C.P. No. 39
13185
A.R.C. Technical Report

MINISTRY OF SUPPLY

AERONAUTICAL RESEARCH COUNCIL
CURRENT PAPERS

Low-Speed Wind Tunnel Investigation of the Change in Aerodynamic Centre Position and in C_{m_0} due to Propeller Turbine Nacelles

By

D. A. Kirby, B.Sc., A.C.G.I., D.I.C. and F. W. DEE

LONDON: HIS MAJESTY'S STATIONERY OFFICE

1951

Price 6s 0d net

C.P. No. 39

Report No. Aero.2356

February, 1950

ROYAL AIRCRAFT ESTABLISHMENT

Low-Speed Wind Tunnel Investigation of the Change in Aerodynamic Centre Position and in C_{m_0} due to Propeller Turbine Nacelles

by

D.A. Kirby, B.Sc., A.C.G.I., D.I.C.

and

F.W. Dee

SUMMARY

Low speed wind tunnel tests have been made on the effect of propeller turbine type nacelles on the position of the aerodynamic centre and the pitching moment at zero lift of a multi-engined aircraft. This investigation forms part of a series of tests made to improve stability prediction data, primarily for civil aircraft.

A plain rectangular wing was used to test various lengths of nacelle overhang and rear fairing for both chordline and underslung nacelles parallel and drooped at -4^{o} to the wing chordline. Tests were also made with

(i) two nacelles on a wing to find the mutual interference between them,

(ii) nacelles on both low and high wings on a fuselage to find the interference between the body and a nacelle.

The results have been presented in a form suitable for predicting the total effect on longitudinal stability of the nacelles of a turbine driven multi-engined aircraft.

LIST OF CONTENTS

LIST OF APPENDICES

LIST OF TABLES

LIST OF ILLUSTRATIONS

1 Introduction

A series of tests has been made to improve longitudinal stability prediction at low Mach No. for multi-engined civil aircraft with cylindrical type bodies and propeller turbine engines. The effect of bodies[1] and of slipstream[2] has been covered in other reports. The present report gives the results of tests on the effects of propeller turbine nacelles. The nacelles are relatively small and, when using the complete model, it was not found easy to obtain sufficient accuracy to determine the effect of variations in the nacelles on longitudinal stability i.e. on the position of the aerodynamic centre and on C_{m_0}. Tests have therefore been made, firstly on a single nacelle on a plain wing, then of interference between adjacent nacelles and finally of interference between body and nacelles. Results from a 4-engined and a 6-engined complete model test are also included together with the results of a few earlier unpublished tests on propeller turbine nacelles.

Earlier tests[3] on nacelles for reciprocating engines do not cover the same range of shapes; the reciprocating engines were of relatively greater diameter and were less overhung. The shape of the rear of the nacelles was often complicated by the necessity for housing the undercarriage. There was consequently need for an extension of the previous work.

The method of presentation used in the present report is taken from Ref.3 and the account of its application to any given aircraft is repeated from Ref.3 in the appendix.

2 Details of model and tests

The tests were made at the R.A.E. in December, 1948 and February, 1949. Tests without body were made in the 5 ft wind tunnel on a rectangular wing of aspect ratio 4.33. A wing of aspect ratio 6 was used in the No.1 $11\frac{1}{2}$ ft tunnel for the tests with a body.

The wing section, a modified R.A.F.44, was chosen to give linear lift and pitching moment curves at low Reynolds number. This was the same section as that used for the tests with slipstream of Ref.2. In the 5 ft tunnel a speed of 200 ft/sec gave a Reynolds number of 1.18×10^6 based on the wing chord. A speed of 120 ft/sec was used in the $11\frac{1}{2}$ ft tunnel giving a Reynolds number of 0.71×10^6, and a fine mesh honeycomb was placed 3 ft ahead of the model to increase the turbulence of the airstream, since this is found to straighten the lift and pitching moment curves at low Reynolds number.

Nacelle diameters of 23.7, 27.2 and 35.6% chord were used for the tests. The two smaller diameters were representative of multi-engined aircraft fitted with propeller turbines. The nacelle shape used consisted of an elliptic nose fairing, a constant diameter portion reaching to the wing leading edge and a tapered fairing aft of the leading edge. The part of the nacelle ahead of the wing could be inclined downwards at 4° to the chordline by inserting a wedge at the wing leading edge. The zero lift angle of the wing was -1.4°, so that relative to the no lift line angles of droop of 1.4° and 5.4° were used.

The body used was that of the systematic tests of Ref.1 with the second shortest nose and tail lengths; no fin or tailplane was fitted. A geometric wing-body angle of 0° was used for both high and low wing positions. Fillets were fitted for the low wing only.

Relevant dimensions of the two wings, the nacelles and the body are given in Table I and the nacelles are illustrated in Figs.1 and 2. Fig.3 shows the low wing model and the spanwise positions of the nacelles as used for the tests with body.

Readings of lift and pitching moment about the wing quarter chord points were taken over a C_L range from -0.1 to 0.5 for the following arrangements of the model, where i_N is the angle between the nacelle centreline and the no lift line of the wing, and z is the distance of the centre line below the wing chord at the leading edge.

(a) Nacelle characteristics

5 ft tunnel tests - 1 nacelle on centre line				
$\frac{D}{c}$	$\frac{z}{c}$	$\frac{\text{Overhang}}{\text{Chord}} = \frac{m}{c}$	$\frac{\text{Rear fairing length}}{\text{Chord}} = \frac{n}{c}$	i_N°
0.237	0.121	0.4 0.6 1.0	0.6	1.4
		0.6 1.0	0.6	5.4
		0.6 1.0	0.7	1.4
		0.6 1.0	0.9	1.4
		0.6 1.0	0.9	5.4
	0	0.4 0.6 1.0	0.6	1.4
		0.6 1.0	0.6	5.4
0.272	0.121	0.6 1.0	0.6	1.4
		0.6 1.0	0.7	1.4
		0.6 1.0	0.9	1.4
	0	0.6 1.0	0.6	1.4
0.356	0.121	1.0	0.9	1.4
	0	1.0	0.6	1.4

(b) Mutual nacelle interference

5 ft tunnel tests - nacelles with $\frac{m}{c} = 1.0$ $i_N = 1.4^\circ$				
$\frac{D}{c}$	Number of nacelles	$\frac{z}{c}$	$\frac{n}{c}$	Spanwise positions tested - from centre line = $\frac{l}{D}$
0.237	2	0.121	0.6	2.07 3.80
	1		0.6	3.80
0.356	2	0.121	0.9	2.07 3.80

(c) Body interference

$11\frac{1}{2}$ ft tunnel tests - 2 nacelles with $\frac{m}{c} = 1.0$ $i_N = 1.4^\circ$							
Wing	$\frac{D}{c}$	$\frac{z}{c}$	Spanwise Position / Body Diameter $= \frac{y}{D_b}$				
High	0.237	0.121	1	1.21	1.56	1.95	2.34
		0		1	2.34		
	0.356	0.121		1	2.28		
Low	0.237	0	1	1.21	2.34		
	0.356	0.121	1	1.21	2.28		
No body	0.237	0.121		2.34			

The results of tests made with nacelles in two spanwise positions on the model of Ref.1 are also included in the text of this report (see paragraph 5.1). These tests were made in the R.A.E. No.1 $11\frac{1}{2}$ x $8\frac{1}{2}$ ft tunnel in January, 1948. The wind speed was 120 ft/sec which gave a Reynolds number of 0.65 x 10^6 based on wing mean chord, or 0.85 x 10^6 based on wing centre line chord. A honeycomb was in position 3 ft ahead of the model.

The model consisted of the body used for the present tests fitted to a 2 : 1 tapered wing. No fin or tailplane was fitted. The nacelles tested were similar to the present series, but, as the same size of nacelle was fitted in both inner and outer positions different values of $\frac{D}{c}, \frac{m}{c}, \frac{n}{c}$ and $\frac{z}{c}$ were obtained for the two spanwise positions. No propellers were represented. The dimensions of the model are given in Table II and the model is illustrated in Fig.4.

Tests were made with two nacelles on both high and low wing configurations for the two spanwise positions.

3 Presentation of Results

The results are presented as in Ref.3, using $\Delta C_m' = \frac{\Delta M}{qc^2D}$ as the non-dimensional coefficient, D being the maximum width of the nacelle. The slope of the curve of $\Delta C_m'$ against local lift coefficient C_L' may be interpreted as the mean distance, as a fraction of the wing chord, through which the aerodynamic centre moves forward over the nacelle span D. ($\Delta k_n'$).

In the present tests on the wing and nacelles pitching moments were measured about the quarter chord of the wing. From a test of the wing alone, the aerodynamic centre of the wing without nacelles was at 0.217c. Since earlier tests[3] were measured on a wing with its aerodynamic centre at 0.25c, the present results have been corrected (see Appendix I) to give results applicable to a wing with its aerodynamic centre at 0.25c.

When a body is present the aerodynamic centre is at 0.145c, and since the lift on the wing which compensates the negative lift on the nacelle acts here a correction is necessary if the tests on the wing alone are to be applied to this case (or to a complete model).

4 Results and Discussion

4.1 Tests with a nacelle on a wing

4.11 Forward movement of aerodynamic centre on nacelle

The majority of the tests were made with the smallest diameter nacelle $\left(\frac{D}{c} = 0.237\right)$. The values of $\Delta k_n'$ obtained with this size of nacelle are given in the following table:-

Nose length $\frac{m}{c}$	Rear fairing $\frac{n}{c}$	$\frac{z}{c} = 0.121$, $i_N = 1.4^\circ$	$\frac{z}{c} = 0.121$, $i_N = 5.4^\circ$	$\frac{z}{c} = 0$, $i_N = 1.4^\circ$	$\frac{z}{c} = 0$, $i_N = 5.4^\circ$
0.4	0.6	0.125		0.173	
0.6	0.6	0.160	0.164	0.213	0.224
	0.7	0.164			
	0.9	0.162	0.160		
1.0	0.6	0.239	0.233	0.289	0.304
	0.7	0.244			
	0.9	0.244	0.234		

The table shows that there is little change in $\Delta k_n'$ with change in rear fairing length $\frac{n}{c}$, and mean values of $\Delta k_n'$ over a range of rear fairing length have been plotted in Fig.8. There is a small increase in $\Delta k_n'$ with i_N for the chordline nacelles $\left(\frac{z}{c} = 0\right)$ and a very small decrease for the underslung nacelle $\left(\frac{z}{c} = 0.121\right)$ $\Delta k_n'$ is decreased considerably by lowering the nacelle. These variations are consistent with the position of maximum upwash being below the wing chord, so that a chordline nacelle with 5.4° of droop is nearer the region of maximum upwash than the chordline nacelle with no droop. The 12% underslung nacelle lies below the region of maximum upwash. It is probable that a nacelle with a small amount of underslinging might be more in this region than the present chordline nacelles and consequently might give a higher value of $\Delta k_n'$.

Values of $\Delta k_n'$ have been plotted against diameter/chord ratio in Fig.9 for the three nacelle diameters tested. It is observed that for the range $\frac{D}{c} = 0.20$ to 0.30 (that associated with propeller turbine nacelles) there is about 20% increase in $\Delta k_n'$. Values of $\Delta k_n'$ estimated from Ref.3 are also plotted in Fig.9 and appear to give good agreement with an extrapolation of the present results.

4.12 Change in pitching moment at zero lift $\left(\frac{\Delta M_o}{qc^2D} = \Delta C_{m_o}'\right)$

For any given value of $\frac{D}{c}$ the principal parameters which determine the value of the pitching moment at zero lift due to a nacelle are the length of overhang $\left(\frac{m}{c}\right)$, the angle of droop (i_N) the amount of underslinging $\left(\frac{z}{c}\right)$ and the length of the rear fairing $\left(\frac{n}{c}\right)$. It is found that a convenient way of expressing most of these parameters is to use $\frac{z_m}{c}$, where z_m is the distance of the mid point of the overhanging part of the nacelle below the no lift line of the wing, as a basis for plotting. Values of $\frac{z_m}{c}$ are given at the end of Table I and values of $\Delta C_{m_o}'$ are plotted against $\frac{z_m}{c}$ in Fig.10 for the small nacelles $\left(\frac{D}{c} = 0.237\right)$, different lines being drawn for the various lengths of rear fairing. The curves give sufficient accuracy for estimation purposes within the range tested i.e. for overhangs between 0.4 - 1.0 wing chord.

Values of $\Delta C_{m_o}'$ have been plotted against diameter/chord ratio in Fig.11 for the three nacelle diameters tested. Over the range $\frac{D}{c} = 0.20$ to 0.30 the change in $\Delta C_{m_o}'$ is very slight.

4.13 Loss of lift $\left(\frac{\Delta L}{qcD} = \Delta C_L'\right)$

The values of the lift loss given in Table III are plotted against nacelle overhang in Fig 12. The values have been obtained from analysis of the values of lift at the zero lift angle of the wing alone. In order to generalise the values of $\Delta C_L'$ a modification of the method suggested by Smelt and Smith in Ref.4 has been used.

The effective incidence of the nacelle centre line relative to the wing (β) has been calculated (see Appendix II) and used as a basis for plotting in Fig.13. It is seen that it is possible to draw two separate lines through the experimental points, one representing no droop relative to the chordline (i_N = 1 4°) and one representing 4° of droop relative to the chordline (i_N = 5.4°). The lines are drawn for overhangs of 0.6 - 1.0 chord. Shorter nacelles tend to give larger lift losses (Fig.12) but the difference is negligible for the purpose of correcting values of $\Delta C_{m_o}'$.

4.14 Comparison with previous method of estimation of $\Delta k_n'$ and $\Delta C_{m_o}'$

The tests of Ref 3 were made on reciprocating engine nacelles with a diameter of 0.463 chord and for overhangs of 0.1, 0.3 and 0.5c. The curves of Ref.3 have been used to estimate $\Delta k_n'$ for overhangs of 0.6 and 1.0 chord (see Fig.9) and the agreement between the two sets of tests is good. With the larger diameter reciprocating engine nacelles there is no variation of $\Delta k_n'$ with vertical height. This tendency is also noticed with the results of tests on the nacelles of diameter 0.356 chord where the ratio $\frac{\Delta k_n' \text{ Chordline}}{\Delta k_n' \text{ Underslung}}$ is less than that obtained for the smaller nacelles. To give a more direct comparison within the ranges of overhang tested the results of the present tests have been used to estimate values of $\Delta k_n'$ and $\Delta C_{m_o}'$ for values $\frac{m}{c} = 0.5$, $\frac{z}{c} = 0.093$ and 0:-

$\frac{z}{c}$	$\frac{n}{c}$	$\frac{h}{c}$	$\Delta k_n'$		$\Delta C_{m_o}'$	
			Estimated from present results	Measured (Ref.3)	Estimated from present results	Measured (Ref.3)
0.093	0.80	0.115	0.205	0.212	-0.105	-0.080
0	0.80	0.022	0.253	0.211	-0.055	-0.013

The agreement is good for $\Delta k_n'$ although there is no variation with $\frac{z}{c}$ in the measured values. Differences in $\Delta C_m'$ are possibly due to the difference in shape of the two rear fairings, coupled with errors introduced by extrapolation.

4.2 Tests with mutual interference between nacelles and interference between body and nacelles

4.21 Effect of mutual interference between two nacelles on the stability changes due to a nacelle

The values of $\Delta k_n'$ and $\Delta C_{m_o}'$ obtained with two nacelles on the wing are given in Table III, Section III.

The results show that in any practical position for propeller turbines, there is no mutual interference between nacelles.

4.22 Effect of a body on the stability changes due to a nacelle

The results of the tests made in the $11\frac{1}{2}$ ft tunnel with a body on the wing in both high and low positions and with no body in position are given in Table V. At a spanwise position of 2.34 body diameters the value of $\Delta k_n'$ due to a nacelle is found to be the same with and without a body in position for underslung nacelles of diameter 23.7% chord. Assuming that the amount of disturbance of the flow with the body in position depends only upon the body diameter this equality at 2.34 body diameters may be assumed for the chordline nacelles. It is then convenient to express the effect of the body as the ratio of the value of $\Delta k_n'$ due to a nacelle at a given spanwise position divided by the value of $\Delta k_n'$ due to a nacelle unaffected by the body i.e. at 2.34 body diameters outboard of the centre line. The ratios or interference factors obtained by this method are given in Table V and plotted against the spanwise positions of the nacelle in Fig.14. Two curves are drawn, for high and low wing respectively. The higher values associated with the high wing combination may be expected from the geometry of the model, the body being below the nacelles and causing more disturbance of the flow than would be associated with a low wing.

The values of the pitching moment at zero lift for the nacelle on a wing alone and on a wing with a body are the same at 2.34 body diameters outboard of the centre line. A simple ratio depending on spanwise position cannot be used, as the values of $\Delta C_{m_o}'$ depend largely upon the amount of underslinging. It is possible, however, to examine the differences existing between the values obtained with nacelles at spanwise positions less than 2.34 body diameters and the value for the nacelle at that position. These differences are given in Table V and plotted in Fig.15. Using the nacelles of diameter 23 7% chord two curves are drawn, one for the high and one for the low wing model. The nacelles of diameter 35.6% chord give a ΔC_{m_0} of smaller magnitude at a spanwise position of 1 body diameter than at a position of 2.18 diameters outboard. The opposite sign of the interference in this case may result from the narrow expanding passage with the large nacelle so close to the body.

Brief calculations indicate that the effect of the body on the longitudinal velocity at the nacelle positions is insignificant. Consideration of the potential flow round an inclined infinite cylinder gives values of upwash angle at the nacelle positions, of the right order to explain the interference effect on $\Delta k_n'$. From this it would be expected that the body effect on $\Delta C_{m_0}'$ would be proportional to the aerodynamic wing body angle. Results of tests on the nacelles of the Saunders Roe 10/46 (Ref.5) support this conclusion:-

Spanwise position of nacelle in body diameters from centre line	Estimated for an aerodynamic wing-body angle of 1.4°		Measured with an aerodynamic wing-body angle of 5.5°	
	$\Delta C_{m_0}'$ per nacelle	Interference increment	$\Delta C_{m_0}'$ per nacelle	Interference increment
1.05	-0.084	-0.013	-0.137	-0.056
2.10	-0.073	-0.002	-0.093	-0.012
3.15	-0.071	0	-0.081	0

5 Comparison with existing results for propeller turbine nacelles

5.1 Previous tests with nacelles on a tapered wing (Fig.4)

The differences in the parameters $\frac{D}{c}$, $\frac{m}{c}$, $\frac{n}{c}$ and $\frac{z}{c}$ between identical nacelles in inner and outer positions on a tapered wing prevent the determination of interference factors and increments. The results of the two series of tests have therefore been compared by using the later results to estimate the earlier ones. Estimated and measured values of $\Delta k_n'$ and $\Delta C_{m_0}'$ are presented in the table. These values are converted to values of Δk_n and ΔC_{m_0} by multiplying by a factor of the order of $\frac{1}{30}$.

/Table

		i_N^o	HIGH WING		LOW WING	
			Estimated	Measured	Estimated	Measured
I Δk_n' per nacelle						
Underslung $\frac{z}{c}$ = 0.121	Inner	2	0.304	0.342	0.271	0.271
		6	0.294	-	0.262	0.266
Underslung $\frac{z}{c}$ = 0.138	Outer	2	0.271	0.279	0.271	0.284
		6	0.261	-	0.261	0.280
Chordline $\frac{z}{c}$ = 0	Inner	2	0.358	0.364	0.320	0.332
Chordline $\frac{z}{c}$ = 0	Outer	2	0.315	0.304	0.315	0.310
II ΔC_{m_o}' per nacelle						
Underslung $\frac{z}{c}$ = 0 121	Inner	2	0.122	0.160	0.117	0.144
		6	0.157	-	0.153	0.157
Underslung $\frac{z}{c}$ = 0.138	Outer	2	0.112	0.129	0.112	0.136
		6	0.151	-	0.151	0.176
Chordline $\frac{z}{c}$ = 0	Inner	2	0.035	0.047	0.031	0.041
Chordline $\frac{z}{c}$ = 0	Outer	2	0.023	0.024	0.024	0.027

It is seen that the agreement between estimated and measured values of Δk_n' is good. The small discrepancy between the estimated and measured values of ΔC_{m_o}' is possibly due to slight differences in the shape of the rear fairing existing between the two series of tests.

5.2 Other results for propeller turbine nacelles

At present there is little information available on the effects of nacelles for propeller turbine installations on the stability of an aircraft. There are however results of firms tests on the Viscount, a low wing four-engined aircraft and R.A.E. tests on the S.R.10/46, a six-engined flying boat (Ref.5). The layout of these two models is illustrated in Figs.5 and 6 respectively.

Estimated and measured values of Δk_n, ΔC_{m_o} and ΔC_L for both aircraft are given in the following tables:-

(i) Viscount

	Δk_n	ΔC_{m_o}	ΔC_L
Estimate for 2 Inner nacelles	0.0395	-0.070	0.0065
Estimate for 2 Outer nacelles	0.0265	-0.085	0.0115
Estimate for all 4 nacelles	0.0660	-0.155	0.0180
Measured values for all 4 nacelles	0 0650	-0.135	0.0150

(ii) S.R.10/46

	Δk_n		ΔC_{m_0}		ΔC_L	
	Estimated	Measured	Estimated	Measured	Estimated	Measured
2 Inner nacelles	0.012	0.011	-0.0055	-0.009	0.006	0.008
2 Centre nacelles	0.008	0.008	-0.0045	-0.006	0.008	0.008
2 Outer nacelles	0.008	0.008	-0.0045	-0.005	0.008	0.008
Total for 6 nacelles	0.028	0.027	-0.0145	-0.020	0.022	0.024

It is seen that the agreement between estimated and measured values is good for Δk_n and an interference factor of 1.37 is obtained between the inner and outer nacelles of the S.R.10/46 which agrees with the factor of 1.39 used in the estimation. Discrepancies between the estimated and measured ΔC_{m_0} for the S.R.10/46 are due to a difference in aerodynamic wing body angle between the present test model and the S.R.10/46 (see paragraph 4.22). Insufficient test data are available to analyse the small discrepancy for the Viscount.

The present report may be used to estimate value of of Δk_n' and ΔC_{m_0}' but its scope is limited by the lack of tests with more than one wing body angle and amount of underslinging. The small amount of data available does suggest that the fuselage interference of ΔC_{m_0}' due to a nacelle is proportional to the aerodynamic wing-body angle.

LIST OF SYMBOLS

c = local wing chord at nacelle

$\bar{c}$ = standard mean chord of wing

D = nacelle maximum width (= diameter for circular nacelles)

D_b = maximum body width at the fore and aft position of the nacelle (= diameter for circular bodies)

i_N = aerodynamic wing-nacelle angle

m = overhang of nacelle

n = length of nacelle behind leading edge of wing (rear fairing length)

q = dynamic pressure

S = wing area

y = spanwise co-ordinate (+ve from centre line towards starboard wing tip)

z = the distance of the centre line of the nacelle below the L.E. of the wing i.e. a vertical co-ordinate (+ve downwards)

z_m = distance of mid point of overhanging part of nacelle below the no-lift line drawn through the local quarter chord point of the wing

β = effective incidence of the nacelle centre line relative to the wing

θ = angle of nacelle centre line to wing chordline

ϕ = angle of wing nacelle chordline to wing chordline

C_L = lift coefficient of whole model without tail

$C_{L_{local}}$ = local lift coefficient at nacelle centre line

Δk_n = $\dfrac{-\partial \Delta M}{qS\bar{c}} / \partial C_L$ = forward movement of aerodynamic centre due to a nacelle (based on whole wing area)

$\Delta k_n'$ = $\dfrac{-\partial \Delta M}{qc^2 D} / \partial C_{L_{local}}$ = forward movement of aerodynamic centre due to a nacelle (based on local wing area at nacelle)

ΔC_{m_o} = $\dfrac{\Delta M}{qS\bar{c}}$ = change in pitching moment at zero lift due to a nacelle (based on the whole wing area)

LIST OF SYMBOLS (Continued)

$\Delta C_{m_o}{}'$ = $\frac{\Delta M}{qc^2D}$ = change in pitching moment at zero lift due to a nacelle (based on local wing area at nacelle)

ΔC_L = $\frac{\Delta L}{qS}$ = lift loss due to a nacelle (based on whole wing area)

$\Delta C_L{}'$ = $\frac{\Delta L}{qcD}$ = lift loss due to a nacelle (based on local wing area at nacelle)

REFERENCES

No.	Author	Title, etc.
1	Anscombe and Raney	Low Speed Tunnel investigation of body effect on C_{m_0} and aerodynamic centre with unswept wings Current Paper No.16. April, 1949
2	Hartley, Spence and Kirby	Slipstream effects at various tail positions on aircraft with four contra propellers ARC 12,355. April, 1949
3	Smith and Smelt	Note on pitching moment changes due to a nacelle on a wing R & M 2406 August, 1938
4	Smelt and Smith	The installation of an engine nacelle on a wing Part II - Underslung nacelles on cambered wings R & M 2406 August, 1938
5	Worrall	Wind tunnel tests on a six-engined flying boat (Saunders Roe 10/46 with slipstream R.A.E. Report No. Aero.2226 October, 1947
6	Glauert	A theory of thin aerofoils R & M 910

APPENDIX I

Correction to $\Delta C_{m_o}'$ (Extracted from Ref.3)

"When a nacelle is underslung, so that the lift is reduced locally, a correction is necessary to the value of $\Delta C_{m_o}'$ found in complete model tests, before comparison with results of systematic tests with a nacelle on a wing can be made. For zero lift then indicates a lift ΔL on the nacelle, and a compensating lift $-\Delta L$ on the rest of the wing; the couple formed by the two forces contributes to ΔM_o. On the rectangular wing of the systematic tests, the wing lift $-\Delta L$ acts at the quarter-chord line, and the contribution to ΔM_o is thus $\Delta L \cdot x$ where x is the distance of the line of action of the nacelle lift ΔL forward of the quarter-chord point. On a complete aeroplane the lift of the nacelle is compensated at the aerodynamic mean centre, which is usually ahead of the quarter-chord point of the wing section at the nacelle. The moment of the lift forces in this case becomes $\Delta L\,(x - y)$, where y is the distance of the aerodynamic mean centre ahead of the quarter-chord point at the nacelle; ΔM_o is thus less, on a complete model, by the amount $\Delta L \cdot y$. Expressed in non-dimensional form, the value of ΔC_{m_o} is reduced in going from rectangular wing to complete model by an amount $\Delta C_L' \, y/c$ where $\Delta C_L' = \dfrac{\Delta L}{\frac{1}{2}\rho V^2 cD}$ is a coefficient of lift increase due to a nacelle".

In the present report the values of $\Delta C_{m_o}'$ for all tests have been corrected for this wing lift moment i.e. a moment $\Delta C_L' \cdot y/c$ has been added to all values of $\Delta C_{m_o}'$ measured. Values of y/c were

0.033 for the wing alone

0.143 for a low wing with body

0.148 for a high wing with body.

APPENDIX II

Estimation of β, the effective incidence of the nacelle centre-line relative to the wing

The lift loss due to a nacelle on a wing depends upon the amount the nacelle changes the local wing camber and thus the local no lift angle. This will vary at different spanwise positions across the nacelle but for similarly shaped nacelles (e.g. the roughly cylindrical shape of all propeller-turbine nacelles) the change of the no-lift angle at the nacelle centre-line may be considered as a measure of the total lift loss due to a nacelle. The change in no-lift angle and the effective incidence of the nacelle centre line relative to the wing may be deduced from separate calculations of the no lift angles of the wing alone and of the nacelle-wing combination. Both may be calculated by the method of Ref.6, using the formula:-

$$\beta = -\frac{180}{\pi^2}\int_0^c \frac{y_d\,dx}{x^{\frac{1}{2}}(c-x)^{\frac{3}{2}}}\ \text{degrees}$$

where

c is the "chord" from nose to trailing edge

x is measured parallel to the "chord" from the nose

y_d is the distance of the camber line from the "chord"

Calculations of β_W - the wing no lift angle and β_N the no lift angle of the wing-nacelle combination are given in Table IV. In finding the total change $\Delta\beta$ it is necessary to include the angle ϕ between the wing chord-line and wing-nacelle combination chordline as the wing and wing-nacelle are relatively at different incidences

$$\Delta\beta = \beta_N - \beta_W + \phi$$

Fig.7 shows the construction for

(i) a nacelle underslung 12.1, chord and drooped at 4° to the chordline, with a 100% chord overhang and a 50% chord rear fairing

(ii) a nacelle underslung 12.1, chord and parallel to the chordline with a 100% chord overhang and a 60% chord rear fairing.

TABLE I

Model Dimensions

(a) 5 ft Tunnel model

Wing

Gross area	532.8 sq.in.
Span	48 in.
Aspect ratio	4.33
Mean chord	11.1 in.
Maximum thickness	15% chord
Position of maximum thickness	30% chord
Camber	2.4% chord
Section	R.A.F.44 (modified to have straight portion from 65.5% chord to trailing edge on upper surface)

Body

None fitted

Nacelles

No propellers represented	
Geometric wing nacelle angle	0° and 4°
Details of nacelles tested are given in tables in text (see para.2)	

(b) $11\frac{1}{2}$ ft Tunnel model

Wing

Aspect ratio	6
Mean chord	11.1 in.
Section	Same section as that of 5 ft tunnel model

Body

Diameter of cylindrical portion	9 in.
Elliptic nose length	16.2 in.
Tapered rear length	27.0 in.
Front length (forward of wing L.E.)	27.1 in.
Rear length (aft of wing T.E.)	36.4 in.

Wing and Body junction

Wing position	Low and High
Geometric wing body angle	0°
Wing no lift angle	-1.4°
Aerodynamic wing-body angle	1.4°
Fillets (low wing only)	"Small" (Ref.1)

TABLE I (Continued)

Fin and Tailplane

None fitted

Nacelles

No propellers represented
Geometric wing nacelle angle 0°
Details of nacelles tested are given in tables in text (see para.2)

(c) Distance of mid-point of overhanging part of nacelle below no lift line of wing drawn through $\frac{1}{4}$ chord point = z_m

$\frac{m}{c}$	$\frac{z_m}{c}$ for all diameters			
	Underslung	Underslung	Chordline	Chordline
	$\frac{z}{c} = 0.121$ $i_N = 1.4^\circ$	$\frac{z}{c} = 0.121$ $i_N = 5.4^\circ$	$\frac{z}{c} = 0$ $i_N = 1.4^\circ$	$\frac{z}{c} = 0$ $i_N = 1.4^\circ$
0.4	0.132		0.011	
0.6	0.134	0.153	0.013	0.032
1.0	0.139	0.174	0.018	0.053

TABLE II

Dimensions of Tapered Wing Model

Wing

Gross area	980.1 sq.in.
Span	99 in.
Aspect ratio	10
Mean chord	9.9 in.
Centre line chord	13.5 in.
Chord at inner nacelle centre line	11.95 in.
Chord at outer nacelle centre line	10.38 in.
Taper ratio	2:1
Centre t/c	18%
Tip t/c	12%
Camber	2% chord
Dihedral	Upper surface flat
Section	N.A.C.A. 2418-2412

Quarter chord line is straight and at right angles to body centre line

Body

Diameter of cylindrical portion	9 in.
Elliptic nose length	16.2 in.
Tapered rear length	27 in.
Front piece (forward of centre-line wing chord L.E.)	26.5 in.
Rear piece (aft of centre-line wing chord T.E.)	34.6 in.

Wing-Body Junction

Wing height	Low and High
Geometric wing/body angle	0°
Wing no-lift angle	-2° to chord
Hence aerodynamic wing-body angle	2°
Fillet	"Medium" fillet of Ref.1 (low wing only)

Fin and Tailplane

None fitted

Nacelles

Number of nacelles	2
No propellers represented	
Spanwise position of nacelles from body centre-line	
Inner	10.9 in
Outer	21.8 in.
Maximum diameter	2.63 in.
Elliptic nose length	4.78 in.
Rear fairing length (aft of L.E.)	7.17 in.
Overhang (same for inner and outer nacelle)	11.95 in.
For inner nacelle overhang =	1.00 local chord
For outer nacelle overhang =	1.151 local chord

TABLE II (Continued)

Nacelles (contd.)

Distance of centre line of underslung nacelles below wing L.E. (same for inner and outer nacelles)	1.43 in.
Inner nacelle is underslung	0.121 local chord
Outer nacelle is underslung	0.138 local chord
Geometric wing nacelle angle	0° and 4°
Aerodynamic wing nacelle angle	2° and 6°

TABLE III

Forward Movement of Aerodynamic Centre and Change in Pitching Moment at Zero Lift due to a Nacelle on a Wing

Tests in 5 ft Tunnel

(Rectangular Wing, Aspect Ratio = 4.33)

Nacelle Condition		$\Delta k_n'$	$-\Delta C_{m_o}'$ (Meas)	$-\Delta C_L'$	$-\Delta C_{m_o}'$ excluding moment of wing lift
I 1 NACELLE ON CENTRE LINE OF WING					
I(a) Nacelle diameter = 0.237 chord					
Underslung $\frac{z}{c} = 0.121$ $i_N = 1.4^o$					
$\frac{n}{c} = 0.6$	$\frac{m}{c} = 0.4$	0.125	0.107	0.216	0.115
	0.6	0.160	0.114	0.154	0.120
	1.0	0.239	0.125	0.198	0.133
$\frac{n}{c} = 0.7$	$\frac{m}{c} = 0.6$	0.164	0.099	0.216	0.107
	1.0	0.244	0.108	0.216	0.116
$\frac{n}{c} = 0.9$	$\frac{m}{c} = 0.6$	0.162	0.067	0.307	0.078
	1.0	0.244	0.073	0.235	0.082
Underslung $\frac{z}{c} = 0.121$ $i_N = 5.4^o$					
$\frac{n}{c} = 0.6$	$\frac{m}{c} = 0.6$	0.164	0.130	0.162	0.136
	1.0	0.233	0.154	0.154	0.159
$\frac{n}{c} = 0.9$	$\frac{m}{c} = 0.6$	0.160	0.072	0.298	0.083
	1.0	0.234	0.092	0.270	0.102
Chordline $\frac{z}{c} = 0$ $i_N = 1.4^o$					
$\frac{n}{c} = 0.6$	$\frac{m}{c} = 0.4$	0.173	0.013	0.090	0.016
	0.6	0.213	0.016	0.054	0.018
	1.0	0.289	0.025	0.054	0.027
Chordline $\frac{z}{c} = 0$ $i_N = 5.4^o$					
$\frac{n}{c} = 0.6$	$\frac{m}{c} = 0.6$	0.224	0.029	0	0.028
	1.0	0.304	0.051	-0.018	0.050

TABLE III (Continued)

Nacelle Condition	$\Delta k_n'$	$-\Delta C_{m_o}'$ (Meas)	$-\Delta C_L'$	$-\Delta C_{m_o}'$ excluding moment of wing lift
I(b) Nacelle diameter = 0.272 chord				
Underslung $\frac{z}{c} = 0.121$ $i_N = 1.4^\circ$				
$\frac{n}{c} = 0.6$ $\frac{m}{c} = 0.6$	0.171	0.113	0.220	0.121
1.0	0.258	0.126	0.204	0.134
$\frac{n}{c} = 0.7$ $\frac{m}{c} = 0.6$	0.175	0.104	0.204	0.112
1.0	0.260	0.112	0.204	0.120
$\frac{n}{c} = 0.9$ $\frac{m}{c} = 0.6$	0.176	0.068	0.315	0.080
1.0	0.256	0.071	0.330	0.083
Chordline $\frac{z}{c} = 0$ $i_N = 1.4^\circ$				
$\frac{n}{c} = 0.6$ $\frac{m}{c} = 0.6$	0.226	0.016	0.063	0.018
1.0	0.300	0.022	0.063	0.024
I(c) Nacelle diameter = 0.356 chord				
Underslung $\frac{z}{c} = 0.121$ $i_N = 1.4^\circ$				
$\frac{n}{c} = 0.9$ $\frac{m}{c} = 1.0$	0.310	0.082	0.339	0.095
Chordline $\frac{z}{c} = 0$ $i_N = 1.4^\circ$				
$\frac{n}{c} = 0.6$ $\frac{m}{c} = 1.0$	0.353	0.050	0.024	0.051
II 1 NACELLE ON WING				
Nacelle diameter = 0.237 chord				
Underslung $\frac{z}{c} = 0.121$ $i_N = 1.4^\circ$				
$\frac{n}{c} = 0.6$ $\frac{m}{c} = 1.0$ $\frac{y}{D} = 3.80$	0.239	0.124	0.181	0.131
III 2 NACELLES ON WING				
III(a) Nacelle diameter = 0.237 chord				
Underslung $\frac{z}{c} = 0.121$ $i_N = 1.4^\circ$				
$\frac{n}{c} = 0.6$ $\frac{m}{c} = 1.0$ $\frac{y}{D} = 2.07$	0.239	0.123	0.198	0.131
$\frac{y}{D} = 3.80$	0.241	0.122	0.198	0.130
III(b) Nacelle diameter = 0.356 chord				
Underslung $\frac{z}{c} = 0.121$ $i_N = 1.4^\circ$				
$\frac{n}{c} = 0.9$ $\frac{m}{c} = 1.0$ $\frac{y}{D} = 1.38$	0.323	0.072	0.350	0.086
$y/D = 2.07$	0.307	0.068	0.350	0.082

TABLE IV

Values of β the Effective Incidence of the Nacelle Centre-Line Relative to the Wing

	Angle of droop relative to chord-line θ degrees	Angle of wing-nacelle chordline to wing chordline φ degrees	No lift angle relative to wing-nacelle chordline β_N degrees	No lift angle of wing β_W degrees	Δβ (degrees) $\beta_N-\beta_W+\phi$ degrees
(a) Nacelle diameter = 0.237 chord					
Underslung $\frac{z}{c}=0.121$					
$\frac{n}{c}=0.6$ $\frac{m}{c}=0.4$	0	4.92	-1.94	-1.02	4.00
0.6	0	4.32	-1.17		4.17
1.0	0	3.45	-0.41		4.06
0.6	4	5.80	-2.14		4.68
1.0	4	5.43	-1.64		4.81
$\frac{n}{c}=0.7$ $\frac{m}{c}=0.6$	0	4.32	-0.72		4.52
1.0	0	3.45	-0.09		4.38
$\frac{n}{c}=0.9$ $\frac{m}{c}=0.6$	0	4.32	+1.28		6.62
1.0	0	3.45	+1.67		6.14
0.6	4	5.80	+0.47		7.29
1.0	4	5.43	+0.42		6.87
Chordline $\frac{z}{c}=0$					
$\frac{n}{c}=0.6$ $\frac{m}{c}=0.4$	0	0	-0.44		0.58
0.6	0	0	-0.40		0.62
1.0	0	0	-0.37		0.65
0.6	4	1.51	-1.54		0.99
1.0	4	2.00	-1.61		1.41
(b) Nacelle diameter = 0.272 chord					
Underslung $\frac{z}{c}=0.121$					
$\frac{n}{c}=0.6$ $\frac{m}{c}=0.6$	0	4.32	[illegible]		4.17
1.0	0	3.45	-0.37		4.10
$\frac{n}{c}=0.7$ $\frac{m}{c}=0.6$	0	4.32	-0.62		4.72
1.0	0	3.45	+0.11		4.58
$\frac{n}{c}=0.9$ $\frac{m}{c}=0.6$	0	4.32	+1.49		6.83
1.0	0	3.45	+1.37		6.34

TABLE IV (Continued)

	Angle of droop relative to chord-line θ degrees	Angle of wing-nacelle chordline to wing chordline ϕ degrees	No lift angle relative to wing-nacelle chordline β_N degrees	No lift angle of wing β_W degrees	$\Delta\beta$ (degrees) $\beta_N - \beta_W + \phi$ degrees
Chordline $\frac{z}{c} = 0$					
$\frac{n}{c} = 0.6$ $\frac{m}{c} = 0.6$	0	4.0	-0.44		0.58
1 0	0	0	-0.40		0.62
(c) Nacelle diameter = 0.356 chord					
Underslung $\frac{z}{c} = 0.121$					
$\frac{n}{c} = 0.9$ $\frac{m}{c} = 1.0$	0	3.45	+3.08		7.55
Chordline $\frac{z}{c} = 0$					
$\frac{n}{c} = 0\ 6$ $\frac{m}{c} = 1.0$	0	0	-0.40		0.62

TABLE V

Forward Movement of Aerodynamic Centre and Change in Pitching Moment at Zero Lift due to a Nacelle in the Presence of a Body

No.1 $11\frac{1}{2}$ x $8\frac{1}{2}$ ft tunnel (Rectangular wing, aspect ratio = 6.0)

Aerodynamic Wing-Body angle = 1.4°

Condition	$\Delta k_n'$	$-\Delta C_{m_0}'$ (meas)	$-\Delta C_L'$	$-\Delta C_{m_0}'$ excluding moment of wing lift	Interference factor (on $\Delta k_n'$)	Interference increment (on $\Delta C_{m_0}'$)
I HIGH WING						
(a) Nacelle diameter = 0.237 chord						
Underslung $\frac{z}{c}$ = 0.121, i_N = 1.4°						
$\frac{y}{D_b}$ = 1.0	0.329	0.1155	0.191	0.1435	1.395	-0.0125
1.21	0.310	0.112	0.203	0.142	1.315	-0.011
1.56	0.268	0.107	0.203	0.137	1.135	-0.006
1.74	0.244	0.104	0.210	0.135	1.035	-0.004
2.34	0.236	0.104	0.184	0.131	1.000	0
Chordline $\frac{z}{c}$ = 0, i_N = 1.4°						
$\frac{y}{D_b}$ = 1.0	0.356	0.0255	0.051	0.033	1.364	-0.013
2.34	0.261	0.0115	0.057	0.200	1.000	0
(b) Nacelle diameter = 0.356 chord						
Underslung $\frac{z}{c}$ = 0.121, i_N = 1.4°						
$\frac{y}{D_b}$ = 1.0	0.466	0.012	0.591	0.0995	1.410	+0.003
2.29	0.331	0.0395	0.424	0.1025	0	0
II LOW WING						
(a) Nacelle diameter = 0.237 chord						
Chordline $\frac{z}{c}$ = 0, i_N = 1.4°						
$\frac{y}{D_b}$ = 1.0	0.383	0.033	0	0.033	1.270	-0.008
1.21	0.347	0.0265	0.038	0.032	1.150	-0.007
2.34	0.302	0.02[illegible]	0.013	0.025	1.000	0

TABLE V (Continued)

Condition	$\Delta k_n'$	$-\Delta C_{m_0}'$ (meas)	$-\Delta C_L'$	$-\Delta C_{m_0}'$ excluding moment of wing lift	Interference factor (on $\Delta k_n'$)	Interference increment (on $\Delta C_{m_0}'$)
(b) Nacelle diameter = 0.356 chord						
Underslung $\frac{z}{c} = 0$						
$i_N = 1.4^\circ$						
$\frac{y}{D_b} = 1$	0.384	0.027	0.422	0.0875	1.210	+0.004
1.21	0.355	0.0275	0.422	0.088	1.115	+0.0035
2.29	0.318	0.043	0.340	0.0915	1.00	0
III WING ALONE (Without Body)						
Nacelle diameter = 0.237 chord						
Underslung $\frac{z}{c} = 0.121$						
$i_N = 1.4^\circ$						
$\frac{y}{D_b} = 2.34$	0.236	0.127	0.254	0.129		

Wt.2078.CP39.K3. Printed in Great Britain.

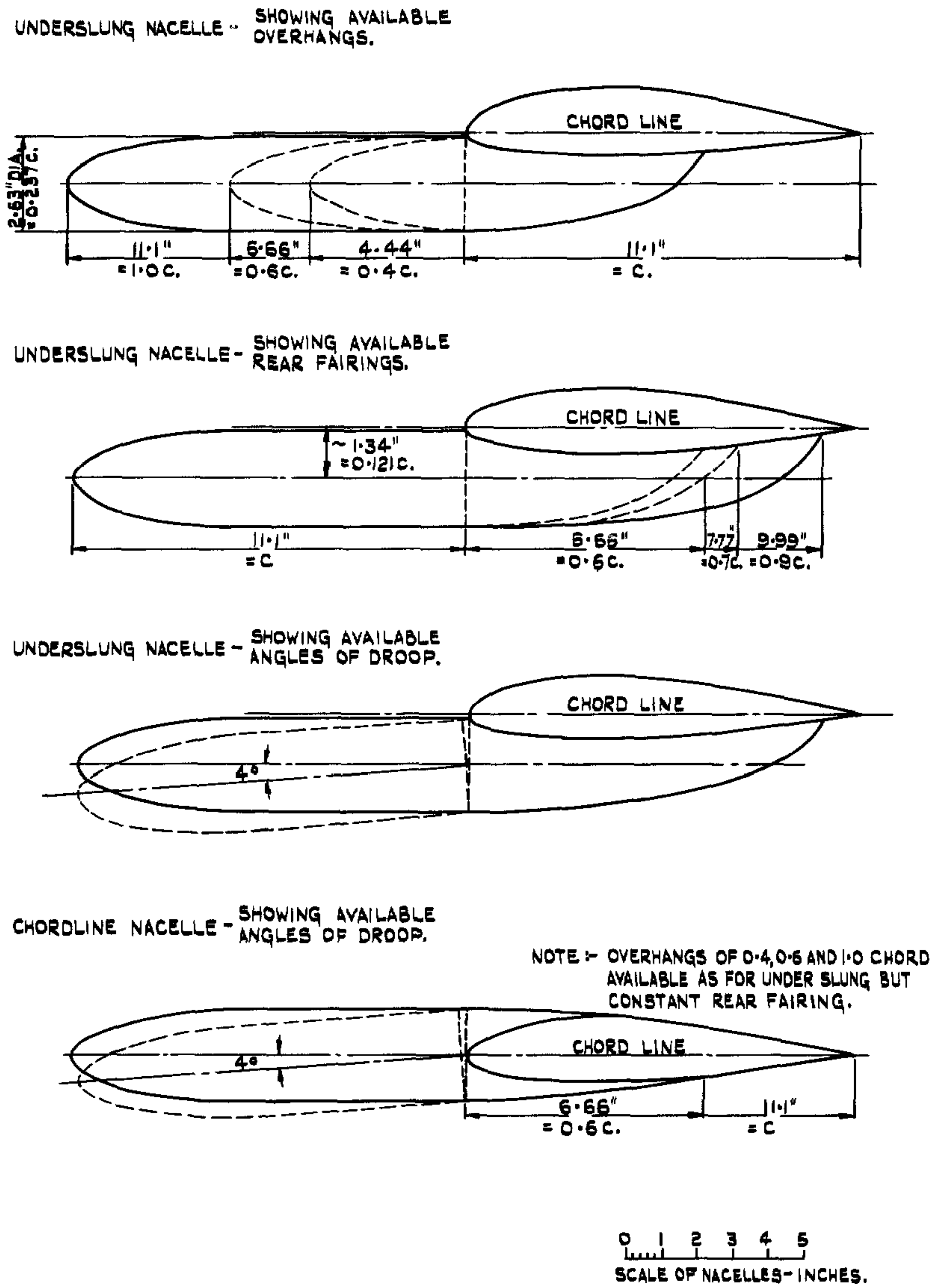


FIG.1. NACELLES OF DIAMETER 0·237 CHORD.

FIG. 2.

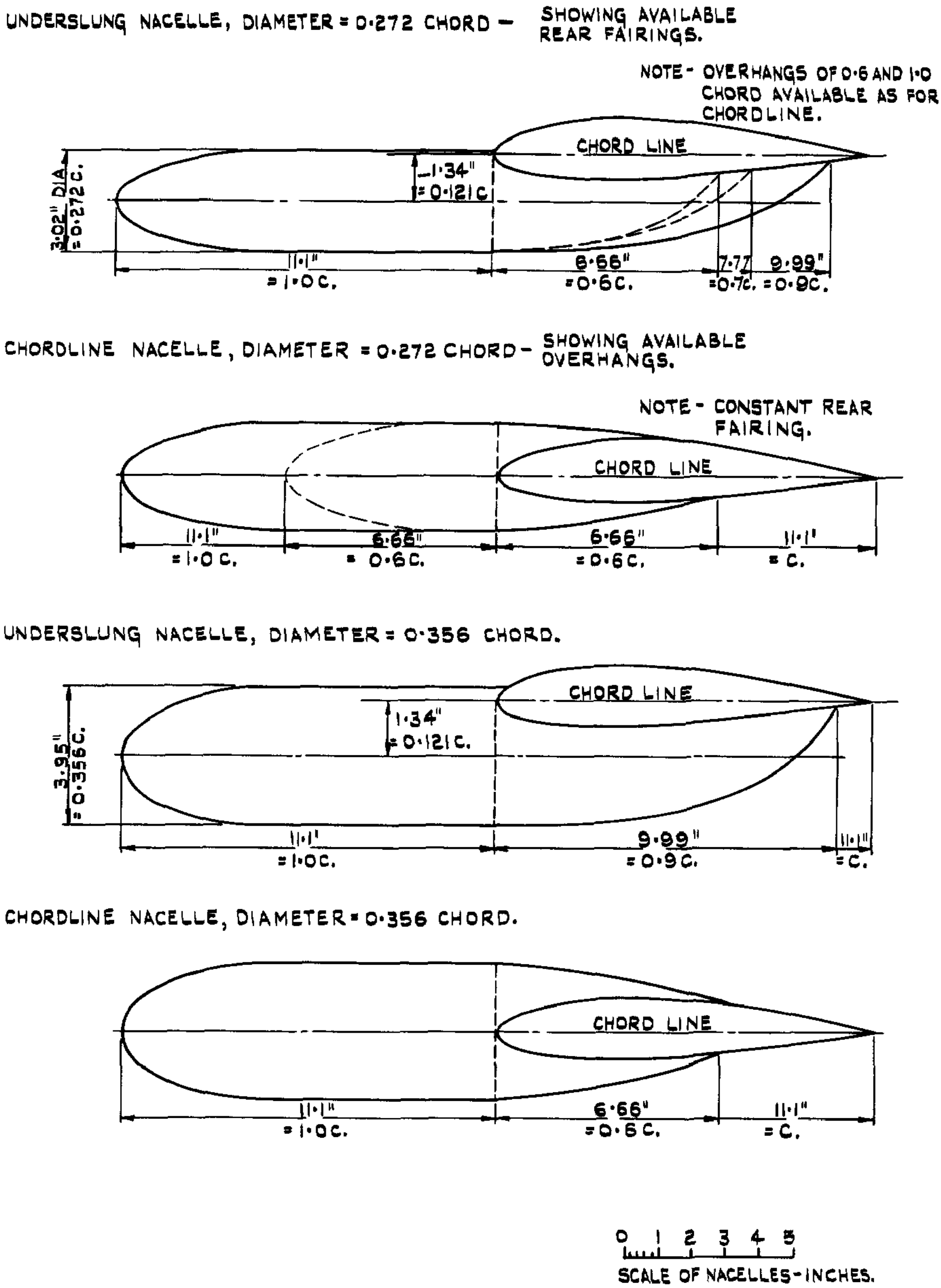


FIG. 2. NACELLES OF DIAMETER 0·272 AND 0·356 CHORD.

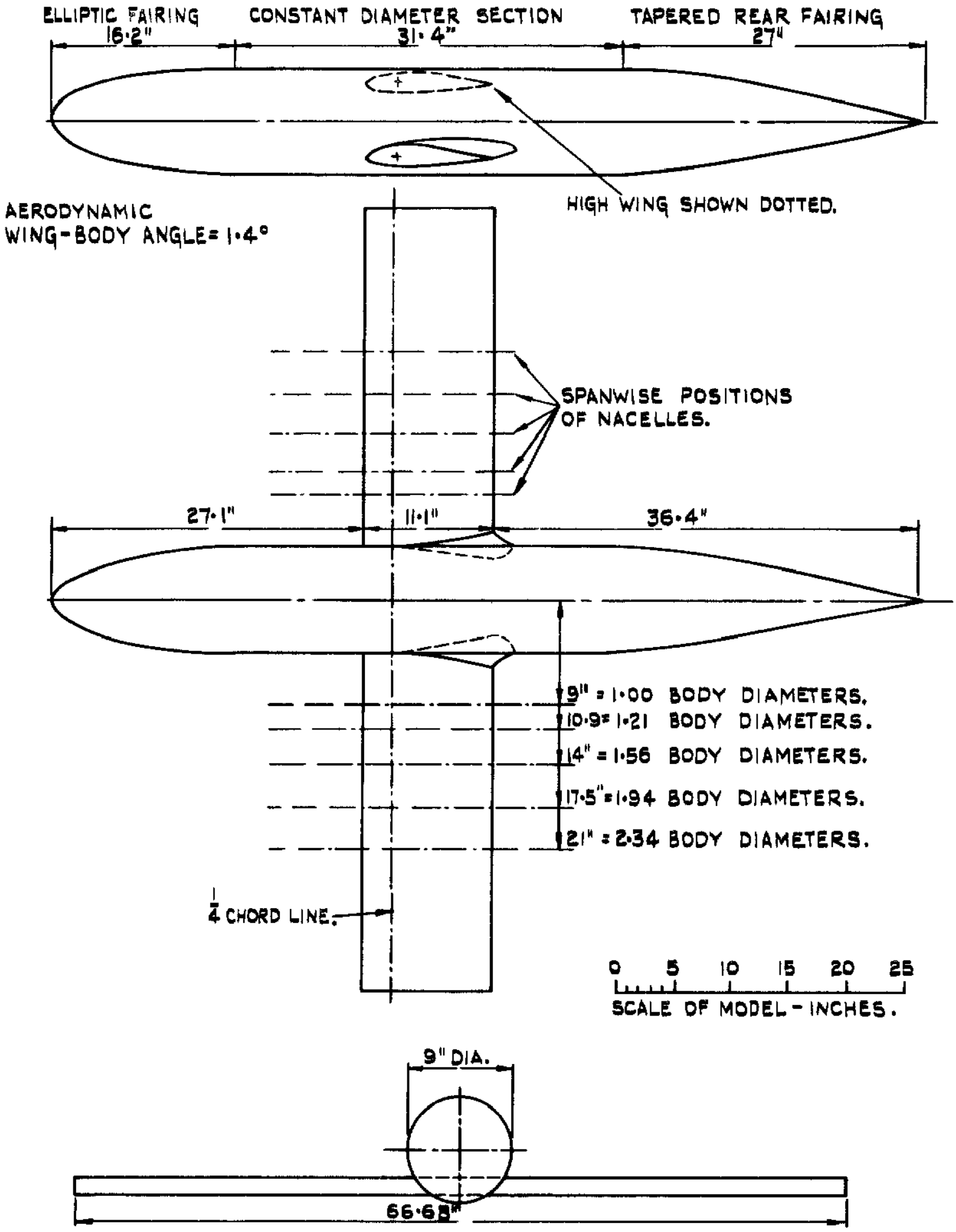


FIG.3. G.A. OF MODEL USED FOR BODY INTERFERENCE TESTS.

FIG.4.

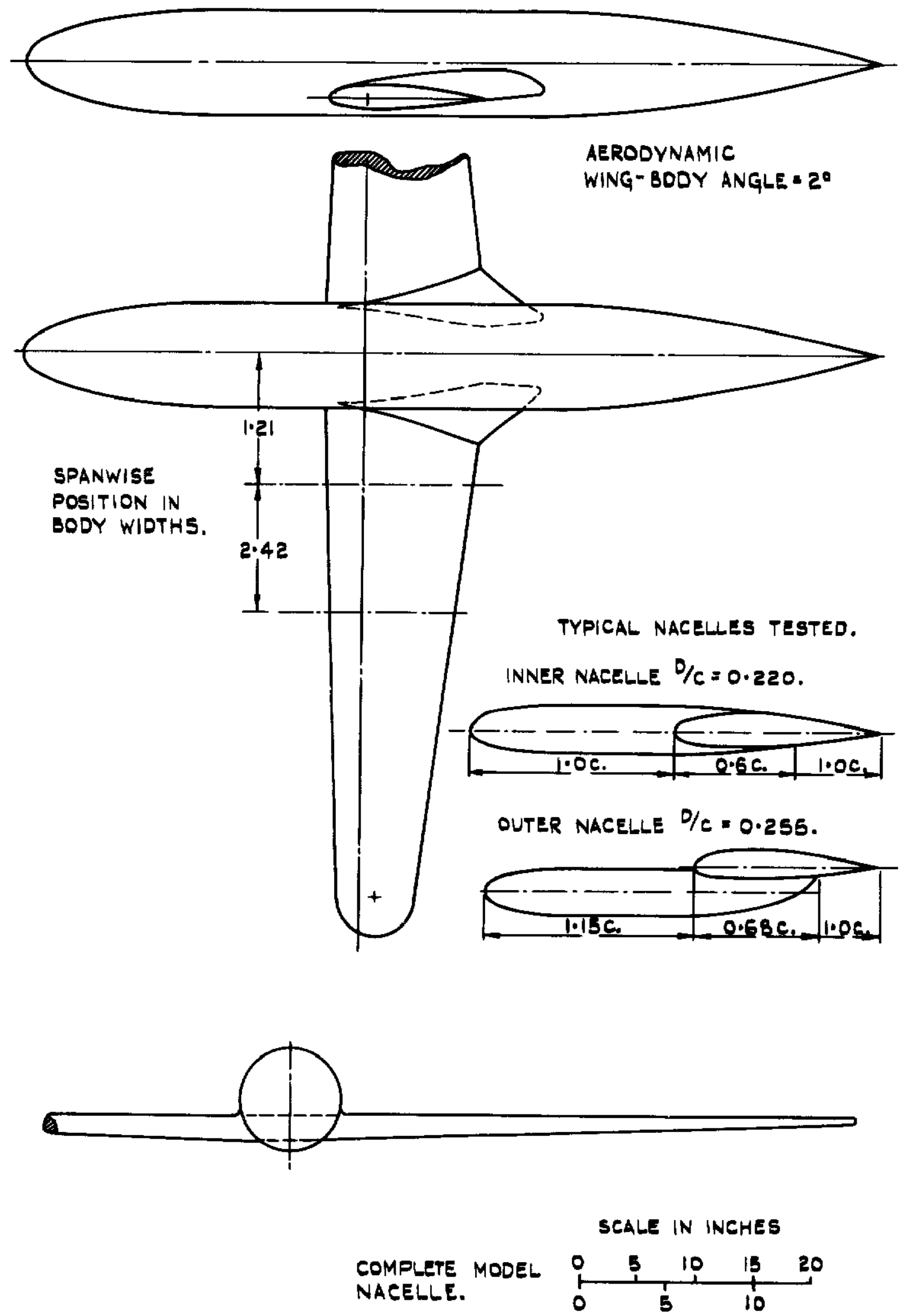


FIG. 4. G.A. OF TAPERED WING MODEL.

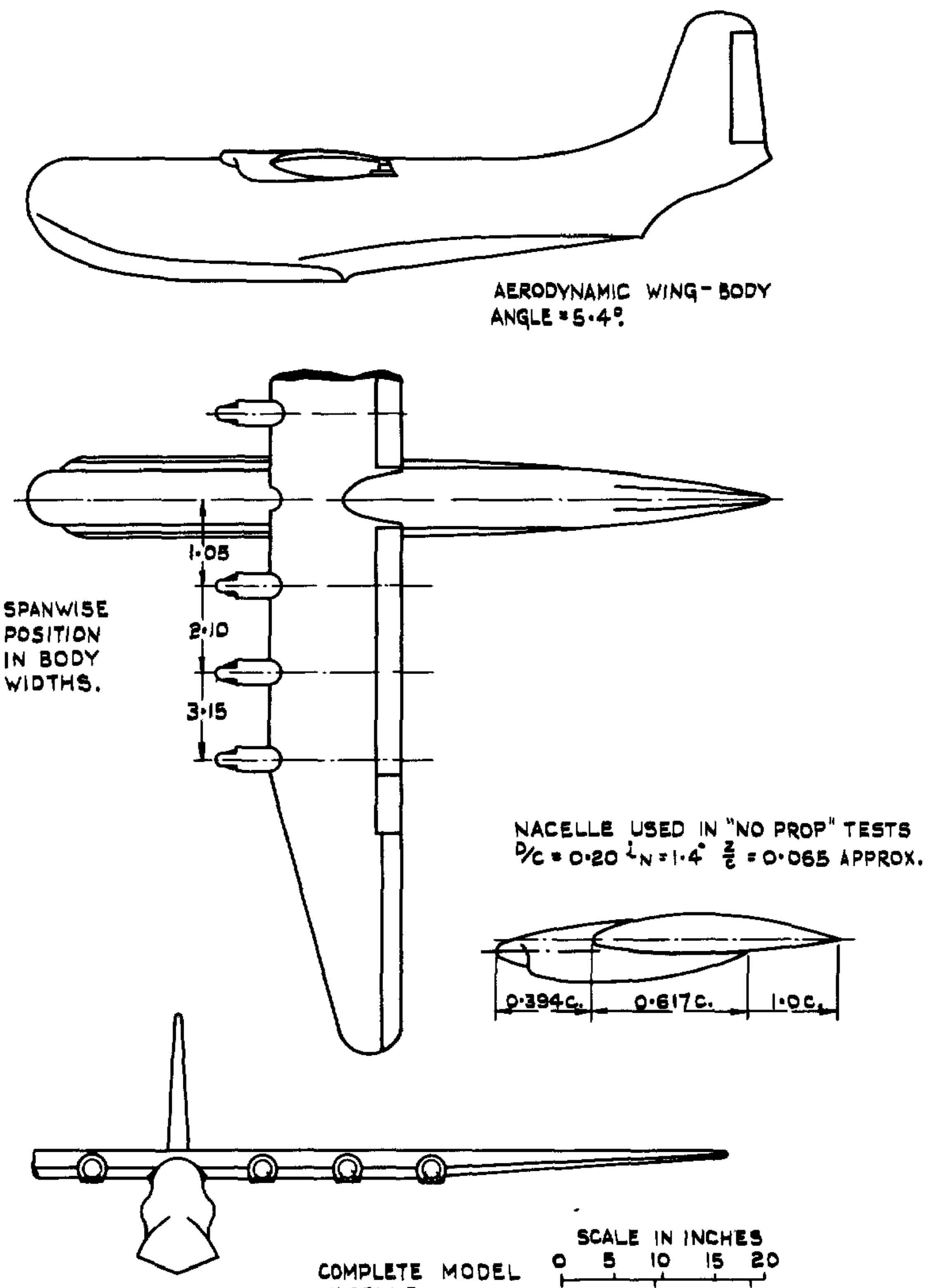
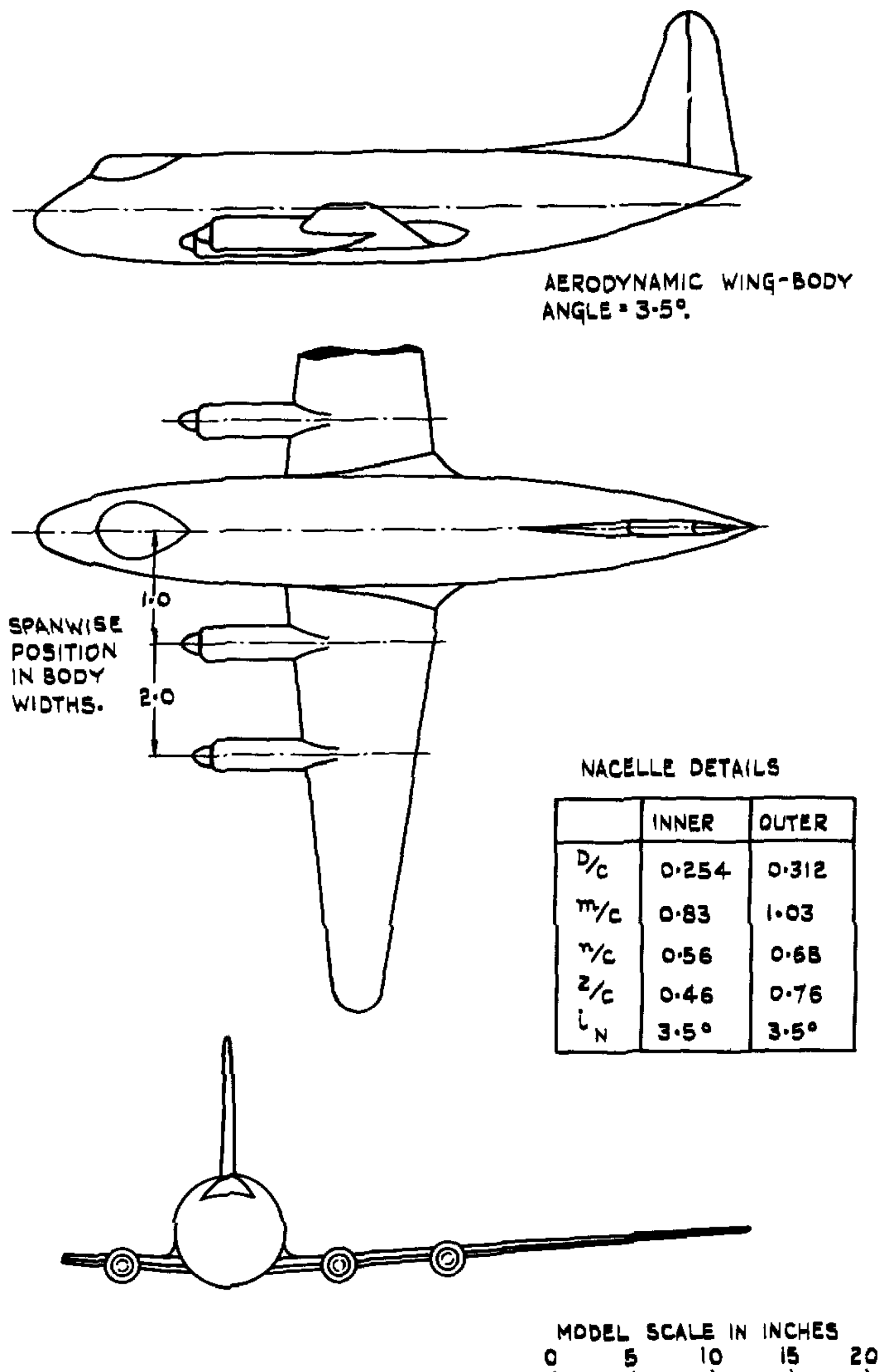


FIG. 5. G.A. OF MODEL OF S.R. 10/46.

FIG. 6.



NACELLE DETAILS

	INNER	OUTER
D/c	0·254	0·312
m/c	0·83	1·03
n/c	0·56	0·68
z/c	0·46	0·76
i_N	3·5°	3·5°

FIG. 6. G.A. OF MODEL OF VISCOUNT.

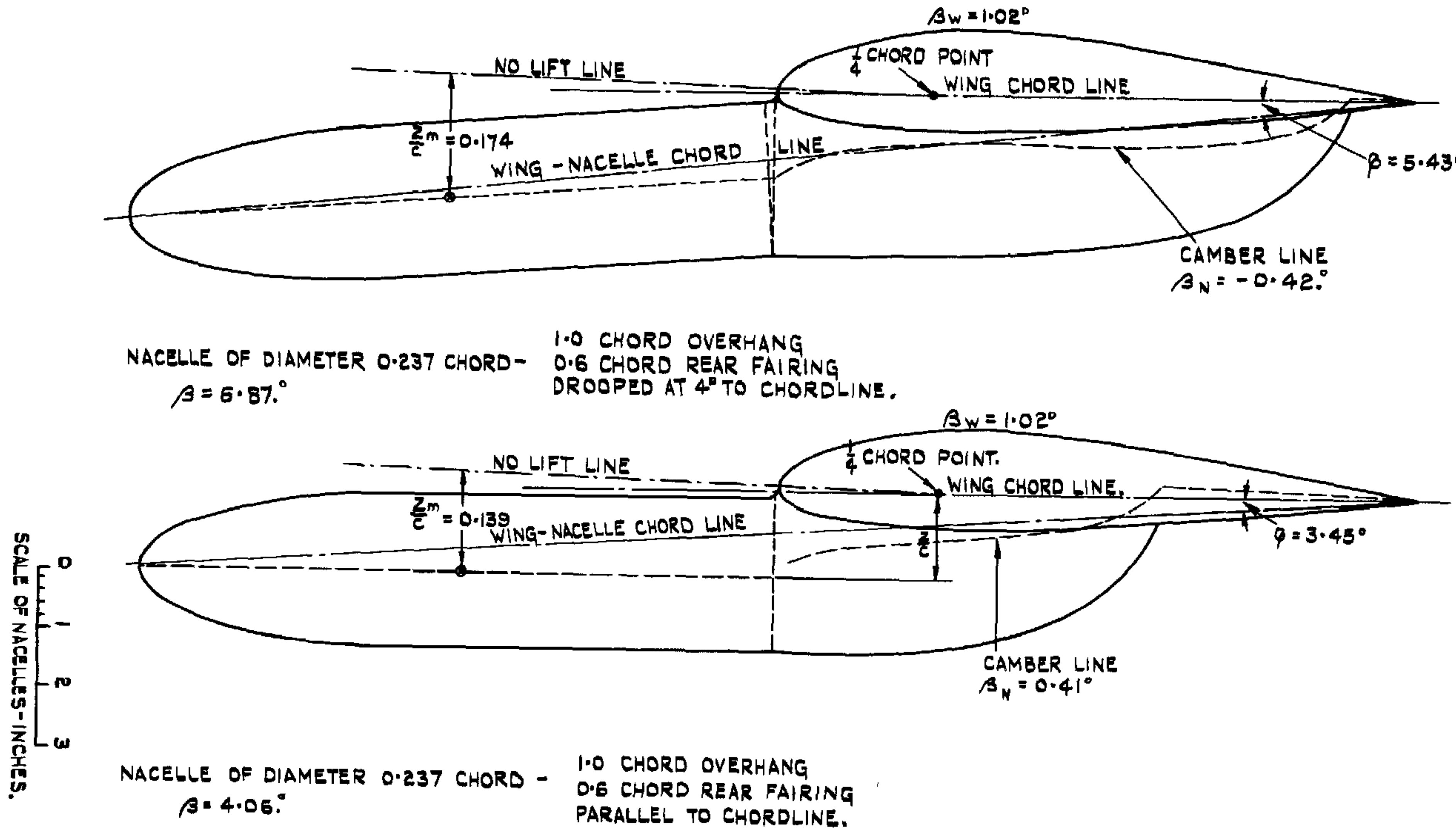


FIG.7. ESTIMATION OF β.

FIG. 8 & 9.

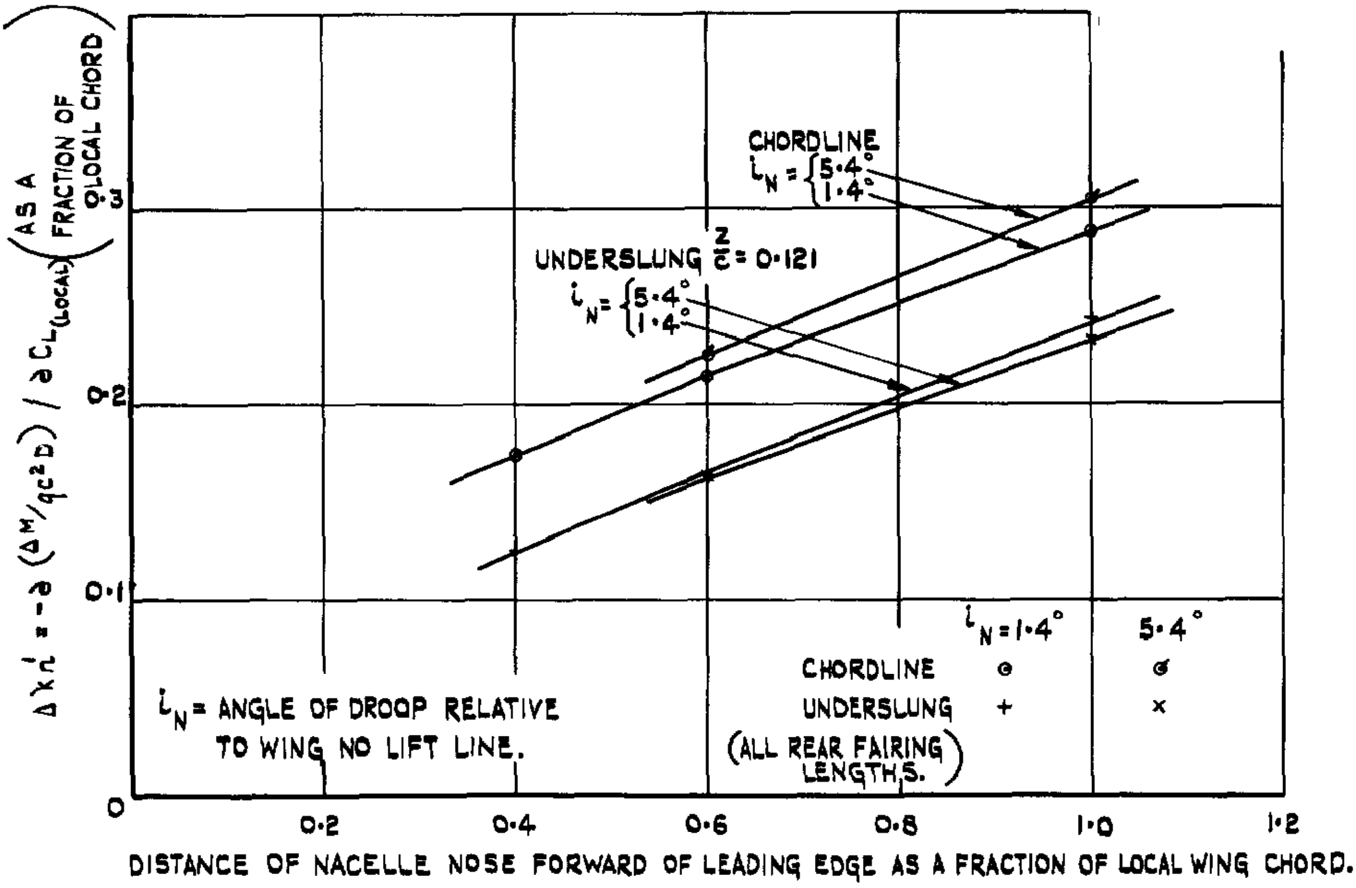


FIG. 8. FORWARD MOVEMENT OF AERODYNAMIC CENTRE ON NACELLE OF DIAMETER 0·237 CHORD.

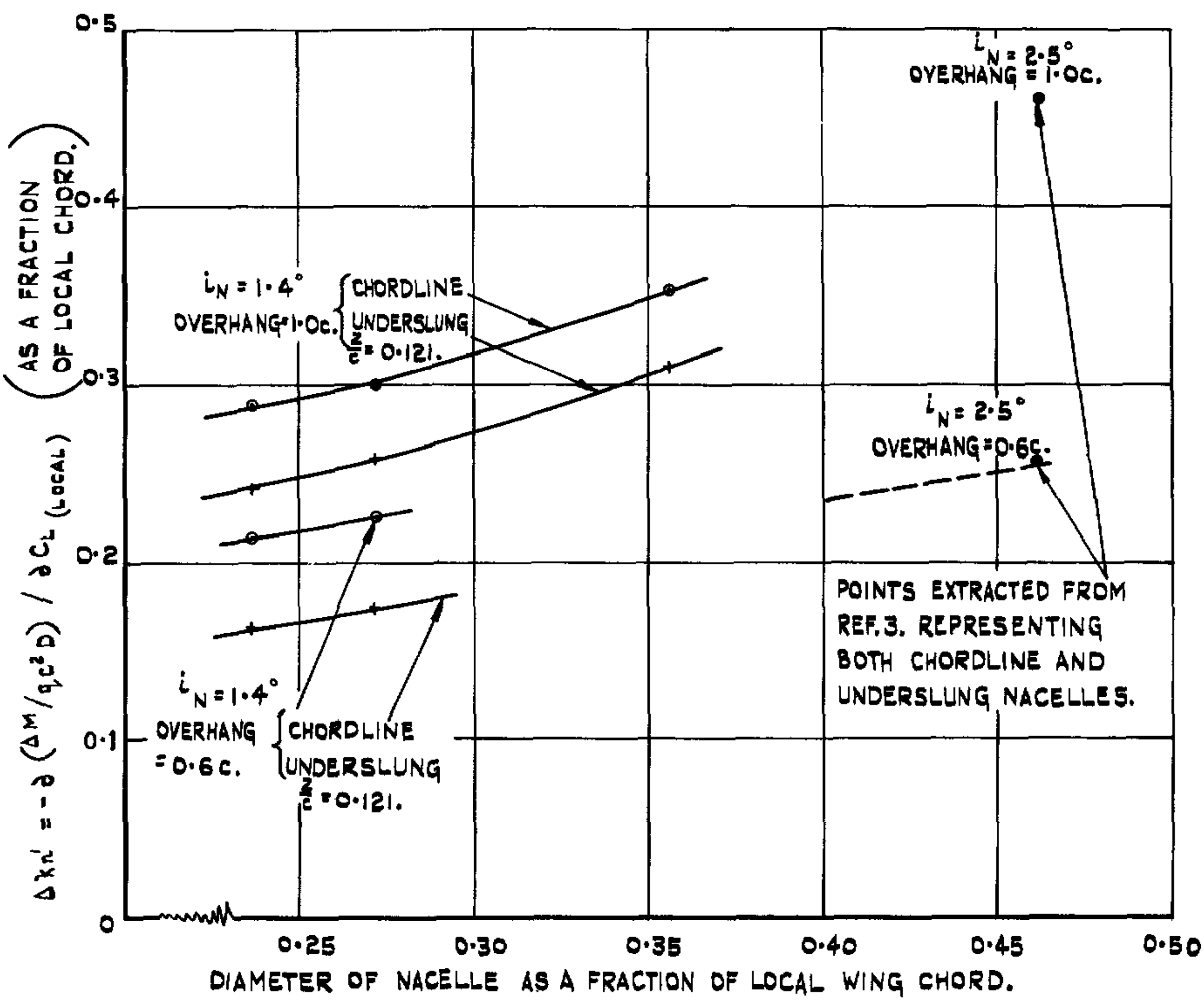


FIG. 9. VARIATION WITH DIAMETER OF FORWARD MOVEMENT OF AERODYNAMIC CENTRE ON NACELLE.

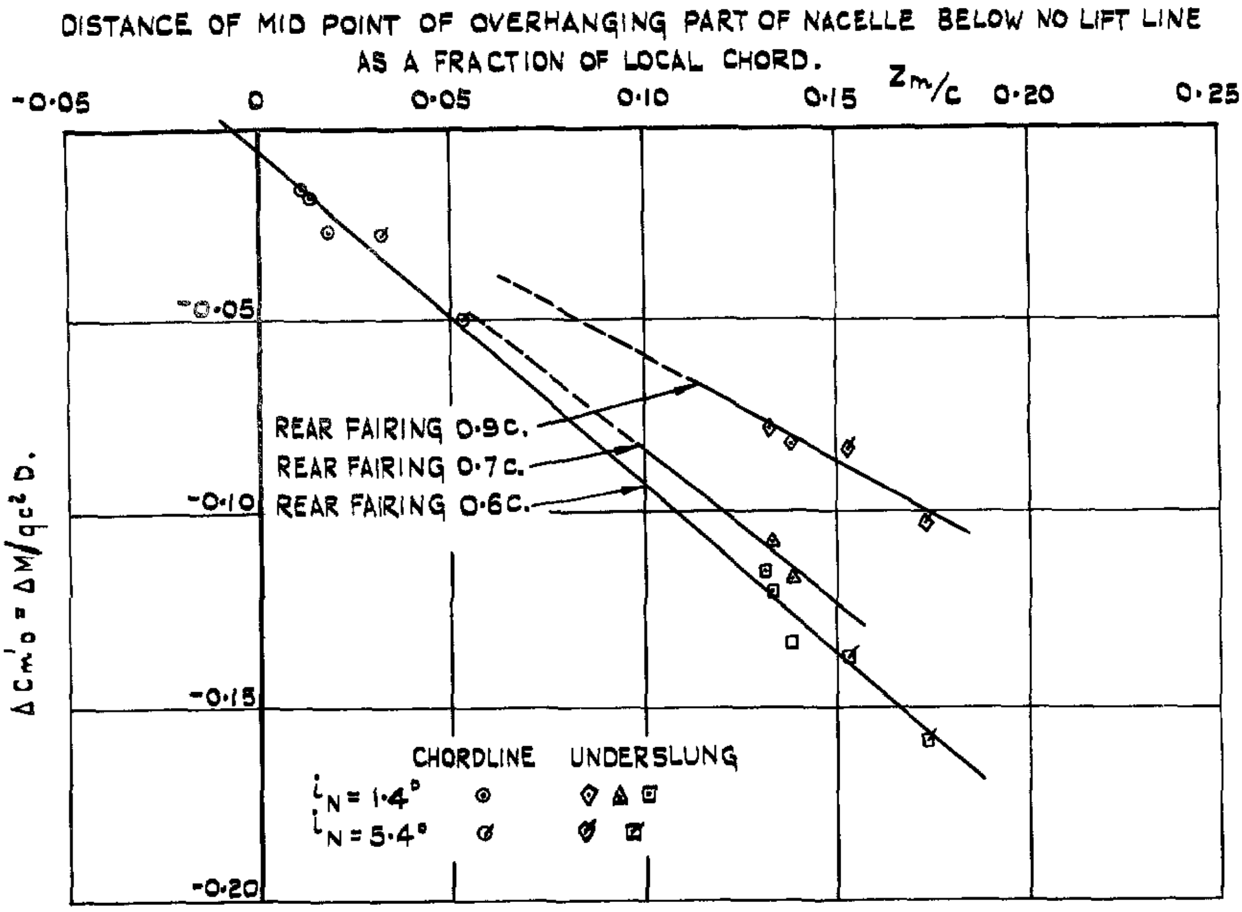


FIG.10. PITCHING MOMENT AT ZERO LIFT DUE TO A NACELLE OF DIAMETER 0·237 CHORD.

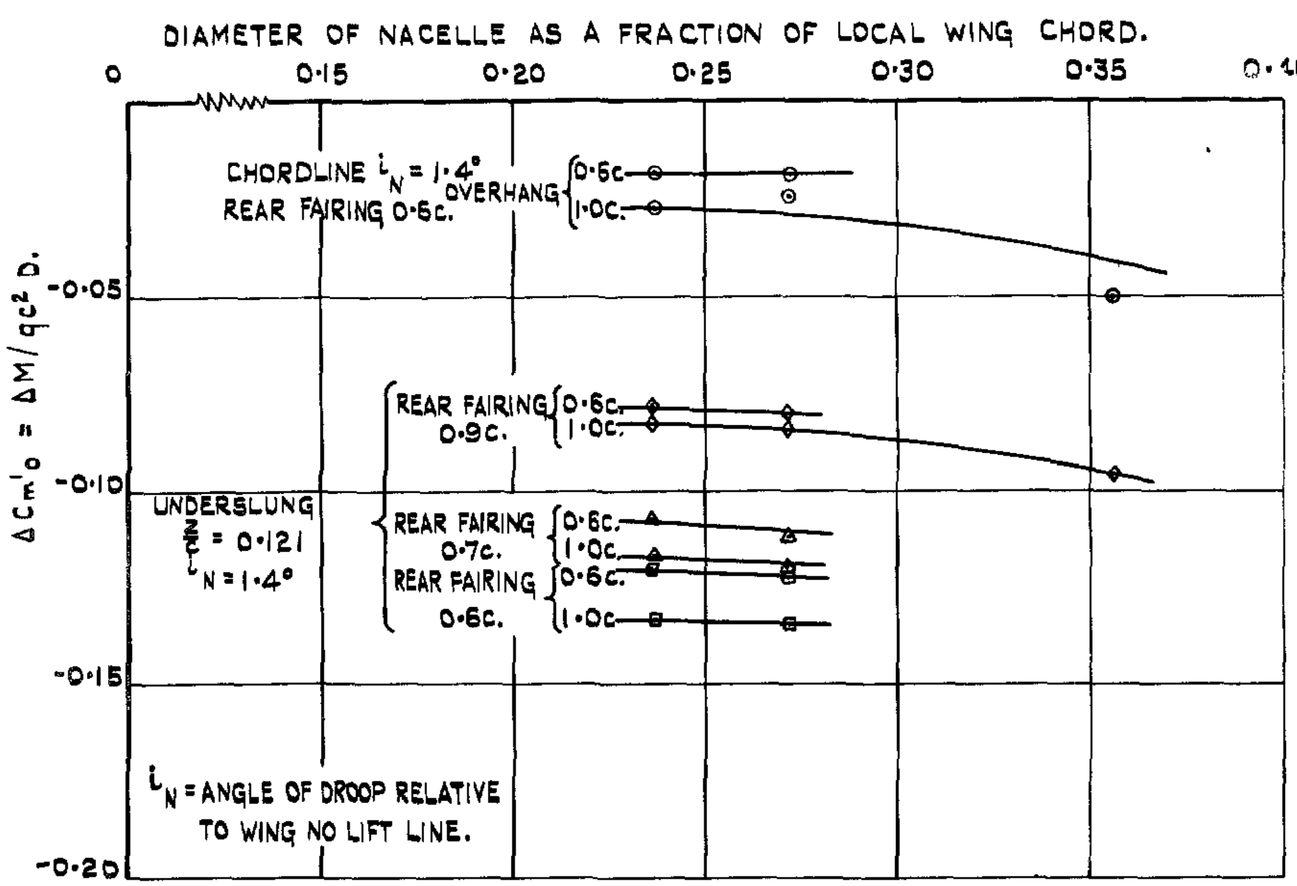


FIG.11. VARIATION WITH DIAMETER OF PITCHING MOMENT AT ZERO LIFT DUE TO A NACELLE.

FIG. 12 & 13.

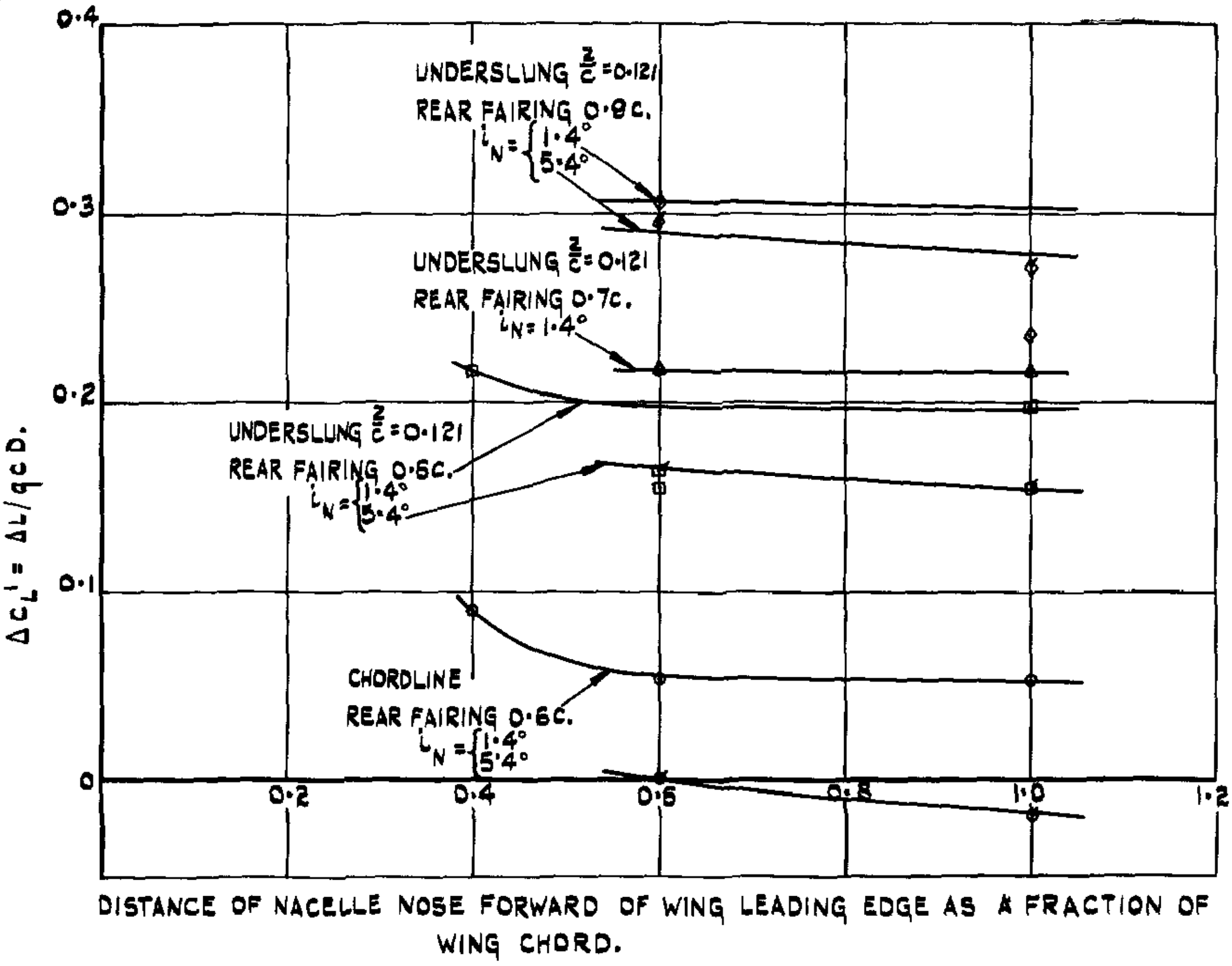


FIG. 12. LIFT LOSS DUE TO A NACELLE OF DIAMETER 0·237 CHORD ON A WING.

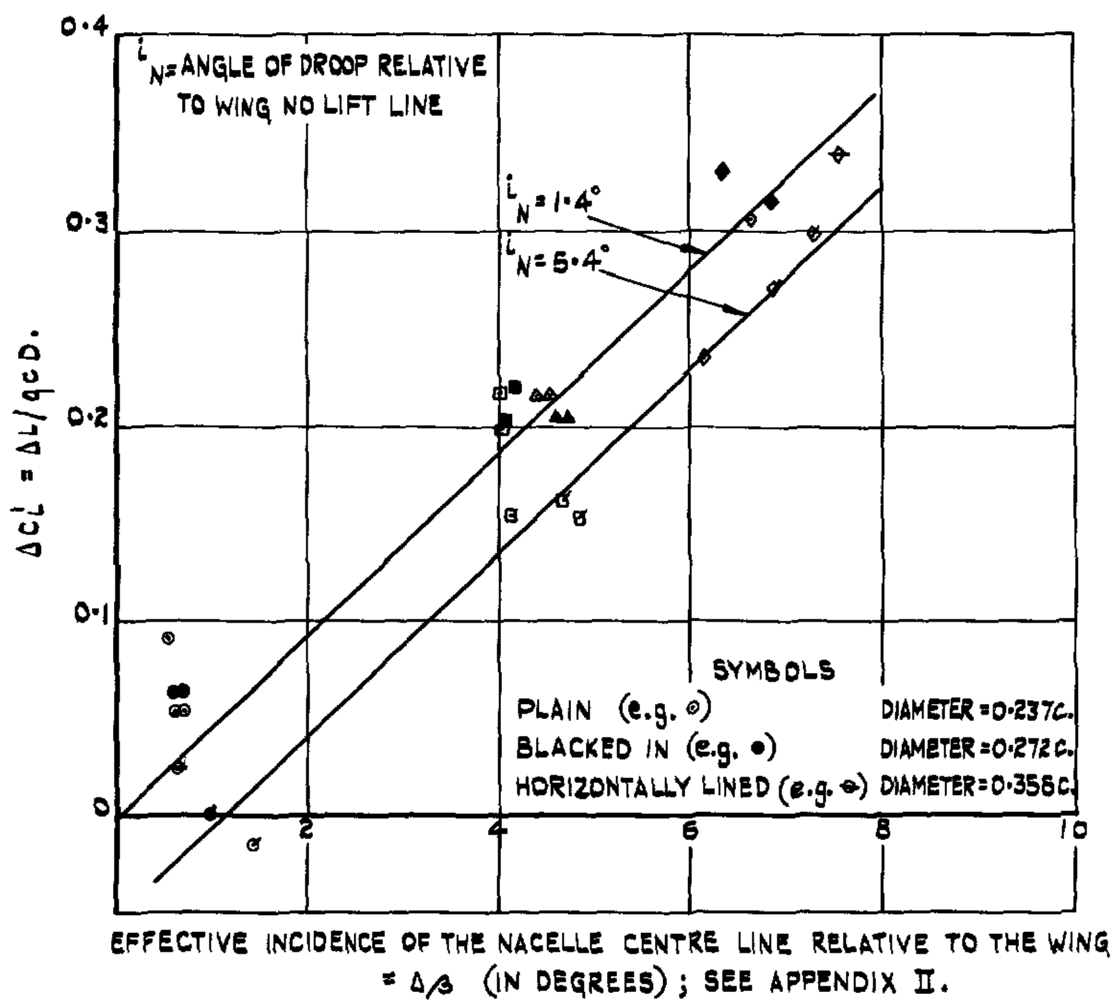


FIG. 13. LIFT LOSS DUE TO A NACELLE ON A WING.

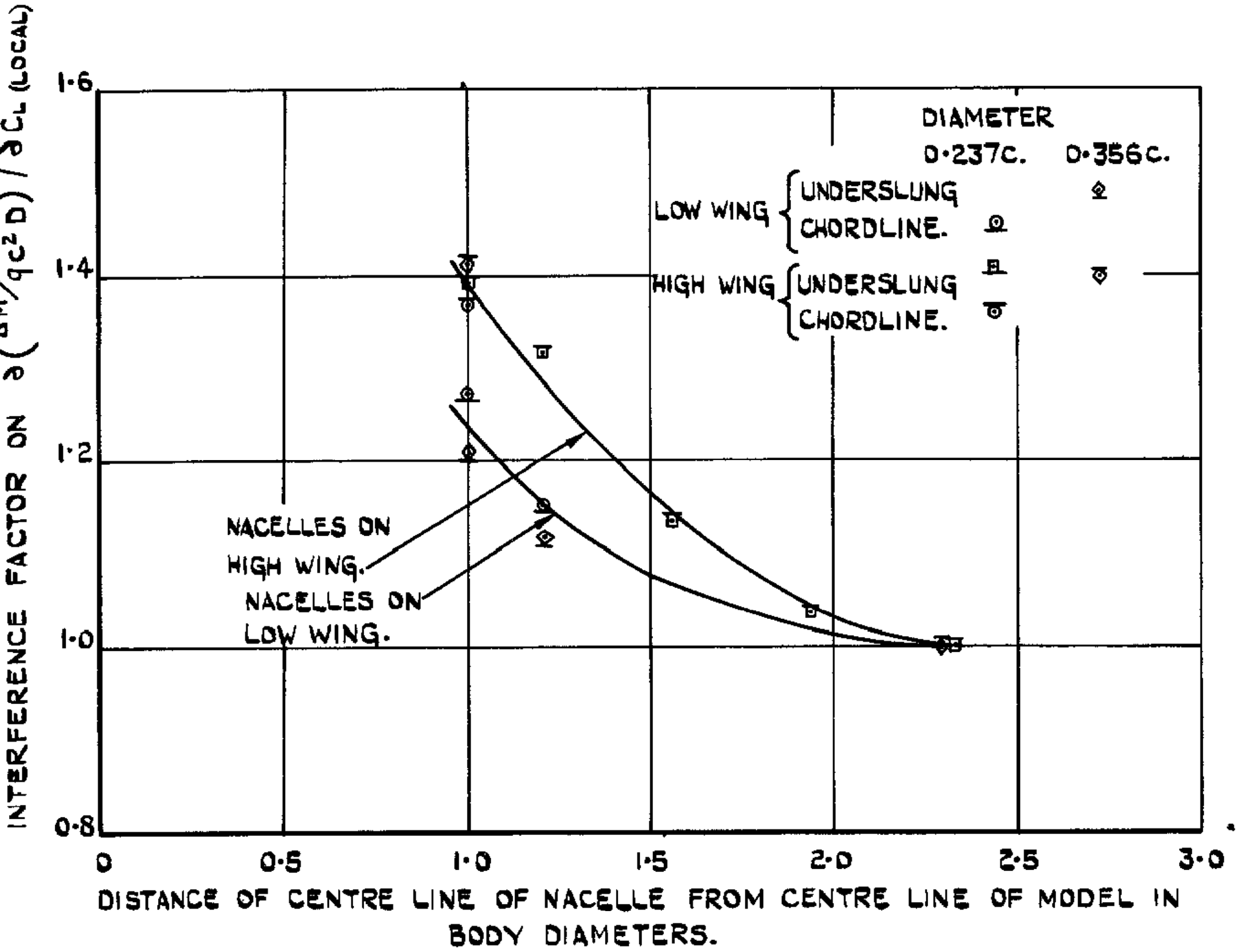


FIG.14. EFFECT OF BODY ON FORWARD MOVEMENT OF AERODYNAMIC CENTRE.

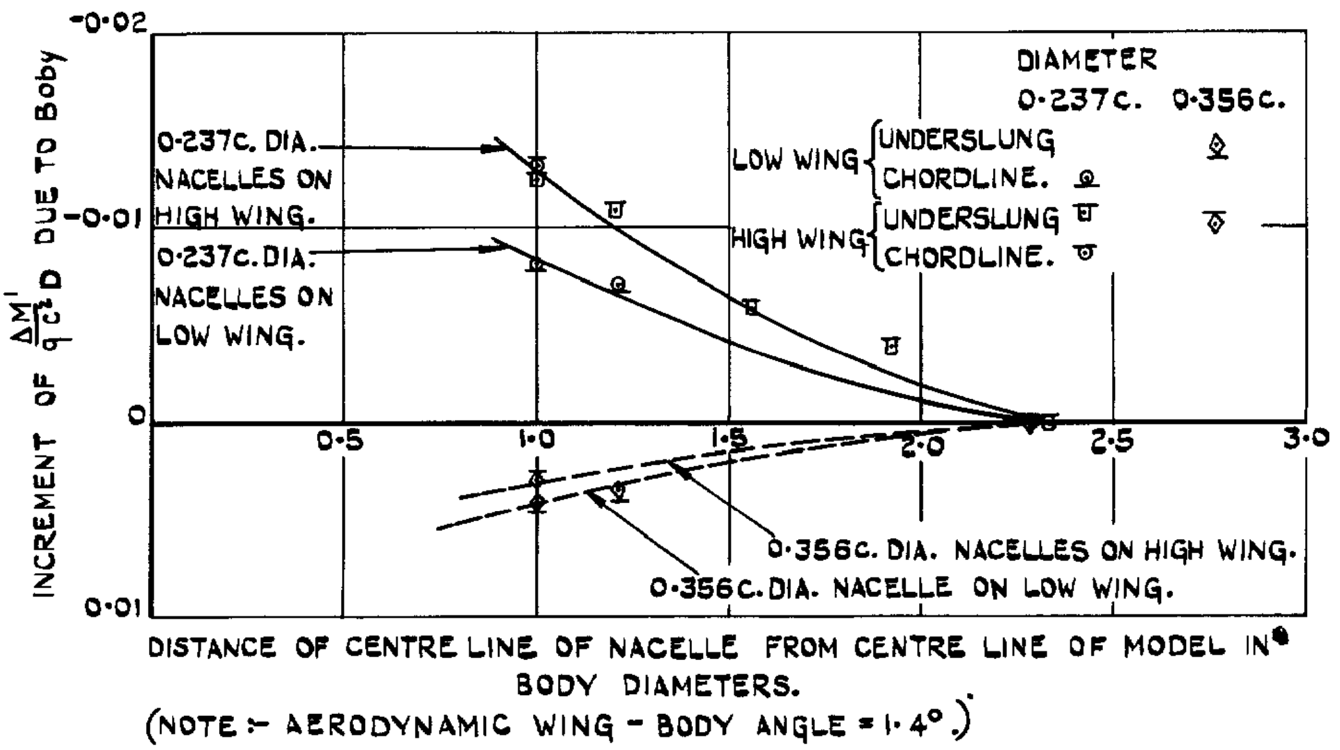


FIG.15. EFFECT OF BODY ON PITCHING MOMENT AT ZERO LIFT.

C.P. No. 39
13185
A.R.C. Technical Report

PUBLISHED BY HIS MAJESTY'S STATIONERY OFFICE
To be purchased from
York House, Kingsway, LONDON, W C.2, 429 Oxford Street, LONDON, W 1,
P.O. Box 569, LONDON, S E 1,
13a Castle Street, EDINBURGH, 2 | 1 St Andrew's Crescent, CARDIFF
39 King Street, MANCHESTER, 2 | 1 Tower Lane, BRISTOL, 1
2 Edmund Street, BIRMINGHAM, 3 | 80 Chichester Street, BELFAST,
or from any Bookseller
1951
Price 6s. 0d. net

S.O. Code No. 23-9006-39