C.P. No. 732

C.P. No. 732

MINISTRY OF AVIATION

AERONAUTICAL RESEARCH COUNCIL

CURRENT PAPERS

Wind Tunnel Measurements of Normal Force and Pitching Moment at a Mach Number of 2.00 on a 1:30 Scale Model of Blue Streak

by

E. Huntley, B.Sc.

LONDON: HER MAJESTY'S STATIONERY OFFICE

1964

SEVEN SHILLINGS NET

U.D.C. No. 623.451-519:533.6.013.412:533.6.013-413:533.6.011.5:533.6.013.5

C.P. No.732

May, 1959

WIND TUNNEL MEASUREMENTS OF NORMAL FORCE AND PITCHING MOMENT AT A MACH NUMBER OF 2.00 ON A 1:30 SCALE MODEL OF BLUE STREAK

by

E. Huntley, B.Sc.

SUMMARY

Tests have been made in the 3' x 3' tunnel at R.A.E. Bedford, to determine the stability of a model of the Blue Streak missile both in pitch and in yaw, at a Mach number of 2.00. The effects on the normal force and pitching moment characteristics of changes in the various components of the model were also determined; these included the effects of nose shape, longitudinal splines on the nose, motor fairings, fuel pipes and fins. The effect of the step in the body profile was also determined both at transonic speeds and at M = 2.00.

The model without fins was found to be statically unstable both in pitch and in yaw. With four stabilizing fins attached to the rear of the model it was also unstable but the moments were reduced by approximately 50% at any given incidence.

Replaces R.A.E. Tech. Note No. Aero 2624 - A.R.C. 21 590.

PRELIMINARY NOTE

Tests on a model of Blue Streak have been made in three R.A.E. wind tunnels to investigate the missile stability characteristics.

Results from tests in the 3 ft × 3 ft tunnel are given in this paper and are predominately for a Mach number of 2.0. Two heads were tested and the effects of nose splines, engine fairings, internal fuel pipes and stabilizing fins were investigated. A limited study, through the Mach number range 0.7 to 2.0, was made of the effect of a step in the rear body profile.

Results from tests in the 8 ft × 6 ft tunnel are given in A.R.C. 21 756 by A.L. Courtney. These covered the Mach number range 0.8 to 1.25 and were more intensive in scope. Six component force measurements were made at body incidences up to 15° and roll angles up to 90° for configurations both without fins and with those fins used for the 3 ft tunnel tests. Three head shapes were tested and the effects of the various missile components investigated.

Tests done in the 8 ft × 8 ft tunnel are reported in A.R.C. 23 743 by C.F. Moss and D. Isaacs. Six component measurements were made for a Mach number range 0.95 to 2.80 over a range of body incidences and for several roll angles. In addition to two of the heads tested previously a further two were tested. The effects of the rear step, slight alterations to the shape of the motor fairings and another set of stabilizing fins were investigated. Some measurements of static pressure over the engine pods were made and an investigation of the dynamic stability in pitch was carried out.

LIST OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

1 INTRODUCTION

Blue Streak is a ballistic missile which is at present being developed. Control moments for stability and guidance during ascent are provided by swivelling the propulsive motors. In order to obtain information on the aerodynamic stability of the missile during the early stages of its flight (when the air-loads are greatest) a 1:30 scale model was made for testing at transonic speeds in the 8' x 6' tunnel at Farnborough. It was proposed that the same model should be tested at supersonic speeds at a later date in the 8' x 8' tunnel at R.A.E. Bedford. Before this tunnel came into operation the model was tested in the 3' x 3' tunnel at R.A.E. Bedford at M = 2.00 this being the only Mach number (the maximum of the tunnel) at which the model could be tested without any uncertainties arising because of shock wave reflection. Tests were made, at this one Mach number, on various configurations, to determine the effects on stability of:-

(i) changing the nose shape,

(ii) fairing-in the splines on the nose,

(iii) rolling the model through 90° relative to the balance,

(iv) removing the pods representing the motor fairings,

(v) removing the fuel pipes,

and (vi) adding four fins of small aspect ratio.

In addition, the effect of eliminating the step in the body profile was determined at subsonic speeds and at M = 2.00 using the present model and at M = 1.32 using a cone-cylinder model of similar shape.

2 MODEL DETAILS

The layout of the model is shown in Fig.1. The body was cylindrical and of total length 4.85 calibres, the last 0.63 calibres being reduced in diameter to 0.9 calibres. To this body could be added one of two nose shapes:-

(i) a blunt nose (nose A) giving an overall fineness ratio of 5.70

and (ii) a conical nose (nose B) giving an overall fineness ratio of 6.30.

Along each of the noses and along the rear part of the main body were a series of splines, though for some tests the splines on the nose were faired-in with an epoxy resin.

The pods representing the motor fairings were fastened to the rear section of the body and they were detachable. Two sleeves were made to fit over the rear section of the body in order to eliminate the step in the body profile, one to be used when the pods were in position and the other when the pods were off.

For the tests with fins on, the whole rear section could be detached and replaced by one fitted with four fins. These fins were of double wedge section with blunt trailing edges and were of 6% thickness-chord ratio. Various protruberances such as the two fuel pipes, a longitudinal control fairing of trapezoidal section running the length of the body, the nose blister etc., were also represented. In the discussion the word 'pipes' is used to denote the fuel pipes and the longitudinal control fairing. For the test to determine the effect of the pipes (para. 5.3), only the short fuel pipe and the control fairing were removed. The long fuel pipe proved difficult to remove and was left in position.

The model was sting supported and the normal force and pitching moment components were measured by a resistance type strain gauge balance inside the model. The sting had a 2.25° taper and its diameter at the base of the model was 1.56 inches (0.39 model calibres).

For most of the tests the model was positioned in roll so that the pods were in the plane of incidence. This is referred to as the datum roll position (ϕ = 0°). Information was also required on the stability of the missile in the yaw plane, although this was expected to be less critical than in the incidence plane as the lift from the pods would be stabilizing. Since at the time the model was designed the 8' x 6' tunnel had no means of rolling the sting and balance, provision was made for rotating the model relative to the balance (which continued to measure normal force and pitching moment in the sting incidence plane). It was convenient to adopt the same practice in the 3' x 3' tunnel and roll the model relative to the balance rather than to roll the model, balance and sting together.

3 TEST DETAILS

The test programme took place during the period April - July, 1957 when the following configurations were tested at M = 2.00.

Config.	Nose	Splines	Pods	Pipes	Fins	Sleeve	ϕ	
1	A	On	On	On	Off	Off	0°	1st series
2	B	"	"	"	"	"	"	
3	A	"	"	"	"	"	90°	
4	A	Off	On	On	Off	Off	0°	2nd series
5	B	"	"	"	"	"	"	
6	A	"	Off	"	"	"	"	
7	"	"	On	Off	"	"	"	
8	"	"	"	On	On	"	"	
9	"	"	Off	"	Off	On	"	
10	"	"	On	"	"	"	"	

There was a short interval of time between the first and second series of tests during which data from tests in the 8' x 6' tunnel were analysed[1]. The results from these tests indicated that at transonic speeds the centre of pressure was 0.5 to 0.7 calibres further forward than had been estimated. Two possible factors contributing to this discrepancy were the longitudinal splines on the nose and the step in the body profile. The nose splines were therefore faired-in with an epoxy resin and a sleeve was made which could be fitted over the rear part of the body eliminating the step.

As further tests within a reasonable period were not possible in the 8' x 6' tunnel, tests at subsonic speeds were made in the 3' x 3' tunnel even though the blockage was greater than is normally regarded as satisfactory. Configurations 6 and 9 in the above table were tested at M = 0.70 and 0.90.

(In the table and in the discussion of results the terms 'splines on' and 'splines off' have been used to indicate the cases where the splines on the nose were exposed or faired-in respectively.)

The incidence range for most tests was from θ = - 5° to + 10°, readings being taken at 1° intervals.

The Reynolds number for all tests on the model with blunt nose (nose A) was 1.24×10^6, based on body diameter. When testing configurations with the conical nose (nose B) there was considerable vibration of the model at maximum total pressure, thought to be due to some disturbance in the wake caused by the reflected nose shock wave*. This vibration could only be reduced by decreasing the tunnel total pressure so that most of the tests on configurations with the conical nose were done at a Reynolds number of 0.43×10^6.

4 ACCURACY OF RESULTS

The presented data, for any configuration, have the following maximum probable errors.

Configurations		C_N	C_m	θ
Fins off	Nose A	±0.003	±0.004	±0.02
	Nose B	±0.010	±0.012	±0.02
Fins on		±0.004	±0.006	±0.02

These errors in C_N and C_m give rise to errors in the centre of pressure position, x_{cp}, which vary with incidence. In the following table, the errors in x_{cp} in terms of body calibres are presented for 'low θ' ($\theta \doteqdot 2^\circ$) and 'high θ' ($\theta \doteqdot 9^\circ$) and the error varies continuously between these two values.

		low θ	high θ
Fins off	Nose A	0.06	0.01
	Nose B	0.12	0.02
Fins on		0.06	0.02

The results from the tests on nose B are less accurate than the results from Nose A because of the lower total pressure used in these tests. There are two points to note with respect to the accuracy of x_{cp}. Firstly, there is slight curvature of the flow in the tunnel giving rise to pitching moments at a nominal zero incidence. Before using the results therefore to determine x_{cp} the curves were translated so that they passed through the origin. Secondly, for $\theta > 2^\circ$, x_{cp} was determined by dividing C_m by C_N (and adding a constant to give the result relative to the shoulder of the model); for $\theta = 0$ it was determined from the ratio of the mean slopes of the C_m v θ and C_N v θ curves as obtained by using the method of least squares on the experimental points between ±2°. The values of x_{cp} obtained at $\theta = 0$ therefore should be more accurate than is suggested above for low θ.

5 RESULTS FOR M = 2.00

This section deals with all the results for M = 2.00 with the exception of those concerned with the effect of the sleeve. The relevant figures are Nos. 2 to 10. The first part of each figure is a plot of the normal force coefficient, C_N, against incidence, θ, and the second part a plot of centre of pressure position, x_{cp}, against θ. Each figure shows a comparison between

* Recently, the vibration has been found to occur in tests on this model in the 8' × 8' tunnel and has now been attributed to flow separation over the rear end of the body.

two configurations differing in only one respect and thus indicates the effect of changing one component of the model. (In the comparisons between the two nose shapes the different values of the Reynolds number is an additional factor.) For each figure, unless stated otherwise, the model configuration was as follows: Nose A, splines off, pods on, pipes on, fins off, sleeve off, $\phi = 0^o$. The results from all configurations show the same general character, the C_N v θ curves being smooth and non-linear and the x_{cp} v θ curves showing gradual rearward movements of the centre of pressure with increasing incidence (see for example Fig.2). The non-linearity of each C_N v θ curve can be attributed to the lift from the viscous cross flow over the body which causes the centre of pressure to move rearward with increase of incidence since the lift from the nose varies more or less linearly with incidence. An assessment of the characteristics of any configuration can be obtained, therefore, from the normal force curve slope and centre of pressure position at zero incidence and, to show the effect of incidence, values of C_N and x_{cp} at some higher incidence which has been arbitrarily taken as 8^o. In an effort to avoid repetition and confusion when discussing the effect of changing any component, this information has been tabulated in each section.

5.1 Effect of nose shape and fairing in of nose splines

Configuration	Variables		$\theta = 0^o$		$\theta = 8^o$	
	Nose	Splines	C_{N_θ}	x_{cp}	C_N	x_{cp}
1	A	On	0.0549	-0.07	0.520	-0.46
2	B	On	0.0610	-0.10	0.560	-0.38
4	A	Off	0.0539	-0.17	0.515	-0.48
5	B	Off	0.0602	-0.11		

Factors constant for all tests: sleeve off, pods on, pipes on, fins off, $\phi = 0^o$.

The comparison between the results for the two nose shapes, with the splines on, is shown in Fig.2 and for the splines faired-in, in Fig.3.

The conical nose (nose B) is seen to contribute more lift than the blunt nose (nose A), the increment in C_{N_θ} at zero incidence being 0.006 (a percentage increase of about 11%) but there is very little difference between the positions of the centres of pressure. This is true whether the splines are faired-in or not. The percentage difference in C_N at 8^o incidence is 8% and the positions of the centres of pressure differ by 0.12 calibres. These figures apply to the case when the splines were on but they probably apply also to the case when the splines were faired-in. (No results were obtained above $\theta = 6^o$). The results from the same four configurations are plotted in Figs. 4 and 5, but they are re-arranged to show the effect of the splines. Thus each figure refers to one nose shape and gives the comparison of splines on and splines off. The effect of fairing-in the splines is very small at zero incidence, there being only a 2% decrease in C_{N_θ} for both noses together with a rearward movement of the centre of pressure of 0.1 calibres for nose A and no movement at all for nose B. For higher incidences the effect of the splines is negligible.

5.2 Effect of rolling the model through 90°

Most of the tests were made at zero roll angle as the missile was expected to be least stable in the plane of the pods. However as the missile can deviate from its flight path in any direction one test was made with the model rolled through 90° in order to determine the stability of the missile in the plane normal to the plane of the pods. It should be noted that the axes taken are sting axes and that C_N and x_{cp} are obtained from forces measured in the sting pitch plane. This corresponds to the yaw plane of the model when it is rolled through 90°.

The results are as follows:-

Fig.	Config.	ϕ	$\theta = 0^o$		$\theta = 8^o$	
			C_{N_θ}	x_{cp}	C_N	x_{cp}
6	1	0°	0.0549	-0.07	0.520	-0.45
	3	90°	0.0584	-0.53	0.530	-0.70

Factors constant for all tests:- Nose A, splines on, sleeve off, pods on, pipes on, fins off.

For the model rolled through 90° the normal force curve slope at zero incidence was 6% greater than for $\phi = 0$ and the centre of pressure was 0.46 calibres further back. The C_N v θ curve for the $\phi = 90^o$ case is rather more linear than for the $\phi = 0^o$ case and the two curves cross at $\theta = 9^o$ so that differences between them are negligible at high incidence. The centre of pressure also moves back less rapidly with incidence, for $\phi = 90^o$, and at 8° the difference between the two cases is only 0.24 calibres. Presumably this is because the lift from the pods, when they are in this plane, is more nearly linear than when they are in the pitch plane.

5.3 Effect of pods, pipes and fins

In Figs. 7, 8, 9 are shown the results of tests on configurations 6, 7, 8 respectively each of which differed in only one respect from the so-called datum configuration (No.4). The results from the tests on the datum configuration are plotted in each figure to make the comparison easier. The results are summarised in the following table and it can be seen that a comparison of configuration 6 with configuration 4 gives the effect of removing the pods, configuration 7 with configuration 4 gives the effect of removing the pipes, and configuration 8 with configuration 4 gives the effect of adding the fins.

Fig.	Config.	Pods	Pipes	Fins	$\theta = 0^o$		$\theta = 8^o$	
					C_{N_θ}	x_{cp}	C_N	x_{cp}
	4	On	On	Off	0.0539	-0.17	0.515	-0.48
7	6	Off	On	Off	0.0494	+0.15	0.492	-0.30
8	7	On	Off	Off	0.0508	-0.10	0.485	-0.42
9	8	On	On	On	0.0797	-1.48	0.720	-1.55

Factors constant for all tests:- Nose A; splines off; $\phi = 0^o$.

It can be seen that the pods carry a fair amount of lift even when they are in the incidence plane. For the model without pods the normal force curve slope at zero incidence is 8% less than for the model with pods and the centre of pressure is 0.32 calibres further forward. On increasing incidence their effect falls off slightly and at 8° incidence the percentage difference in C_N is 5% and the change in x_{cp} only 0.18 calibres.

For the model without pipes the normal force curve slope at zero incidence is 6% less than for the model with pipes and the centre of pressure is slightly further forward. These differences between the two cases do not change with incidence and at θ = 8° there is still 6% difference between the values of C_N and a slight change in the centre of pressure position.

The effect of adding the fins is, of course, considerable. For the model with fins on, the normal force curve slope at zero incidence is 48% greater than for the model without fins and the centre of pressure is 1.31 calibres further back. As the lift from the body increases with incidence more rapidly than does the lift from the fins, the effectiveness of the fins falls off slightly and at θ = 8° the percentage difference in C_N is 39% and the change in centre of pressure position only 1.08 calibres.

6 STABILITY OF THE MISSILE

The pitching moment coefficient about the missile centre of gravity is plotted against normal force coefficient in Fig.10(a) and against incidence in Fig.10(b), for the following four configurations:-

Config.	Nose	φ	Fins
2	B	0°	Off
4	A	0°	Off
3	A	90°	Off
8	A	0°	On

The position of the centre of gravity was taken to be 2.27 calibres aft of the shoulder.

It can be seen that the model is unstable at this Mach number for all four cases. As was to be expected the model is most unstable in pitch. It is slightly less unstable in yaw because of the greater lift from the motor fairings in this plane. The model with conical nose is seen to be slightly less stable than the model with blunt nose though this is only really apparent at the higher values of C_N. The addition of the fins considerably decreases the unstable moment, the value for any incidence being only about 50% of the value for the fins off case at zero roll.

It is interesting to note that for the fins off cases the $C_{m_{cg}}$ v θ curves are effectively linear. If the linear lift is assumed to have a constant centre of pressure position, it appears that the centre of pressure position of the non-linear lift also remains constant and coincident with the position of the missile centre of gravity.

It should be appreciated that this note gives an assessment of the stability under aerodynamic loads only. The overall stability of the missile also involves the stabilizing effect obtained by the automatic control of the swivelling motors.

7 EFFECT OF SLEEVE AT M = 0.70, 0.90, 1.32 AND 2.00

7.1 Results for M = 0.70 and 0.90

The model was tested in the transonic section of the 3' × 3' tunnel in order to obtain a quick check on the effect on the centre of pressure position of the step in the body profile. Tests were made on configuration 6 with the step in the profile present (sleeve off) and on configuration 9 where the step was eliminated by the addition of the sleeve.

Fig.	Config.	Variables		θ = 0°		θ = 8°	
		M	Sleeve	C_{N_θ}	x_{cp}	C_N	x_{cp}
13	6	0.70	Off	0.0402	0.49	0.352	0.25
	9		On	0.0459	-0.12	0.390	-0.18
	6	0.90	Off	0.0406	0.65	0.365	0.29
	9		On	0.0476	-0.15	0.408	-0.22

Factors constant for all tests:- Nose A, splines off, pods off, pipes on, fins off, $\phi = 0°$.

It can be seen from Fig.13 that the effect of the sleeve is quite considerable. At M = 0.70, on adding the sleeve, the zero incidence normal force curve slope increases by 14% and this increase in lift is retained on increasing incidence, the difference in C_N being about 11% at 8° incidence. At M = 0.90, the effect is even greater the differences being 17% in C_{N_θ} at zero incidence and 12% in C_N at 8° incidence.

These changes in lift are accompanied by corresponding changes in the centre of pressure positions. At M = 0.70, for the model with sleeve, the centre of pressure at zero incidence is 0.61 calibres further back than for the sleeve off case. At higher incidences the difference is smaller and at 8° it is only 0.43 calibres. On increasing Mach number to 0.90 the value of x_{cp} for θ = 0 remains constant for the sleeve on case but moves forward 0.15 calibres for the sleeve off case. Hence the differences between sleeve on and sleeve off cases are even greater at M = 0.90 than 0.70, the values of these differences being 0.80 calibres at zero incidence and 0.51 calibres at 8° incidence.

7.2 Results for M = 1.32

To provide confirmatory results on the effect of the sleeve at low supersonic Mach numbers the cone-cylinder model of Ref.2, was modified to make the body length correspond to that of Blue Streak. The step in the body profile of Blue Streak was reproduced and a sleeve was made which could be fitted over the rear part of the body. The nose shape was a 10° semi-angle cone with small tip radius. Details of the model are shown in Fig.12.

Tests were made on this model with and without sleeve at M = 1.32. The results are plotted in Fig.14 and are summarised in the table.

Fig.	Sleeve	θ = 0°		θ = 8°	
		C_{N_θ}	x_{cp}	C_N	x_{cp}
14	Off	0.0402	0.91	0.365	0.44
	On	0.0412	0.72	0.377	0.25

The effect of the sleeve is still significant at M = 1.32 though it is not nearly so important as at M = 0.70 and 0.90.

7.3 Results for M = 2.00

Since the effect of the sleeve was so marked at transonic speeds there was the possibility of a small but appreciable effect at M = 2.00. In order to determine this, therefore, tests were made with pods off, with and without sleeve; also since in any model of the actual missile the pods should be represented, tests were made with pods on, with and without sleeve. The results are as follows:-

Fig.	Config.	Variables		θ = 0		θ = 8°	
		Sleeve	Pods	C_{N_θ}	x_{cp}	C_N	x_{cp}
15	6	Off	Off	0.0494	0.15	0.492	-0.30
	9	On	Off	0.0512	0.05	0.508	-0.39
16	4	Off	On	0.0539	-0.17	0.515	-0.48
	10	On	On	0.0532	-0.10	0.515	-0.45

Factors constant for all tests: Nose A, splines off, pipes on, fins off, $\phi = 0°$.

When the pods are off, adding the sleeve causes a 3% increase in C_{N_θ} at zero incidence and a rearward movement of the centre of pressure of 0.1 calibres. At higher incidences there is a similar increase of 3% in C_N and again a rearward movement of 0.1 calibres in x_{cp}. When the pods are on, the effects of adding the sleeve are smaller at zero incidence (as would be expected since the pods cover part of the step) and, in fact, they become negligible on increasing incidence.

Since the effect of the sleeve varies so much with Mach number it is worthwhile summarising the main results. In the table below are shown the changes in the normal force curve slope and centre of pressure position at zero incidence, of the body without pods, caused by eliminating the step in the body profile by the addition of the sleeve.

M	% increase in C_{N_θ}	Δx_{cp}	Model
0.70	14	-0.61	Blue Streak
0.90	17	-0.80	Blue Streak
1.32	3	-0.19	Cone-cylinder
2.00	3	-0.10	Blue Streak

8 COMPARISON WITH RESULTS FROM A CONE-CYLINDER AT M = 2.00

Ref.2 gives the results of tests on cone-cylinders of small fineness ratio, corresponding approximately to the fineness ratio of Blue Streak. One nose shape (a 10° semi angle cone with large tip radius) is comparable with nose A of the present tests. Diagrams of the two models are shown in Fig.11 for comparison. In Fig.17 the results from the tests on the cone-cylinder are compared with the results from configuration 9 of the present tests i.e. sleeve on and pods off. The results from the Blue Streak model were modified to allow for the effect of the pipes.

Fig.	Model	θ = 0°		θ = 8°	
		C_{N_θ}	x_{cp}	C_N	x_{cp}
17	Blue Streak Config. 9	0.0481	0.11	0.475	-0.35
	Cone-cylinder	0.0451	0.51	0.440	-0.05

There is an appreciable difference between the two sets of results. The Blue Streak model has 7% more lift and the centre of pressure is 0.3 - 0.4 calibres further back for all incidences.

The reasons for these discrepancies are not clear but the following points should be considered. Firstly, the Blue Streak model differs from the cone-cylinder in that it has a slightly different nose shape, a slightly shorter body length and splines along the rear part of the body. The values of the test Reynolds numbers were also different being 1.24×10^6 for Blue Streak and 0.43×10^6 for the cone-cylinder.

Compared with the cone cylinder, Blue Streak has more lift which appears to act near the base of the model since it has a centre of pressure further aft than the cone-cylinder. This suggests that the different nose shape is not responsible for the discrepancies. The lower lift and more forward centre of pressure of the longer body suggest that the cone-cylinder carried negative lift over the last 0.26 calibres. (This possibility has been demonstrated in Ref.3.) In order to check this brief tests were made on the cone-cylinder model but the results indicated that the effect of the longer body length is small.

The splines could affect the results at zero incidence since they might have an appreciable effect on the boundary layer thickness at the base. This would modify the effective base area and thus the normal force curve slope since it is proportional to the base area according to slender body theory. The splines could also affect the results at incidence since they might modify the viscous cross flow over the body.

9 CONCLUSIONS

At a Mach number of 2.00, the model without fins is unstable, both in pitch and in yaw, but is slightly less unstable in yaw because of the greater lift from the motor fairings in this plane. With four fins of small aspect ratio attached to the rear of the body, the instability is considerably reduced $\left[\frac{dC_{m_{cg}}}{dC_N}\right]_{C_N=0}$ being reduced by approximately 50%.

The effects of the various components of the model on the zero incidence normal force curve slope and centre of pressure position, are as follows:

(i) The value of C_{N_θ} for the body with the conical nose is 11% greater than for the body with the blunt nose but there is very little difference in the centre of pressure positions. In each case the effect of fairing-in the splines is almost negligible.

(ii) With the model rolled through 90°, relative to the balance, the value of C_{N_θ} is 6% greater than in the unrolled condition and the centre of pressure is 0.46 calibres further back. This is mainly due to the increased lift from the motor fairings in this position. Even in the unrolled condition, however, the fairings contribute some lift and the effect of removing them is to reduce C_{N_θ} by about 8% and to move the centre of pressure 0.32 calibres further forward.

(iii) The short fuel pipe and the longitudinal control fairings, together produce an appreciable amount of lift and increase C_{N_θ} by 6%, though with little effect on the centre of pressure position.

(iv) The four stabilizing fins of very low aspect ratio, set at 45° to the incidence plane, add considerably to the overall lift from the model. With the fins in position the value of C_{N_θ} is 48% greater than with the fins off and the centre of pressure is 1.31 calibres further back.

The effect of the step in the body profile at transonic speeds was quite considerable giving a value of C_{N_θ} which was 12 - 15% less than that obtained without the step and a centre of pressure position 0.6 to 0.8 calibres further forward; at M = 2.00 the difference in slope was only 3% and the centre of pressure change only 0.1 calibres.

LIST OF SYMBOLS

C_N		Normal force coefficient
	=	$\frac{\text{Normal force}}{q.\ S.}$
C_m		Pitching moment coefficient
	=	$\frac{\text{Pitching moment about balance centre}}{q.\ S.\ d}$

Balance centre is 0.307 calibres aft of model shoulder

$C_{m_{cg}}$ = $\frac{\text{Pitching moment about centre of gravity}}{q.\ S.\ d}$

Centre of gravity position taken to be 2.27 calibres aft of model shoulder

cp	centre of pressure
x_{cp}	distance, in calibres, of centre of pressure forward of model shoulder
d	Maximum body diameter (neglecting splines)
S	Maximum cross-sectional area = $\frac{\pi d^2}{4}$
q	Free stream dynamic pressure
M	Mach number
θ	Sting incidence
φ	Roll angle

LIST OF REFERENCES

No.	Author	Title, etc.
1	Courtney, A.L.	8' x 6' tunnel tests on a model of the De Havilland Blue Streak at Mach nos. of 0.80 to 1.25. A.R.C. 21 756. April 1959.
2	Huntley, E.	Wind tunnel measurements of normal force and pitching moments on four cone-cylinder combinations at transonic and supersonic speeds. A.R.C. C.P.507. May 1959.
3	Dorrance, W.H. Norell, R.G.	Correlation of cone-cylinder normal force and pitching moment data by the hypersonic similarity rule. Jo. Ae. Sci. Vol.24 No.5 May 1957.

TABLE 1

Results at M = 2.00

(Re. No. 1.24×10^6 unless stated otherwise)

Configuration No.1

θ	C_N	C_m	x_{cp}
-3.00	-0.163	-0.039	-0.07
-1.98	-0.108	-0.030	-0.03
-0.97	-0.054	-0.015	
0.05	0	0.001	-0.07
1.07	0.058	0.013	
2.08	0.115	0.022	-0.12
3.10	0.168	0.032	-0.12
4.11	0.229	0.032	-0.17
5.13	0.294	0.025	-0.22
6.14	0.367	0.002	-0.30
7.15	0.446	-0.034	-0.38
8,15	0.538	-0.093	-0.48
9.16	0.634	-0.170	-0.58
10.15	0.747	-0.279	-0.68
11.15	0.866	-0.411	-0.78

Configuration No.2

Re. No. 0.85×10^6

θ	C_N	C_m	x_{cp}
-4.00	-0.245	-0.034	-0.17
-2.99	-0.178	-0.032	-0.13
-1.98	-0.123	-0.032	-0.05
-0.96	-0.057	-0.016	
0.05	0.003	0.001	-0.11
1.06	0.065	0.019	
2.07	0.133	0.021	-0.15

Re. No. 0.43×10^6

θ	C_N	C_m	x_{cp}
-8.99	-0.671	0.118	-0.13
-7.99	-0.570	0.051	-0.22
-5.98	-0.393	-0.025	-0.24
-3.97	-0.244	-0.050	-0.10
-1.96	-0.114	-0.030	-0.04
0.05	0.002	0.001	-0.10
2.06	0.125	0.021	-0.14
4.07	0.252	0.039	-0.15
6.09	0.397	0.030	-0.23
8.09	0.570	-0.047	-0.39
9.10	0.668	-0.107	-0.47
10.10	0.779	-0.199	-0.56

Configuration No.3

θ	C_N	C_m	x_{cp}
-9.03	-0.650	0.301	-0.77
-8.03	-0.554	0.225	-0.71
-6.01	-0.387	0.120	-0.62
-4.00	-0.241	0.053	-0.53
-1.98	-0.115	0.018	-0.46
-0.96	-0.058	0.011	
0.05	0	-0.001	-0.53
1.06	0.063	-0.017	
2.07	0.120	-0.034	-0.59
3.08	0.181	-0.041	-0.53
4.09	0.244	-0.057	-0.54
5.10	0.311	-0.084	-0.58
6.11	0.380	-0.117	-0.61
7.11	0.456	-0.164	-0.67
8.12	0.539	-0.214	-0.70
9.12	0.630	-0.280	-0.75
10.13	0.730	-0.367	-0.81

Configuration No.4

θ	C_N	C_m	x_{cp}
-5.18	-0.300	-0.006	-0.29
-4.17	-0.236	-0.018	-0.23
-3.15	-0.174	-0.024	-0.17
-2.14	-0.116	-0.020	-0.13
-1.12	-0.060	-0.008	
-0.11	-0.008	0.001	-0.17
0.90	0.049	0.005	
1.92	0.103	0.010	-0.22
2.93	0.158	0.019	-0.19
3.95	0.217	0.022	-0.21
4.96	0.283	0.018	-0.24
5.97	0.351	0.001	-0.30
6.98	0.429	-0.036	-0.39
7.99	0.514	-0.088	-0.48
8.99	0.608	-0.162	-0.57

Config.	Nose	Splines	Pods	Pipes	Fins	Sleeve	φ
1	A	On	On	On	Off	Off	0°
2	B	"	"	"	"	"	"
3	A	"	"	"	"	"	90°
4	A	Off	"	"	"	"	0°
5	B	"	"	"	"	"	"
6	A	"	Off	"	"	"	"
7	"	"	On	Off	"	"	"
8	"	"	"	On	On	"	"
9	"	"	Off	"	Off	On	"
10	"	"	On	"	"	"	"

TABLE 1 (Contd)

θ	C_N	C_m	x_{cp}
Configuration No.5			
Re. No.	0.43×10^6		
-5.14	-0.331	-0.045	-0.17
-4.14	-0.259	-0.050	-0.12
-2.12	-0.130	-0.034	-0.05
-1.12	-0.071	-0.013	
-0.11	-0.011	-0.001	-0.11
0.89	0.051	0.004	
1.90	0.111	0.017	-0.16
2.91	0.170	0.015	-0.22
3.91	0.239	0.029	-0.19
4.92	0.301	0.037	-0.19
5.92	0.383	0.024	-0.25
Configuration No.6			
-5.19	-0.312	-0.051	-0.15
-4.18	-0.222	-0.062	-0.03
-3.16	-0.162	-0.060	0.06
-2.15	-0.107	-0.047	0.13
-1.13	-0.056	-0.027	
-0.11	-0.006	-0.003	0.15
0.91	+0.045	0.021	
1.92	0.094	0.046	0.18
2.94	0.148	0.068	0.15
3.96	0.203	0.072	0.05
4.97	0.266	0.074	-0.03
5.98	0.334	0.075	-0.08
7.00	0.409	0.049	-0.19
8.00	0.494	0.004	-0.30
9.01	0.587	-0.074	-0.43
10.01	0.690	-0.157	-0.53
Configuration No.7			
-5.18	-0.280	-0.030	-0.20
-4.17	-0.217	-0.038	-0.13
-3.16	-0.162	-0.034	-0.10
-2.14	-0.107	-0.025	-0.07
-1.13	-0.056	-0.014	
-0.11	-0.006	0.001	-0.10
0.90	0.047	0.009	
1.92	0.100	0.017	-0.13
2.93	0.152	0.027	-0.13
3.94	0.208	0.030	-0.16
4.96	0.267	0.027	-0.21
5.97	0.333	0.015	-0.26
6.98	0.403	-0.013	-0.34
7.99	0.485	-0.062	-0.43

θ	C_N	C_m	x_{cp}
Configuration No.8			
-5.08	-0.422	0.513	-1.52
-4.09	-0.332	0.400	-1.51
-3.09	-0.245	0.299	-1.53
-2.10	-0.167	0.200	-1.50
-1.10	-0.088	0.109	
-0.11	-0.012	0.023	-1.48
0.89	+0.070	-0.070	
1.89	0.151	-0.163	-1.38
2.88	0.224	-0.260	-1.46
3.88	0.306	-0.361	-1.49
4.87	0.400	-0.477	-1.50
5.86	0.492	-0.599	-1.53
6.85	0.594	-0.731	-1.54
7.84	0.702	-0.875	-1.55
8.83	0.815	-1.031	.57
Configuration No.9			
-5.18	-0.293	-0.035	-0.19
-4.17	-0.227	-0.045	-0.11
-3.16	-0.166	-0.047	-0.03
-2.14	-0.110	-0.039	0.05
-1.13	-0.057	-0.020	
-0.11	-0.005	-0.004	0.05
0.91	0.047	0.016	
1.92	0.098	0.036	0.06
2.94	0.153	0.055	0.06
3.95	0.211	0.060	-0.02
4.97	0.276	0.059	-0.09
5.98	0.344	0.045	-0.18
6.99	0.420	0.012	-0.28
8.00	0.508	-0.041	-0.39
9.00	0.592	-0.111	-0.50
10.00	0.710	-0.206	-0.60
Configuration No.10			
-5.18	-0.300	-0.015	-0.26
-4.17	-0.234	-0.026	-0.20
-3.15	-0.171	-0.029	-0.14
-2.14	-0.115	-0.024	-0.10
-1.13	-0.059	-0.013	
-0.11	-0.006	-0.001	-0.10
0.90	0.047	0.009	
1.92	0.102	0.021	-0.10
2.93	0.155	0.032	-0.10
3.95	0.214	0.035	-0.14
4.96	0.276	0.031	-0.20
5.97	0.349	0.012	-0.27
6.98	0.425	-0.022	-0.36
7.99	0.512	-0.078	-0.46
8.99	0.609	-0.154	-0.56
9.99	0.719	-0.258	-0.67

TABLE 2

Results at M = 0.70 and 0.90

(Re. No. 1.76×10^6)

θ	C_N	C_m	x_{cp}
Configuration No. 6			
M = 0.70			
-5.12	-0.218	-0.140	0.44
-4.10	-0.168	-0.121	0.41
-3.09	-0.128	-0.097	0.45
-2.07	-0.084	-0.066	0.48
-1.05	-0.044	-0.033	
-0.04	-0.003	-0.002	0.49
0.98	0.039	0.033	
2.00	0.079	0.065	0.52
3.02	0.119	0.096	0.50
4.03	0.164	0.126	0.46
5.05	0.207	0.153	0.43
6.07	0.256	0.175	0.38
7.08	0.303	0.189	0.32
8.09	0.354	0.193	0.24
9.11	0.411	0.192	0.16
10.11	0.472	0.175	0.06
M = 0.90			
-5.14	-0.227	-0.174	0.46
-4.12	-0.176	-0.149	0.54
-3.10	-0.130	-0.121	0.62
-2.08	-0.085	-0.083	0.67
-1.06	-0.045	-0.043	
-0.03	-0.002	-0.002	0.65
0.99	0.038	0.038	
2.01	0.081	0.075	0.62
3.04	0.123	0.110	0.59
4.06	0.168	0.146	0.56
5.08	0.217	0.174	0.50
6.10	0.264	0.198	0.44
7.12	0.316	0.214	0.37
8.14	0.374	0.218	0.28
9.15	0.438	0.214	0.18
10.17	0.509	0.193	0.07

θ	C_N	C_m	x_{cp}
Configuration No. 9			
M = 0.70			
-5.10	-0.235	-0.038	-0.15
-4.09	-0.189	-0.037	-0.11
-3.08	-0.139	-0.032	-0.08
-2.06	-0.093	-0.020	-0.09
-1.05	-0.048	-0.010	
-0.04	-0.002	0	-0.12
0.98	0.047	0.002	
1.99	0.092	0.018	-0.11
3.00	0.140	0.028	-0.11
4.02	0.186	0.038	-0.10
5.03	0.237	0.046	-0.11
6.04	0.284	0.052	-0.12
7.05	0.338	0.053	-0.15
8.06	0.392	0.049	-0.18
9.07	0.451	0.037	-0.23
10.08	0.514	0.014	-0.28
M = 0.90			
-5.11	-0.254	-0.034	-0.17
-4.10	-0.201	-0.031	-0.15
-3.08	-0.150	-0.026	-0.13
-2.06	-0.099	-0.018	-0.13
-1.05	-0.050	-0.007	
-0.03	-0.002	0	-0.15
0.98	0.047	0.006	
2.00	0.094	0.014	-0.16
3.01	0.143	0.026	-0.13
4.03	0.192	0.036	-0.12
5.05	0.244	0.043	-0.13
6.06	0.297	0.046	-0.15
7.08	0.350	0.046	-0.18
8.09	0.414	0.036	-0.22
9.11	0.482	0.019	-0.27
10.12	0.552	-0.010	-0.32

Config.	Nose	Splines	Pods	Pipes	Fins	Sleeve	ϕ
6	A	Off	Off	On	Off	Off	0°
9	"	"	"	"	"	On	"

TABLE 3

Results at M = 1.32 on modified cone-cylinder model

θ	C_N	C_m	x_{cp}
Sleeve on			
Re No. 1.13 × 10^6			
-5.37	-0.236	-0.508	0.49
-4.29	-0.186	-0.411	0.55
-3.21	-0.135	-0.313	0.66
-2.14	-0.088	-0.209	0.72
-1.06	-0.044	-0.109	
0.02	0.001	-0.001	0.72
1.10	0.045	0.110	
2.18	0.090	0.212	0.70
3.26	0.137	0.312	0.62
4.34	0.188	0.414	0.54
4.87	0.210	0.460	0.53
Re No. 0.65 × 10^6			
5.22	0.225	0.480	0.47
6.27	0.278	0.573	0.40
7.31	0.336	0.665	0.32
8.35	0.398	0.748	0.22
9.40	0.466	0.829	0.12
10.44	0.544	0.908	0.01

θ	C_N	C_m	x_{cp}
Sleeve off			
Re No. 1.13 × 10^6			
-5.38	-0.229	-0.525	0.63
-4.30	-0.178	-0.420	0.70
-3.22	-0.130	-0.322	0.82
-2.14	-0.089	-0.215	0.76
-1.06	-0.041	-0.108	
0.02	0.001	0.005	0.91
1.10	0.043	0.118	
2.18	0.086	0.229	1.00
3.26	0.131	0.333	0.88
4.34	0.176	0.433	0.80
4.88	0.202	0.483	0.73
Re No. 0.65 × 10^6			
0.01	-0.002	0.001	
2.10	0.081	0.217	1.02
4.19	0.171	0.418	0.78
6.27	0.272	0.610	0.58
7.32	0.323	0.703	0.52
8.36	0.384	0.792	0.40
9.41	0.449	0.881	0.30

Printed in England for Her Majesty's Stationery Office by the Royal Aircraft Establishment, Farnborough. W.T.59.K.4.

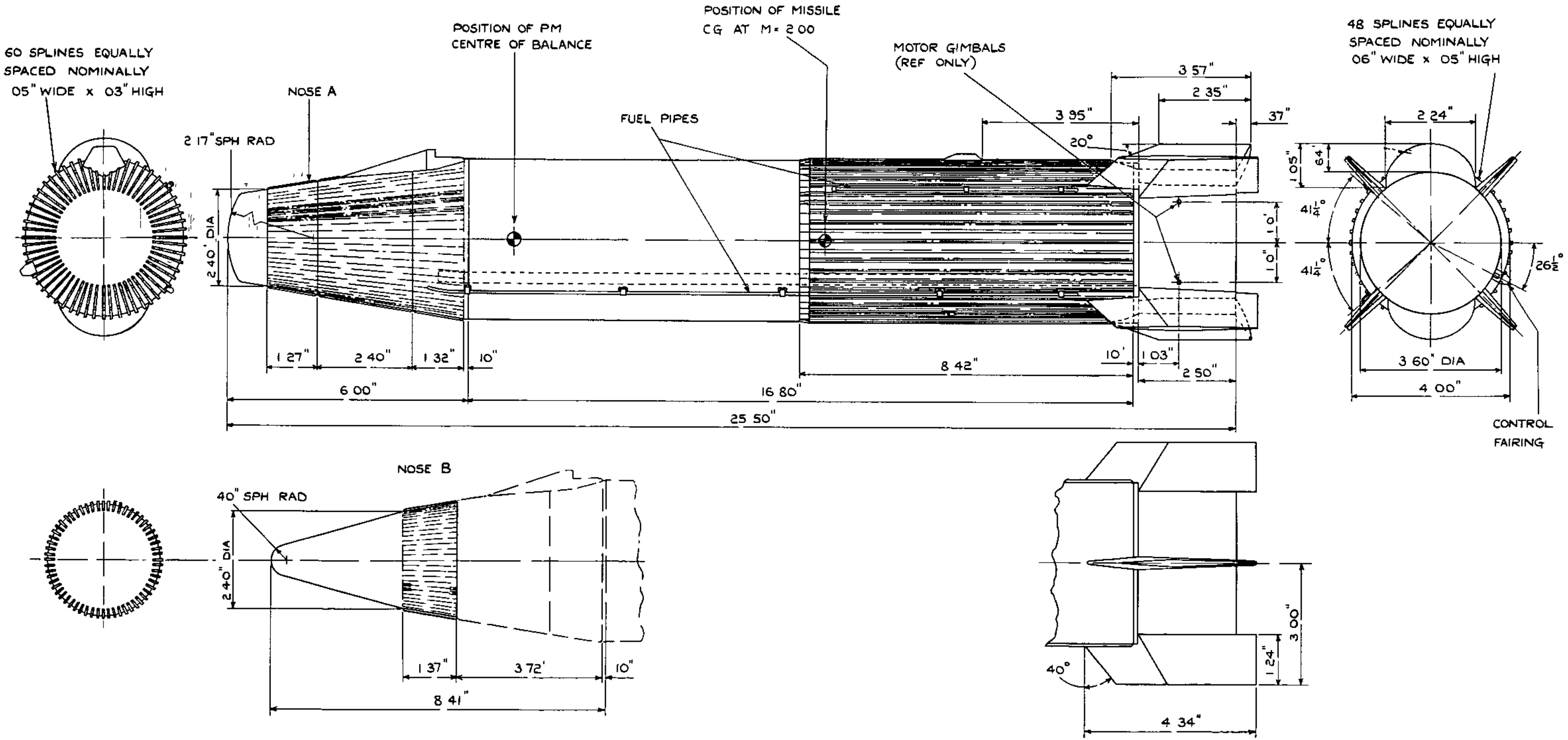
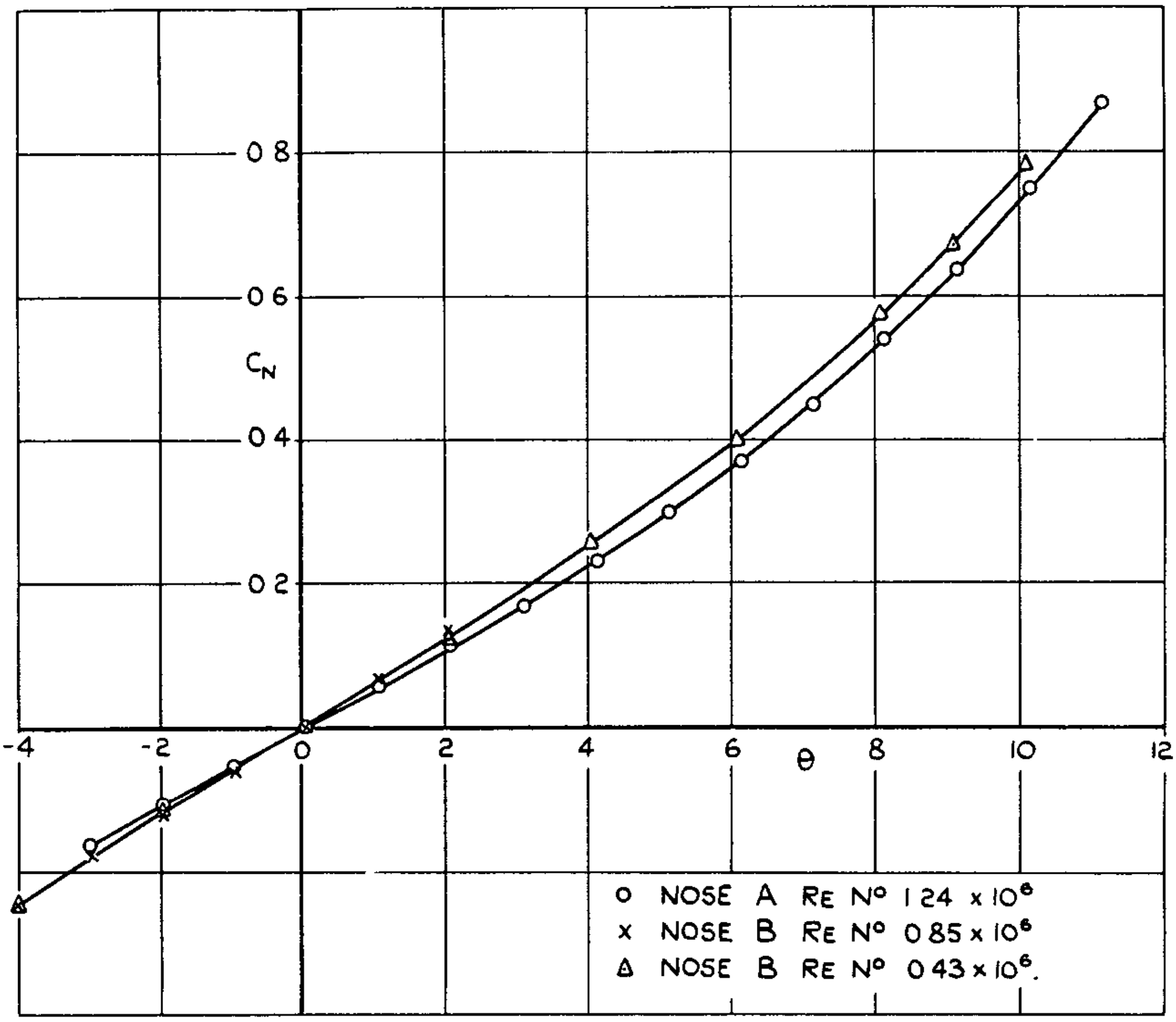
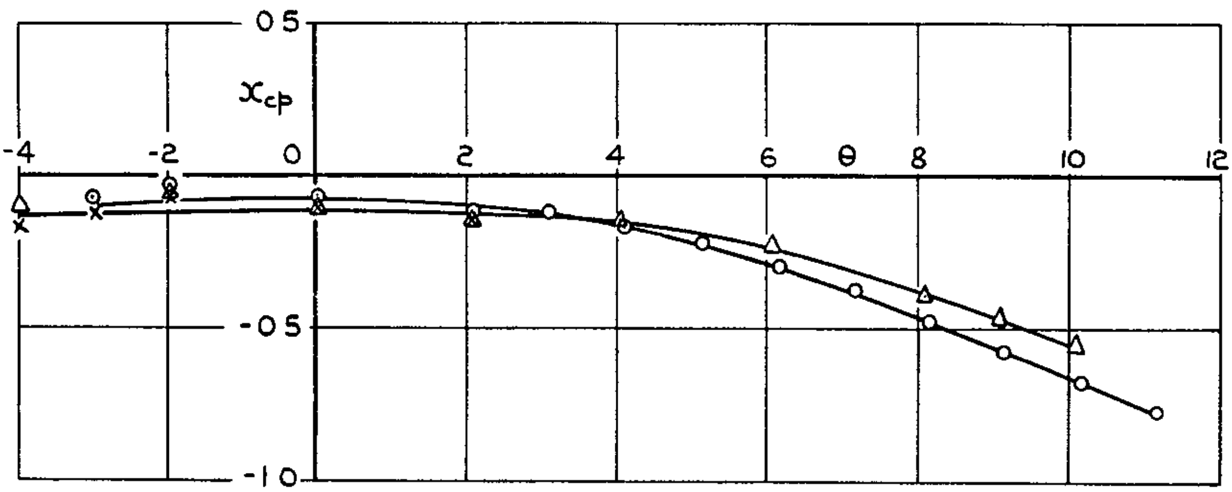


FIG. 1. GENERAL ARRANGEMENT OF MODEL.

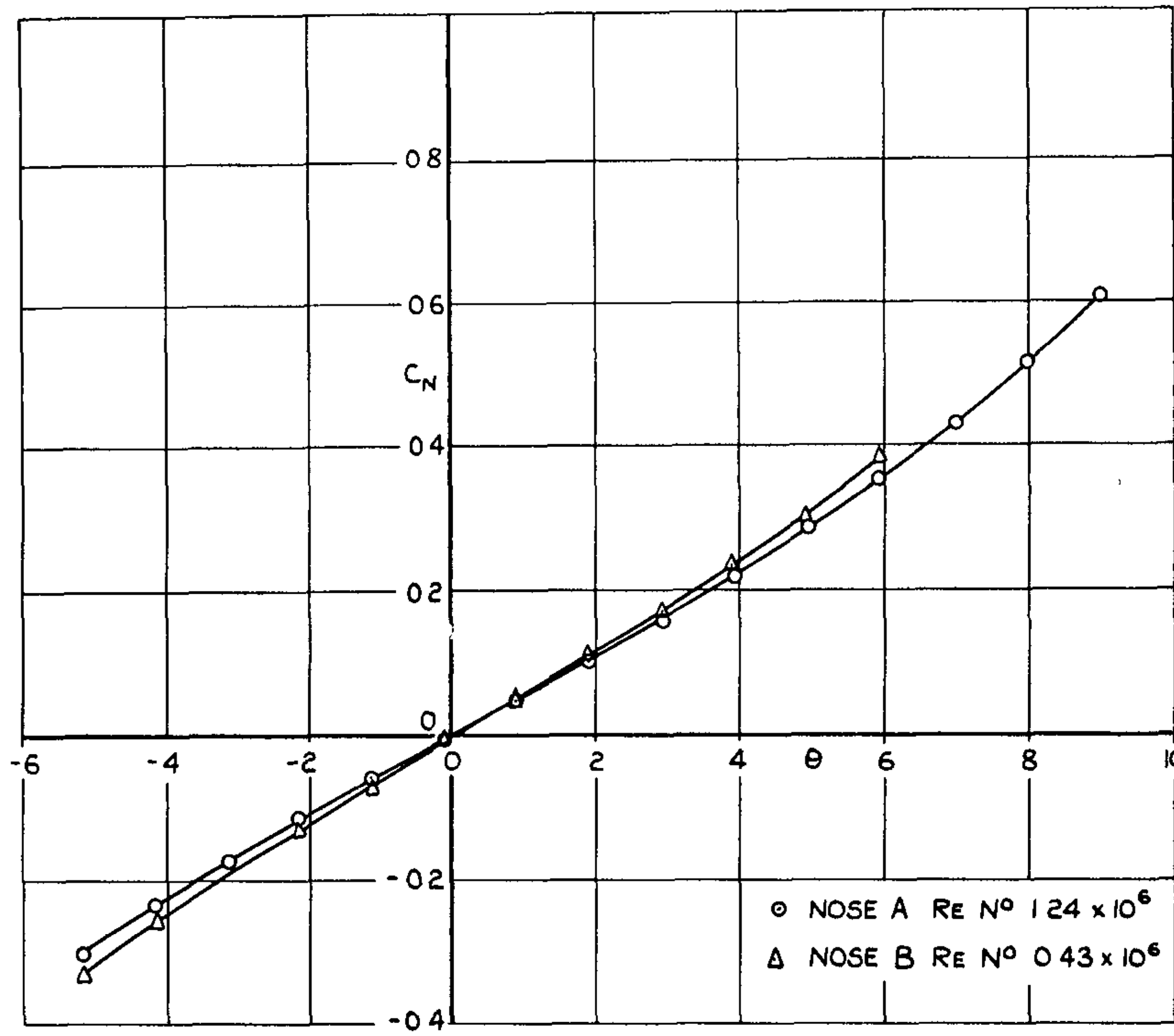


VARIATION OF C_N WITH θ.

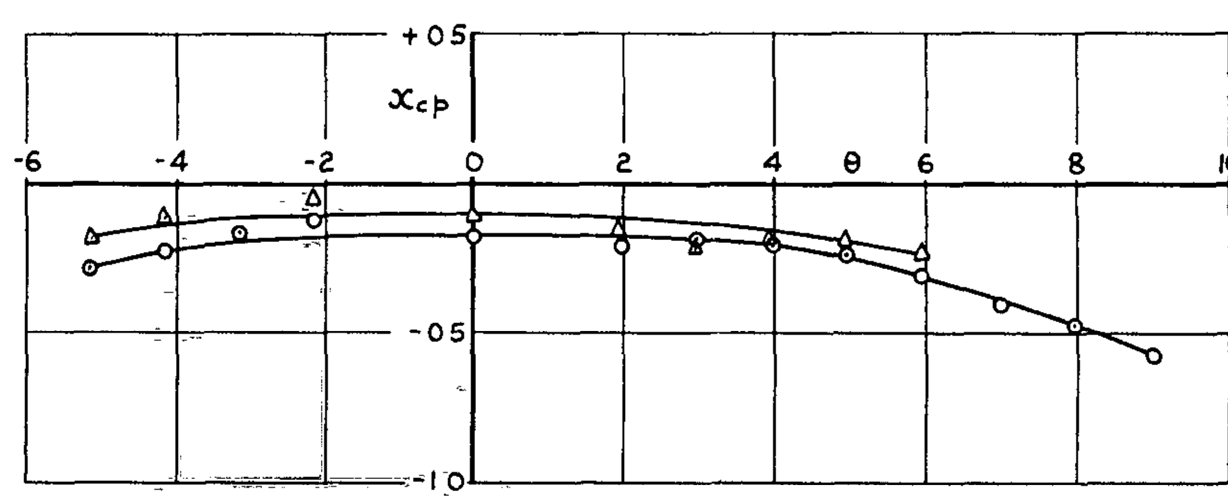


VARIATION OF x_{cp} WITH θ.

FIG. 2. EFFECT OF NOSE SHAPE ; SPLINES ON.

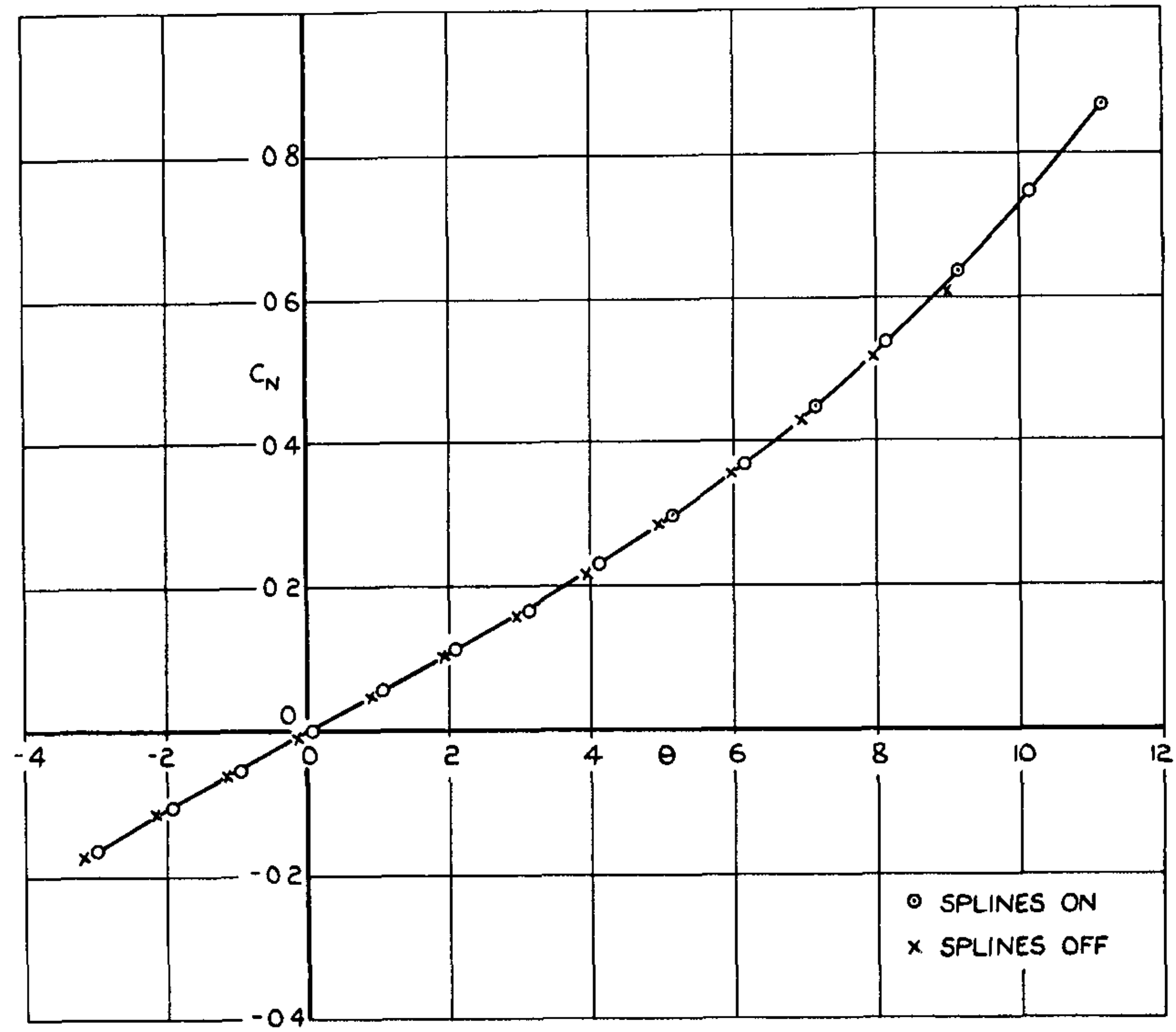


VARIATION OF C_N WITH θ.

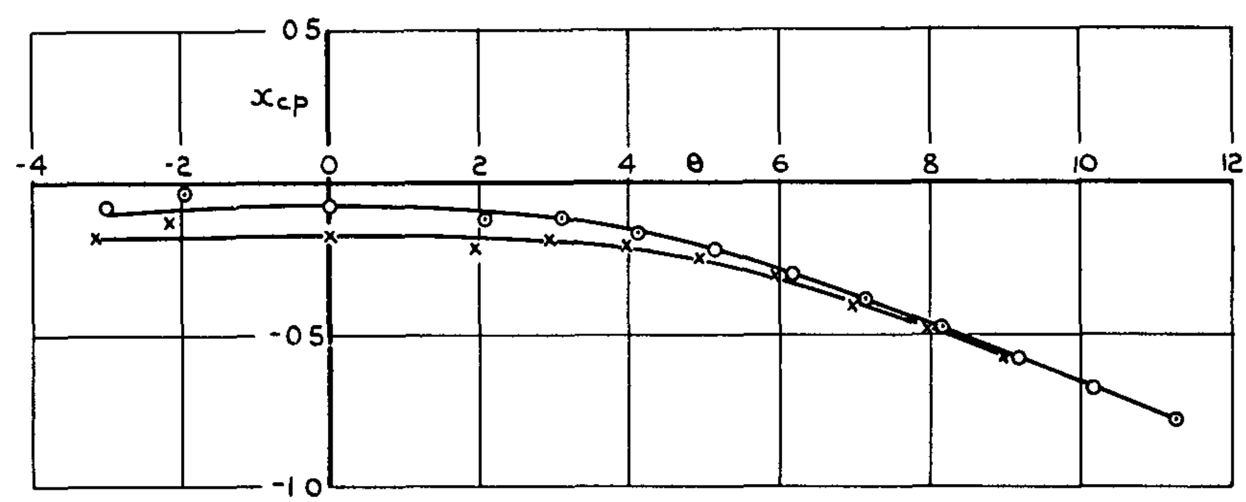


VARIATION OF x_{cp} WITH θ.

FIG. 3. EFFECT OF NOSE SHAPE; SPLINES OFF.

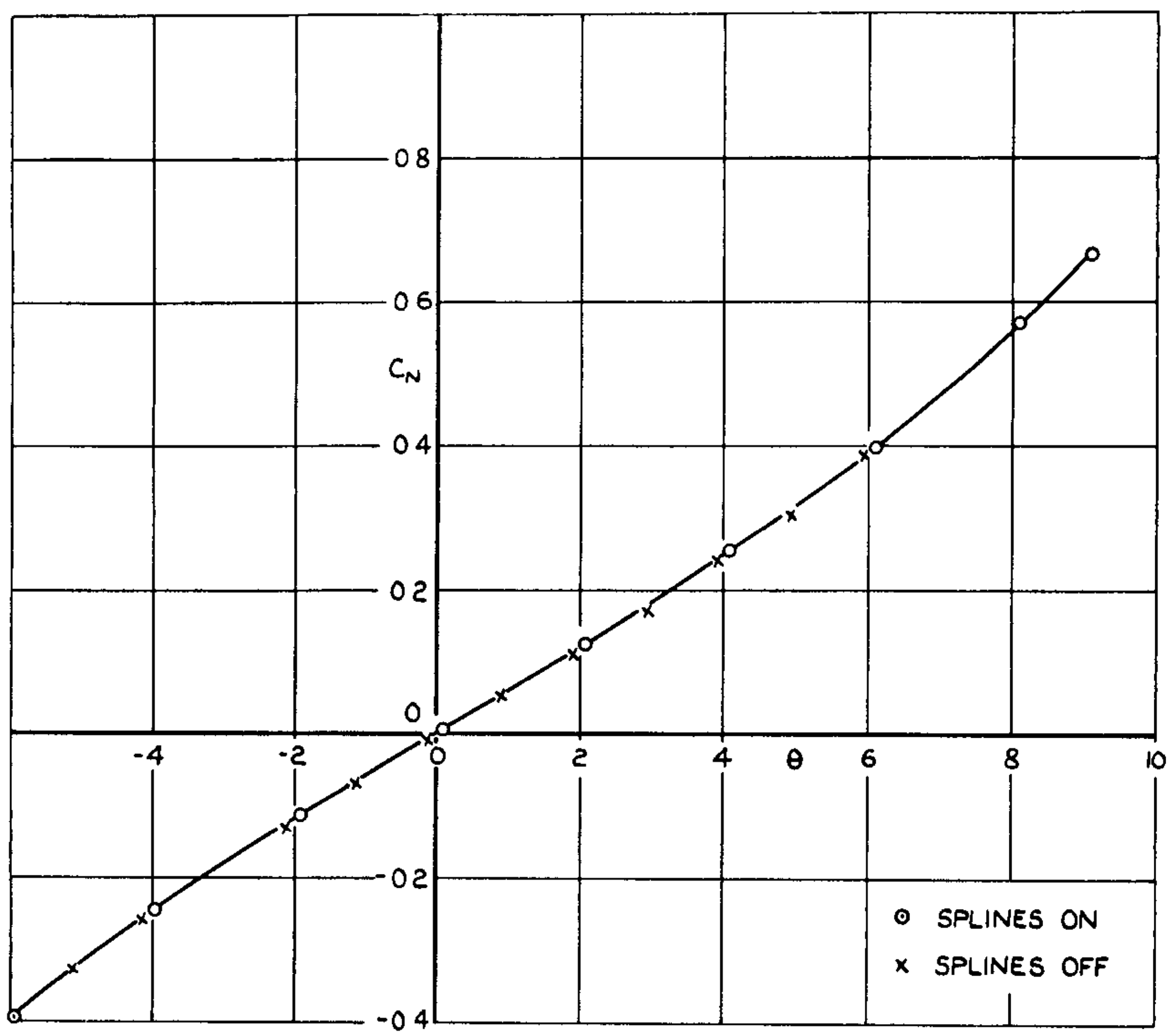


VARIATION OF C_N WITH θ.

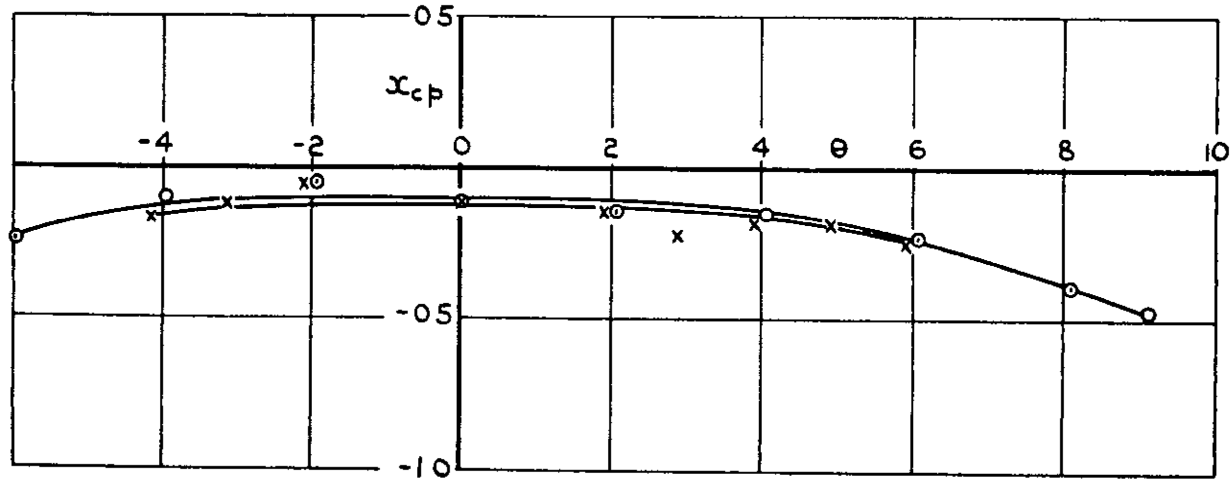


VARIATION OF x_{cp} WITH θ.

FIG. 4. EFFECT OF SPLINES; NOSE A.

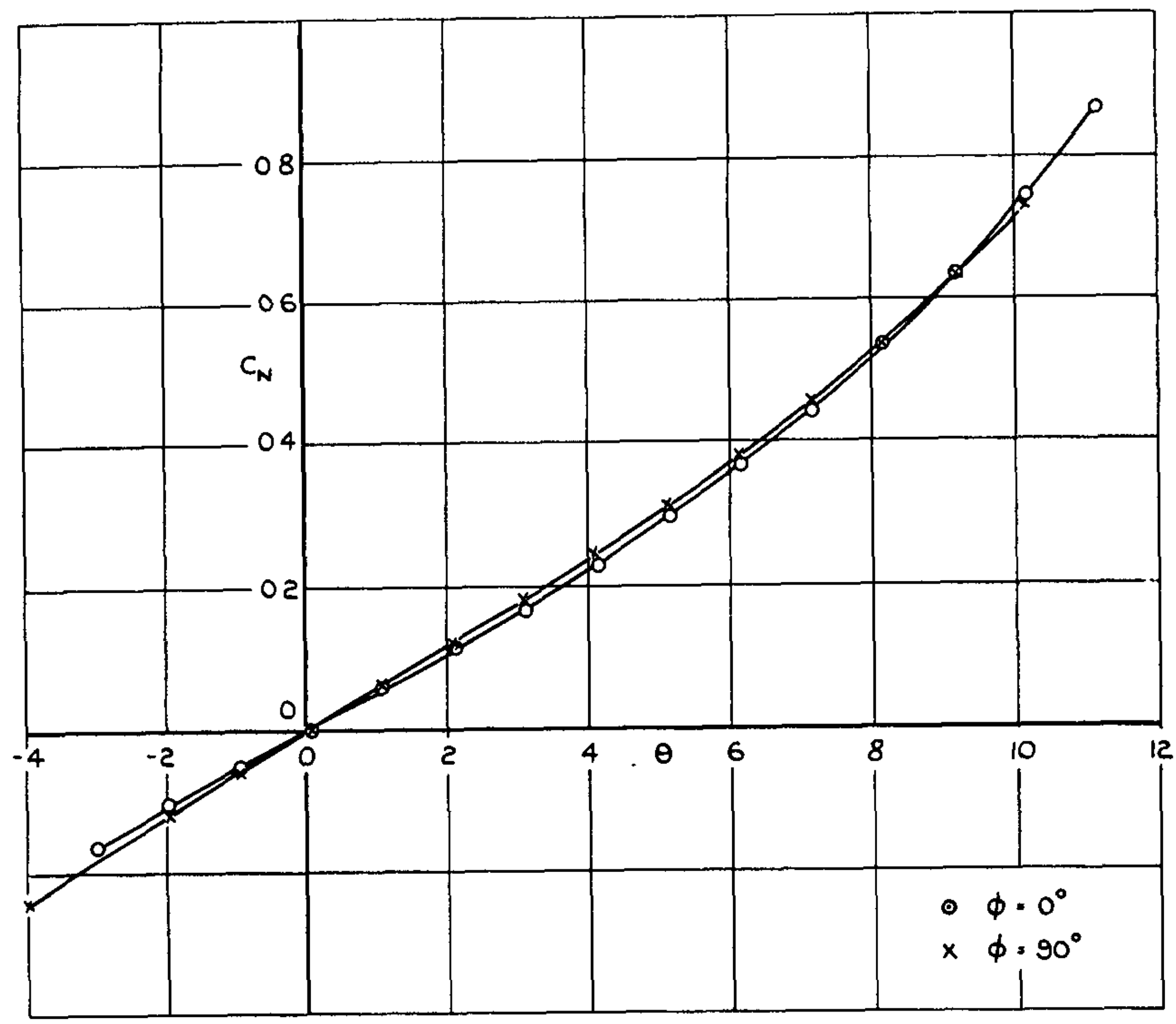


VARIATION OF C_N WITH θ.

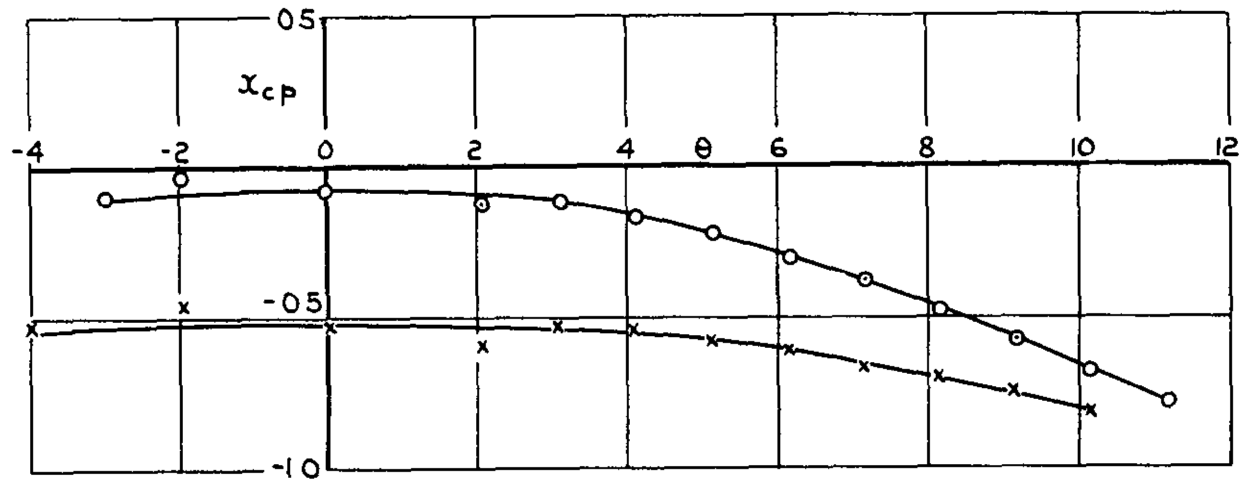


VARIATION OF x_{cp} WITH θ

FIG. 5. EFFECT OF SPLINES; NOSE B.

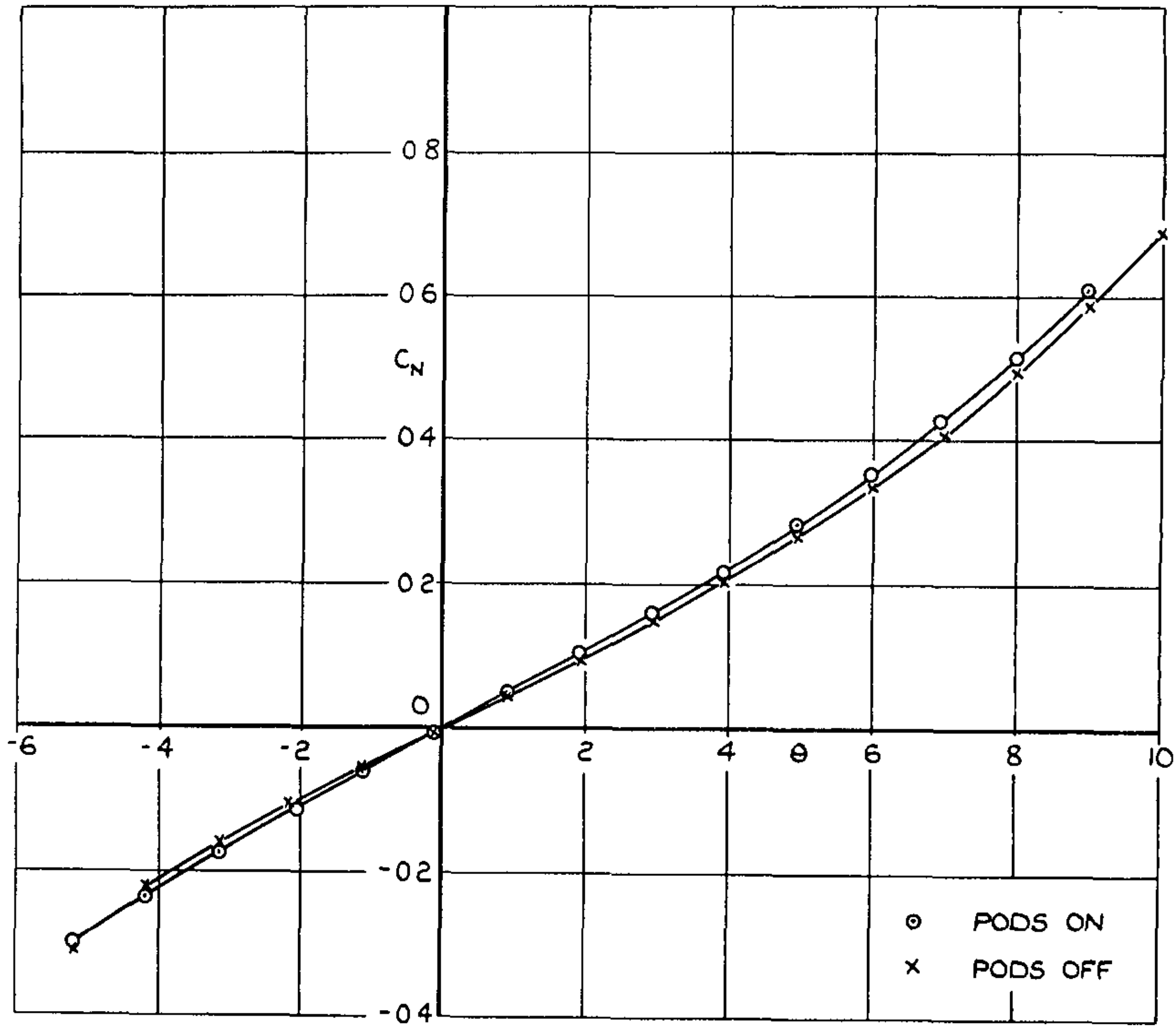


VARIATION OF C_N WITH θ.

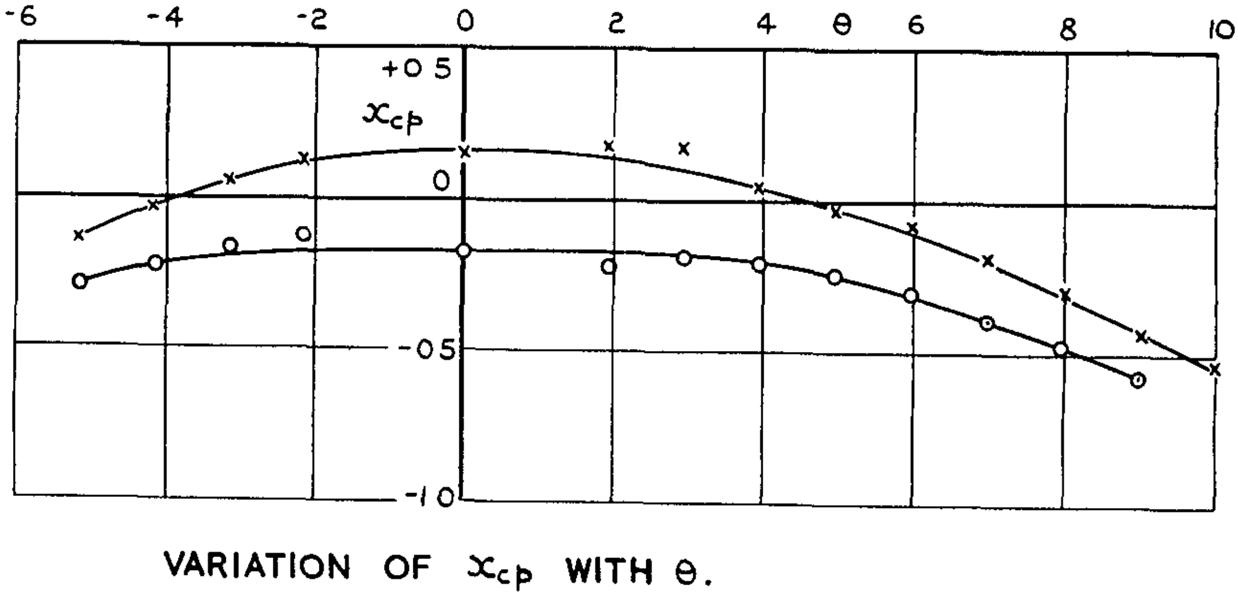


VARIATION OF x_{cp} WITH θ

FIG. 6. EFFECT OF ROLL ANGLE; SPLINES ON.

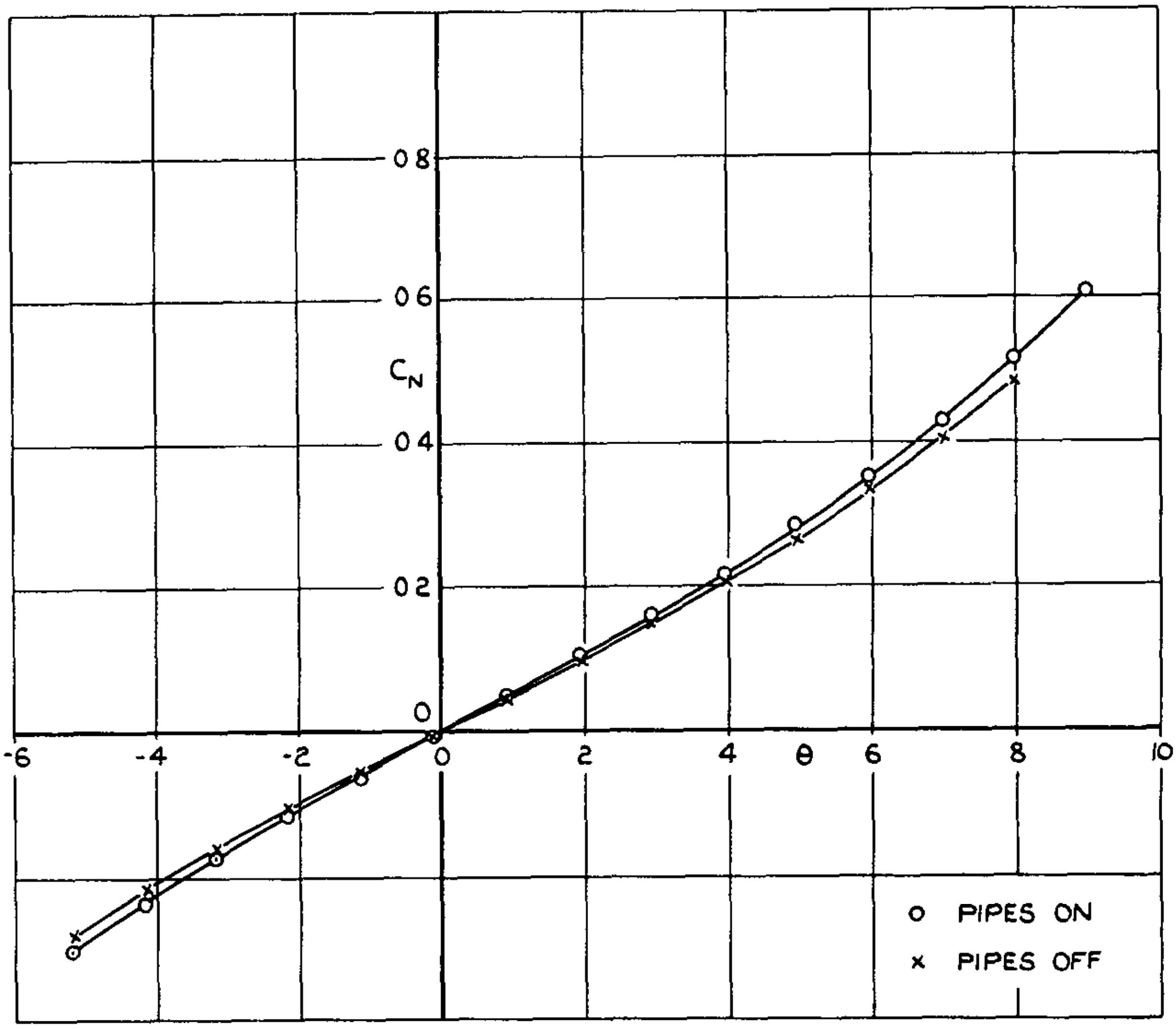


VARIATION OF C_N WITH θ.

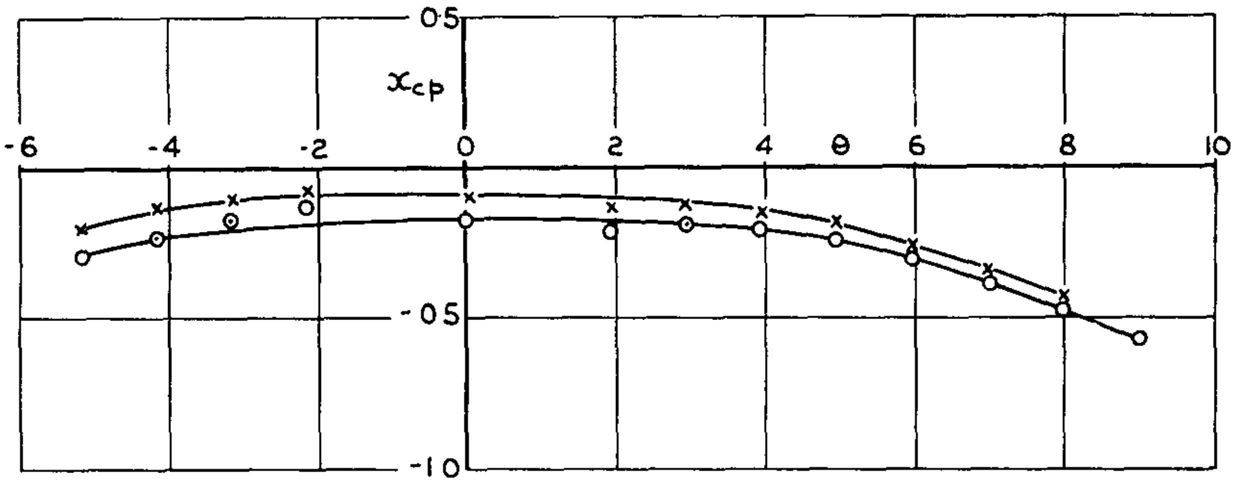


VARIATION OF x_{cp} WITH θ.

FIG. 7. EFFECT OF PODS.

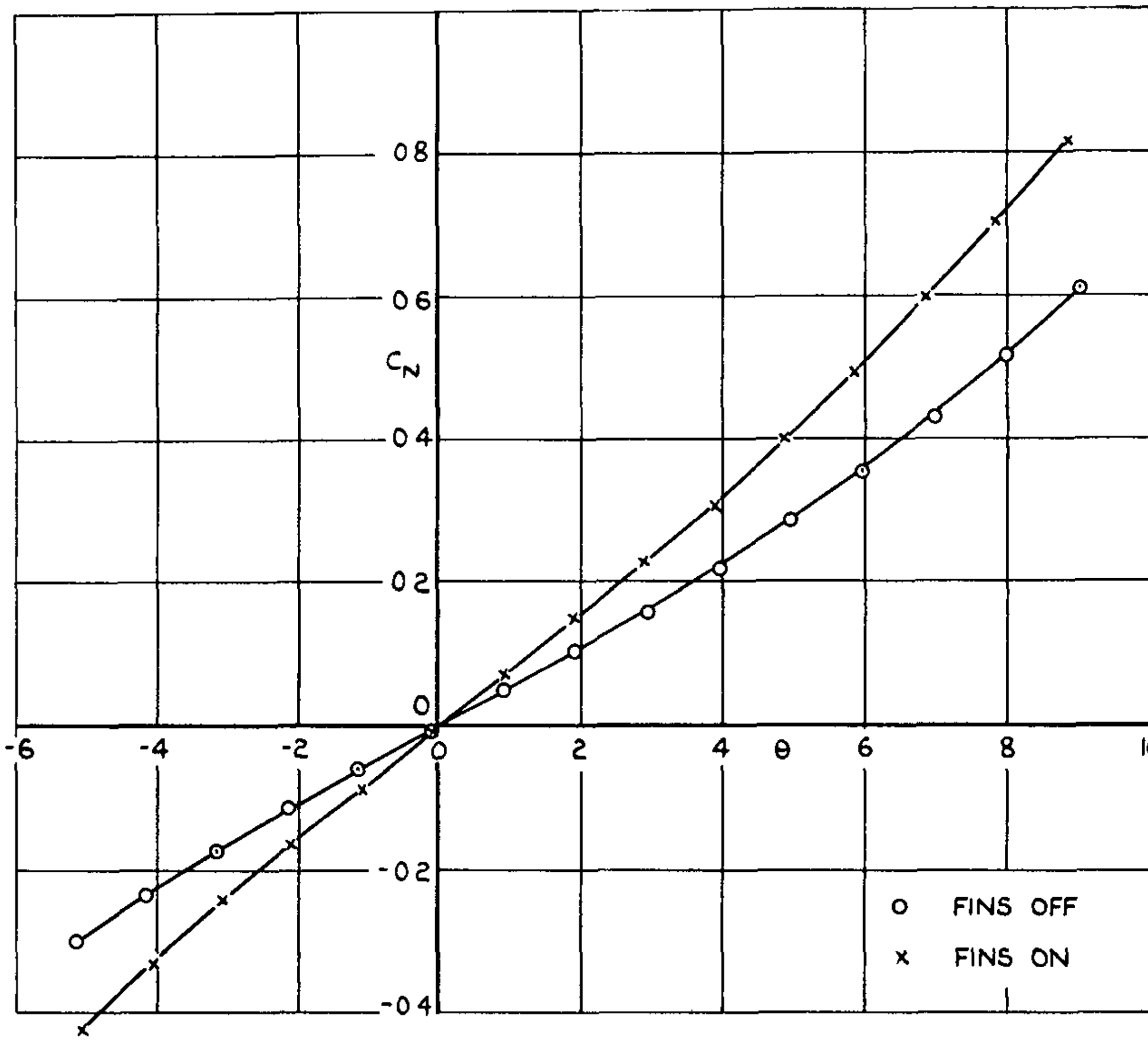


VARIATION OF C_N WITH θ.

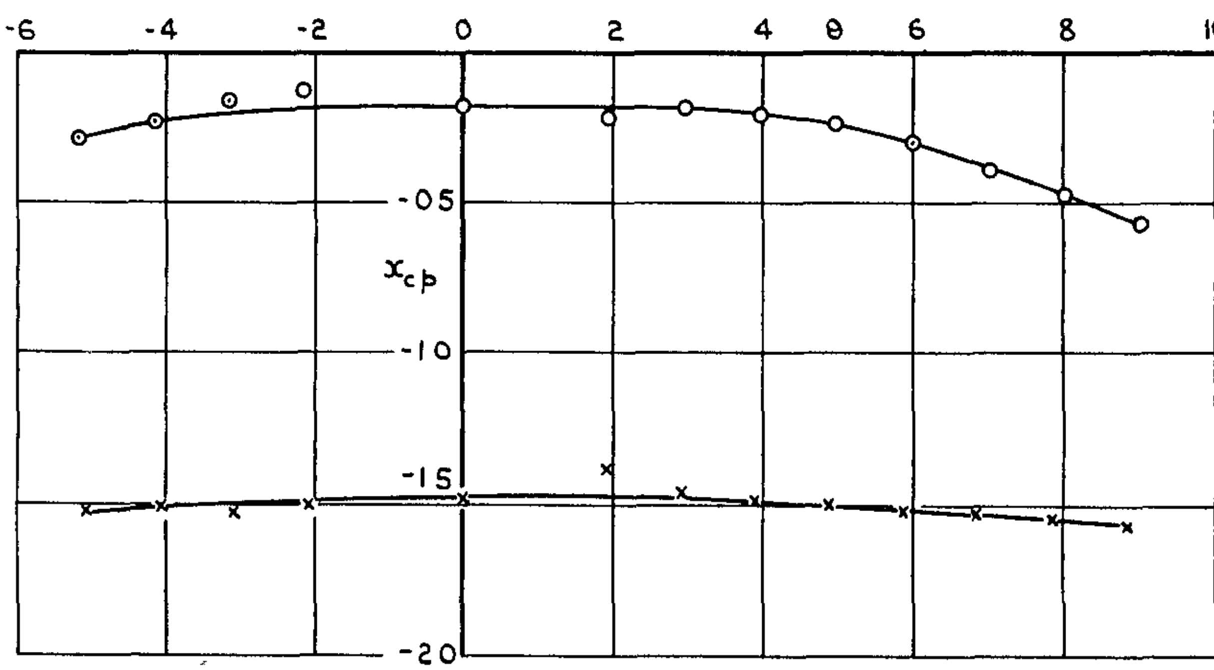


VARIATION OF x_{cp} WITH θ.

FIG. 8. EFFECT OF PIPES.



VARIATION OF C_N WITH θ.



VARIATION OF x_{cp} WITH θ.

FIG. 9. EFFECT OF FINS.

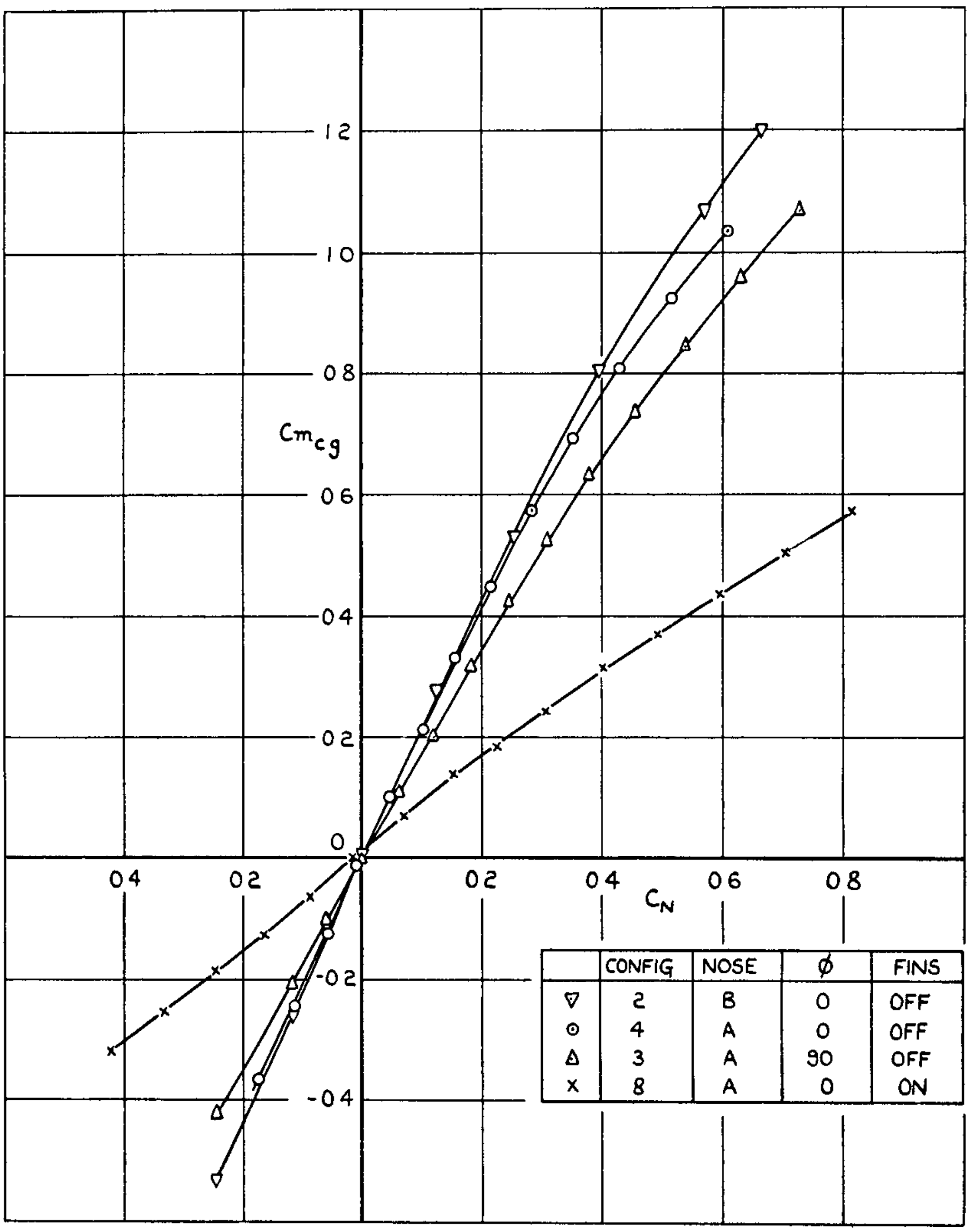
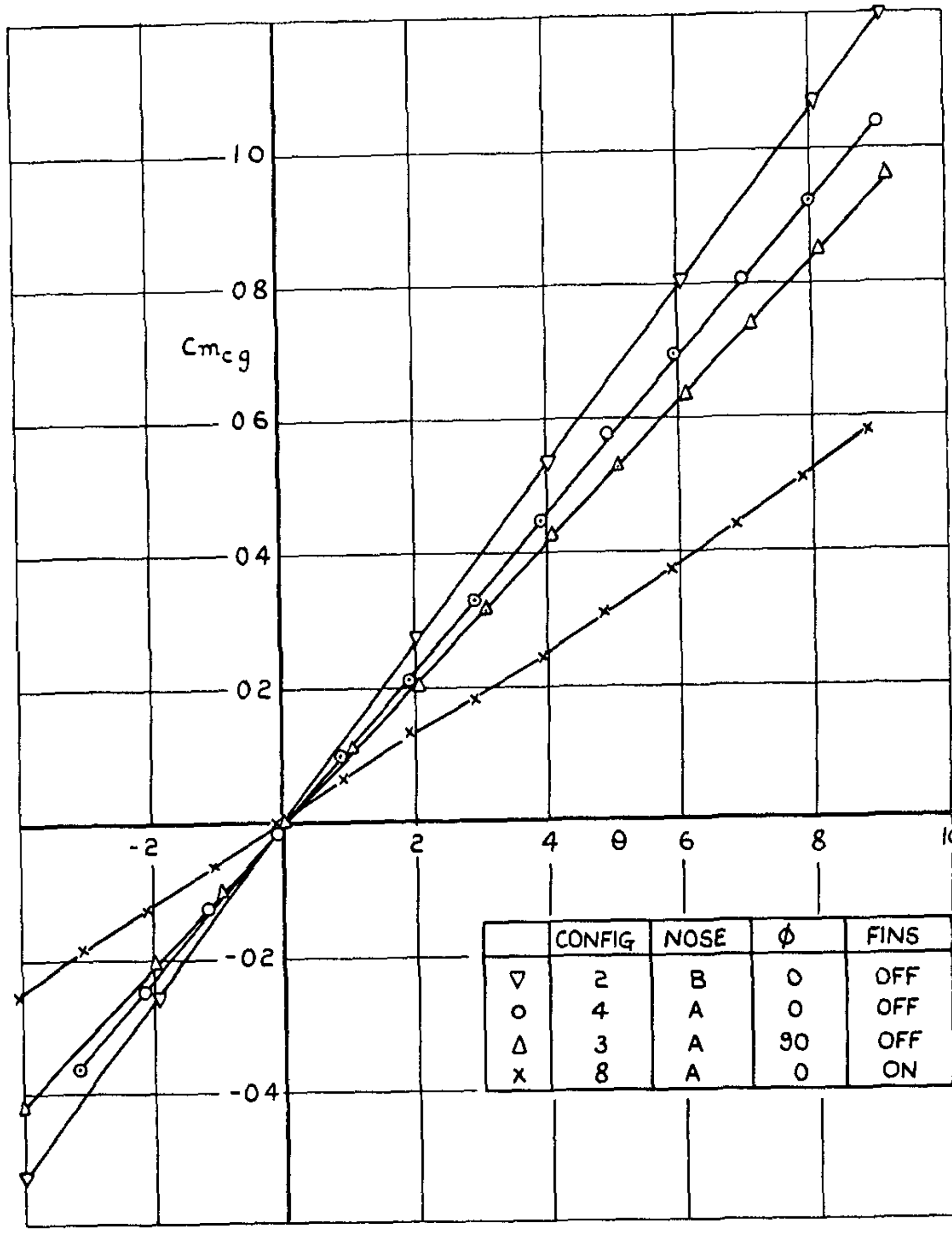


FIG. 10 (a) VARIATION OF $C_{m_{cg.}}$ WITH C_N.



	CONFIG	NOSE	φ	FINS
▽	2	B	0	OFF
o	4	A	0	OFF
Δ	3	A	90	OFF
x	8	A	0	ON

FIG. 10 (b) VARIATION OF $C_{m_{cg}}$ WITH θ.

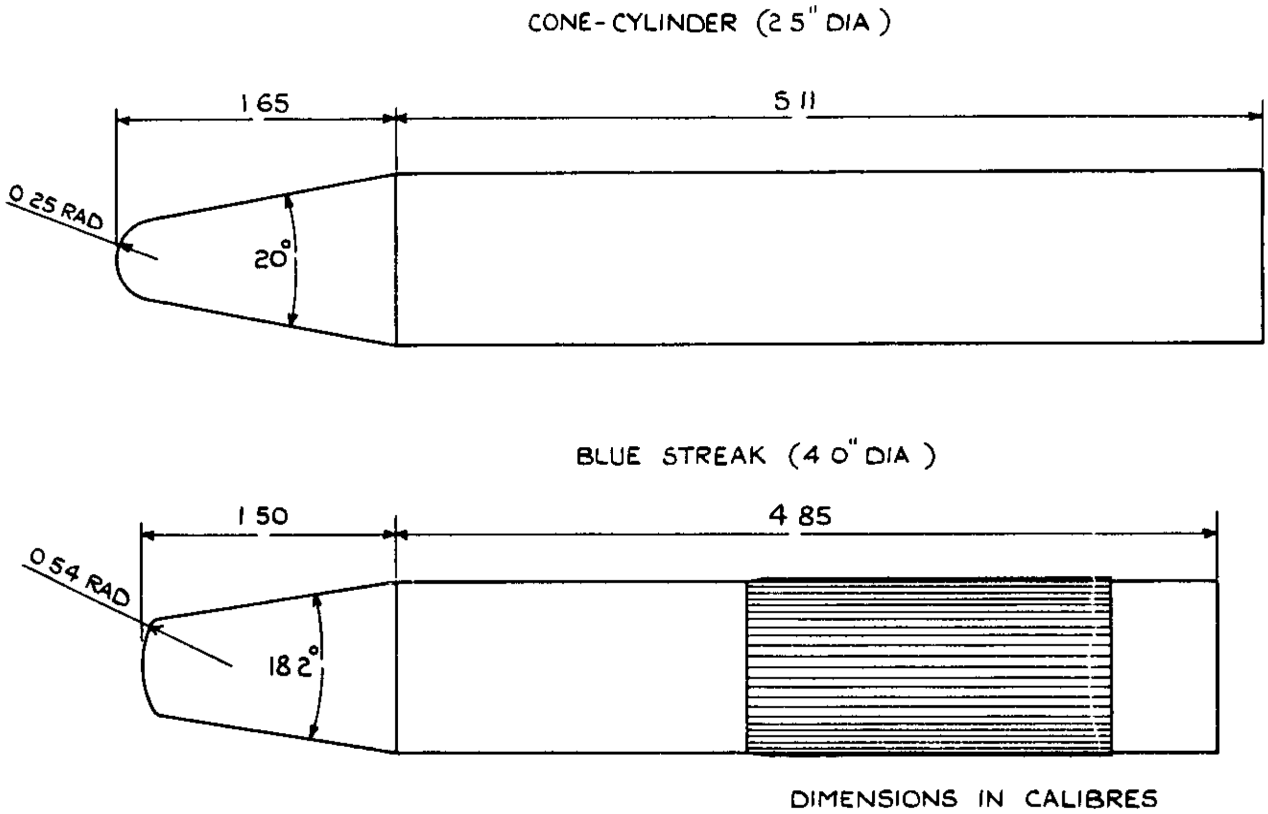


FIG. 11. COMPARISON BETWEEN BLUE STREAK (WITH SLEEVE) AND CONE-CYLINDER MODEL OF REF. 2.

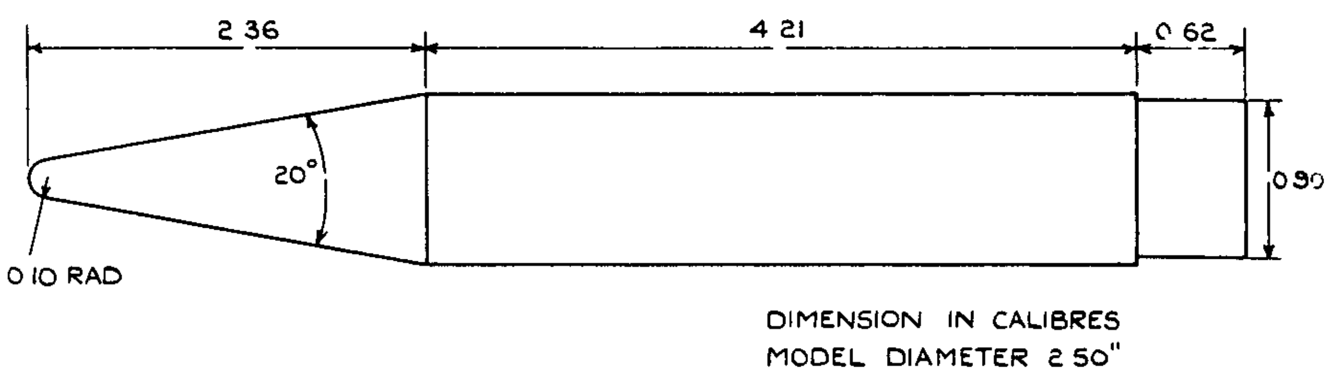


FIG. 12. MODIFIED MODEL OF REF. 2. FOR TESTS ON EFFECT OF SLEEVE AT M = 1·32.

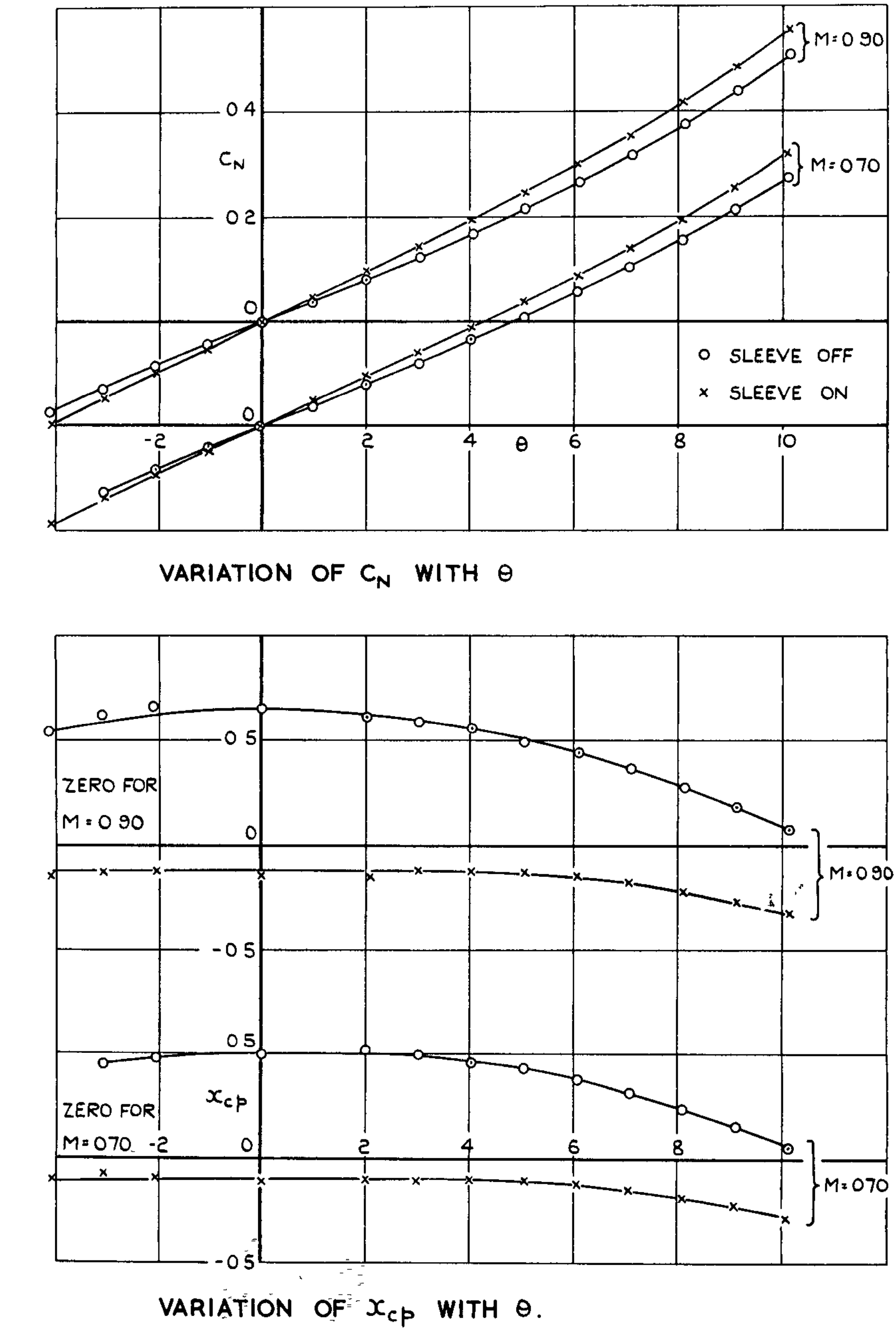


FIG. 13. EFFECT OF SLEEVE AT M = 0·70 AND 0·90; PODS OFF.

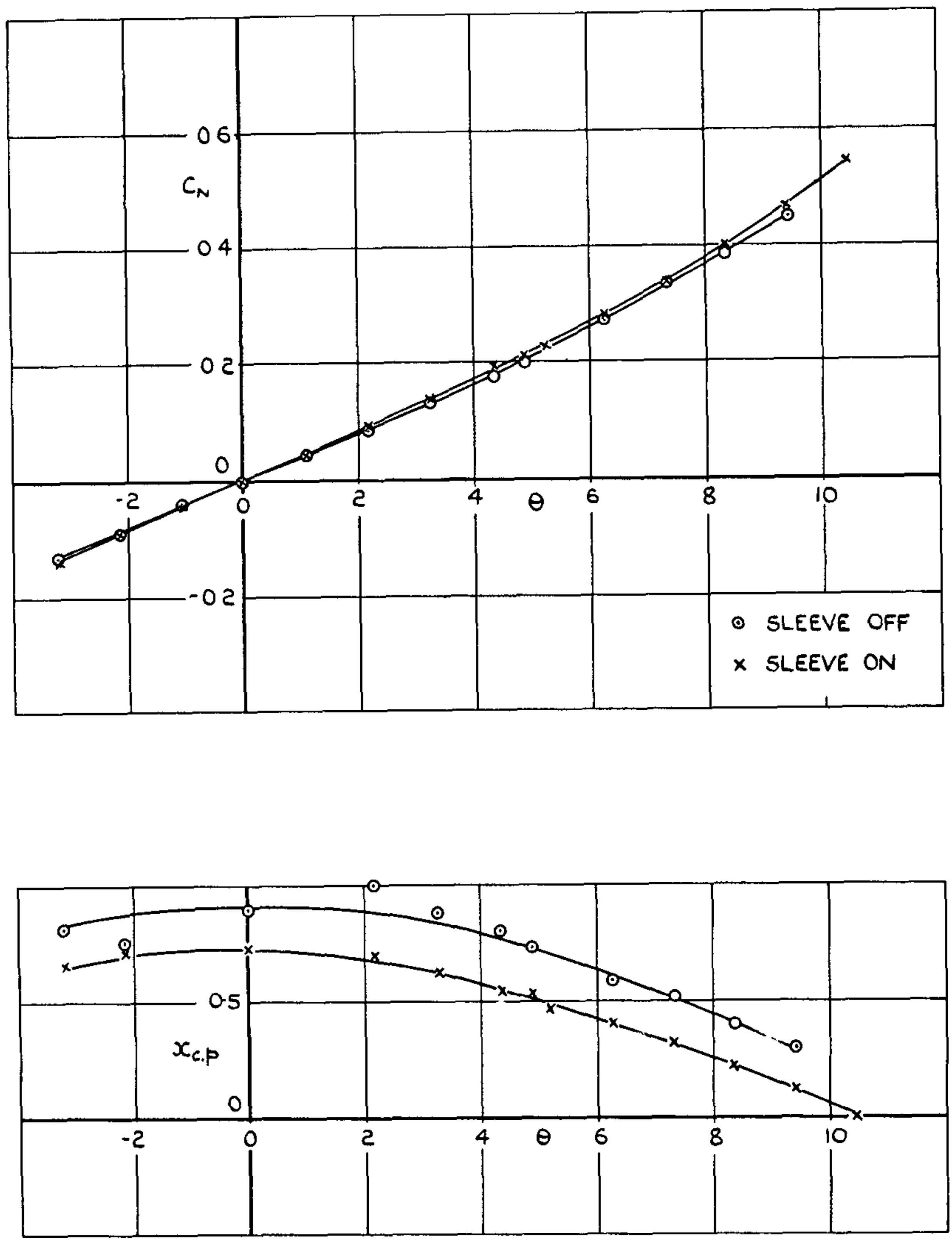
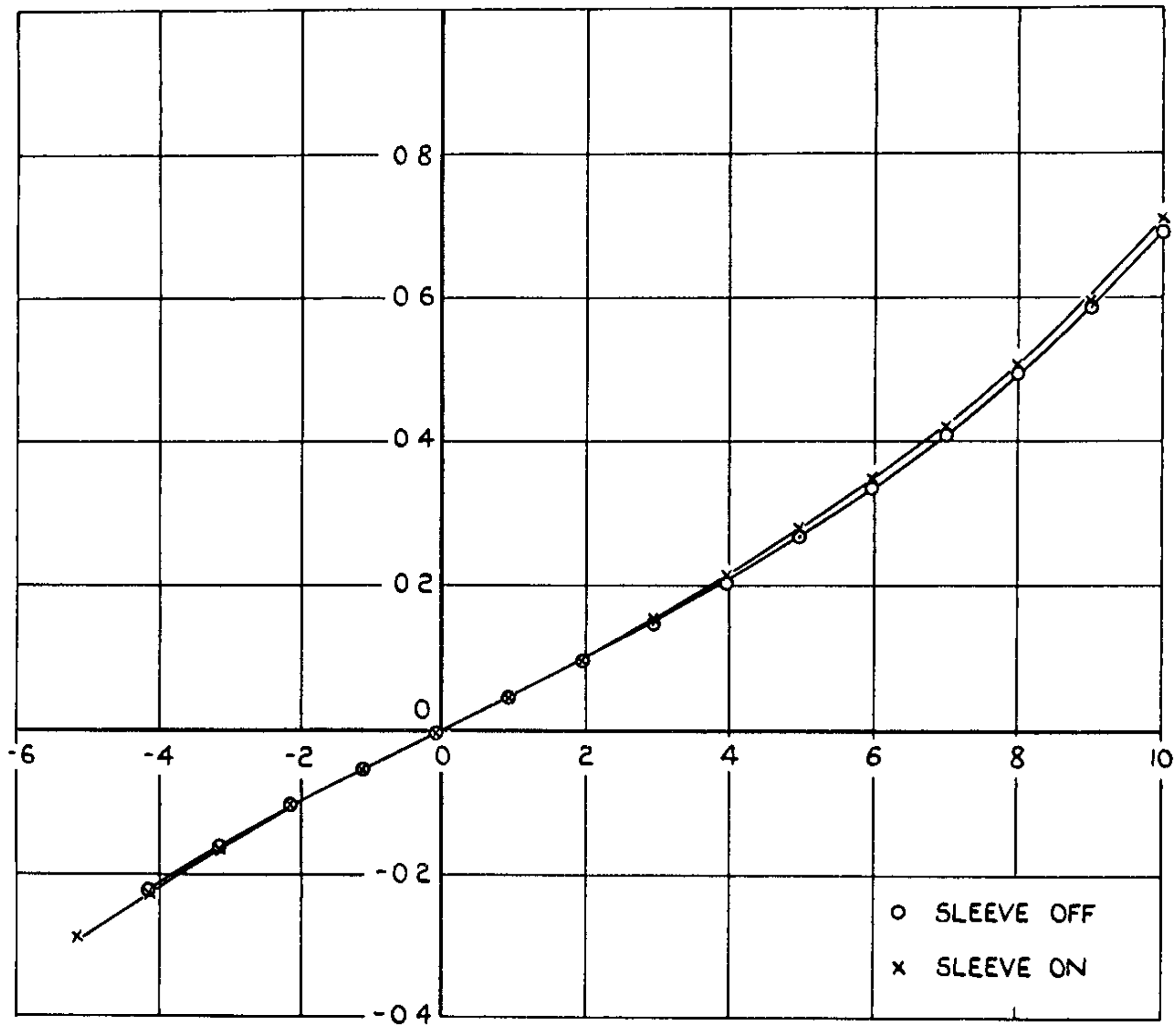
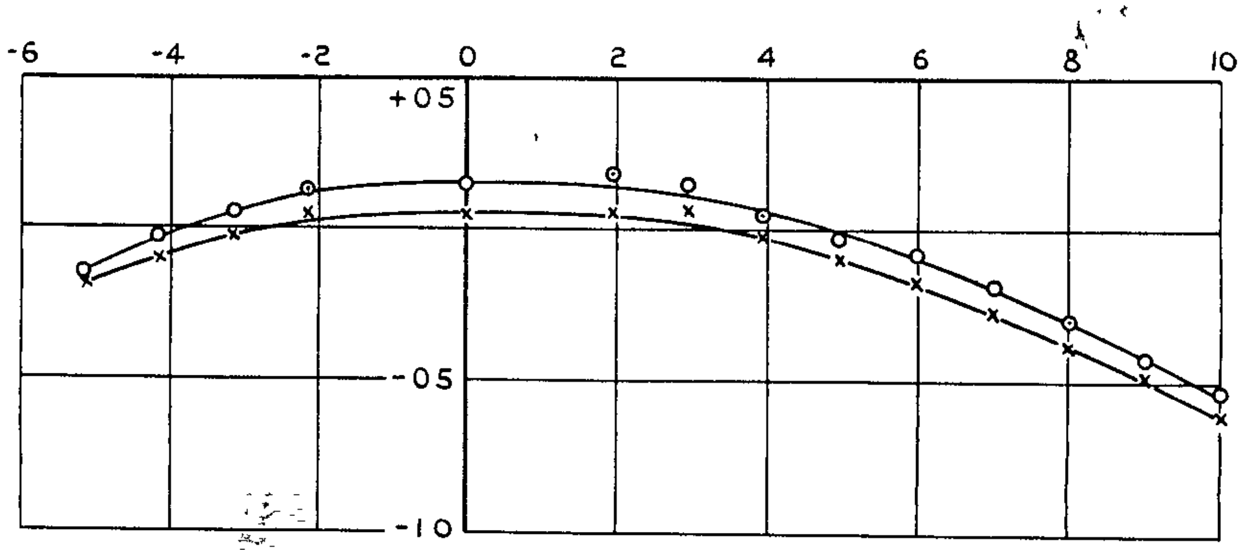


FIG. 14. EFFECT OF SLEEVE AT M = 1·32.
MODIFIED CONE-CYLINDER MODEL OF REF. 2.

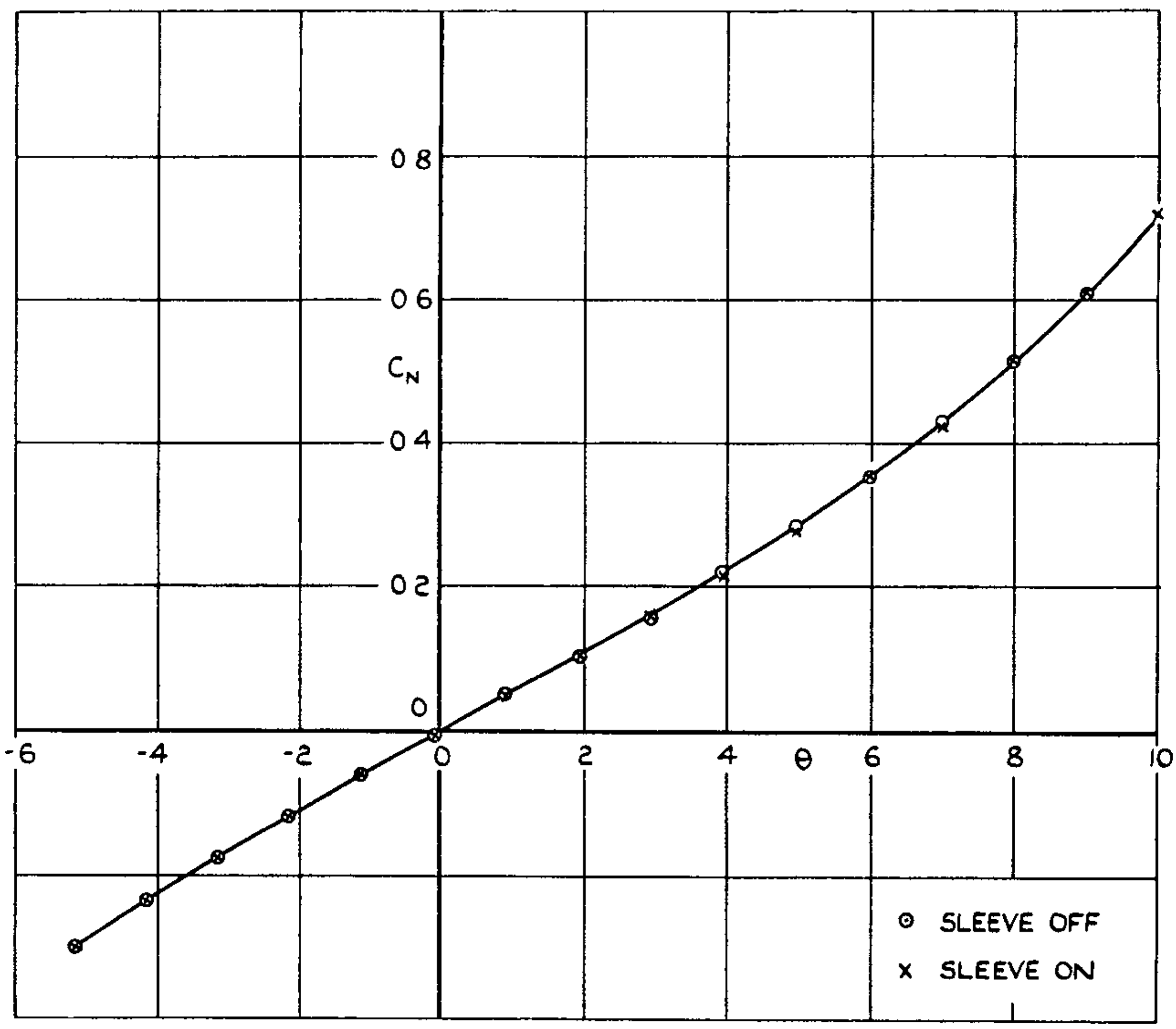


VARIATION OF C_N WITH θ.

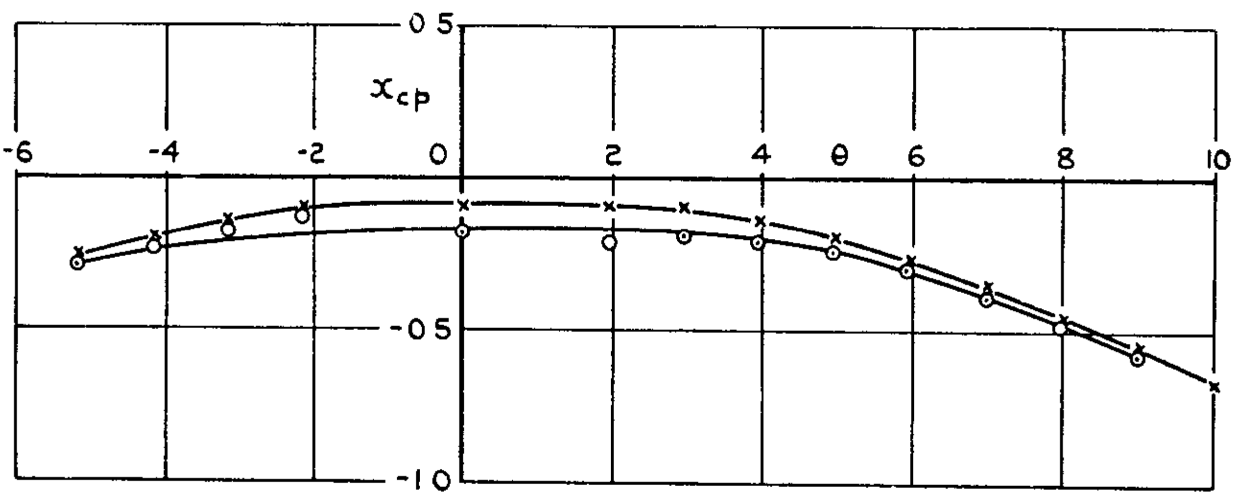


VARIATION OF x_{cp} WITH θ.

FIG. 15. EFFECT OF SLEEVE AT M=2·00; PODS OFF.



VARIATION OF C_N WITH θ.



VARIATION OF x_{cp}. WITH θ.

FIG. 16. EFFECT OF SLEEVE AT M=2·00; PODS ON.

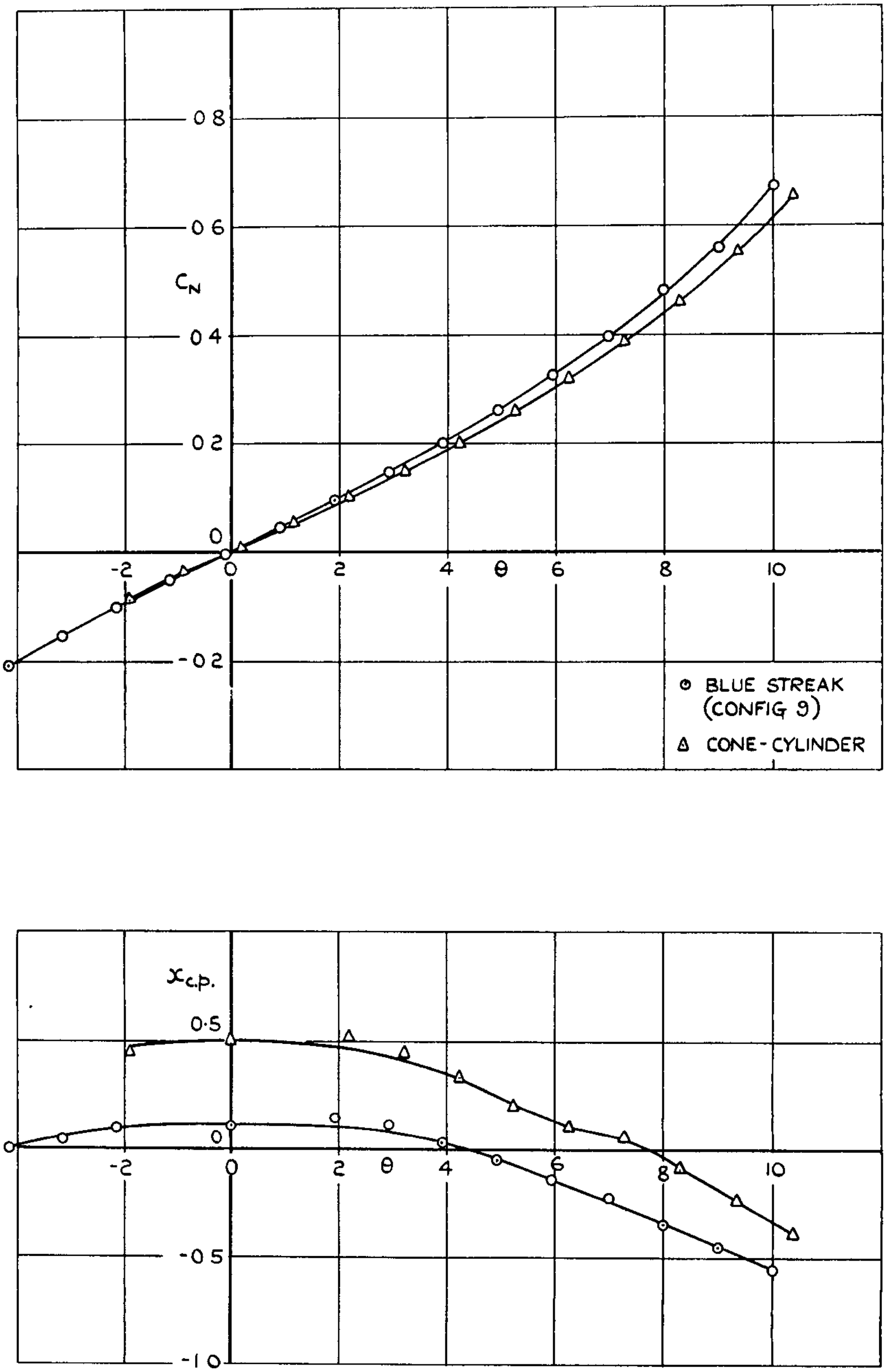


FIG. 17. COMPARISON BETWEEN RESULTS FROM BLUE STREAK MODEL (WITH SLEEVE) AND RESULTS FROM CONE-CYLINDER MODEL OF REF. 2.

A.R.C. C.P. No 732

623.451-519:
533.6.013.412:
533.6.013-413:
533.6.011.5:
533.6.013.5

WIND TUNNEL MEASUREMENTS OF NORMAL FORCE AND PITCHING MOMENT AT A MACH NUMBER OF 2.00 ON A 1:30 SCALE MODEL OF BLUE STREAK. Huntley, E. May, 1959.

Tests have been made in the 3' x 3' tunnel at R.A.E. Bedford, to determine the stability of a model of the Blue Streak missile both in pitch and in yaw, at a Mach number of 2.00. The effects on the normal force and pitching moment characteristics of changes in the various components of the model were also determined; these included the effects of nose shape, longitudinal splines on the nose, motor fairings, fuel pipes

(Over)

A.R.C. C.P. No.732

623.451-519:
533.6.013.412:
533.6.013-413:
533.6.011.5:
533.6.013.5

WIND TUNNEL MEASUREMENTS OF NORMAL FORCE AND PITCHING MOMENT AT A MACH NUMBER OF 2.00 ON A 1:30 SCALE MODEL OF BLUE STREAK. Huntley, E. May, 1959.

Tests have been made in the 3' x 3' tunnel at R.A.E. Bedford, to determine the stability of a model of the Blue Streak missile both in pitch and in yaw, at a Mach number of 2.00. The effects on the normal force and pitching moment characteristics of changes in the various components of the model were also determined; these included the effects of nose shape, longitudinal splines on the nose, motor fairings, fuel pipes

(Over)

A.R.C. C.P. No 732

623.451-519:
533.6.013.412:
533.6.013-413:
533.6.011.5:
533.6.013.5

WIND TUNNEL MEASUREMENTS OF NORMAL FORCE AND PITCHING MOMENT AT A MACH NUMBER OF 2.00 ON A 1:30 SCALE MODEL OF BLUE STREAK. Huntley, E. May, 1959.

Tests have been made in the 3' x 3' tunnel at R.A.E. Bedford, to determine the stability of a model of the Blue Streak missile both in pitch and in yaw, at a Mach number of 2.00. The effects on the normal force and pitching moment characteristics of changes in the various components of the model were also determined; these included the effects of nose shape, longitudinal splines on the nose, motor fairings, fuel pipes

(Over)

and fins. The effects of the step in the body profile was also determined both at transonic speeds and at M = 2.00.

The model without fins was found to be statically unstable both in pitch and in yaw. With four stabilizing fins attached to the rear of the model it was also unstable but the moments were reduced by approximately 50% at any given incidence.

and fins. The effect of the step in the body profile was also determined both at transonic speeds and at M = 2.00.

The model without fins was found to be statically unstable both in pitch and in yaw. With four stabilizing fins attached to the rear of the model it was also unstable but the moments were reduced by approximately 50% at any given incidence.

and fins. The effects of the step in the body profile was also determined both at transonic speeds and at M = 2.00.

The model without fins was found to be statically unstable both in pitch and in yaw. With four stabilizing fins attached to the rear of the model it was also unstable but the moments were reduced by approximately 50% at any given incidence.

C.P. No. 732

Published by
HER MAJESTY'S STATIONERY OFFICE

To be purchased from
York House, Kingsway, London w.c.2
423 Oxford Street, London w.1
13A Castle Street, Edinburgh 2
109 St. Mary Street, Cardiff
39 King Street, Manchester 2
50 Fairfax Street, Bristol 1
35 Smallbrook, Ringway, Birmingham 5
80 Chichester Street, Belfast 1
or through any bookseller

C.P. No. 732

S.O. CODE No. 23-9015-32