft/sec. However, scale effect on the strut or its associated interference (Fig.7) was observed at sideslip angles above 60° so a few further tests were made with strakes or transition wires attached to the fuselage (Fig.8). Although some change in the size of the rolling moments was thus obtained, the general shape of the curves remained unaltered.

As the strut interference may have been of crucial importance at these very large sideslip angles, some comparative tests were also made during August 1965 with the model mounted on a wire rig in the No.1 $11\frac{1}{2} \times 8\frac{1}{2}$ ft wind tunnel at a speed of 120 ft/sec (Fig.7). For these tests, the main cleats were installed in the fuselage so that the model was turned through 90° (in a sideslip sense) relative to the balance which then rotated with the model in the normal way. Again some slight changes in the magnitude of the forces and moments was observed but the basic shapes of the curves remained unaltered.

The usual wire corrections have been applied to the results from the No.1 $11\frac{1}{2} \times 8\frac{1}{2}$ ft tunnel but no corrections have been applied to the strut mounted model in the No.2 $11\frac{1}{2} \times 8\frac{1}{2}$ ft tunnel. The straight-forward strut tares could be calculated but these could well be dwarfed by the interference effects at large sideslip angles. It had been intended to make a detailed investigation of the strut interference on the unblown model using the dummy strut technique but this had to be abandoned through shortage of time. Whilst lack of this knowledge reduces the accuracy of the results it would not be expected to have any material effect on their general behaviour; this is born out by the similarity of the results from tests in the two tunnels at very large sideslip angles.

3.2 Calibration of nozzle

From the start it was appreciated that some difficulty might be experienced in obtaining an acceptably homogeneous flow distribution at the nozzle as only a short distance upstream from it the air was being diffused from a 3 inch to a 4 inch diameter pipe whilst simultaneously being turned through an angle of up to 20° (Fig.4). Provision was therefore made for the insertion of screens in the duct at the downstream end of the diffuser. Initially a perforated plate was chosen for this purpose but proved completely inadequate with large regions of reverse flow in the efflux. It was therefore replaced with a pair of 17 swg stainless steel gauzes and the resulting distribution from the 20° nozzle is shown in Fig.5. Although a small central hole was still apparent in the flow, the distribution was now regarded as acceptable; reduction to one gauze gave a far worse distribution.

For determination of the installed thrust the pressure box was mounted on the top of the strut with the SC 1 model removed. The thrust and its effective angle could then be calculated at a fixed strut pressure (55 psi excess) from measurements on the lift, drag and sideforce balances for various rotational positions of the strut. Thrust variation with rotational position was found to be less than ¼% of the mean value but there was a thrust reduction from 269 lb to 264 lb when the 10° nozzle was replaced with the 20° nozzle. The efflux angle was not quite true with the geometric nozzle angle and varied slightly with rotational position; i.e. the deflections were $9.95^\circ \pm 0.1^\circ$ and $20.0^\circ \pm 0.4^\circ$ for nominal angles of 10° and 20° respectively. Upon assembly of the model there was a further thrust loss of some 9 lb due to tunnel constraint effects. Attempts to measure thrust with the tunnel roof removed had to be abandoned because of the danger to nearby installations.

4 RESULTS AND DISCUSSION

4.1 Unblown model

4.1.1 Complete model

Tests on the unblown model over a wide range of sideslip angle (Figs.9 and 10) showed that the further effects of deflection in pitch and roll were primarily confined to changes in the downward normal force (C_Z) and rolling moment (C_ℓ) though significant nose-up pitching moments (C_m) became apparent at large angles of sideslip. Although the model experienced a negative axial force (i.e. drag) at zero sideslip, rotation in yaw produced a low pressure region near the nose which resulted in a forward axial force; naturally there was still a drag force when forces were referred to wind axes.

In the unrolled configuration, the most significant effect was the rapid fall away in normal force at sideslip angles above 20° (Fig.10c) which, at an incidence of 10°, was sufficient for all normal force to be lost (i.e. virtually no lift) at sideslip angles above 60°. At the lower sideslip angles there was the usual tendency for the forward-going wing to lift (Figs.9a and 10a) (i.e. negative values of C_ℓ at positive sideslip) though there was some reversal associated with the loss of normal force at the higher sideslip angles. However use of the puffer jets should still give adequate roll control on the aircraft.

As would be expected from simple considerations, the downforce on the model increased as the forward-going wing was rolled down (Fig.9c).

Investigation of the effects of roll at zero pitch showed that as the roll angle was increased, with the model sideslipping, there was a tendency for the downward-going wing, whether forward-going or rearward-going, to roll even further down (Fig.9a). The roll control available from the puffers would only give a ΔC_ℓ value of 0.046 at 100 ft/sec though some benefit could also be obtained from deflection of the ailerons provided that the sideslip angle was not too great (Fig.11). Consequently it must be assumed that at this speed an aircraft rolled more than 10° would be uncontrollable at sideslip angles in excess of 50°. To regain control it would appear necessary to reduce sideslip and this presumably would require the use of directional puffer controls as the fin would be stalled at high sideslip angles (section 4.1.4); the rolling moment would then disappear as zero sideslip was approached.

Increase in pitch angle, with the model rolled 20°, had little effect on the rolling moment due to sideslip if the forward-going wing was rolled upward (Fig.10a) though there was some alleviation from increased pitch angle with the forward-going wing down. Thus the severest roll problem occurred at zero pitch angle and the investigation could reasonably be confined to the unpitched model. Taking this into account, it was considered that the following breakdown of the effect of various model components on the rolling phenomenon could be limited to measurements at zero pitch angle.

4.1.2 Isolated wing

The rolling moment due to roll in the presence of sideslip was even greater on the isolated wing than on the complete model (Fig.12a). Furthermore the onset of loss in aileron power occurred at much lower sideslip angles (Fig.11) than those found on the complete model where the presence of the fat fuselage presumably imposed some chordwise component to the flow over the wing. As sideforce was negligible in the absence of the fuselage (Fig.12e), the centre of pressure could be determined for the isolated wing (Fig.13) and was found to move away from the centreline at the higher sideslip angles. The position of the mean quarter chord point of the wing yawed 90° was calculated to be at $0.35\,\frac{b}{2}$ which is very close to the point at which the forces were found to act. Thus the principal cause of the rolling phenomenon at high sideslip can be attributed to the lateral shift of the centre of pressure; a process so fundamental that little could be done in the way of alleviation.

4.1.3 Fuselage contribution to forces and moments

The fuselage contributions to the forces and moments have been deduced by subtracting the measured values obtained on the isolated wing from the appropriate values for the wing-fuselage combinations (Fig.15).

In general, the fuselage contribution to rolling moment was small but where significant it was of the correct sign to reduce the roll angle (i.e. stabilising). As was only to be expected, the large sideforce acting ahead of the centre of gravity had an adverse effect on the directional stability though, at large angles of sideslip, the rearward movement of the load centre gave some reduction in the directional instability. The observed changes in normal force and pitching moment could probably be mainly ascribed to interference effects produced by the shielding action of the fat fuselage on the rearward-going wing.

4.1.4 Effect of fin and dorsal

The force and moment increments produced by the fin and dorsal are shown in Fig.14 where it is seen that roll angle had little effect on these increments. At low values of sideslip angle the fin gave some contribution to both the directional stability derivative ($\partial C_n/\partial\beta$) and the lateral stability derivative ($\partial C_\ell/\partial\beta$) but fin stall at about 35° of sideslip precluded any benefit at the higher sideslip angles.

4.2 Model with efflux represented

As originally conceived, the test programme had been designed to include an investigation of the effect of the lift-jet efflux from a single 4 inch diameter orifice in the fuselage lower surface. Unfortunately the tunnel roof imposed such large constraints on the emergent jet that there was considerable interference with the mainstream flow at the appropriate velocity ratios* (V_o/V_J) required to simulate very low speed flight. However, a few results are quoted in Fig.16 for a (V_o/V_J)-value of 0.09 where, at least there was no sign of reverse flow in the vicinity of the tunnel roof though obviously the constraints were still significant. As usual, the interference between the efflux and mainstream flow led to a low pressure region behind the nozzle[1] resulting in a lift loss ($\Delta C_L \approx 0.2$ at $V_o/V_J = 0.09$) associated with a nose-up pitching moment contribution (Fig.16 c and d). Some deterioration in rolling stability was also observed (Fig.16a), particularly at

* V_o = mainstream speed; V_J = efflux velocity.

moderate sideslip (circa 20°) but, with the forward-going wing down, a sudden change in flow regime appeared to occur at about 30° of sideslip. Obviously further investigation is necessary and it is hoped that a more detailed study of the efflux effects will be possible with the model mounted on a strain-gauge balance in the 24 ft wind tunnel.

5 CONCLUDING REMARKS

The results show that, in the main, the rolling instability can be attributed to a lateral movement of the wing centre of pressure as the side-slip angle is increased; and contrary to expectations the presence of a fat fuselage gives some alleviation. Further complications arise through the interference between the mainstream flow and the efflux though the issue is somewhat obscured by tunnel interference effects. A detailed appraisal of the effect of efflux flow must await tests in a larger tunnel.

Table 1

MODEL DETAILS

	Model scale	Full scale
Wing area	8.46 sq ft	211.5 sq ft
Span	4.70 ft	23.5 ft
Centreline chord	3.40 ft	17.0 ft
Aspect ratio	2.61	
Taper ratio	17:1	
Sweepback of leading edge	54.95°	
Sweepback of trailing edge	3.65°	
Section	NACA 0010	
Elevator area aft of hinge line (Total)	0.590 sq ft	14.76 sq ft
Aileron area aft of hinge line (Total)	0.342 sq ft	8.55 sq ft
cg position on chordline at 0.557 C_o		
Distance cg behind wing apex	1.895 ft	9.477 ft

SYMBOLS

Geometric

S	wing area
c_o	centreline chord
b	span

Velocity and pressure

V_o	mainstream velocity
V_J	efflux velocity
q	dynamic pressure = $\frac{1}{2}\rho V_o^2$
ρ	air density
P_o	atmospheric pressure
P_T	total pressure

Coefficients (relative to model axes)

C_X	axial force/qS	positive forwards
C_Y	sideforce/qS	positive to starboard
C_Z	normal force/qS	positive downwards
C_ℓ	rolling moment/qSb	positive clockwise viewed from behind
C_m	pitching moment/qSC_o	positive nose-up
C_n	yawing moment/qSb	positive clockwise viewed from above

REFERENCE

No.	Author	Title, etc.
1	W.J.G. Trebble	Wind tunnel experiments on a simple lifting-jet body with and without wings. A.R.C. Current Paper 718, A.R.C. 24,898 (1963)

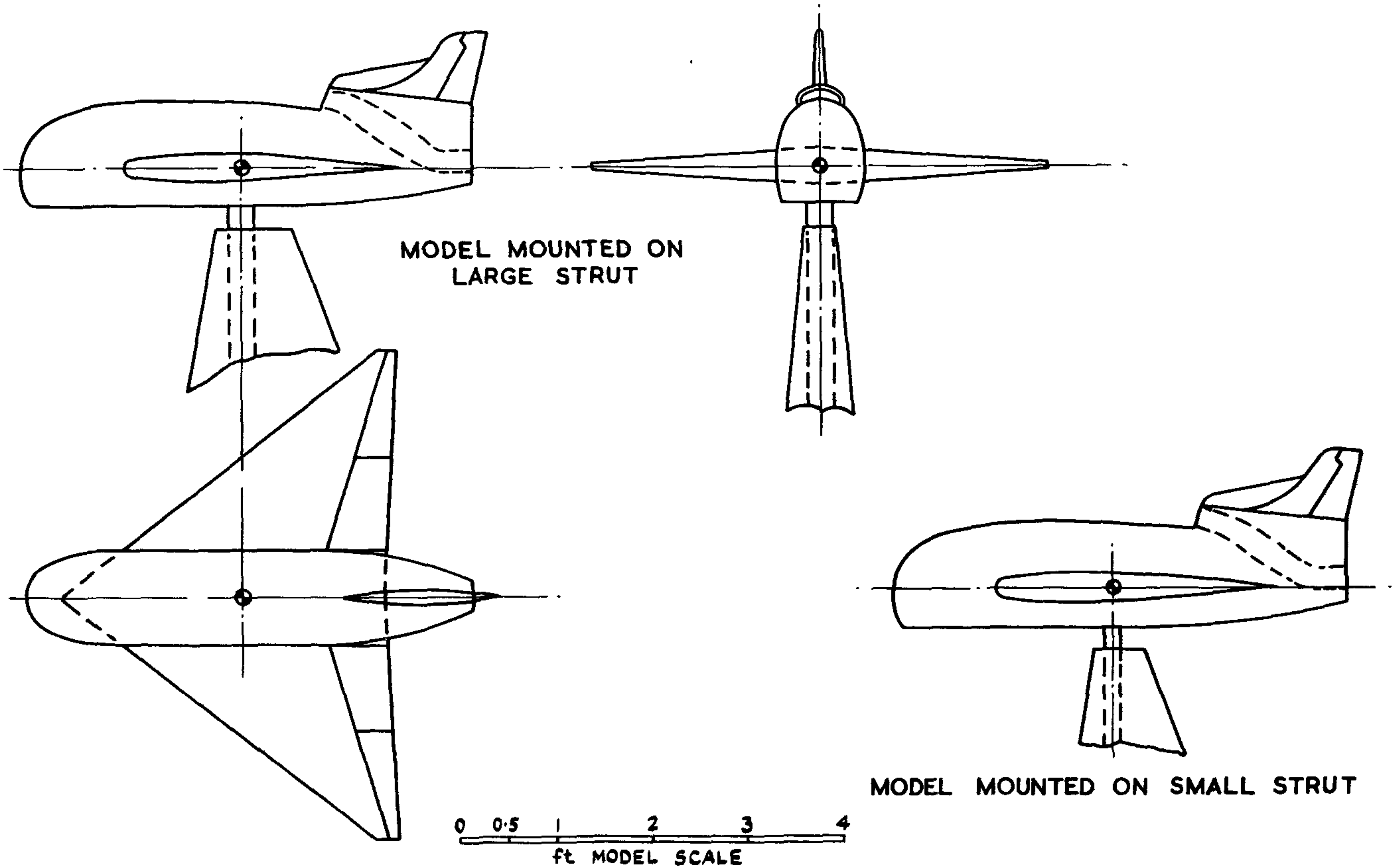


FIG. 1 G.A. OF MODEL

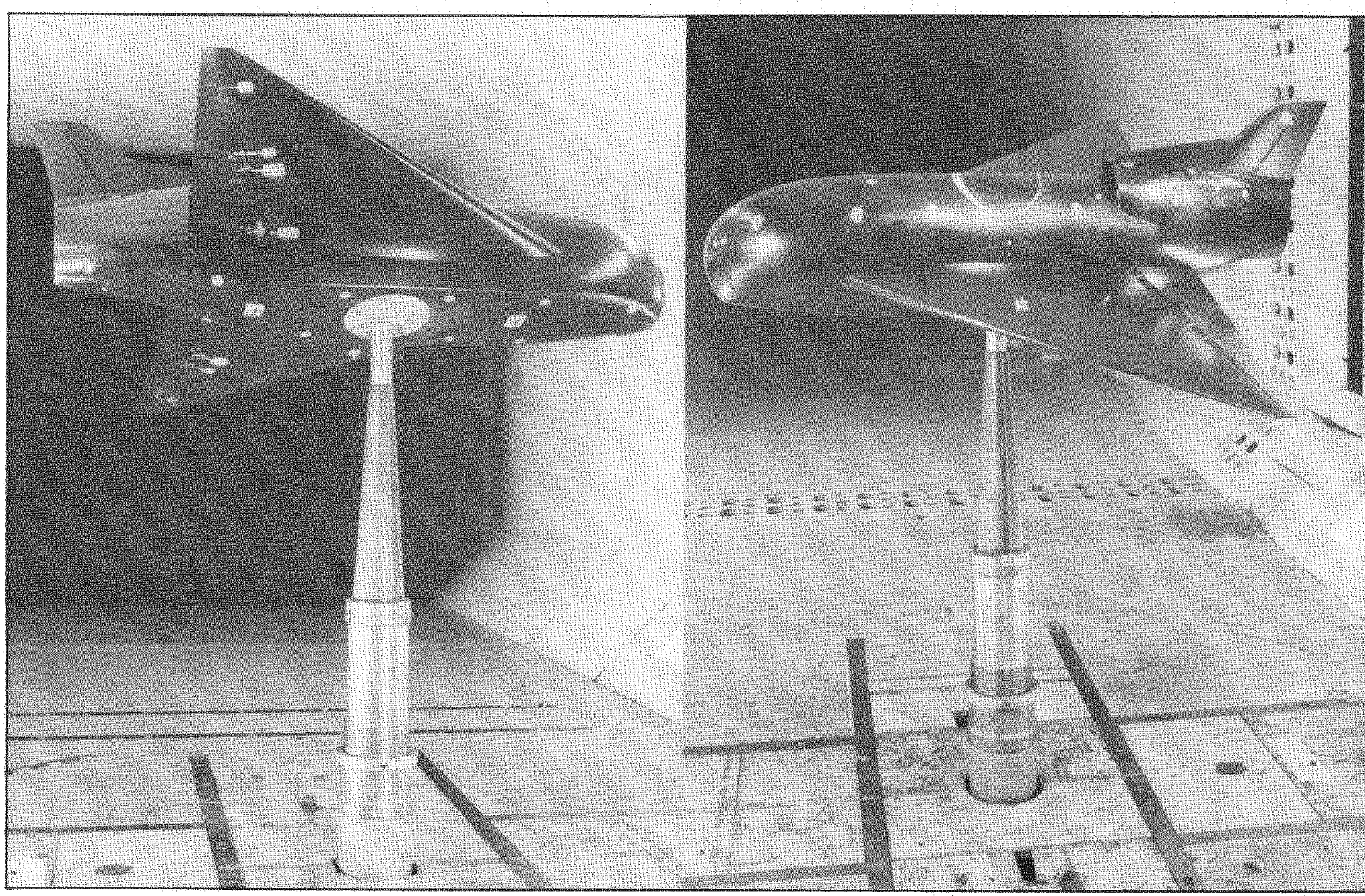


Fig.2. Model mounted on small strut (strut guard removed)

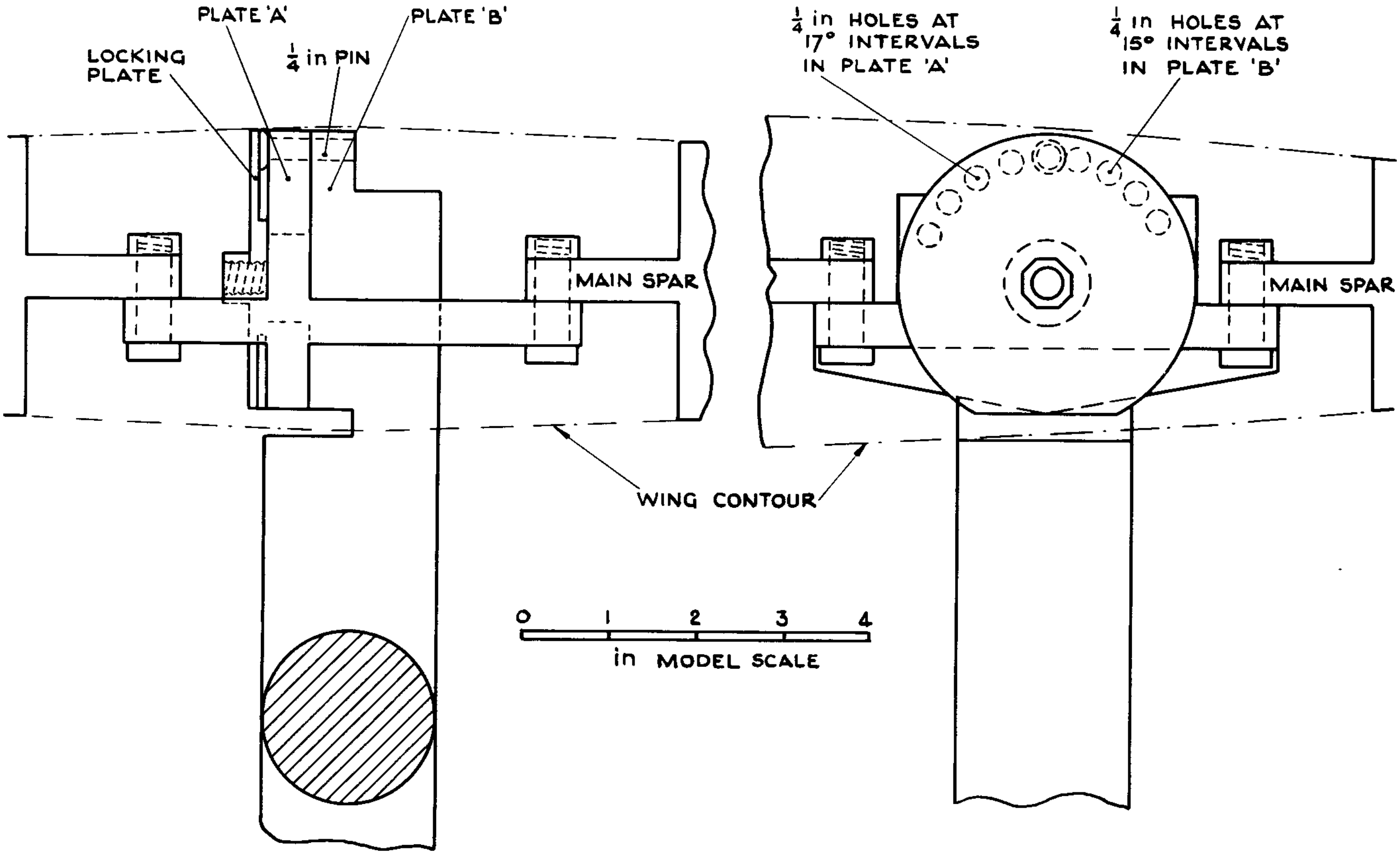


FIG. 3 ATTACHMENT OF MODEL TO SMALL STRUT.

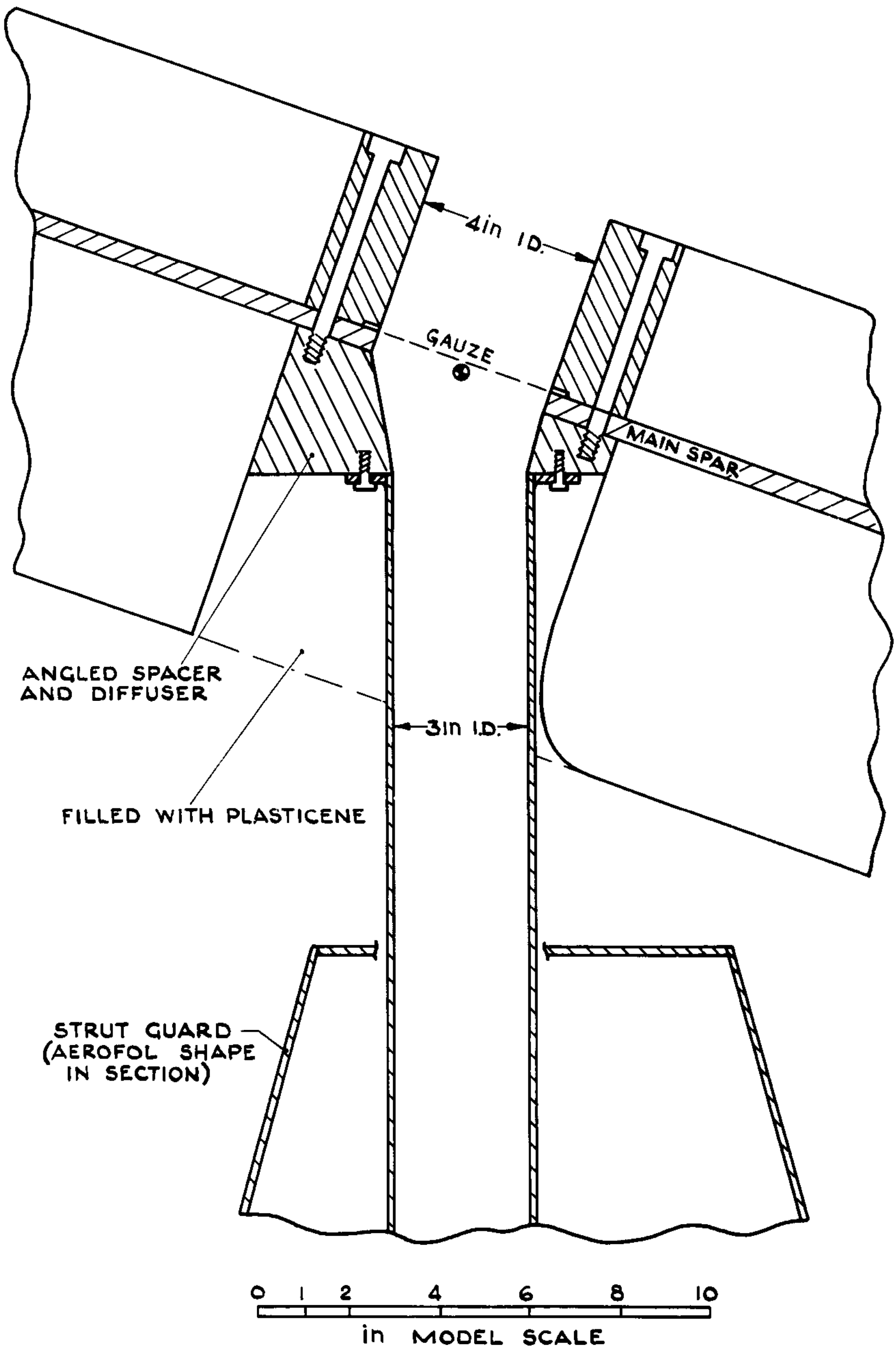


FIG. 4 DETAILS OF BLOWING BOX ASSEMBLY.

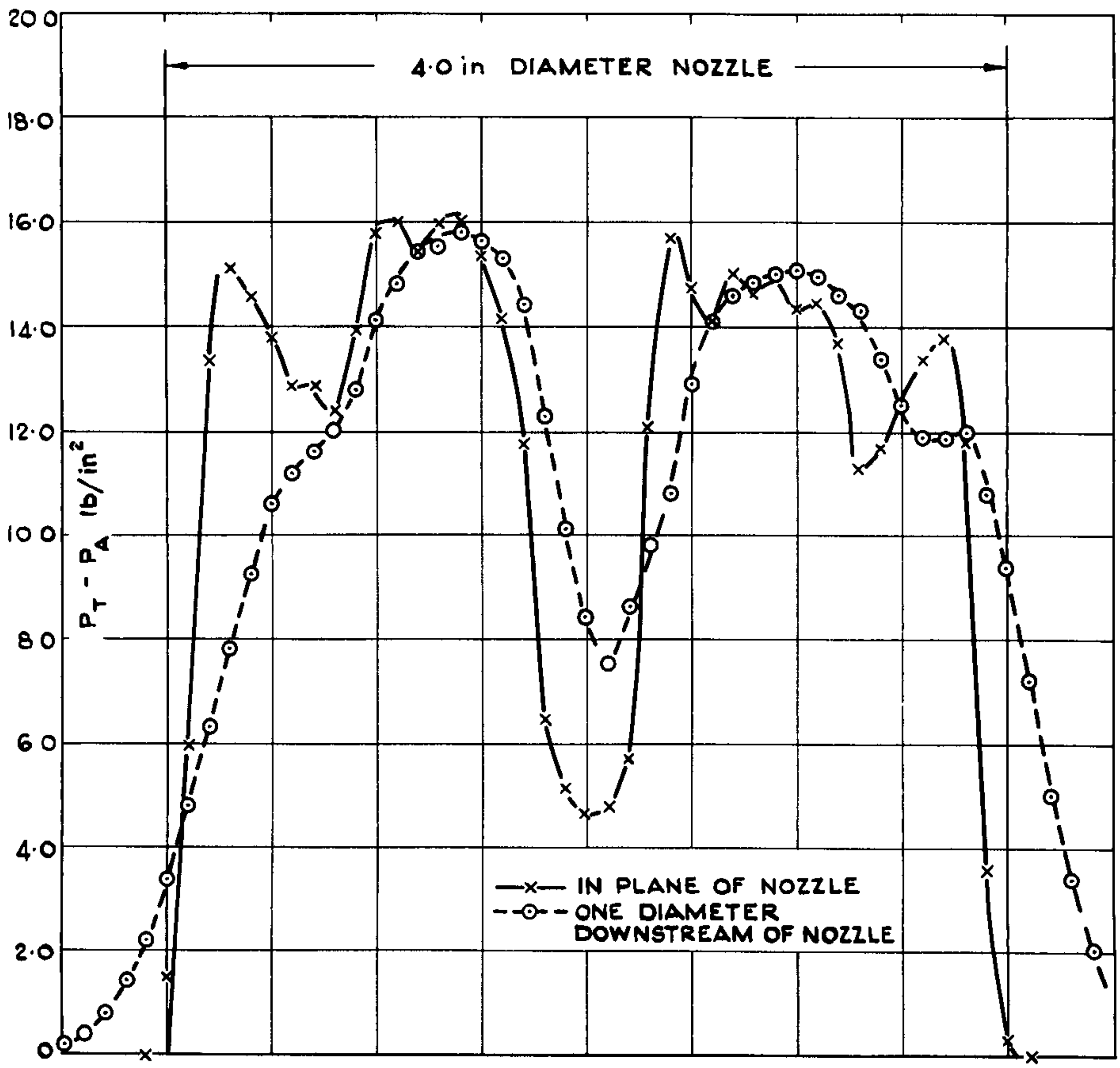
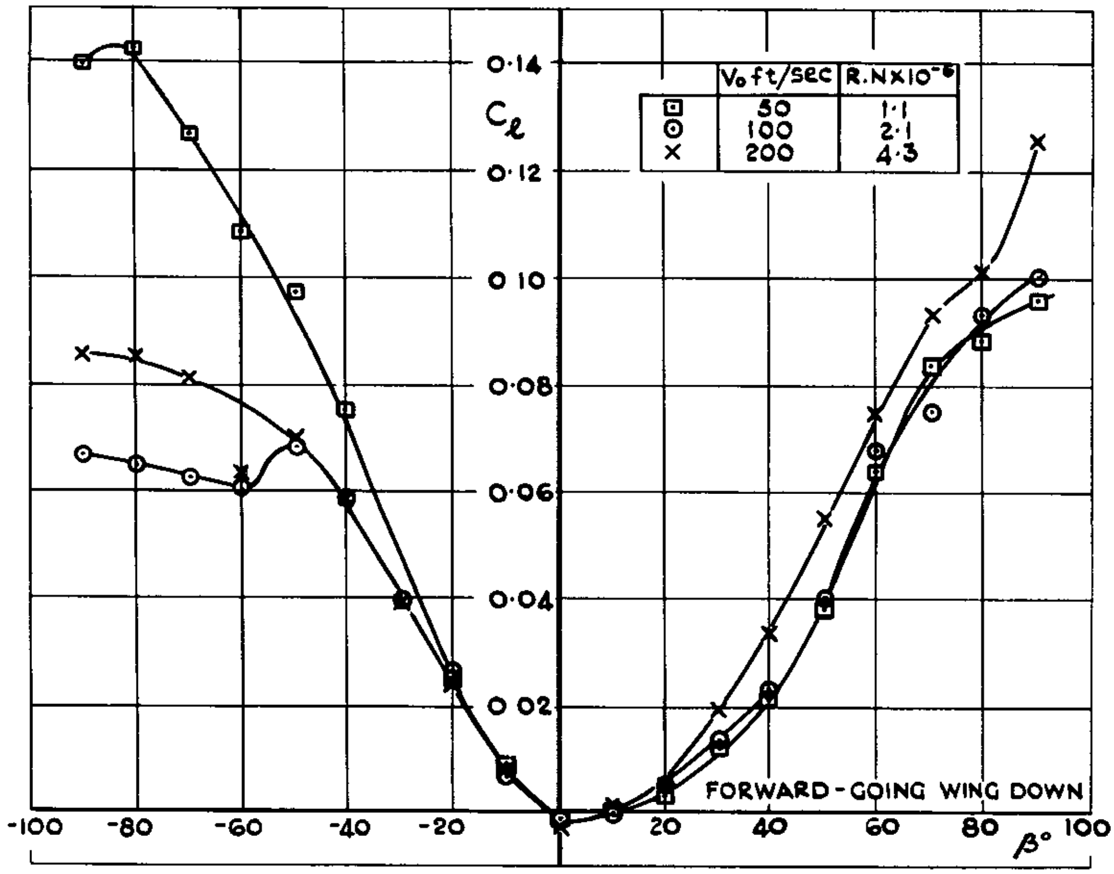
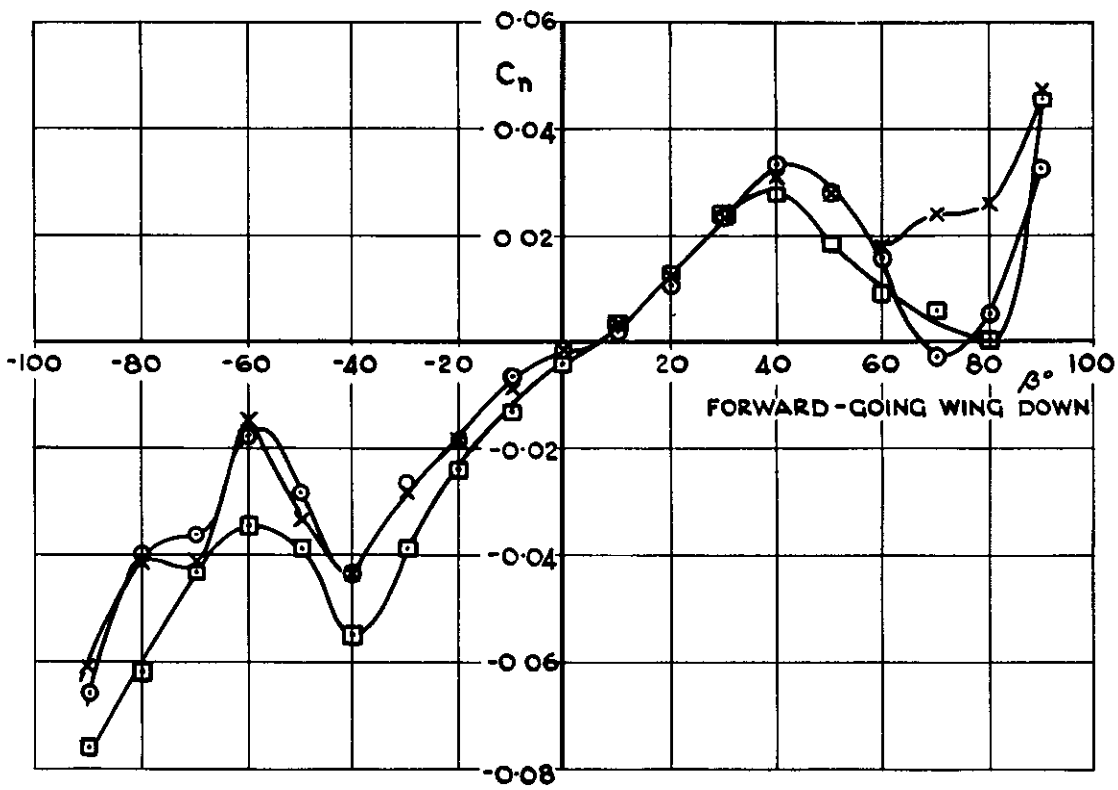


FIG.5 PRESSURE DISTRIBUTION ACROSS EFFLUX
MASS FLOW RATE = 7 lb/sec.



a ROLLING MOMENT

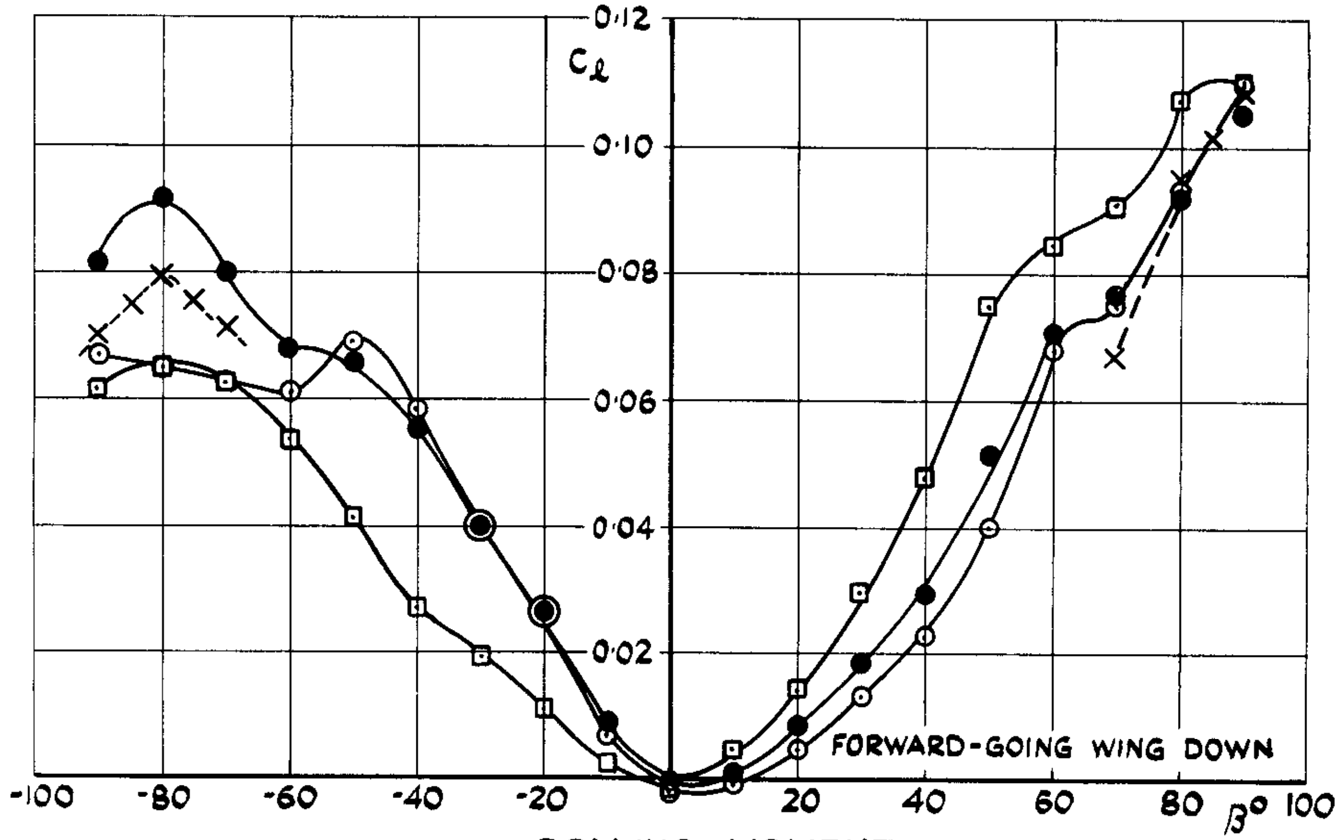


b YAWING MOMENT

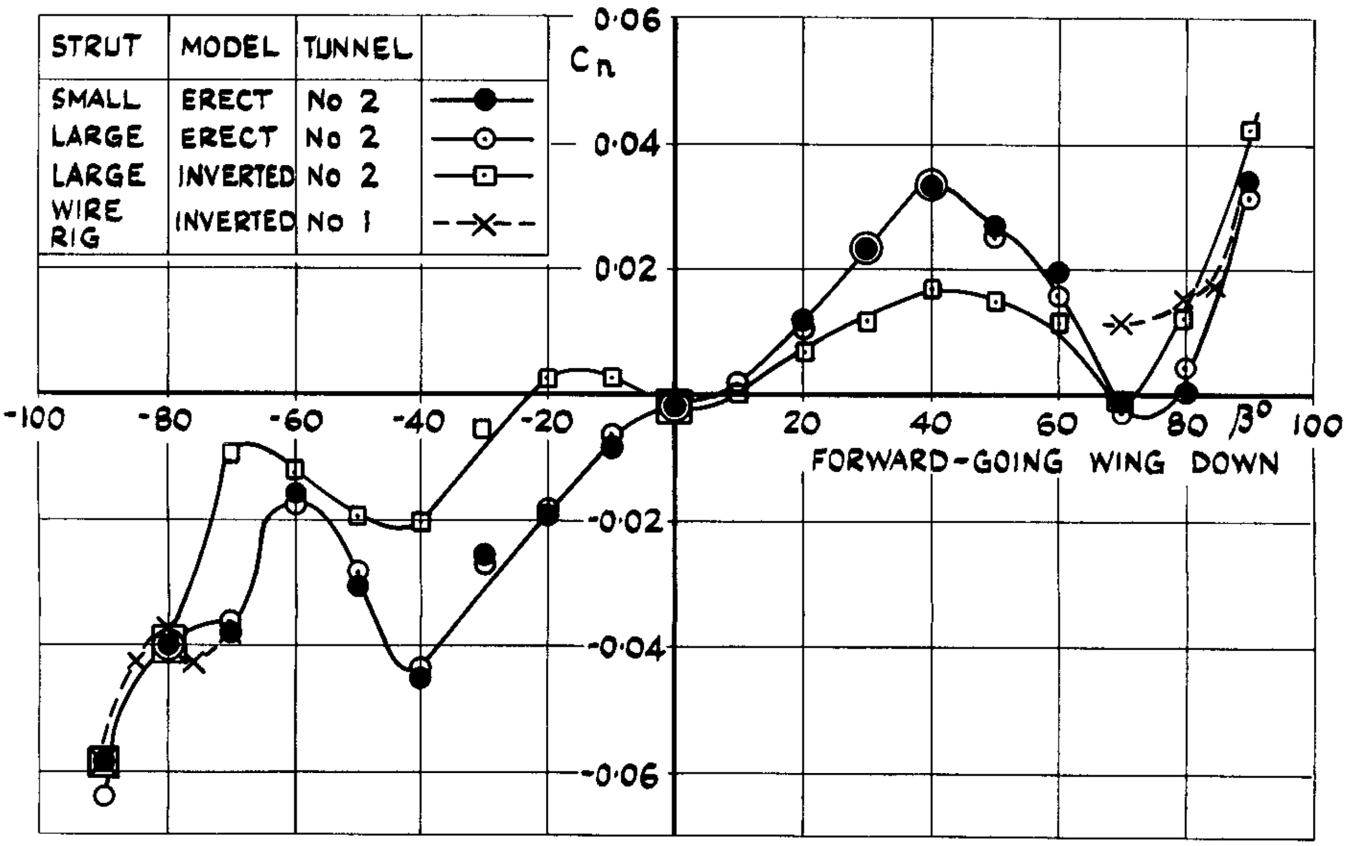
FIG. 6 a & b. EFFECT OF REYNOLDS NUMBER WITH TRANSITION FREE

ERECT COMPLETE MODEL ON LARGE STRUT

$\theta = 0; \ \phi = +20°.$



a ROLLING MOMENT



b YAWING MOMENT

FIG. 7 a & b. EFFECT OF SUSPENSION SYSTEM

$\theta = 0; \ \phi = 20^\circ$, UNBLOWN

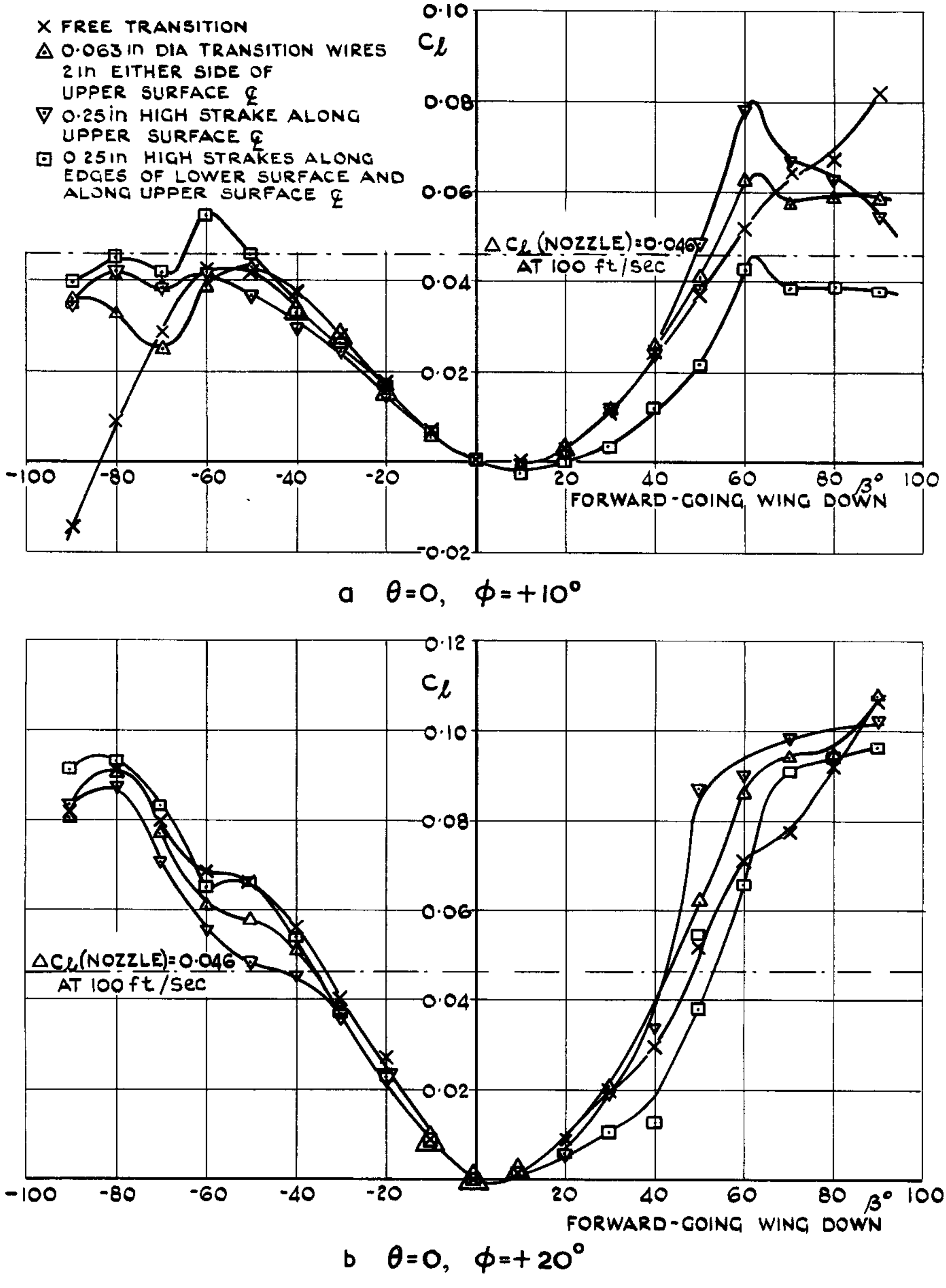
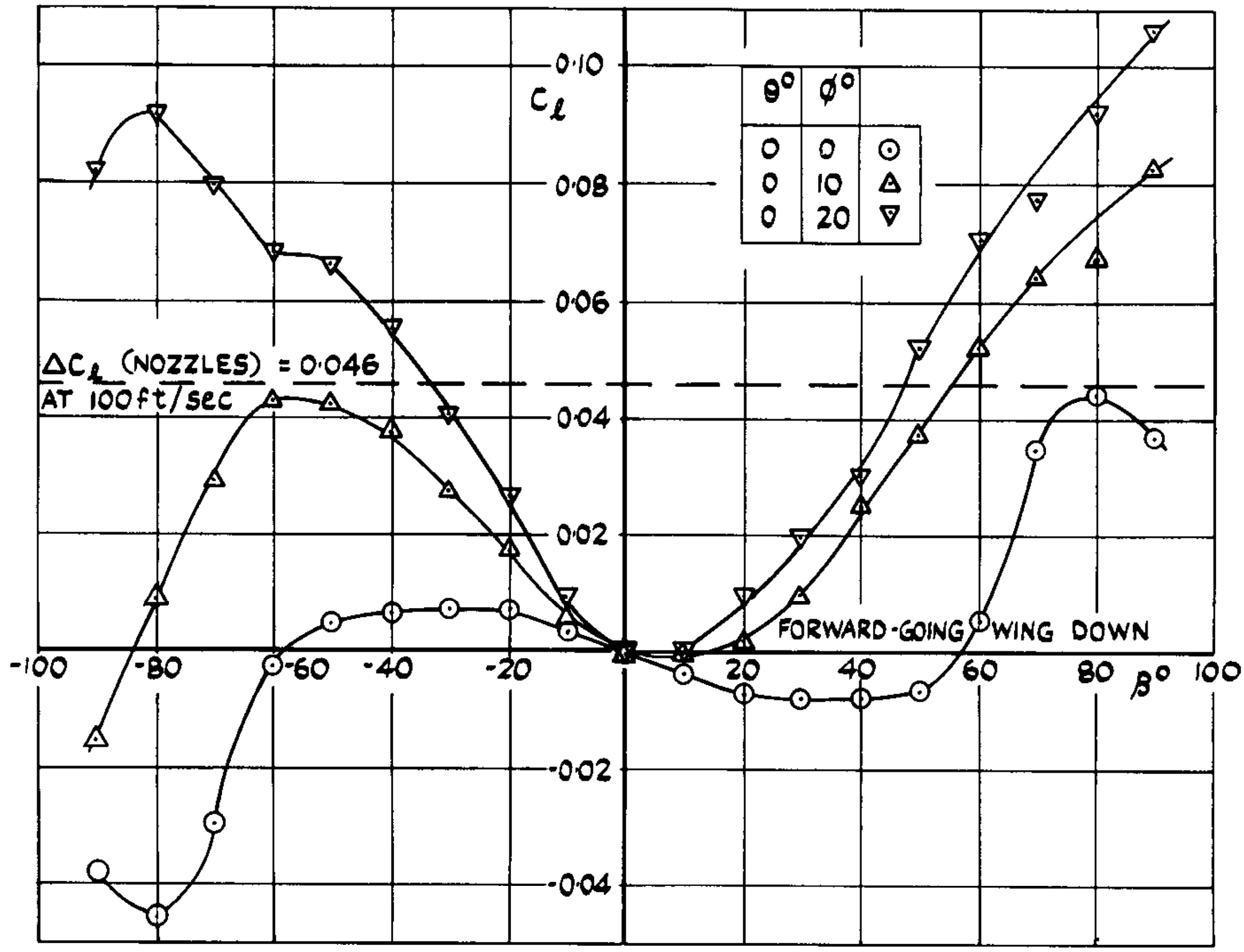
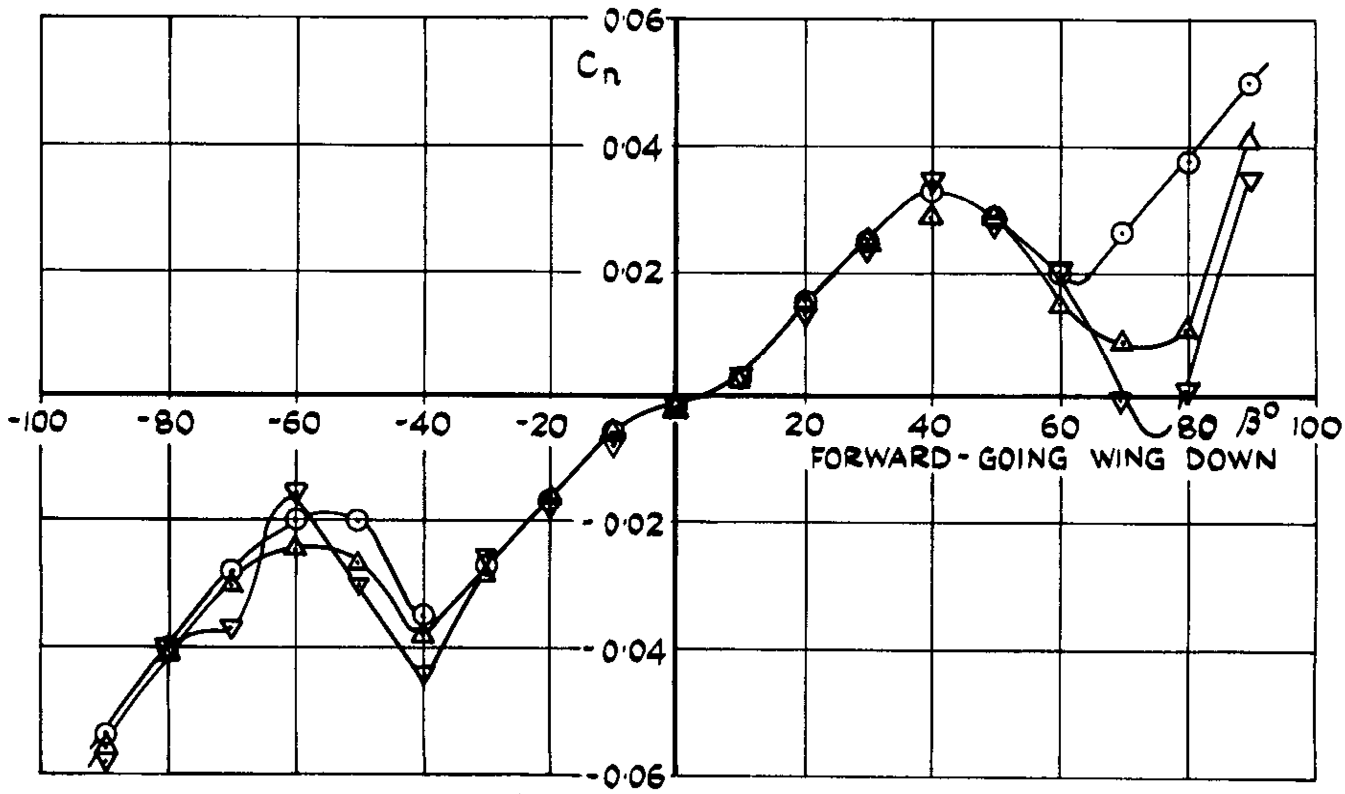


FIG. 8 a & b EFFECT OF FIXING FUSELAGE TRANSITION. ZERO PITCH ANGLE
ERECT COMPLETE MODEL ON SMALL STRUT

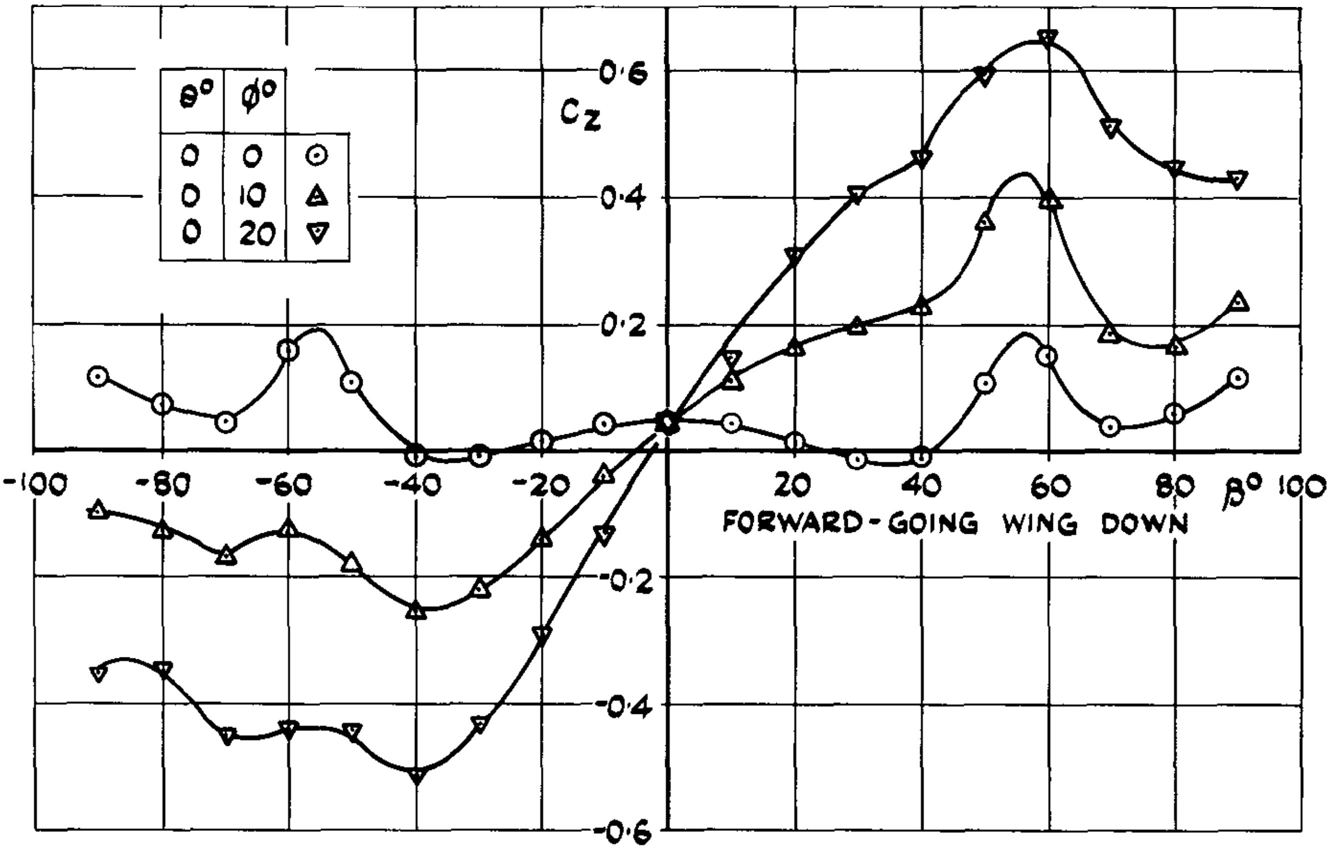


a ROLLING MOMENT

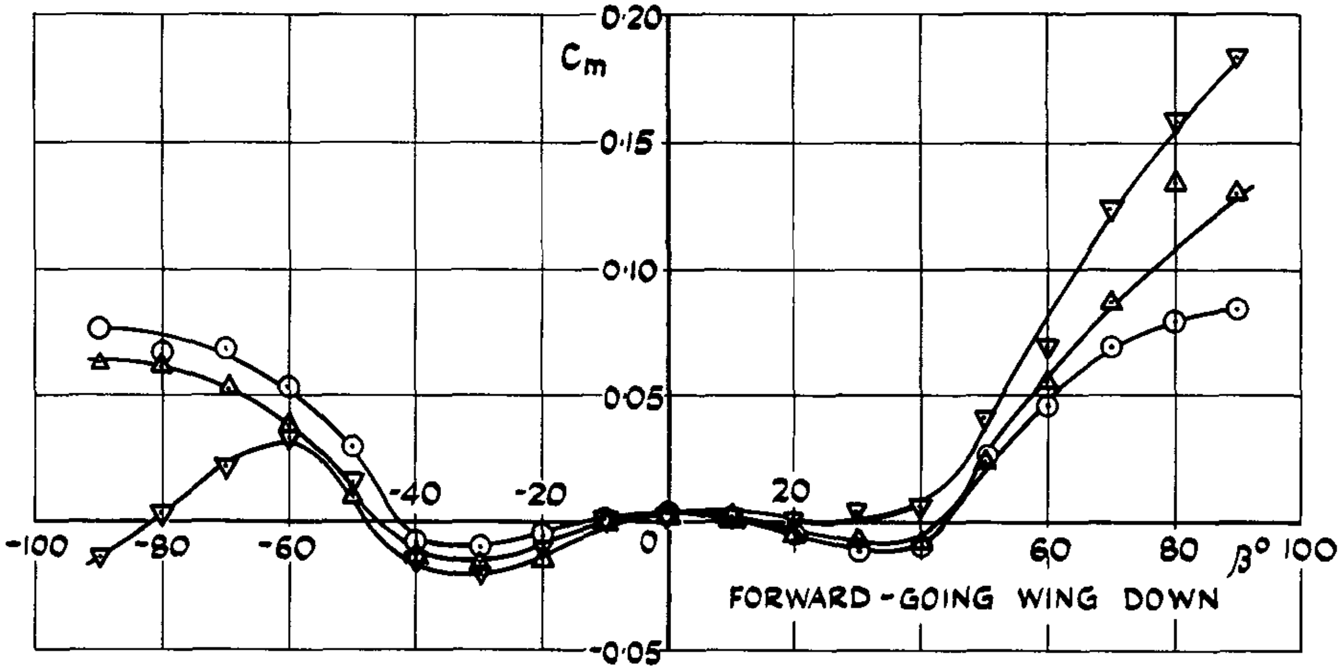


b YAWING MOMENT

FIG. 9 a & b EFFECT OF ROLL AT ZERO PITCH
ERECT COMPLETE MODEL ON SMALL STRUT, TRANSITION FREE

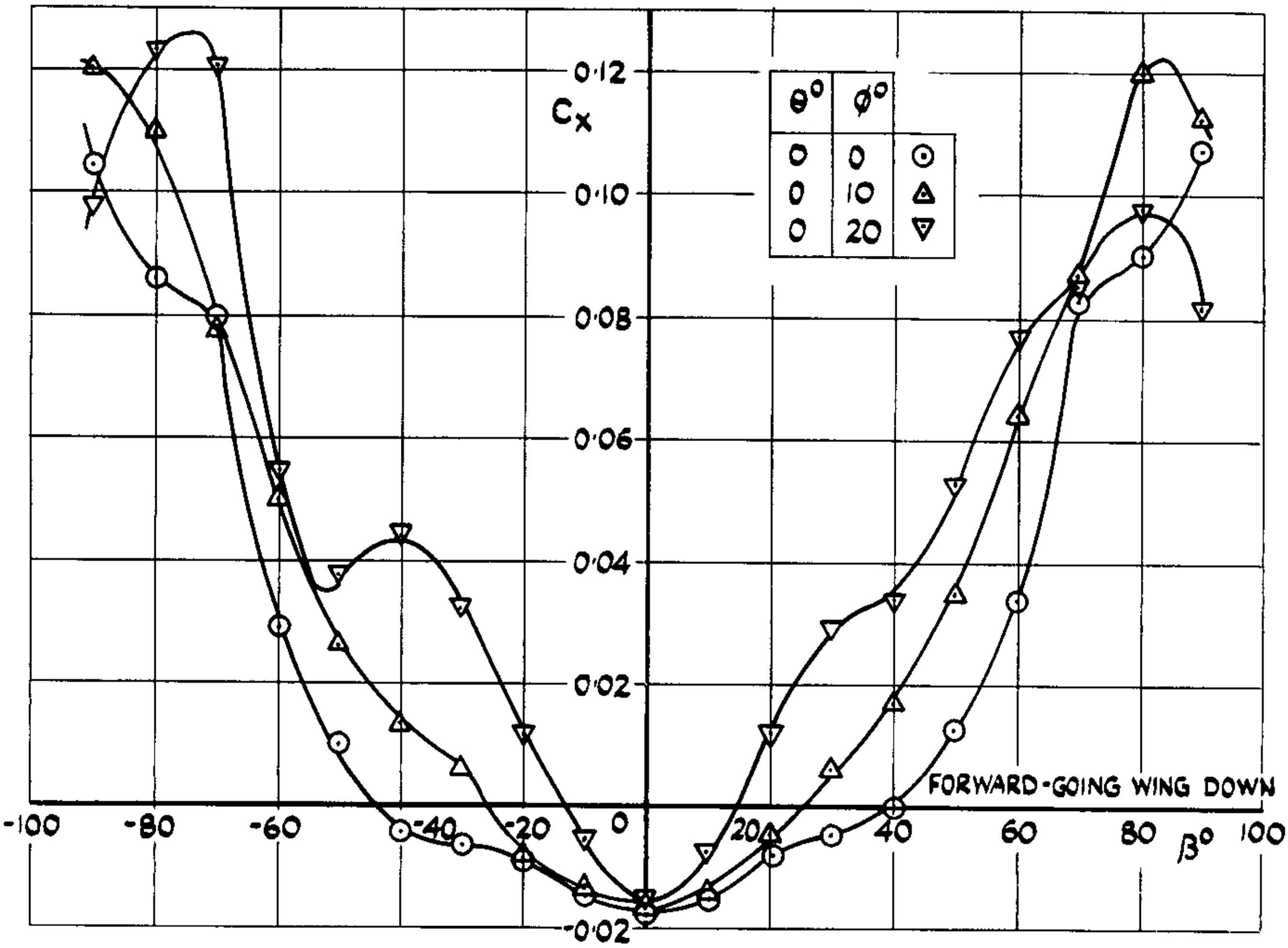


c NORMAL FORCE

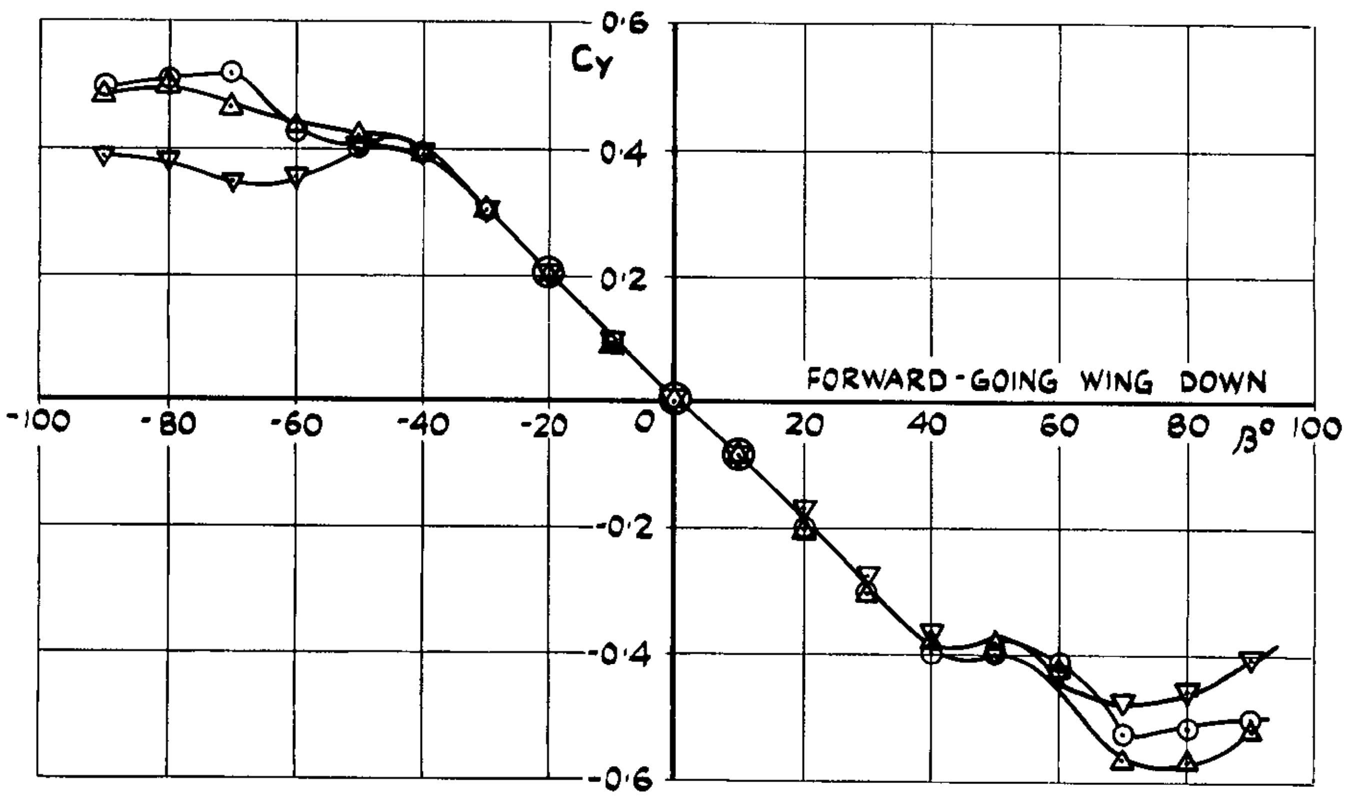


d PITCHING MOMENT

FIG 9 c & d EFFECT OF ROLL AT ZERO PITCH
ERECT COMPLETE MODEL ON SMALL STRUT, TRANSITION FREE



e AXIAL FORCE



f SIDE FORCE

FIG. 9 e & f EFFECT OF ROLL AT ZERO PITCH
ERECT COMPLETE MODEL ON SMALL STRUT, TRANSITION FREE

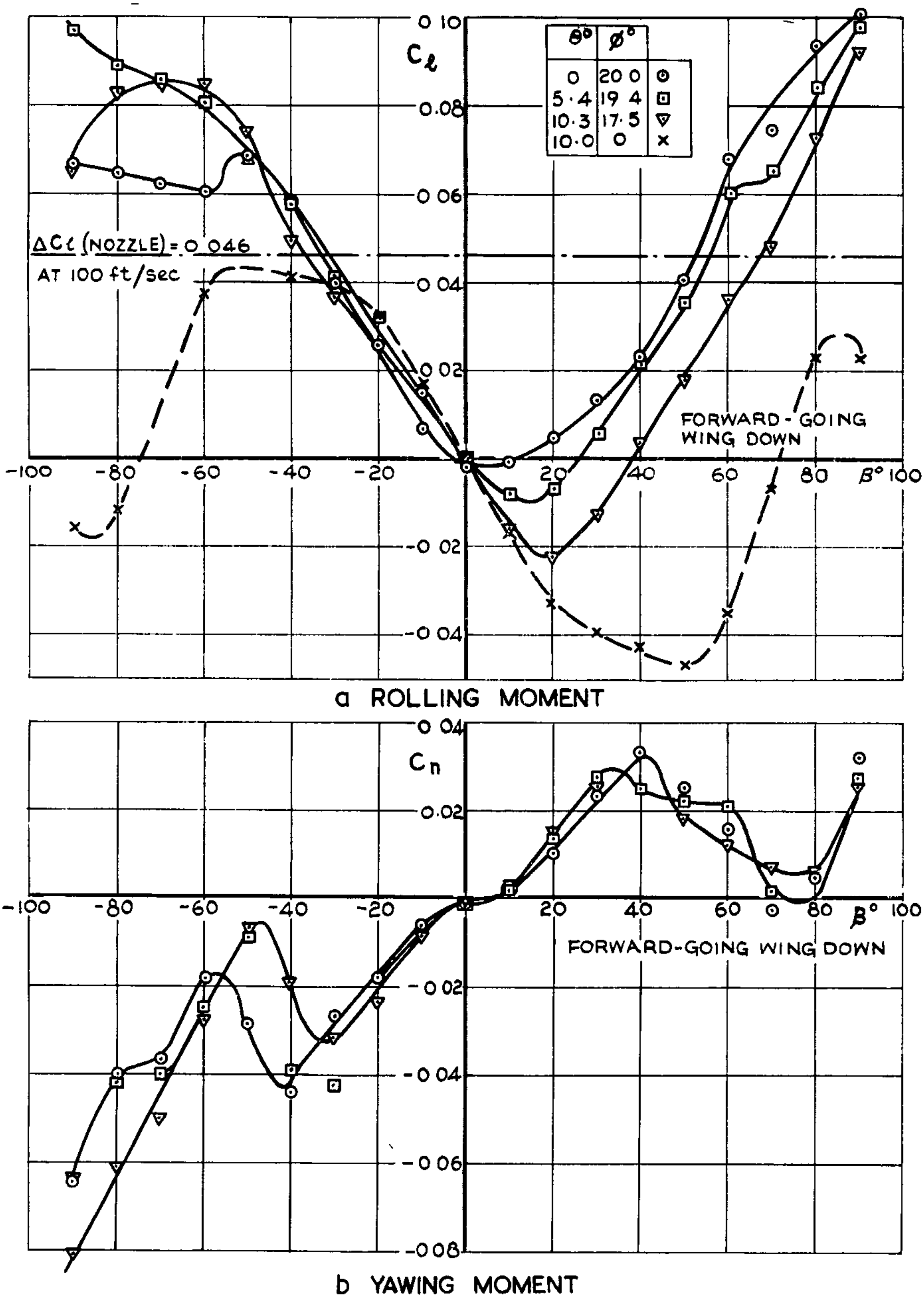
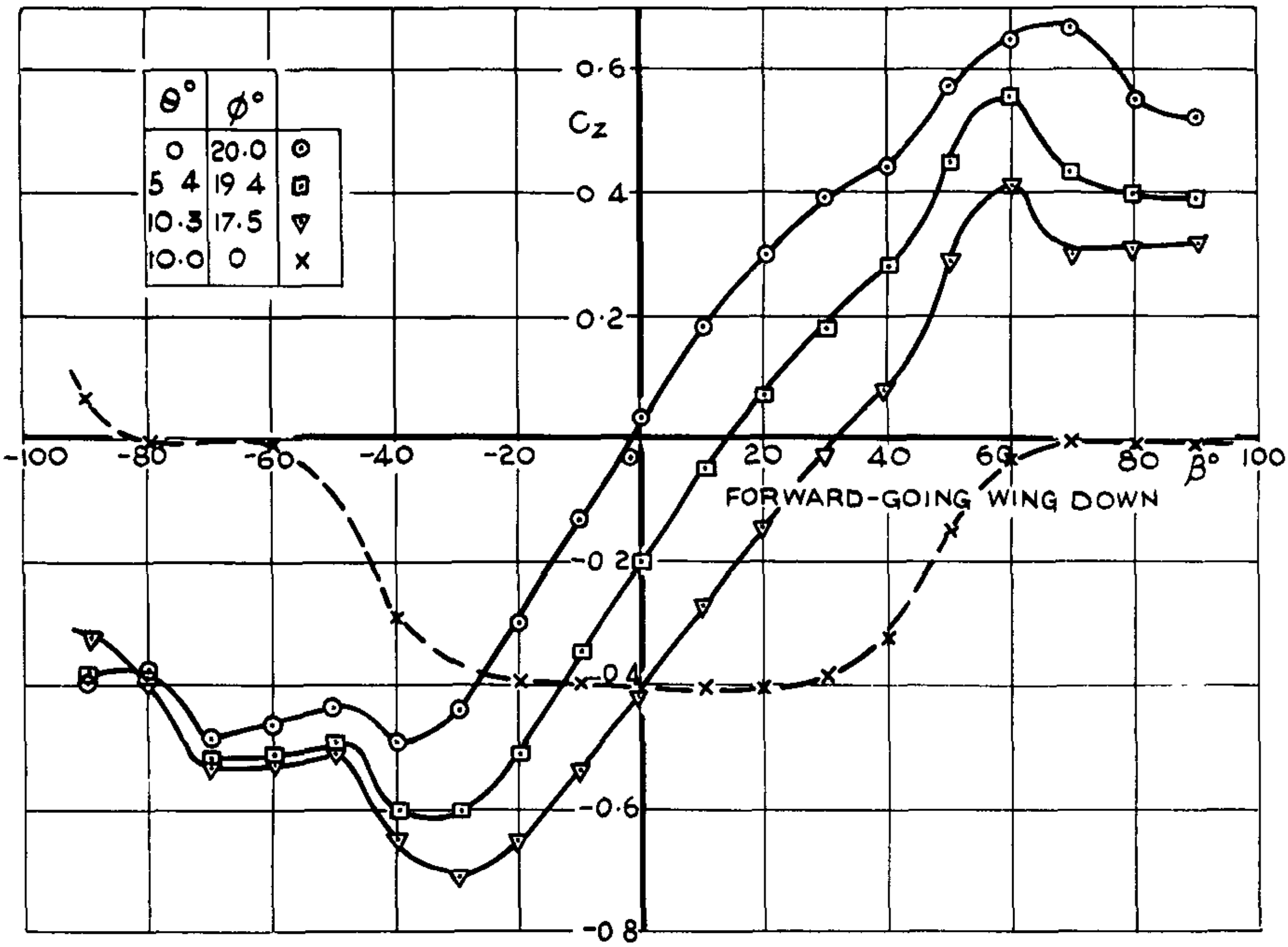
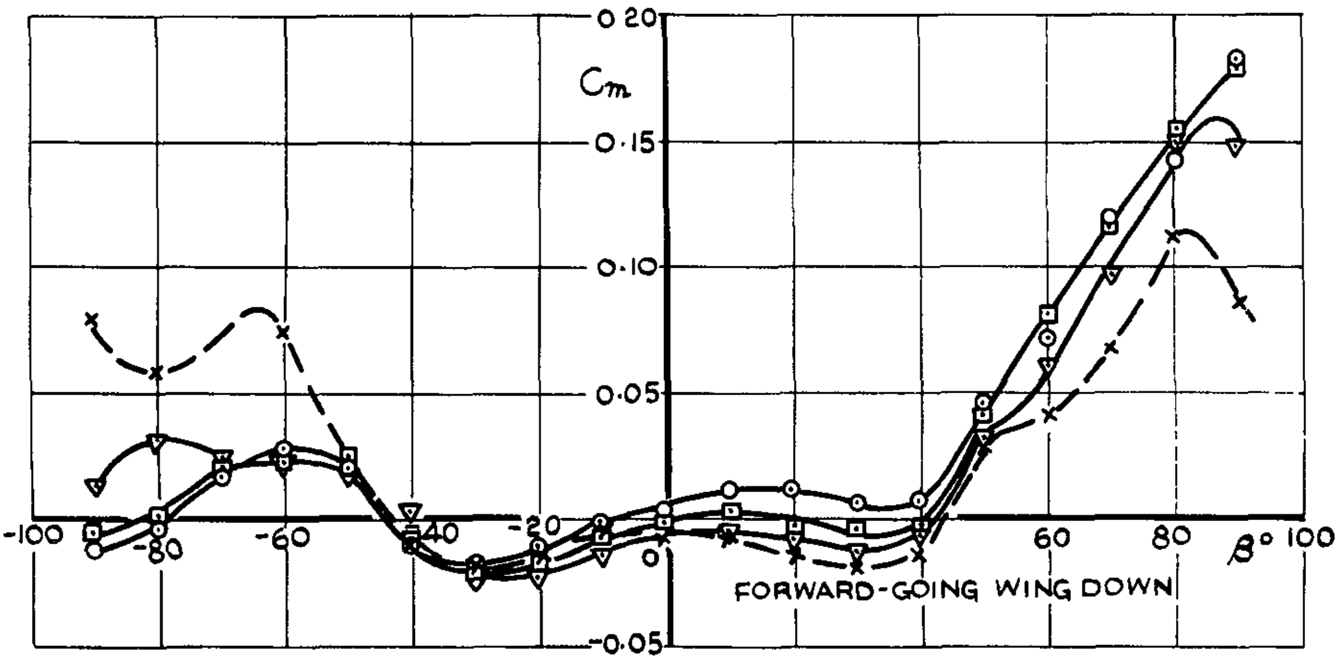


FIG. 10 a & b EFFECT OF INCIDENCE AND ROLL.
ERECT COMPLETE MODEL ON LARGE STRUT, TRANSITION FREE

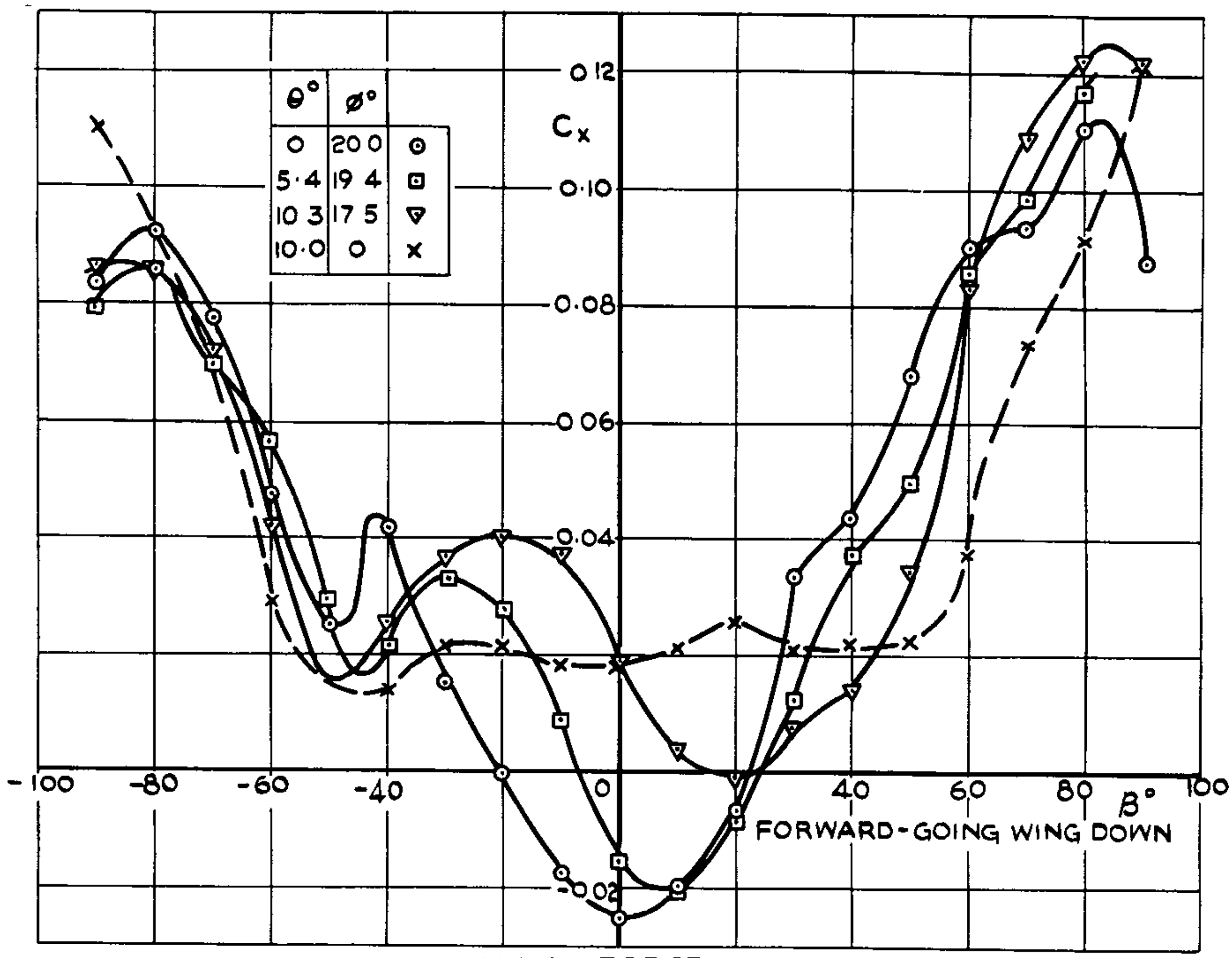


c NORMAL FORCE

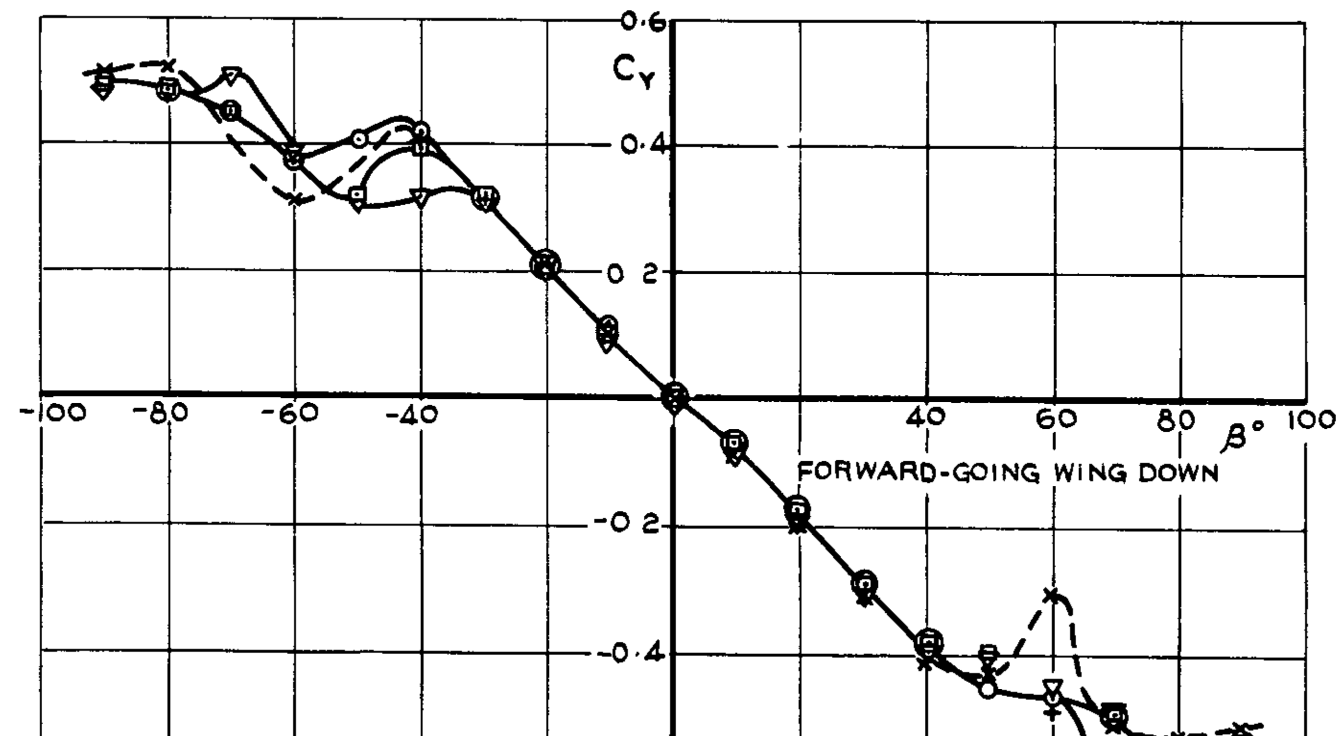


d PITCHING MOMENT

FIG. 10 c & d EFFECT OF INCIDENCE AND ROLL.
ERECT COMPLETE MODEL ON LARGE STRUT, TRANSITION FREE



e AXIAL FORCE



f SIDEFORCE

FIG. 10 e & f EFFECT OF INCIDENCE AND ROLL

ERECT COMPLETE MODEL ON LARGE STRUT, TRANSITION FREE

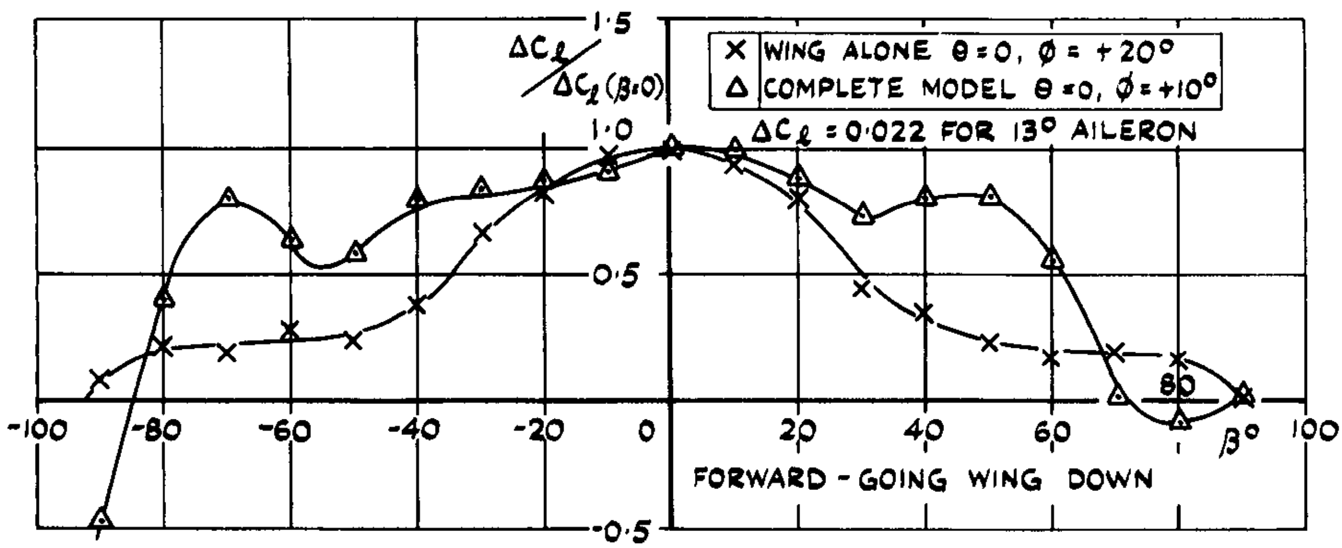


FIG. 11 EFFECT OF SIDESLIP ON AILERON POWER AT ZERO PITCH

MODEL ON SMALL STRUT, TRANSITION FREE

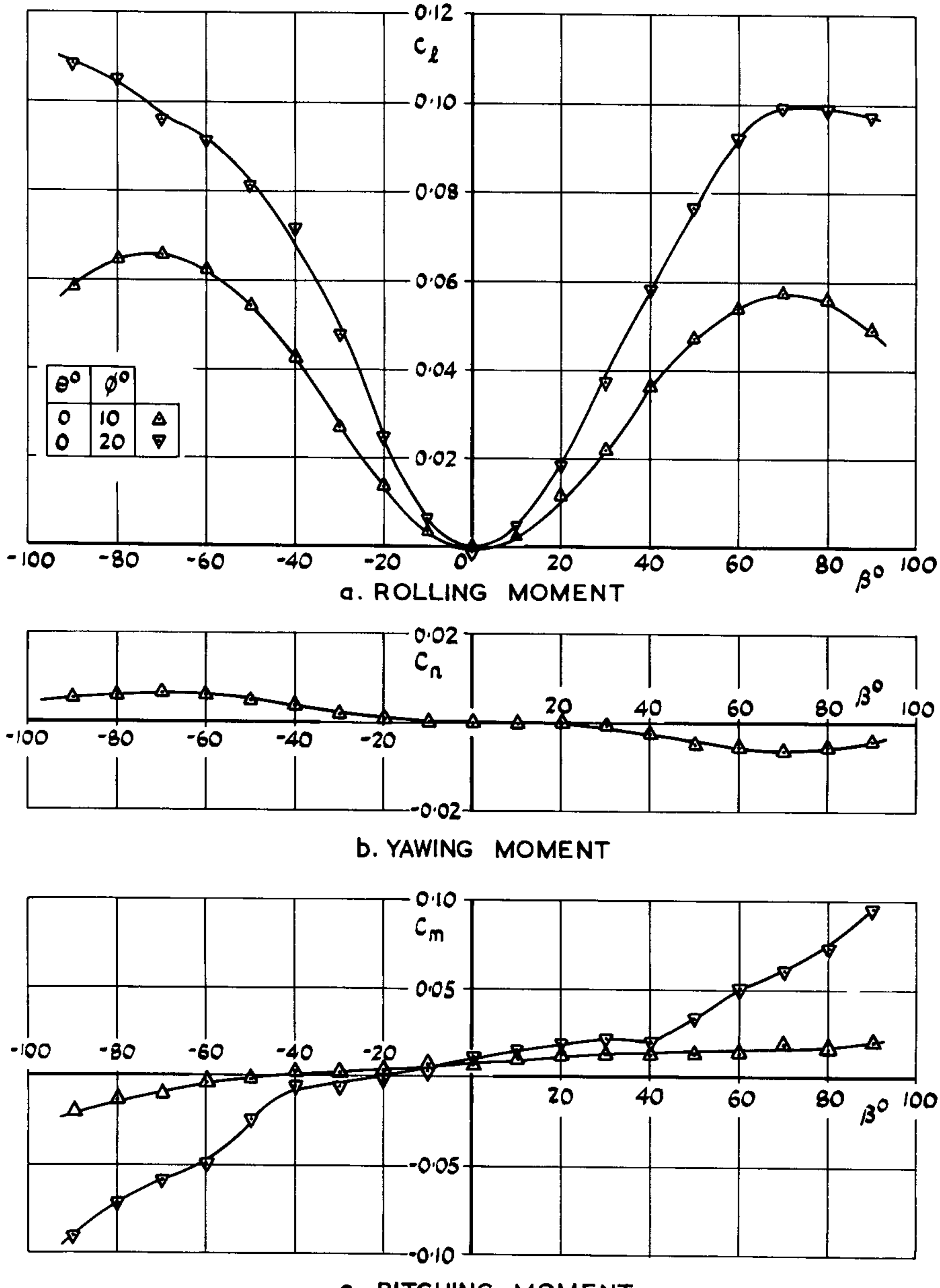


FIG. 12 a-c WING ALONE ON SMALL STRUT.
EFFECT OF ROLL AT ZERO PITCH, TRANSITION FREE

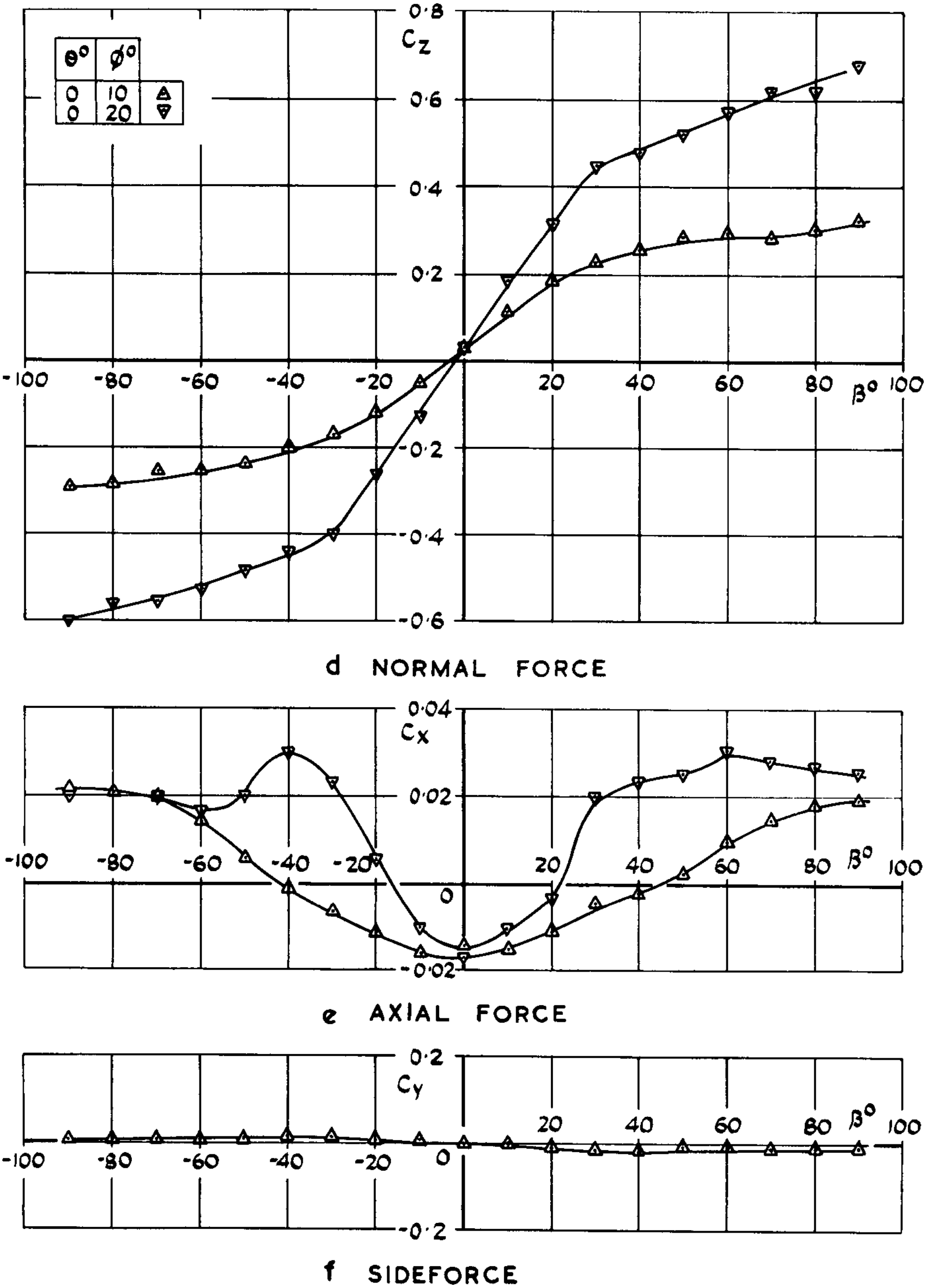
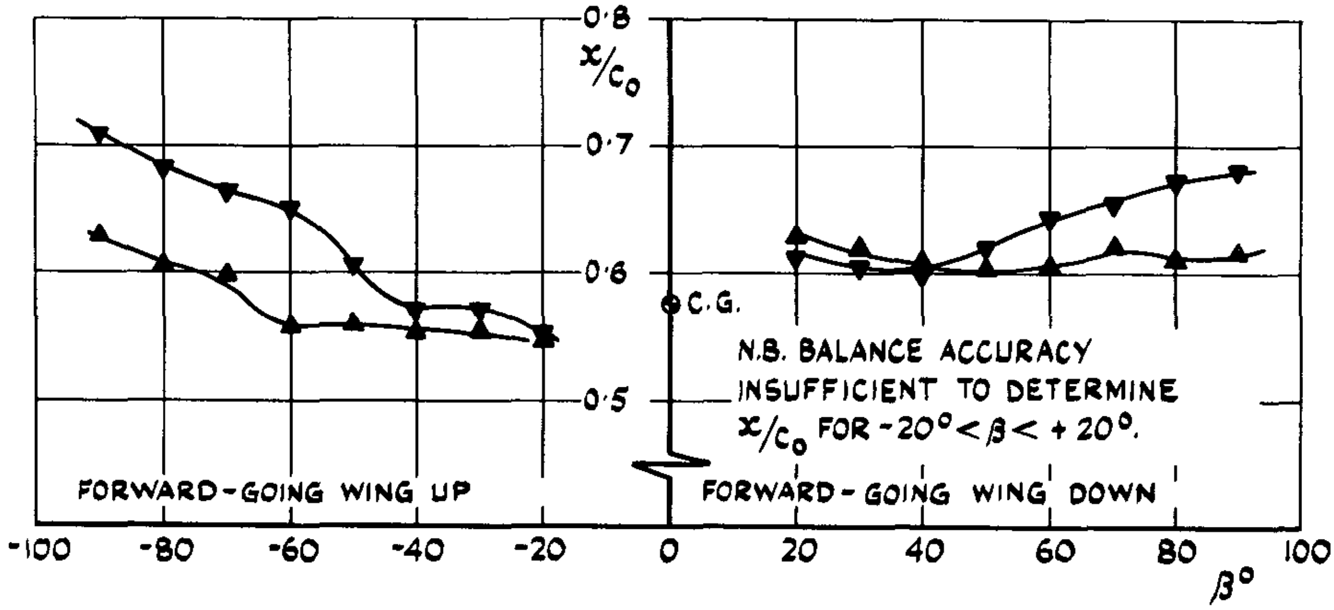


FIG 12 d-f WING ALONE ON SMALL STRUT.
EFFECT OF ROLL AT ZERO PITCH, TRANSITION FREE



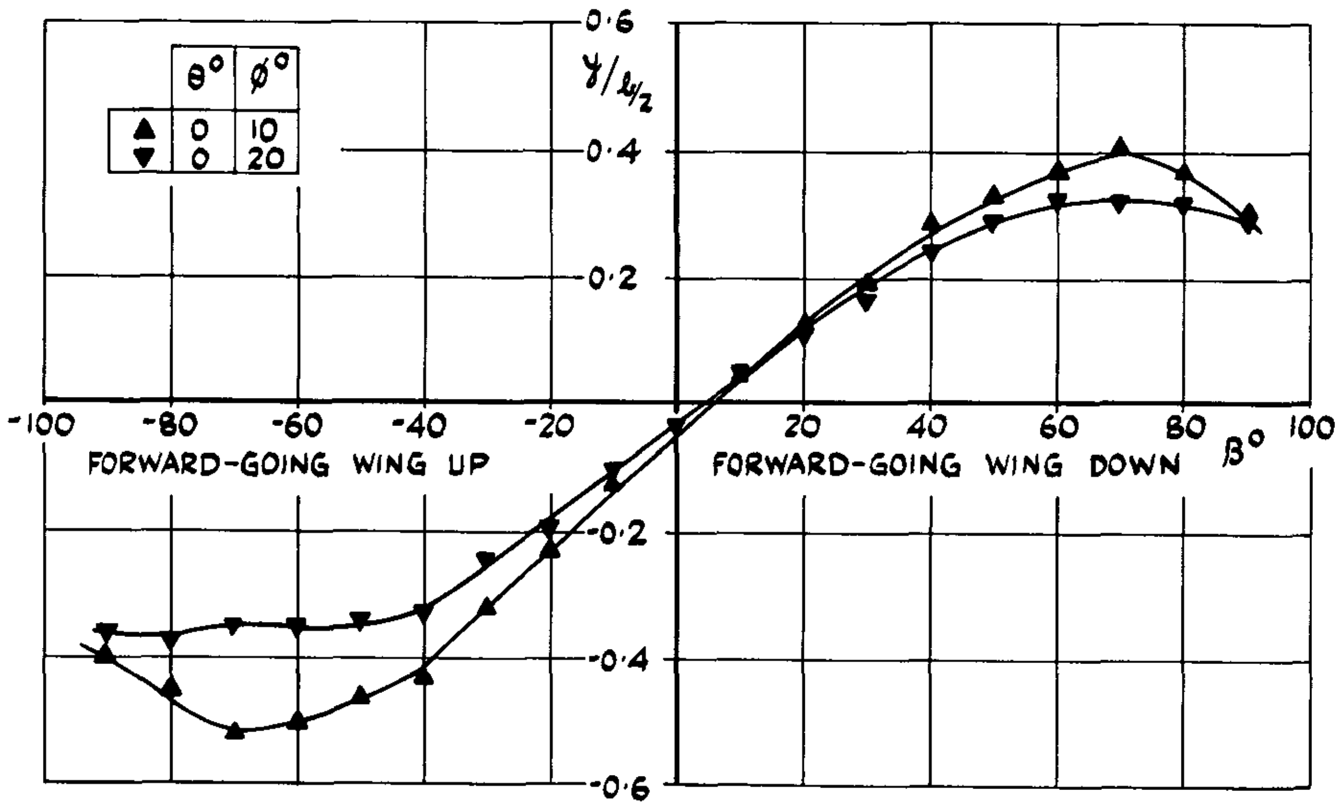


FIG.13 CENTRE OF PRESSURE MOVEMENTS ON ISOLATED WING, AT ZERO PITCH SMALL STRUT, TRANSITION FREE.

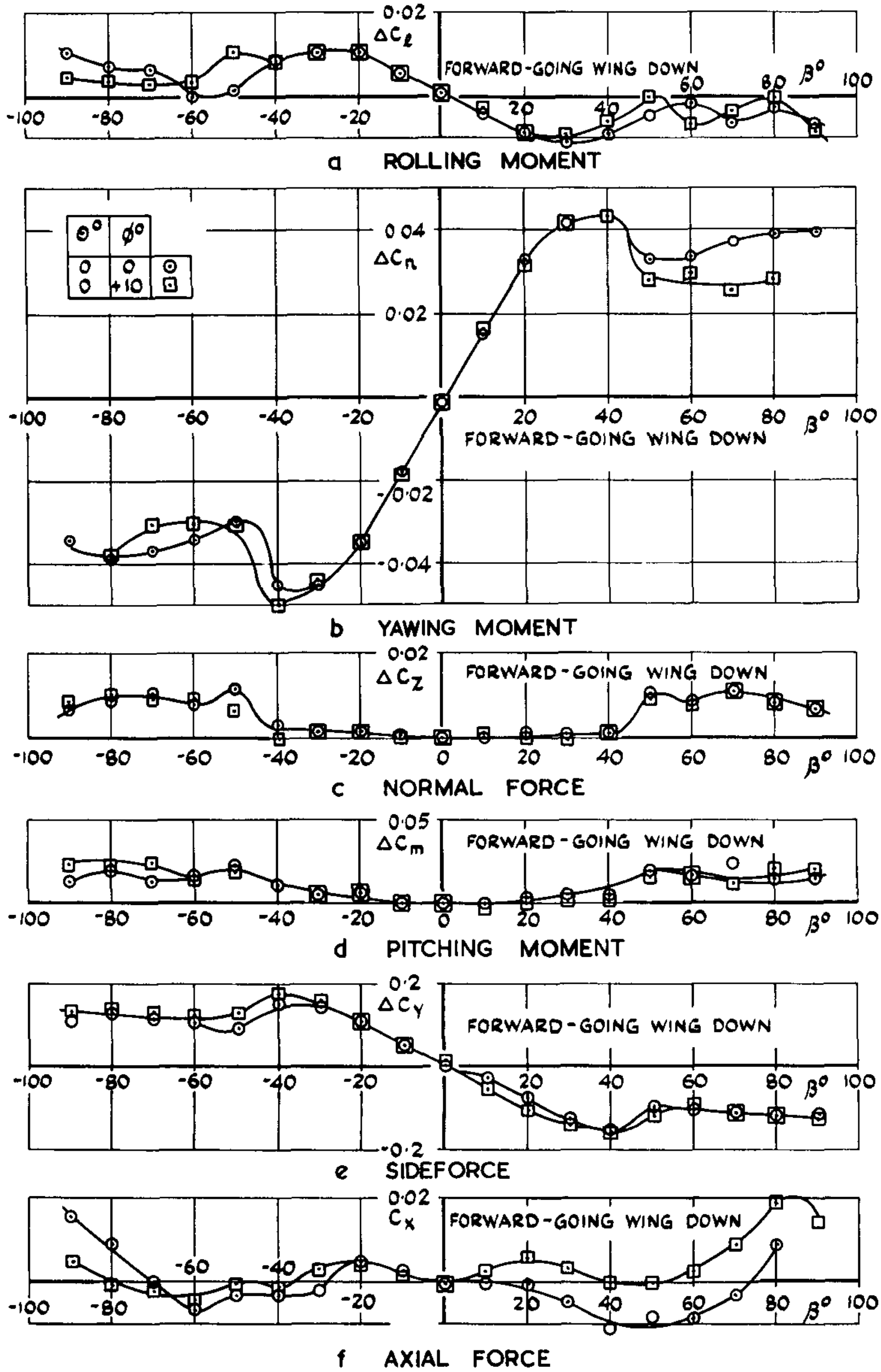
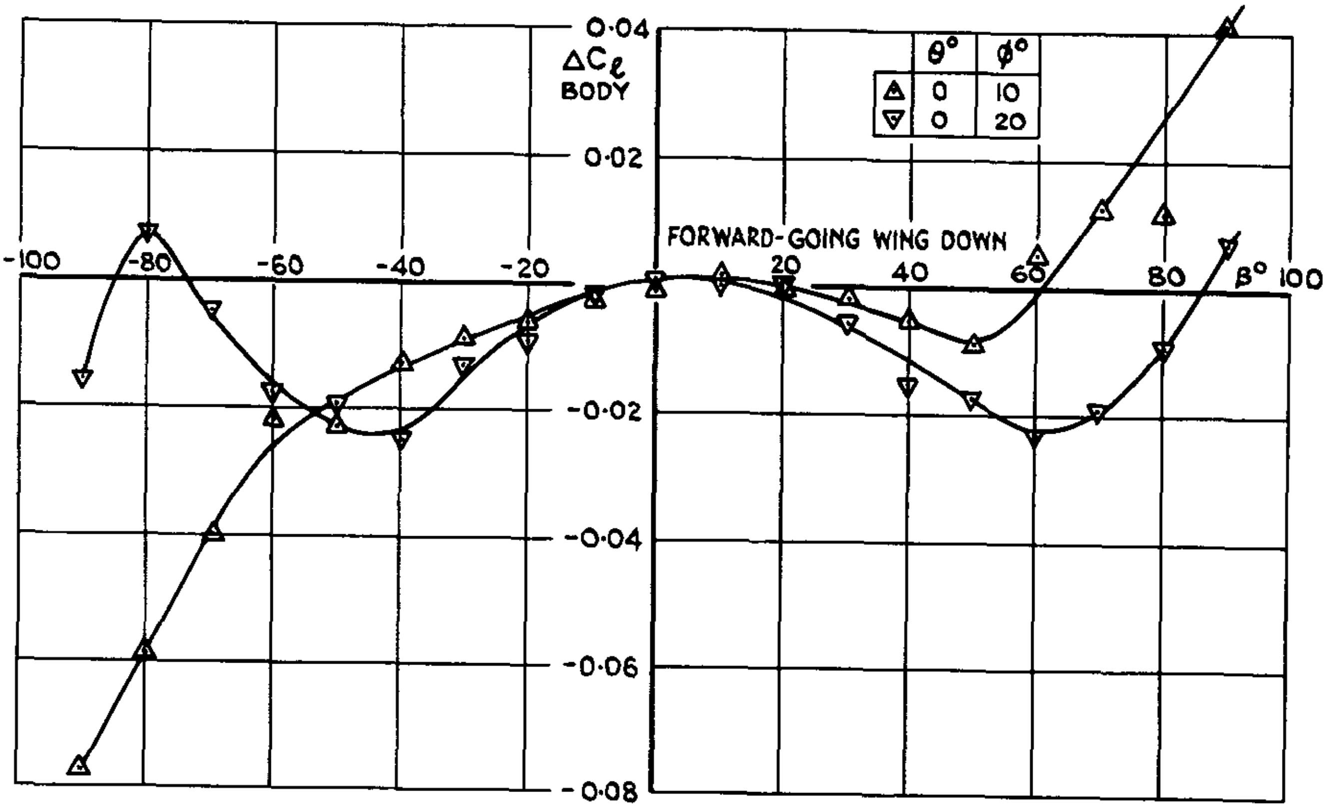


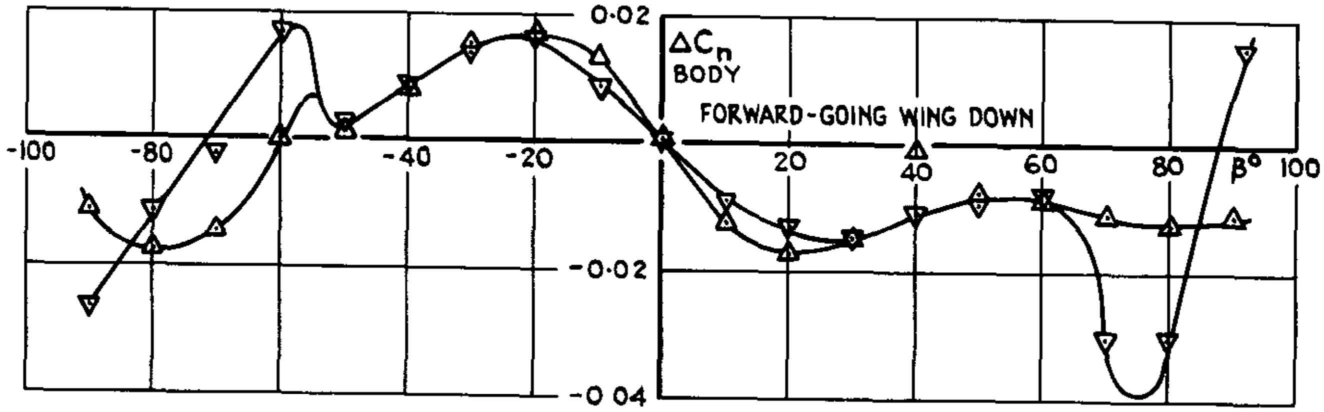
Fig.14a-f INCREMENTS IN FORCES AND MOMENTS DUE TO FIN AND DORSAL

ERECT MODEL ON LARGE STRUT, TRANSITION FREE

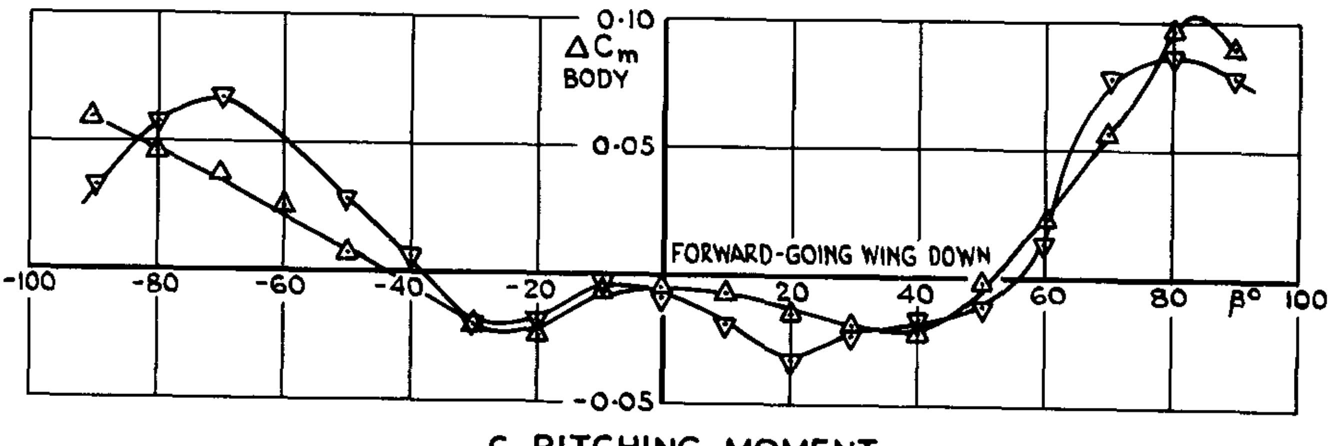
(ZERO PITCH ANGLE)



a ROLLING MOMENT



b YAWING MOMENT



c PITCHING MOMENT

FIG. 15 a-c FUSELAGE CONTRIBUTION TO FORCES AND MOMENTS ZERO PITCH ANGLE

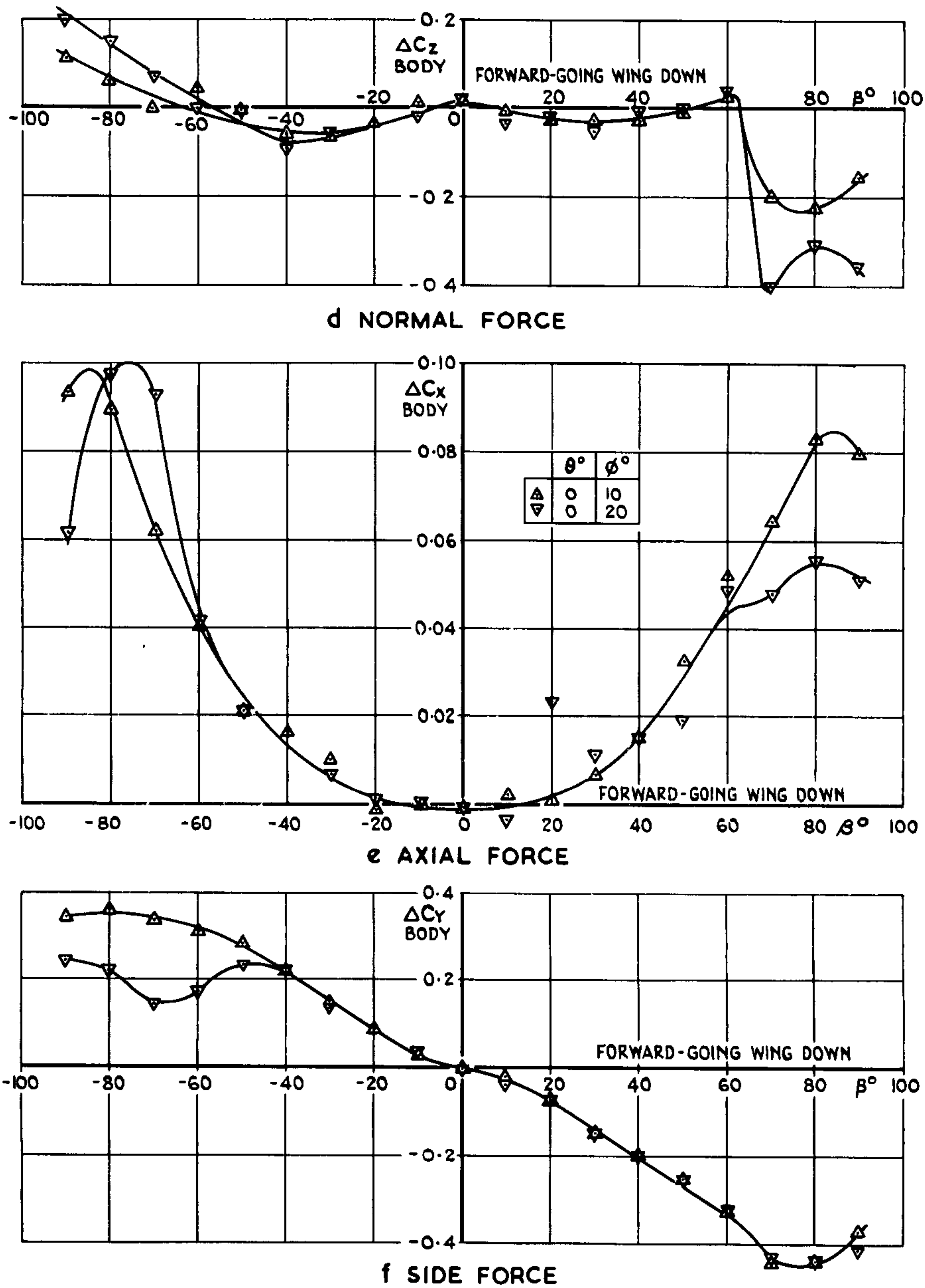
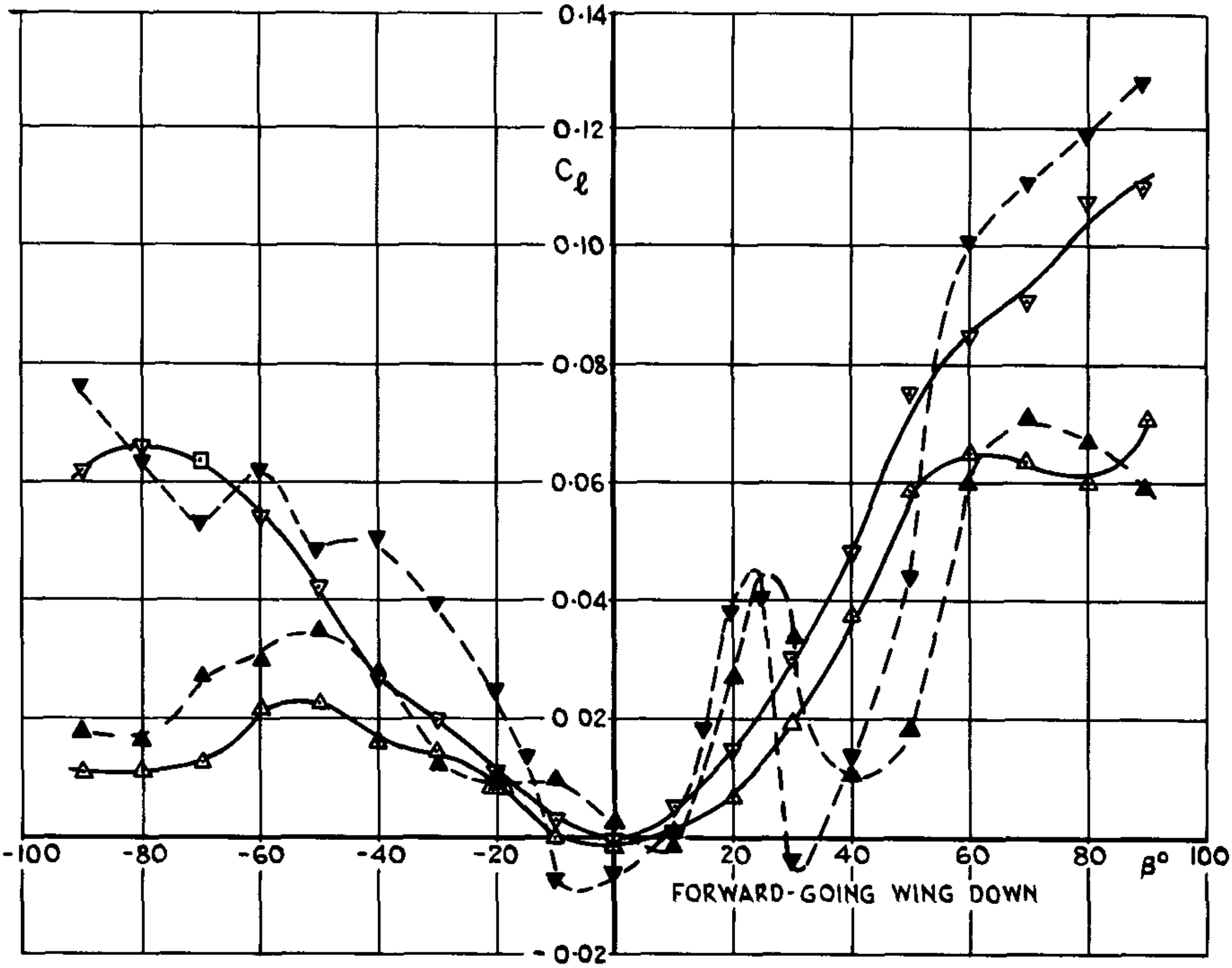
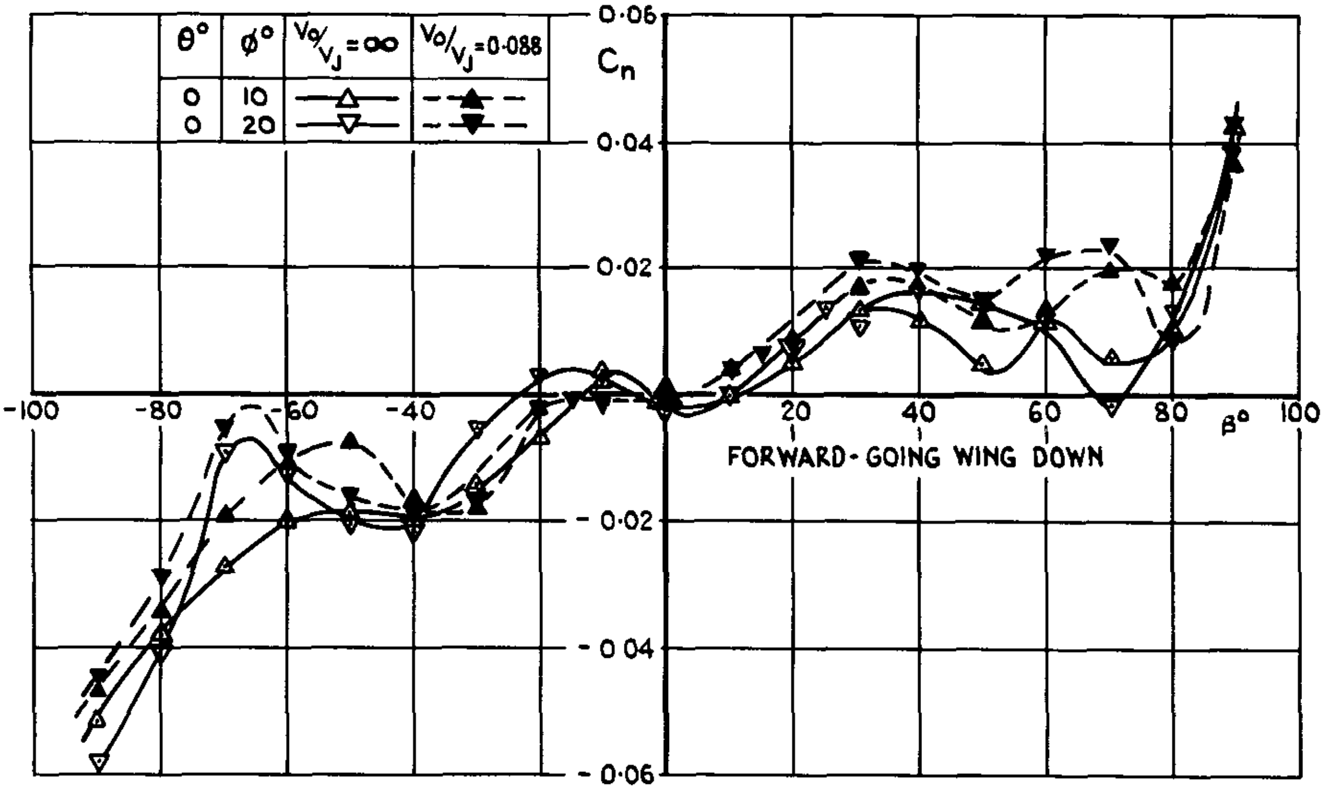


FIG 15 d–f FUSELAGE CONTRIBUTION TO FORCES AND MOMENTS ZERO PITCH ANGLE

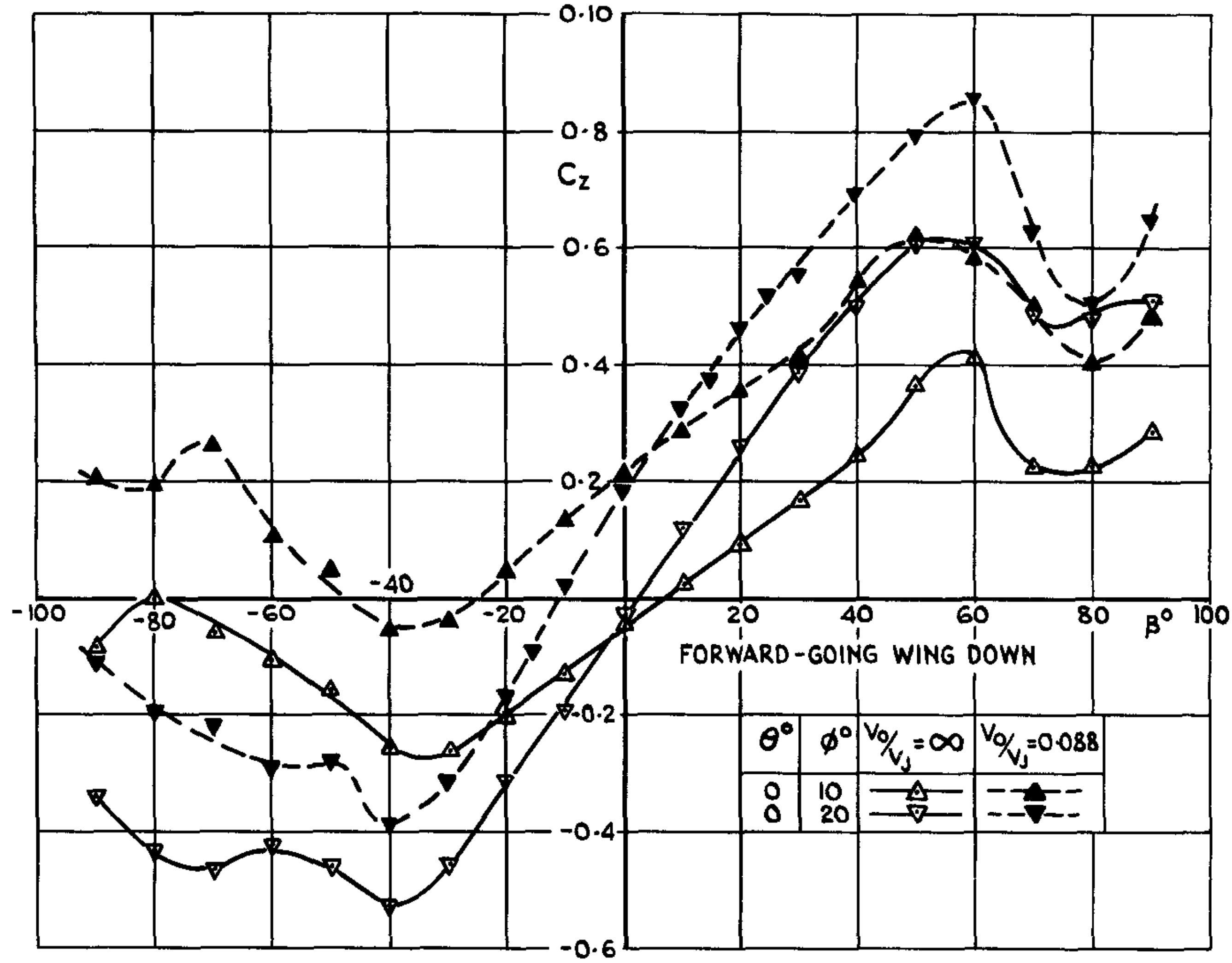


a ROLLING MOMENT

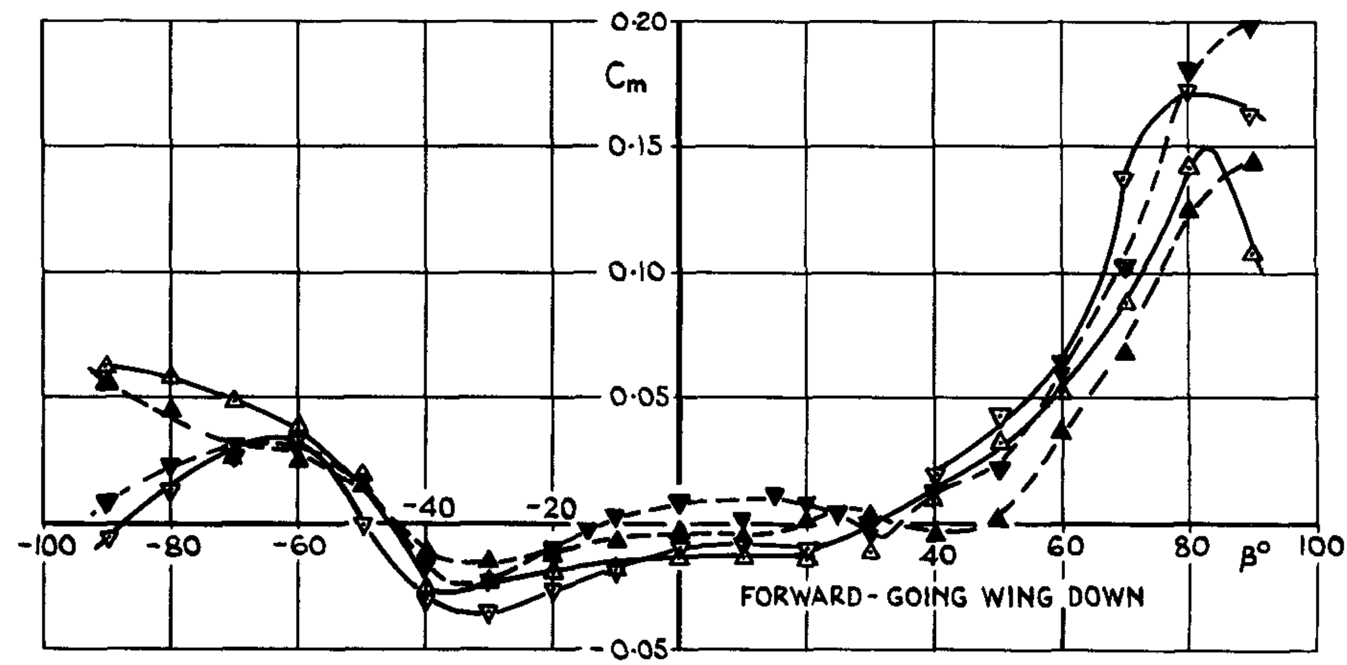


b YAWING MOMENT

FIG 16 a & b EFFECT OF EFFLUX AT ZERO PITCH, INVERTED COMPLETE MODEL ON LARGE STRUT, TRANSITION FREE



c NORMAL FORCE



d PITCHING MOMENT

FIG 16 c & d EFFECT OF EFFLUX AT ZERO PITCH, COMPLETE MODEL INVERTED ON LARGE STRUT, TRANSITION FREE

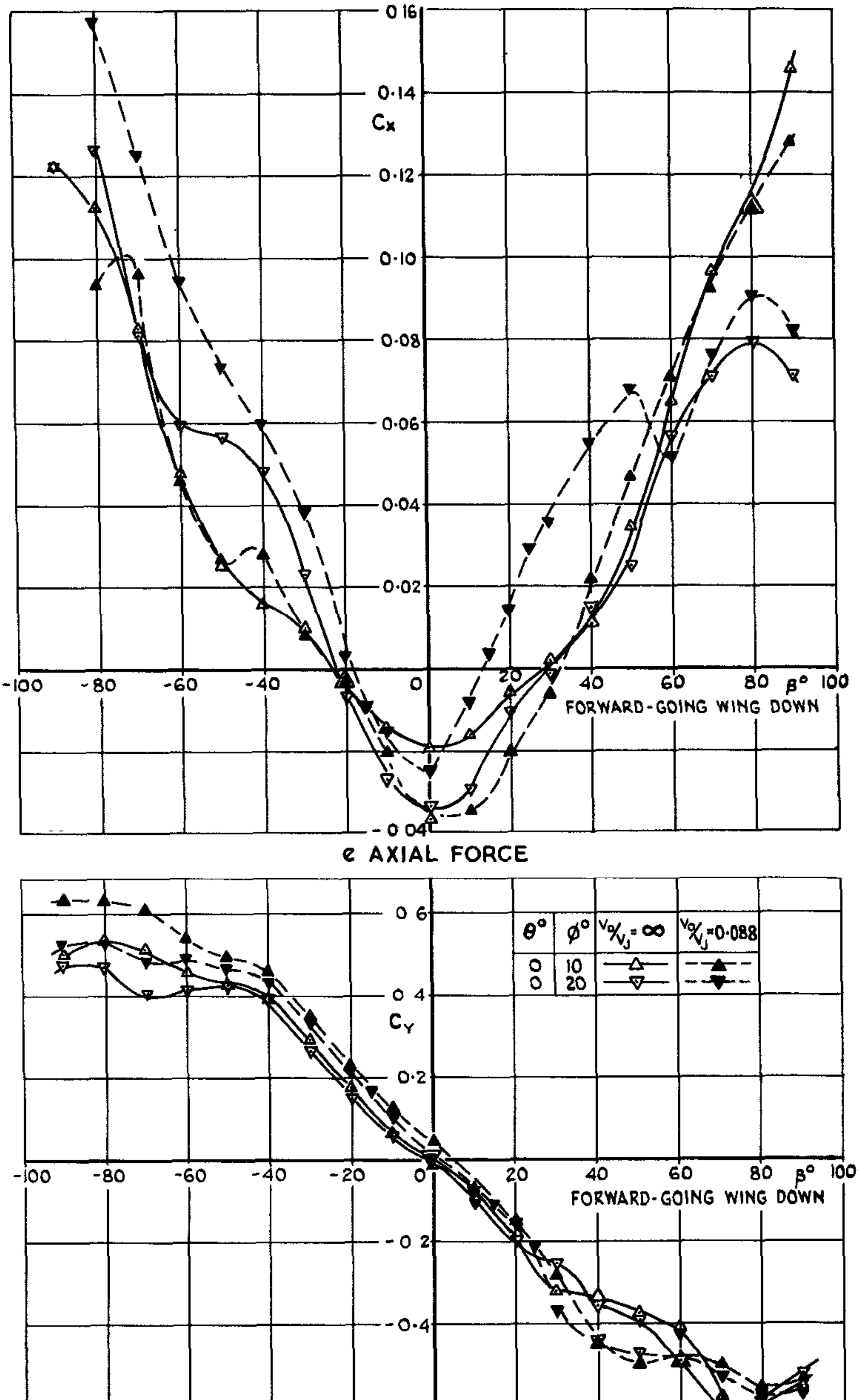


FIG 16 e & f EFFECT OF EFFLUX AT ZERO PITCH, INVERTED COMPLETE MODEL ON LARGE STRUT, TRANSITION FREE

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May 1967
Trebble, W.J.G.

533.652.6 :
533.6.013.153 :
533.6.013.413 :
533.6.013.67

LOW SPEED WIND TUNNEL INVESTIGATION OF THE ROLL STABILITY OF A 1/5 SCALE MODEL OF THE SHORT SC 1 AT LARGE SIDESLIP

In order to facilitate the study of the roll stability of V/STOL aircraft at large angles of sideslip, low speed wind-tunnel tests have been made on a 1/5 scale model of the Short SC 1. The results show that very large rolling moments can be produced if roll and sideslip are present together because of the lateral movement of the wing centre of pressure. This rolling problem is aggravated by a loss in aileron power as sideslip angle is increased.

Recovery is feasible by turning into wind (reducing sideslip) and thus reducing the rolling moments to an acceptable level.

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DETACHABLE ABSTRACT CARDS

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