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Wind-tunnel Tests on the Shetland

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Summary.—Wind-tunnel tests were needed to obtain aerodynamic data on the Shetland.

Range of Investigation.—The following measurements were made :—

1. Lift, drag and pitching moment for various conditions of the model over the complete flight range, with flaps up and down.
2. Directional and lateral stability.
3. Elevator, rudder and aileron effectiveness.
4. Effect of return-flow nacelles on lift and pitching moment.

Conclusions.—The lift and drag increments due to the flaps suggest that their design is satisfactory, and no modifications have been recommended.

There is a sufficient margin of stick-fixed longitudinal stability without slipstream at normal speeds, but with flaps up there is a loss in stability near the stall. With flaps down there are appreciable changes in longitudinal stability and trim.

The values of $-l_v$ (0·105) and n_v(0·068) give a somewhat high value to the $-l_v/n_v$ ratio.

The effectiveness of the elevators, rudders and ailerons appears to be satisfactory, although the upgoing aileron stalls at about 15 deg.

The return-flow nacelles as designed reduced $C_{L\,\max}$, but they were modified to maintain the same $C_{L\,\max}$ as the normal nacelles. The modified nacelles have a destablising effect $0{\cdot}045\bar{c}$ greater than the normal nacelles, due mainly to the changed plan form of the wing.

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1. *Introduction.*—Wind-tunnel tests have been made to obtain aerodynamic data on the Shetland (Short-Saro R.14/40). The Shetland has four Centaurus engines; and as an alternative to the normal nose-entry engine cooling, tests have been included on a proposed scheme for return-flow cooling.

The tests were made without slipstream in the $11\frac{1}{2} \times 8\frac{1}{2}$ ft closed-jet wind tunnel at the Royal Aircraft Establishment between March and June, 1942.

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* R.A.E. Report No. Aero. 1780.

2. *Range of Investigation*.—The measurements made were as follows:—

(1) Lift and drag with the flaps at 0, 15, 30, 40, 45 and 50 deg over the complete flight range, in order to determine the optimum flap settings for take-off and landing.

(2) Lift, drag and pitching moment with flaps at 0 deg over the complete flight range, for various conditions of the model, to enable an analysis of the drag and longitudinal stability to be made, including the effect of Reynolds number on longitudinal stability.

(3) The effects of flaps at 30 and 50 deg on longitudinal stability and trim.

(4) The effectiveness of the tailplane and elevators.

(5) Yawing and rolling moments at a wing incidence of 7 deg with flaps at 0, 30 and 50 deg for various conditions of the model, to determine the directional and lateral stability.

(6) Rudder effectiveness at a wing incidence of 7 deg.

(7) Aileron effectiveness at three incidences.

(8) Effect of aileron droop on lift and drag with flaps at 30 deg.

(9) Effect of the return-flow nacelles on lift, and longitudinal stability.

In addition, measurements were made of the drags of nacelles and gun turrets.

The majority of the tests were made with no transition wire on the hull, but as inconsistent drag results were obtained some check tests were made with transition on the hull fixed at $0 \cdot 05l$ by means of a wire. It is considered that only the drag results would be appreciably affected by the uncertainty of the hull transition.

The tests were made at a wind speed of 120 ft/sec except where otherwise stated. The results of the tests are given in tables and figures at the end of the report. The usual wind-tunnel constraint corrections have been applied, but in general no allowance has been made for scale effects.

3. *Conditions of Test*.—The main particulars of the model are given in Table 1 and Figs. 1 and 2; the layout of the return-flow nacelles is shown in Figs. 3 and 4. In Fig. 1 are shown the disposition of the gun turrets, the A.S.V. fairings on the lower surface of the wing near the tips, and the position of the mine bays in the wing. Turrets were represented by their block outline; and the mine bays, when closed, by grooves along their leading edges approximately $1\frac{1}{4}$ in. deep (full-scale dimension). The open condition of the mine bays was represented by removing wooden blocks which left wells about 6·7 in. deep (full-scale) in the lower surface of the wing.

Unless otherwise stated, the test condition of the model was as follows:—cooling gills 0 deg, mid-upper turret removed, nose turret faired in, A.S.V. fairings removed, mine bays closed, and no transition wire on the hull. Wing-tip floats were not represented on the model.

4. *Results*.—4.1. *Effect of Flaps on Lift and Drag*. (Tables 2, 3, 4; Figs. 5, 6, 7).—The increase in lift coefficient due to the flaps has been plotted against flap angle and is shown in Fig. 5. These increments have been taken at an incidence of 10 deg from the no-lift angle without flaps, in accordance with the practice adopted in R. & M. 2545[1]. By comparison with the results given in this reference, the increments in lift are satisfactory for the type of flap used. The flaps give their maximum C_L increment of 0·75 at an angle of 50 deg. Lift coefficient, for various conditions of the model with flaps 0 and 50 deg, has been plotted against wing incidence in Fig. 7.

The increase in profile-drag coefficient ΔC_{D0} due to the flaps is plotted against flap angle in Fig. 6. C_{D0} has been obtained from the measured drag coefficient by subtracting the minimum induced drag coefficient $C_{Di} = C_L^2/\pi A$. The increments have been taken at an incidence of 6 deg from the no-lift angle without flaps in accordance with R. & M. 2545[1].

The effect on the lift and drag characteristics of drooping the ailerons at take-off was investigated, using a flap setting of 30 deg. Drooping to 10 deg with flaps 30 deg gave a lift increment of 0·08, equivalent to an increase in flap angle of 6 deg. The profile-drag coefficient was decreased by 0·003. Drooping to 15 deg gave a lift increment of 0·11, equivalent to an increase in flap angle of 8 deg; but the drag coefficient was only reduced by 0·0015. These effects are shown in Figs. 5 and 6.

4.2. *Drag Analysis.* (Tables 2, 3, 5; Fig. 9).—The main use that can be made of the model drag results lies in the study of the variation of the profile drag with lift. Writing C_{D0} = const + kC_L^2, k is given from Fig. 9 by the slope of C_{D0} against C_L^2. Mean values of k over the range of C_L from 0·3 to 0·9 for various conditions are as follows:—

Condition	k
Wing alone	0·004
Wing + hull	0·0055
Wing + hull + inner nacelles only	0·009
Wing + hull + four nacelles	0·012
Wing + hull + four nacelles, entries and exits sealed	0·0085

It was found that the wire on the hull to fix its transition did not affect the values of k.

4.21. *Hull drag.*—The profile drag of the model hull with the nose turret faired in was 317 lb full-scale at 100 ft/sec E.A.S. at $C_L = 0·4$. This was with transition on the hull fixed at 0·05 × length at a Reynolds number R = 4·75 millions.

4.22. *Nacelle drags.*—The 1/18 scale nacelles were too small to measure the flow through them, and thus correct their drag to the required flow to correspond to flight conditions. As measured on the model at $C_L = 0·4$, the drag of the two inner nacelles was 80 lb, and of the two outer nacelles 60 lb. As the baffle plates on all the nacelles were similar, it can be accepted that the inner nacelles have 20 lb more drag than the outer ones at $C_L = 0·4$.

The drag of an outer nacelle has been estimated from the results of previous tests on a larger scale model to be about 17 lb with the correct cooling flow. The present results may be used to extend this to cover the range of C_L, and to give the drag of the inner nacelles. Using the values of k given above we get:—

Two outer nacelles (gills 0 deg), drag = 34 + 68 C_L^2 lb at 100 ft/sec.

Two inner nacelles (gills 0 deg), drag = 46 + 119 C_L^2 lb at 100 ft/sec.

All four nacelles (gills 0 deg), drag = 80 + 187 C_L^2 lb at 100 ft/sec.

4.23. *Tail unit drag.*—The drag of the tail unit was measured at zero tailplane lift, and the results were:—

Drag in lb full-scale at 100 ft/sec E.A.S.		
Tailplane only	Fin only	Complete tail unit
45	40	84

These results indicate that there is negligible fin-tailplane interference drag.

4.24. *Turret drags.*—To get the full gun movement of the F.N.66 nose turret it would be necessary to cut back the hull leaving a recess. Methods of closing this gap were under consideration by the firm, and the main tests were made with the recess faired. The drag of opening this recess was, however, measured and a value of about 26 lb obtained. These tests were made over a range of wind speeds up to 200 ft/sec at a C_L of 0·7, but no systematic scale effect was found. Similarly the drag of the F.N.36 mid-upper turret was about 22 lb (measured with the tail unit on), corresponding to 2·2 lb/sq ft frontal area. This value is low, and cannot be accepted as reliable.

No attempt was made to measure the drag of the F.N.59 rear turret.

4.3. *Longitudinal Stability and Trim.* (Tables 2, 3, 6, 7, 8, 9, 10, 11; Figs. 10, 11, 12, 13, 15).

4.31. *Complete model.*—From Fig. 10 the positions of the neutral point stick-fixed without slipstream for the complete model, under the main conditions of flight, are as follows:—

	C_L					
Flaps	0·1	0·4	0·7	1·0	1·3	1·6
0°	0·410	0·430	0·442	0·438	0·338	
30°			0·398	0·406	0·420	
50°			0·384	0·398	0·406	0·420

The model was tested at a C.G. position of 0·398$\bar{c}$ (3·4 ft full-scale ahead of the datum). Since the tests were completed a revised estimate has given the aft C.G. position as being at 0·335$\bar{c}$ (4.5 ft full-scale ahead of the datum) corresponding to an all-up weight of 120,000 lb. At this position there is a margin of static stability, with flaps 0 deg, of about 0·1$\bar{c}$ except near the stall. This margin will probably be reduced by the effects of slipstream, of freeing the stick, and by scale effect. To determine the scale effect at the Reynolds number of the tunnel, tests of the complete model were made at 40, 120 and 200 ft/sec ($R = \frac{1}{4}, \frac{3}{4}$ and $1\frac{1}{4}$ millions respectively, based on $\bar{c}$), and the results are shown in Fig. 12. There is a slight forward movement of neutral point with Reynolds number, as follows:—

Reynolds number (millions)	0·25	0·75	1·25
Neutral point ($C_L = 0{\cdot}4$)	0·438	0·430	0·430

With flaps lowered there is less stability at the smaller incidences but little change near maximum lift. The C.G. position for landing was stated by the firm to be at the forward limit of 0·292$\bar{c}$ (5·25 ft full-scale ahead of the datum) corresponding to a landing weight of 80,000 lb.

There is a nose-up pitching moment due to lowering the flaps; at a C_L of 1·0 this is equivalent to a change in elevator angle to trim of 6 deg for flaps at 30 deg, and 8 deg for flaps at 50 deg.

The pitching-moment curve corrected to the revised aft limit (0·335$\bar{c}$ aft of the leading edge, 0·142$\bar{c}$ below the mean chord) is shown in Fig. 12. A second curve is drawn for the same fore-and-aft C.G., but with the vertical position on the mean chord. The linearity of this curve shows that the curvature of the C_m against C_L curve below the stall for the correct C.G. position is due to the low position of the C.G. relative to the wing.

With flaps 0 deg there is marked instability near the stall, but as the stall is gradual (*see* Fig. 7) this may not be serious. The instability is more clearly shown in Fig. 15, where pitching moments have been measured past the stall with tail on and tail off. It will be seen that the pitching moment without tail (without nacelles) does not fall off until a wing incidence of 23 deg; whereas there is usually an increase in nose-down pitching moment when the wing begins to stall, which in this case occurs at about 16 deg (*see* Fig. 7).

4.32. *Analysis.*—Tests were made to compare the contributions of the various parts of the model to C_{m0}, and their effect on longitudinal stability. The results obtained from Fig. 13 are as follows:

Condition	C_{m0},	Position of Aerodynamic Centre		
		$C_L = 0\cdot1$	$C_L = 0\cdot4$	$C_L = 0\cdot7$
Wing alone	$-0\cdot048$	$0\cdot232$	$0\cdot242$	$0\cdot268$
Wing + hull..	$-0\cdot074$	$0\cdot206$	$0\cdot208$	$0\cdot230$
Wing + hull + inner nacelles only	$-0\cdot072$	$0\cdot200$	$0\cdot200$	$0\cdot214$
Wing + hull + nacelles	$-0\cdot070$	$0\cdot191$	$0\cdot191$	$0\cdot201$
Wing + hull + nacelles + A.S.V. fairings	$-0\cdot068$	$0\cdot191$	$0\cdot191$	$0\cdot201$

The value of C_{m0} for the wing alone agrees well with the value of $-0\cdot049$ obtained on the Short B.8/41 which has the same wing section[2]; and the rearward movement of the aerodynamic centre with increasing lift coefficient is due to the distance of the C.G. below the mean chord (*see* Fig. 12).

In Fig. 13 the effect of opening the mine bays is shown. To represent mine bays open, wooden blocks were removed from the lower surface of the wing (*see* Fig. 1), leaving wells about $6\cdot7$ in. deep (full-scale dimension). They have little effect on stability, but cause a change of trim equivalent to 1 deg of elevator.

From the two tables given above, it will be seen that the contribution of the tail to stability is about $0\cdot23\bar{c}$. The corresponding values of $\partial C_m/\partial\alpha_T$ and of $d\varepsilon/d\alpha$ are $-0\cdot0255$ per degree and $0\cdot28$ respectively. Lowering the flaps to 30 deg and 50 deg increased $d\varepsilon/d\alpha$ to $0\cdot40$ in each case.

4.4. *Directional and Lateral Stability* (Table 13; Figs. 17, 18).—Yawing and rolling moments and side-force were measured over a range of angles of sideslip for various conditions of the model at a wing incidence of 7 deg. The results, averaged over positive and negative angles of sideslip, are plotted in Figs. 17 and 18. Mean values of n_v, l_v and y_v over $\pm$ 5 deg of sideslip, corrected to the revised C.G. position ($0\cdot335\bar{c}$ aft of the leading edge, $0\cdot142\bar{c}$ below the mean chord) are as follows:—

Flaps deg	Condition	n_v	l_v	y_v
0	Complete model	$0\cdot068$	$-0\cdot105$	$-0\cdot31$
0	Complete model with A.S.V. fairings		$-0\cdot105$	$-0\cdot31$
0	Complete model less nacelles	$0\cdot072$	$-0\cdot105$	$-0\cdot30$
0	Complete model less tailplane		$-0\cdot105$	$-0\cdot31$
0	Complete model less fin and tailplane	$-0\cdot058$	$-0\cdot096$	$-0\cdot15$
30	Complete model	$0\cdot098$	$-0\cdot104$	$-0\cdot375$
50	Complete model	$0\cdot111$	$-0\cdot109$	$-0\cdot405$

For the complete model with flap 0 deg, the value of l_v ($-0\cdot105$) is high compared with n_v ($0\cdot068$) by comparison with the collected data given in Ref. 3, but the value of n_v is about the same as for the Sunderland, for which $n_v = 0\cdot077$.

4.5. *Control Effectiveness.* (Tables 12, 14, 15; Figs. 16, 19, 20).—In Fig. 16 are given the pitching moments due to elevators. The mean value of a_2/a_1 over a range of elevator angles of $\pm$ 10 deg is $0\cdot59$.

Yawing moments due to the rudder at a wing incidence of 7 deg are given in Fig. 19 at different angles of sideslip. The rudder power shows no falling off up to $\pm$ 20 deg; the yawing moment produced by 20 deg of rudder is given by $\Delta C_n = 0\cdot0175$ ($n_\zeta = 0\cdot050$).

Yawing and rolling moments due to one aileron at wing incidences of 3, 7 and 11 deg are given in Fig. 20. Up to $\pm$ 10 deg the aileron rolling moment is linear and independent of incidence, but the upgoing aileron stalls at about 15 deg. Ailerons at 10 deg produce a total rolling moment of $\Delta C_l = 0{\cdot}0304$ ($l_\xi = -0{\cdot}174$). A few check tests showed that lowering the flaps had no effect on the aileron effectiveness. The A.S.V. fairings were also found to have negligible effect on the rolling moments produced by the ailerons.

4.6. *Effect of Return-flow Nacelles on Lift and Pitching Moment.* (Tables 3, 4, 9; Figs. 8, 13, 15).—The effect of the return-flow nacelles on lift is shown in Fig. 8. With the layout as designed (*see* Fig. 3) there was a loss of $0{\cdot}1$ in $C_{L\,\max}$ with flaps 0 deg, compared with that obtained with normal nacelles, and tufts showed that this was due to an early breakaway of the flow from the upper surface of the wing, behind the gap between the middle pair of entries on each wing. The effect of thickening the upper surfaces of the middle two entries was tried, and this gave a very slight improvement. By fairing in the gap between the middle pair of entries to a line parallel to the wing leading edge, but leaving sufficient lip to the entries to avoid entry loss (*see* Figs. 3 and 4), the loss in $C_{L\,\max}$ was eliminated. It was found that the thickening on the upper surface of the middle pair of entries was still required even with the gap between them faired in: but a similar thickening on the innermost and outermost entries gave no improvement. The return-flow scheme in this final form was used in all the subsequent tests on the return-flow nacelles, and is referred to as " modified."

Measurements of drag obtained with the return-flow nacelles have no real application, as the entries undoubtedly caused a change in the transition on the wing.

The return-flow units were found to have a larger destabilising effect than the normal nacelles (*see* Fig. 14). The shift in neutral point over the useful range of C_L is $0{\cdot}06\bar{c}$ due to the unmodified return-flow system, and $0{\cdot}065\bar{c}$ after the modifications described above, compared with about $0{\cdot}02\bar{c}$ due to the normal nacelles. Most of this difference is accounted for by the change in plan form of the wing due to the return-flow entries, and the modified leading edge, as indicated in the following table.

Condition	Extra forward shift of neutral point due to return-flow entries	
	Experimental	Predicted from the results of Ref. 4
Unmodified	0·04	0·03
Modified	0·045	0·035

REFERENCES

No.	Author	Title, etc.
1	Young and Hufton	Note on the Lift and Profile Drag Effects of Split and Slotted Flaps. R. & M. 2545. September, 1941.
2	—	Wind Tunnel Tests on the Short B.8/41. R.A.E. Report No. Aero 1772. August, 1942. (To be published).
3	Irving	Notes on the Relationship between Rolling and Yawing Moments due to Sideslip. A.R.C. 5060. March, 1941.
4	Smith and Smelt	Note on Pitching Moment Changes due to a Nacelle on a Wing. R.A.E. Report No. B.A. 1494. August, 1938. (Unpublished).
5	Adamson, Brown and Allen	Note on the Yawing Moment Measurements, Rudder Fixed and Free, on Three Aeroplanes. R. & M. 2534. July, 1941.

TABLE 1

Model Data

Scale: 1/18

Datum:	*Model Scale*	*Full Scale**
The main step at the keel (*see* Fig. 1).		
Wing:		
Gross area S	1166 sq in	2624 sq ft
Span b	100·2 in	150·3 ft
Mean chord† $S/b = \bar{c}$	11·64 in	17·46 ft
Aspect ratio $b/\bar{c} = A$	8·61	
Angle to hull datum	6·6 deg	
Dihedral	4·5 deg	
Sweepback of quarter-chord line	10·4 deg	
Section	Göttingen 436 modified	
Root chord	17·32 in	25·98 ft
Root thickness ratio	20 per cent	
Theoretical tip thickness ratio	10 per cent	
Mean thickness ratio	17½ per cent	
Mean quarter-chord point ahead of datum†	3·785 in	5·68 ft
Tail:		
Gross area S'	180·9 sq in	407 sq ft
Span	30·10 in	45·15 ft
Mean thickness ratio	13½ per cent	
Arm (*C.G.* to mean quarter-chord point) l'	35·0 in	52·5 ft
Volume coefficient, $S'l'/S\bar{c} = \bar{V}'$	0·467	
Dihedral	6 deg	
(Tail setting α_T is relative to the wing-root chord)		
Fin:		
Net area above hull deck S''_n	105·5 sq in	237·5 sq ft
Height above hull deck	13·53 in	20·3 ft
Mean thickness ratio	13½ per cent	
Arm (*C.G.* to mean quarter-chord point) l''	34·5 in	51·9 ft
Volume coefficient $S''_n l''/Sb = \bar{V}''$	0·0312	

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* Not necessarily exactly the same as the full-scale aircraft.

† The position of the mean chord is obtained by making its quarter-chord point coincide with the mean quarter-chord point of the wing.

The mean quarter-chord point of the wing is at $(\bar{x}, \bar{z})$, such that

$$\bar{x} = \int_{-b/2}^{+b/2} c\, x\, dy \bigg/ \int_{-b/2}^{+b/2} c\, dy,$$

$$\bar{z} = \int_{-b/2}^{+b/2} c\, z\, dy \bigg/ \int_{-b/2}^{+b/2} c\, dy,$$

where c is the local chord at a station,
x, y, z, are the coordinate of the local quarter-chord point referred to wing-root chord axes.

The integrations extend across the centre section of the wing intercepted by the hull, formed by joining the leading and trailing edges at the wing roots by straight lines.

N.B. $S = \int_{-\frac{1}{2}b}^{+\frac{1}{2}b} c\, dy$ is the gross (plan) area of the wing.

TABLE 1 (*contd.*)

C.G. Position of Test:			
Distance ahead of hull datum	2·26 in		3·4 ft
Distance above hull datum	9·86 in		14·8 ft
Distance behind leading-edge mean chord		0·398$\bar{c}$	
Distance below mean chord		0·142$\bar{c}$	
Elevators:			
Area ahead of hinge line	19·2 sq in		43·2 sq ft
Area behind hinge line	41·8 sq in		94·0 sq ft
Gap at the nose	0·04 in		0·7 in
Rudder:			
Area ahead of hinge line	11·6 sq in		26·1 sq ft
Area behind hinge line	25·2 sq in		56·7 sq ft
Gap at the nose	0·05 in		0·9 in
Ailerons:			
Type		Frise	
Area ahead of hinge line	25·0 sq in		56·2 sq ft
Area behind hinge line	67·2 sq in		151·2 sq ft
Span/wing span		0·422	
Flaps:			
Type		Slotted	
Chord/wing chord—inboard end		0·188	
outboard end		0·278	
Span/wing span		0·455	
Gills:			
Normal nacelles.			
Chord	0·54 in		9·7 in
Exit area for gills 0 deg	1·31 sq in		2·95 sq ft
Exit area for gills 14 deg	2·54 sq in		5·72 sq ft
Exit area for gills 24 deg	3·46 sq in		7·79 sq ft
Return-flow nacelles.			
Chord	0·54 in		9·7 in
Exit area for gills 0 deg	0·51 sq in		1·15 sq ft
Exit area for gills 25 deg	2·46 sq in		5·53 sq ft

Engines:

These were represented by baffle plates having a free area ratio of 0·13.

TABLE 2

Lift, Drag and Pitching Moment due to Flaps—Wing + Hull + Normal Nacelles

Condition	α deg	C_L	C_{D0}	C_m
Flaps 0 deg . .	$-1\cdot1$	0·060	0·0269	$-0\cdot0601$
	0	0·152	0·0261	
	2·1	0·300	0·0255	$-0\cdot0071$
	3·1	0·386	0·0254	
	5·2	0·545	0·0262	$+0\cdot0430$
	7·3	0·715	0·0281	
	8·3	0·783	0·0306	0·0910
	9·4	0·882	0·0332	
	11·5	1·038	0·0395	0·1313
	13·6	1·174	0·0504	0·1535
	15·6	1·283	0·0695	0·1749
	17·6	1·320		
	18·7	1·334		
	19·7	1·340		
	20·6	1·276		
Flaps 15 deg . .	$-1\cdot0$	0·243	0·0316	
	$+3\cdot2$	0·609	0·0305	
	7·4	0·971	0·0352	
	11·6	1·301	0·0482	
	13·7	1·443	0·0609	
	15·8	1·529		
	17·0	1·559		
	17·8	1·529		
	18·9	1·494		
Flaps 30 deg . .	$-2\cdot9$	0·293	0·0444	
	$-0\cdot8$	0·500	0·0436	$-0\cdot0828$
	$+1\cdot3$	0·681	0·0441	$-0\cdot0502$
	3·4	0·878	0·0450	$-0\cdot0187$
	5·5	1·074	0·0467	$+0\cdot0118$
	7·6	1·261	0·0500	0·0406
	9·7	1·425	0·0550	0·0692
	11·8	1·574	0·0662	0·0985
	12·8	1·624		0·1126
	13·8	1·666	0·0846	0·1261
	14·9	1·714	0·0983	0·1402
	15·9	1·758	0·1161	
	16·9	1·761		
	17·4	1·739		
	17·9	1·714		
Flaps 30 deg Ailerons drooped 10 deg	$-1\cdot8$	0·505	0·0413	
	$+1\cdot4$	0·801	0·0413	
	4·5	1·071	0·0433	
	7·7	1·349	0·0477	
	10·8	1·590	0·0572	
	13·9	1·758	0·0817	
	14·9	1·785		
	15·9	1·800		
	16·9	1·805		
	17·9	1·785		
Flaps 30 deg Ailerons drooped 15 deg	$-1\cdot8$	0·549	0·0423	
	$+1\cdot4$	0·836	0·0420	
	4·5	1·106	0·0445	
	7·7	1·380	0·0482	
	10·8	1·615	0·0586	
	13·9	1·781	0·0854	
	14·9	1·808	0·1032	
	15·9	1·820		
	16·9	1·820		
	17·9	1·763		
Flaps 40 deg . .	$-0\cdot7$	0·650	0·0556	
	$+3\cdot5$	1·018	0·0596	
	7·7	1·389	0·0652	
	11·9	1·708	0·0802	
	13·9	1·812	0·1001	
	14·9	1·834	0·1165	
	16·0	1·863		
	17·0	1·863		
	17·9	1·775		
Flaps 45 deg . .	$-0\cdot7$	0·720	0·0639	
	$+3\cdot5$	1·089	0·0674	
	7·7	1·463	0·0725	
	11·9	1·771	0·0865	
	13·9	1·852	0·1113	
	15·0	1·894	0·1246	
	16·0	1·912		
	17·0	1·895		
	17·9	1·820		
Flaps 50 deg . .	$-0\cdot7$	0·752	0·0714	$-0\cdot0946$
	$+0\cdot4$	0·844		
	3·5	1·129	0·0732	$-0\cdot0308$
	6·7	1·378		
	7·7	1·486	0·0807	$+0\cdot0290$
	11·9	1·809	0·0945	0·0873
	12·9	1·850		
	14·0	1·901	0·1173	0·1166
	15·0	1·924		
	16·1	1·958		
	17·0	1·944		
	17·2	1·885		
	17·9	1·841		

TABLE 3

Lift, Drag and Pitching Moment with Flaps 0 deg

Condition	α deg	C_L	C_{D0}	C_m
Wing alone ..	−2·3	0·038	0·0128	−0·0428
	+0·9	0·276	0·0118	−0·0028
	4·0	0·511	0·0117	+0·0328
	7·1	0·755	0·0129	0·0644
	10·2	0·977	0·0156	0·0910
	12·3	1·111	0·0183	0·1054
	14·4	1·222		
	15·9	1·275		
	16·9	1·289		
	17·8	1·297		
	18·9	1·290		
	19·9	1·272		
Wing + hull ..	−2·1	−0·019	0·0238	−0·0776
	0	+0·149	0·0227	−0·0458
	1·0	0·230	0·0218	−0·0306
	2·1	0·311	0·0212	−0·0157
	4·2	0·467	0·0208	+0·0145
	5·2	0·555	0·0212	0·0281
	7·3	0·719	0·0220	0·0570
	8·3	0·793	0·0228	0·0690
	10·4	0·954		0·0921
	11·5	1·010	0·0285	0·1053
	12·5	1·084		0·1161
	13·6	1·155	0·0327	0·1266
	14·6	1·211		0·1354
	15·6	1·249		0·1441
	16·6	1·278		0·1528
	17·6	1·290		0·1586
	18·6	1·301		0·1683
	19·6	1·302		0·1732
	20·6	1·299		0·1793
	21·6	1·281		0·1874
	22·6	1·287		0·1909
	23·6	1·255		0·1979
	24·5	1·213		0·1888
Wing + hull + inner normal nacelles only	−1·1	0·060	0·0257	−0·0604
	+2·1	0·301	0·0238	−0·0128
	5·2	0·534	0·0236	+0·0340
	8·3	0·788	0·0270	0·0816
	11·5	1·022	0·0346	0·1176
	13·6	1·160	0·0415	0·1405
	15·6	1·264	0·0591	0·1625
	17·6	1·320		
	18·9	1·316		
	19·6	1·316		
	20·6	1·310		
Wing + hull + normal nacelles Gills 14 deg	−1·1	0·071	0·0299	−0·0586
	+3·1	0·389	0·0282	+0·0110
	7·3	0·705	0·0312	0·0763
	11·5	1·009	0·0409	0·1332
	13·6	1·156	0·0504	0·1547
	15·6	1·257	0·0718	0·1752
	16·6	1·282		
	17·6	1·282		
	18·6	1·282		
	19·6	1·282		
	20·6	1·272		
Wing + hull + normal nacelles Gills 24 deg	−1·1	0·066	0·0331	−0·0572
	+3·1	0·380	0·0316	+0·0100
	7·3	0·701	0·0339	0·0754
	11·5	1·006	0·0420	0·1336
	13·5	1·129	0·0519	0·1566
	15·6	1·235	0·0719	0·1730
	16·6	1·246		
	17·6	1·240		
	18·6	1·240		
	19·6	1·238		
Wing + hull + normal necelles + A.S.V. fairings.	−1·1	0·050		−0·0591
	+3·1	0·376		+0·0125
	7·3	0·694		0·0757
	11·5	1·017		0·1314
	13·6	1·168		0·1546
	15·6	1·272		0·1763
	17·7	1·328		
	18·7	1·332		
	19·6	1·293		
Wing + hull + return-flow nacelles (unmodified)	−1·1	0·060		−0·0736
	+2·1	0·293		−0·0147
	5·2	0·541		+0·0461
	8·3	0·787		0·0994
	11·5	1·024		0·1478
	14·6	1·203		0·1758
	15·6	1·203		
	16·6	1·210		0·1768
	17·6	1·235		
	18·6	1·240		
	19·8	1·235		
	20·6	1·218		

TABLE 3 (*contd.*)

Condition	α deg	C_L	C_{D0}	C_m
Wing + hull + return-flow nacelles (modified)	−1·1	0·049		−0·0744
	0	0·144		
	2·1	0·296		−0·0107
	3·1	0·381		
	5·2	0·549		+0·0508
	7·3	0·713		
	8·3	0·785		0·1055
	9·4	0·869		
	11·5	1·033		0·1552
	13·6	1·166		0·1810
	15·6	1·239		
	17·6	1·312		
	19·2	1·334		
	20·2	1·334		
	21·1	1·327		
Wing + hull + return-flow nacelles (modified) Gills 25 deg	−1·1	0·063		
	+2·1	0·293		
	5·2	0·542		
	8·3	0·778		
	11·5	1·001		
	13·6	1·133		
	15·7	1·193		
	16·9	1·240		
	17·6	1·262		
	18·6	1·284		
	19·9	1·302		
	21·1	1·268		

TABLE 4

Lift and Drag with Flaps 50 *deg*

Condition	α deg	C_L	C_{D0}
Wing + hull	−2·8	0·575	
	+0·4	0·857	
	3·5	1·113	
	6·7	1·359	
	9·8	1·612	
	13·1	1·850	
	14·0	1·888	
	15·0	1·941	
	16·0	1·974	
	17·0	1·983	
	18·0	1·933	
	19·0	1·859	

TABLE 4 (*contd.*)

Condition	α deg	C_L	C_{D0}
Wing + hull + normal nacelles Gills 24 deg	−0·7	0·744	0·0758
	+3·5	1·116	0·0787
	7·7	1·464	0·0830
	11·9	1·790	0·0990
	14·1	1·887	0·1233
	15·0	1·901	
	16·1	1·909	
	17·0	1·819	
Wing + hull + return-flow nacelles (modified)	7·7	1·489	
	10·9	1·758	
	13·0	1·878	
	14·0	1·921	
	15·0	1·955	
	15·5	1·955	
	16·0	1·921	
Wing + hull + return-flow nacelles (modified) Gills 25 deg	7·7	1·492	
	10·9	1·747	
	13·0	1·869	
	14·0	1·912	
	15·0	1·942	
	16·0	1·882	

TABLE 5

Lift and Drag with Flaps 0 *deg*

Transition wire on hull at 0·05*l*

Condition	α deg	C_L	C_{D0}
Wing + hull	0	0·151	0·0224
	3·1	0·393	0·0208
	5·2	0·556	0·0210
	7·3	0·715	0·0226
	9·4	0·868	0·0243
	11·5	1·021	0·0281
Wing + hull + normal nacelles.	0	0·139	0·0265
	3·1	0·377	0·0254
	4·2	0·459	0·0259
	5·2	0·542	0·0264
	6·3	0·627	0·0278
	7·3	0·706	0·0292
	9·4	0·871	0·0332
	11·5	1·030	0·0400
Wing + hull + normal nacelles, entries and exits sealed.	0	0·144	0·0244
	3·1	0·390	0·0232
	5·2	0·553	0·0237
	7·3	0·717	0·0258
	9·4	0·873	0·0287
	11·5	1·040	0·0341

TABLE 6

Pitching Moment with Flaps 0 deg—Complete Model with Normal Nacelles

Condition	α deg	C_L	C_m
$\alpha_T = -3\cdot1$ deg ..	$-1\cdot1$	0·022	0·0694
	$+2\cdot1$	0·288	0·0655
	5·2	0·555	0·0562
	8·3	0·824	0·0474
	11·5	1·084	0·0327
	13·6	1·221	0·0318
$\alpha_T = -2\cdot1$ deg ..	$-1\cdot1$	0·021	0·0469
	0	0·116	0·0442
	2·1	0·303	0·0406
	5·2	0·564	0·0324
	8·3	0·818	0·0221
	9·4	0·911	0·0177
	11·5	1·084	0·0090
	12·5	1·165	0·0069
	13·6	1·235	0·0087
	14·6	1·290	0·0093
	15·6	1·320	0·0124
	16·6	1·360	0·0165
	17·6	1·367	0·0201
	18·7	1·369	0·0275
	19·6	1·330	0·0096
	20·6	1·327	0·0029
$\alpha_T = -2\cdot1$ deg .. Mine bays open	$-1\cdot1$	0·073	0·0599
	$+2\cdot1$	0·338	0·0585
	5·2	0·593	0·0496
	8·3	0·857	0·0397
	11·5	1·107	0·0187
	13·6	1·254	0·0178
$\alpha_T = -1\cdot1$ deg ..	$-1\cdot1$	0·038	0·0193
	0	0·124	0·0194
	2·1	0·304	0·0153
	5·2	0·561	$+0\cdot0070$
	8·3	0·834	$-0\cdot0053$
	9·4	0·914	$-0\cdot0098$
	11·5	1·087	$-0\cdot0114$
	12·5	1·170	$-0\cdot0110$
	13·6	1·242	$-0\cdot0093$
	14·6	1·298	$-0\cdot0071$
	15·6	1·333	$-0\cdot0047$
	16·6	1·359	$-0\cdot0060$
	17·6	1·371	$-0\cdot0026$
	18·7	1·384	$+0\cdot0061$

TABLE 7

Scale Effect on Pitching Moment with Flaps 0 deg—Complete Model with Normal Nacelles

Transition wire on hull at $0\cdot05l$
$\alpha_T = -2\cdot1$ deg

Tunnel Speed ft/sec	α deg	C_L	C_m
40	$-1\cdot1$	0·012	0·0520
	$+1\cdot0$	0·187	0·0408
	3·1	0·372	0·0324
	5·2	0·560	0·0242
	7·3	0·735	0·0178
120	$-1\cdot1$	0·024	0·0469
	$+1\cdot0$	0·195	0·0442
	3·1	0·385	0·0364
	4·2		0·0344
	5·2	0·555	0·0327
	6·3		0·0289
	7·3	0·731	0·0263
200	$-1\cdot1$	0·026	0·0462
	$+1\cdot0$	0·198	0·0435
	3·1	0·381	0·0387
	5·2	0·554	0·0321
	7·3	0·734	0·0259

TABLE 8

Pitching Moment with Flaps 0 deg—Complete Model less Nacelles

Condition	α deg	C_L	C_m
$\alpha_T = -2\cdot1$ deg ..	0	0·105	0·0425
	3·1	0·368	0·0321
	5·2	0·513	0·0235
	7·3	0·731	$+0\cdot0097$
	11·5	1·059	$-0\cdot0248$
	13·6	1·195	$-0\cdot0386$
	14·6	1·269	$-0\cdot0452$
	15·6	1·301	$-0\cdot0447$
	16·6	1·329	$-0\cdot0453$
	17·6	1·350	$-0\cdot0463$
	18·6	1·357	$-0\cdot0430$
	19·6	1·357	$-0\cdot0379$
	20·6	1·357	$-0\cdot0305$
	21·6	1·357	$-0\cdot0220$
	22·6	1·362	$-0\cdot0232$
	23·6	1·333	$-0\cdot0354$
	24·3	1·322	$-0\cdot0572$

TABLE 9

Pitching Moment with Flaps 0 deg—Complete Model with Return-flow Nacelles

Condition	α deg	C_L	C_m
$\alpha_T = -2\cdot1$ deg ..	$-1\cdot1$	0·011	0·0328
	$+1\cdot0$	0·192	0·0384
	2·1	0·280	0·0393
	3·1	0·377	0·0407
	5·2	0·559	0·0433
	6·3	0·638	0·0435
	9·4	0·912	0·0419
	11·5	1·084	0·0414
	13·6	1·232	0·0455
	14·6	1·268	0·0486
	15·6	1·329	0·0545
	17·6	1·371	0·0667
	19·7	1·382	0·0764

TABLE 10

Pitching Moment with Flaps 30 deg—Complete Model with Normal Nacelles

Condition	α deg	C_L	C_m
$\alpha_T = -3\cdot1$ deg ..	$-1\cdot9$	0·309	0·1243
	$+0\cdot2$	0·511	0·1258
	2·3	0·719	0·1274
	5·5	1·032	0·1265
	8·7	1·326	0·1224
	11·8	1·570	0·1123
$\alpha_T = -2\cdot1$ deg ..	$-0\cdot8$	0·423	0·1028
	$+0\cdot2$	0·522	0·1051
	0·8	0·578	0·1058
	1·3	0·621	0·1066
	2·3	0·728	0·1058
	5·5	1·033	0·1038
	8·7	1·333	0·0992
	11·8	1·569	0·0903
	13·8	1·693	0·0826
$\alpha_T = -1\cdot1$ deg ..	$-1\cdot9$	0·342	0·0755
	$+0\cdot2$	0·544	0·0763
	2·3	0·748	0·0770
	5·5	1·046	0·0776
	8·7	1·337	0·0725
	11·8	1·580	0·0627

TABLE 11

Pitching Moment with Flaps 50 deg—Complete Model with Normal Nacelles

Condition	α deg	C_L	C_m
$\alpha_T = -3\cdot1$ deg ..	$-1\cdot7$	0·568	0·1499
	$+0\cdot4$	0·764	0·1531
	2·5	0·962	0·1542
	5·6	1·258	0·1546
	8·8	1·538	0·1514
	11·9	1·804	0·1453
$\alpha_T = -2\cdot1$ deg ..	$-1\cdot7$	0·564	0·1256
	$+0\cdot4$	0·767	0·1295
	2·5	0·963	0·1299
	5·6	1·253	0·1284
	8·8	1·530	0·1249
	11·9	1·795	0·1183
	13·0	1·870	0·1180
	14·0	1·900	0·1189
	15·0	1·930	0·1177
	16·0	1·960	0·1162
	17·0	1·914	0·1252 0·1282
	17·9	1·820	0·1343
$\alpha_T = -1\cdot1$ deg ..	$-1\cdot7$	0·584	0·1030
	$+0\cdot4$	0·776	0·1051
	2·5	0·978	0·1036
	5·6	1·272	0·1027
	8·8	1·541	0·1004
	11·9	1·808	0·0930

TABLE 12

Pitching Moment due to Elevators—Complete Model with Normal Nacelles and $\alpha_T = -2\cdot1$ deg—Flaps 0 deg

Elevator Angle	α deg	C_L	C_m
$\eta = -20$ deg ..	0	0·017	0·3016
	2·1	0·177	0·3207
	5·2	0·444	0·3217
	8·3	0·718	0·3014
	9·9	0·851	0·2965
	11·5	0·985	0·2940
	14·6	1·199	0·2816
$\eta = -10$ deg ..	$-1\cdot1$	$-0\cdot027$	0·1888
	$+2\cdot1$	$+0\cdot234$	0·1937
	5·2	0·505	0·1826
	8·3	0·761	0·1730
	11·5	1·022	0·1561
	13·6	1·188	0·1471

TABLE 12 (*contd.*)

Elevator Angle	α deg	C_L	C_m
η = 10 deg.. ..	—1·1	0·066	—0·0932
	+2·1	0·342	—0·1044
	5·2	0·608	—0·1188
	8·3	0·866	—0·1282
	11·5	1·113	—0·1249
	13·6	1·270	—0·1086
η = 20 deg.. ..	—1·1	0·122	—0·2213
	+2·1	0·388	—0·2304
	5·2	0·655	—0·2603
	8·3	0·918	—0·2604
	11·5	1·161	—0·2300
	13·6	1·314	—0·2061

TABLE 13

Yawing and Rolling Moments and Side-Force—Complete Model with Normal Nacelles and $\alpha_T = -2\cdot1$ *deg*, $\alpha \simeq 7$ *deg*

Condition	β deg	C_n	C	C_Y
Flaps 0 deg ..	0	0	0	0
	2	0·0022	—0·0036	—0·022
	5	0·0054	—0·0092	—0·057
	7	0·0083	—0·0131	—0·084
	10	0·0132	—0·0184	—0·133
Flaps 30 deg ..	0	0	0	0
	2	0·0033	—0·0036	—0·026
	5	0·0077	—0·0090	—0·065
	7	0·0122	—0–0128	—0·095
	10	0·0181	—0·0182	—0·148
Flaps 50 deg ..	0	0	0	0
	2	0·0036	—0·0035	—0·028
	5	0·0093	—0·0096	—0·069
	7	0·0132	—0·0136	—0·101
	10	0·0204	—0·0188	—0·156
Flaps 0 deg, Nacelles off.	0	0	0	0
	2	0·0024	—0·0039	—0·022
	5	0·0058	—0·0091	—0·056
	7	0·0087	—0·0126	—0·082
Flaps 0 deg A.S.V. fairings on.	0		0	0
	2		—0·0036	—0·022
	5		—0·0079	—0·059
	7		—0·0132	—0·084

TABLE 13 (*contd.*)

Condition	β deg	C_n	C_l	C_Y
Flaps 0 deg .. Tail off, but fin on	0		0	0
	2		—0·0037	—0·022
	5		—0·0091	—0·057
	7		—0·0131	—0·084
Flaps 0 deg .. Tail and fin off	0	0	0	0
	2	—0·0022	—0·0034	—0·010
	5	—0·0051	—0·0083	—0·027
	7	—0·0068	—0·0113	—0·042
	10	—0·0077	—0·0157	—0·071

TABLE 14

Yawing Moment due to Rudder—Complete Model with Normal Nacelles and $\alpha_T = -2\cdot1$ *deg—Flaps* 0 *deg*, $\alpha \simeq 7$ *deg*

β deg	C_n	
	Rudder angle	
	ζ = 10 deg	ζ = 20 deg
—10	—0·0204	—0·0277
—7	—0·0157	—0·0235
—5	—0·0137	—0·0218
—2	—0·0112	—0·0200
0	—0·0081	—0·0179
2	—0·0066	—0·0151
5	—0·0031	—0·0119
7	—0·0005	—0·0092
10	+0·0050	—0·0038

TABLE 15

Yawing and Rolling Moments due to Aileron—Complete Model with Normal Nacelles and $\alpha_T = -2 \cdot 1$ deg—Flaps 0 deg

Moments given are due to displacing one aileron.

Yawing moment is positive when the wing tends to drag.

Rolling moment is positive when the wing tends to drop.

Aileron Angle ξ deg	Approximate α deg	C_n	C_l
20 down ..	3	0·0022	—0·0259
	7	0·0022	—0·0265
	11	0·0033	—0·0250
10 down ..	3	0·0009	—0·0151
	7	0·0013	—0·0146
	11	0·0016	—0·0146
10 up.. ..	3	+0·0001	0·0158
	7	—0·0003	0·0153
	11	—0·0010	0·0157
15 up.. ..	3	0·0005	0·0219
	7	+0·0002	0·0189
	11	—0·0009	0·0199
20 up.. ..	3	0·0021	0·0194
	7	0·0010	0·0214
	11	0·0004	0·0178

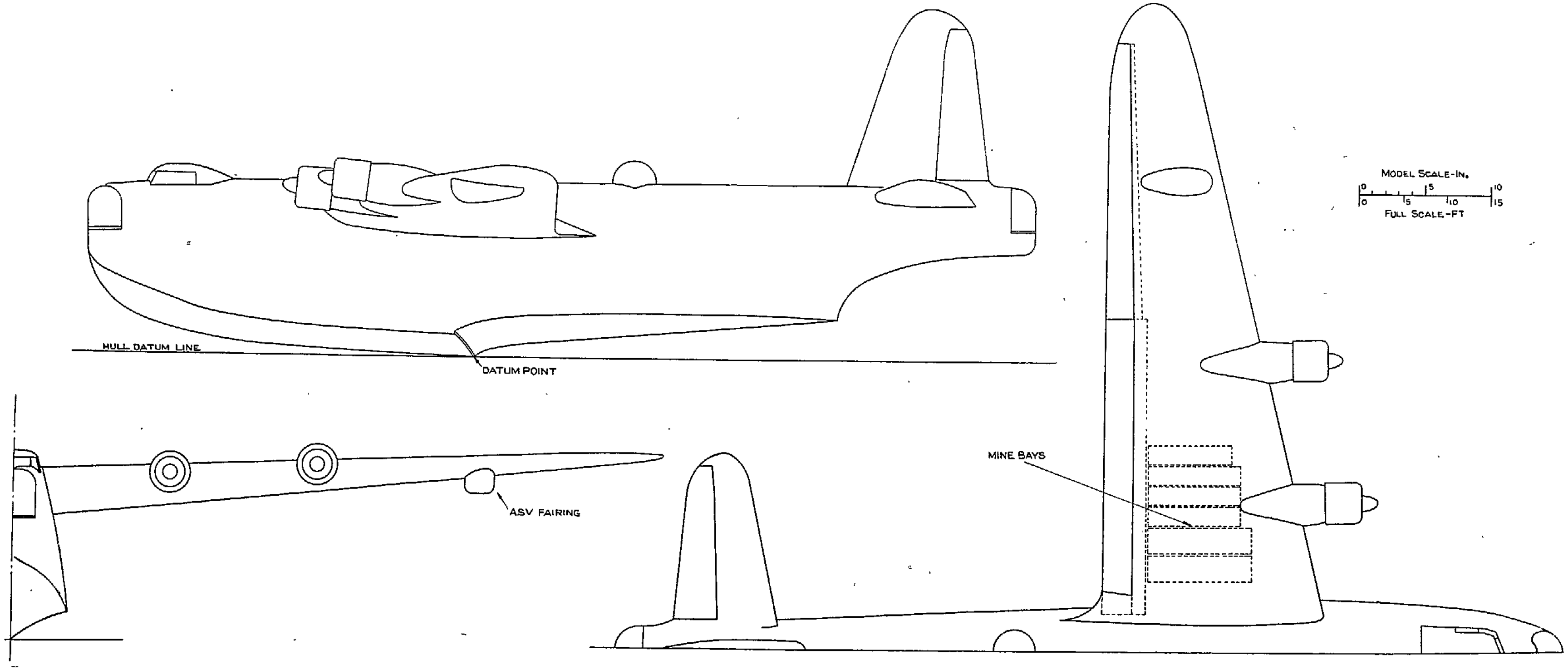

FIG. 1. General Arrangement of Shetland Model.

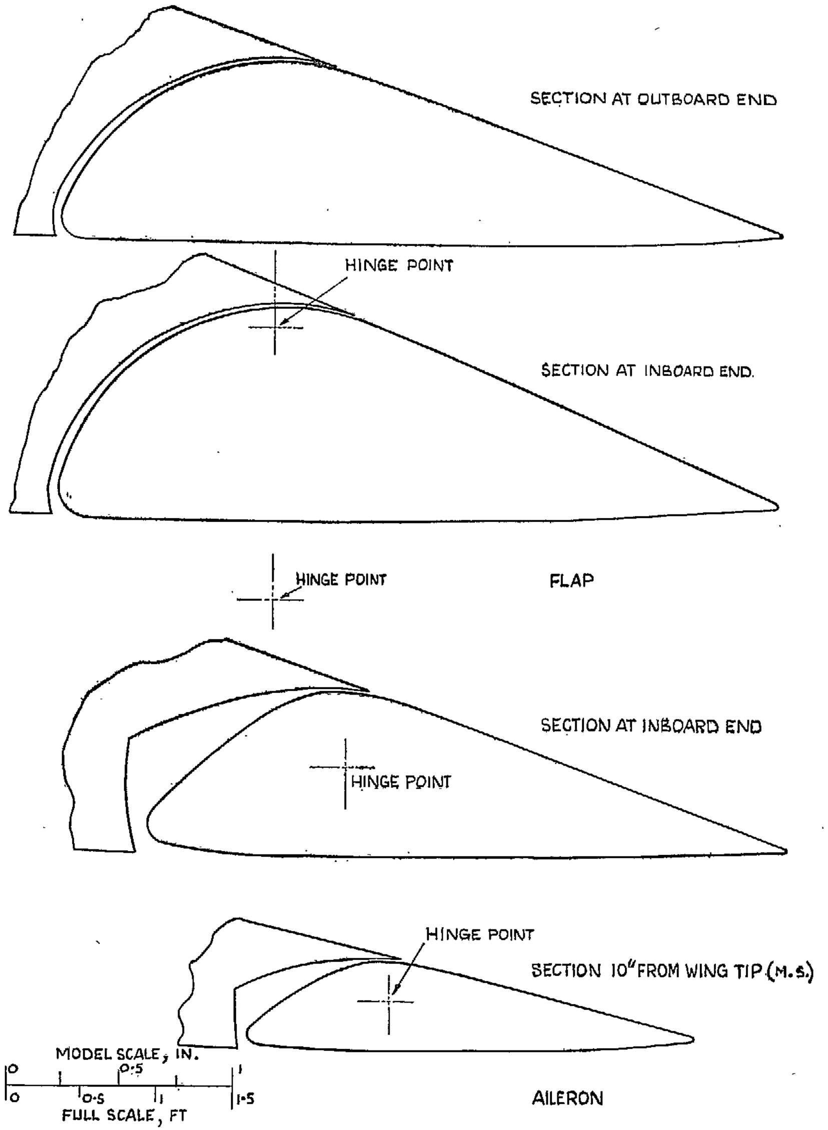

FIG. 2. Flap and Aileron Sections.

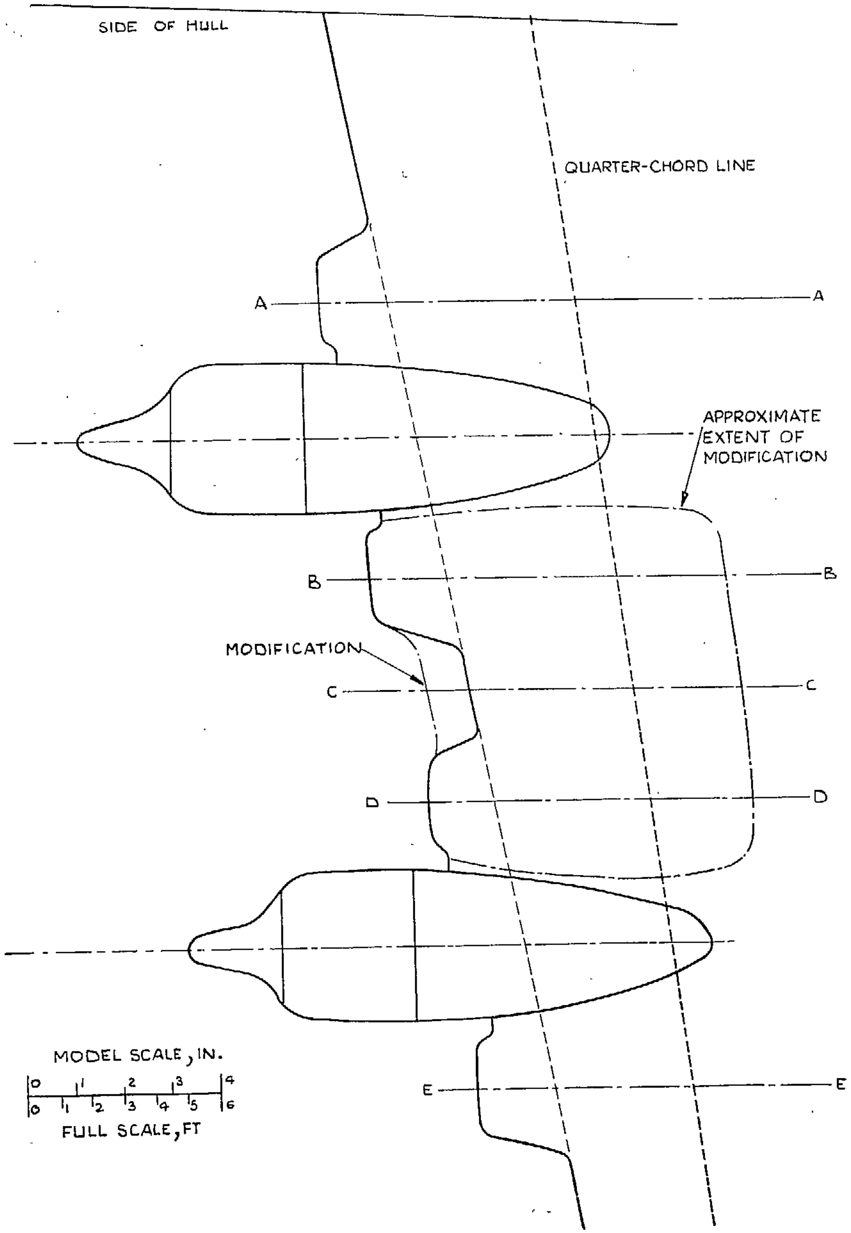

FIG. 3. Layout of Return-flow Nacelles.

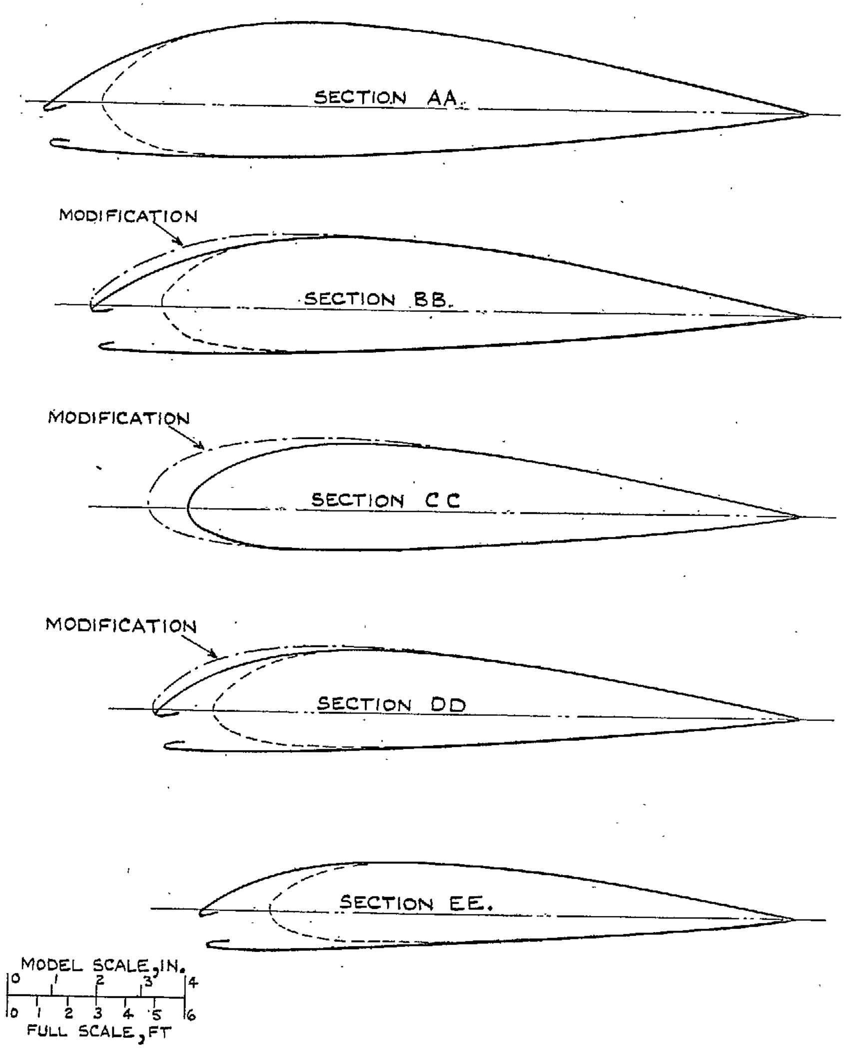

FIG. 4. Wing Sections with Return-flow Nacelles.

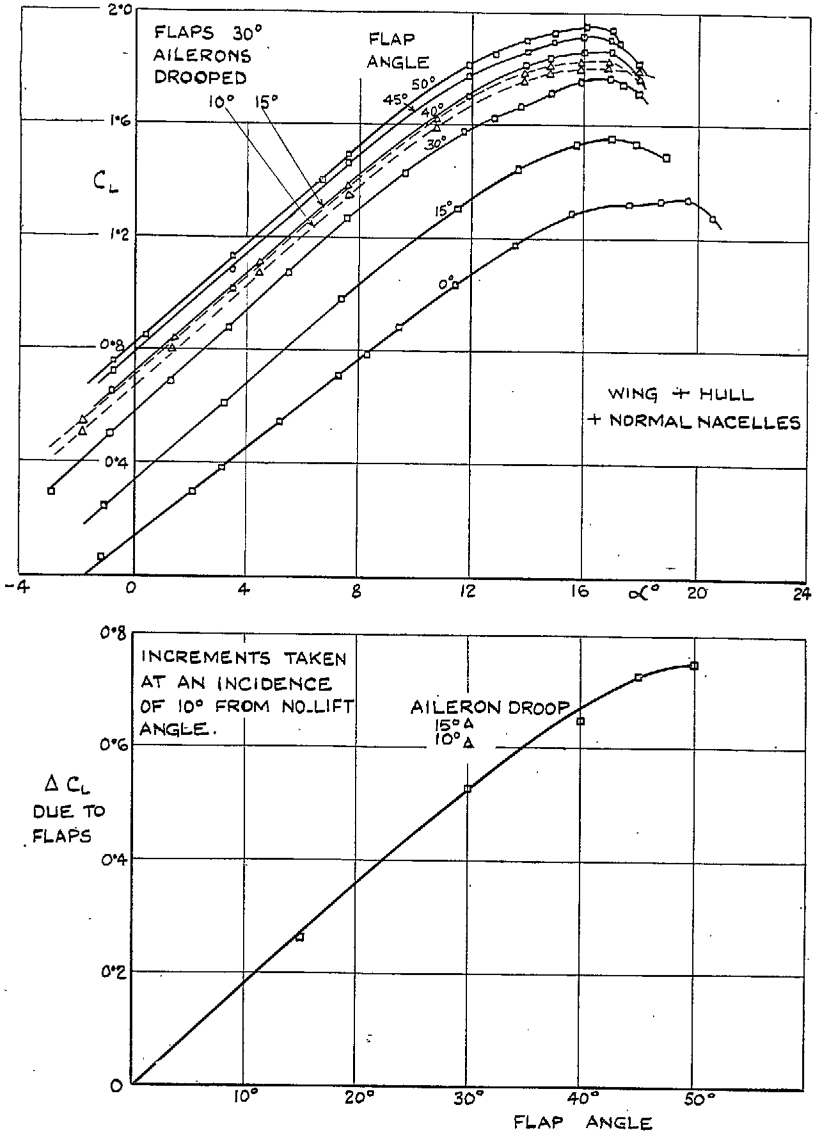

FIG. 5. Lift Due to Flaps.

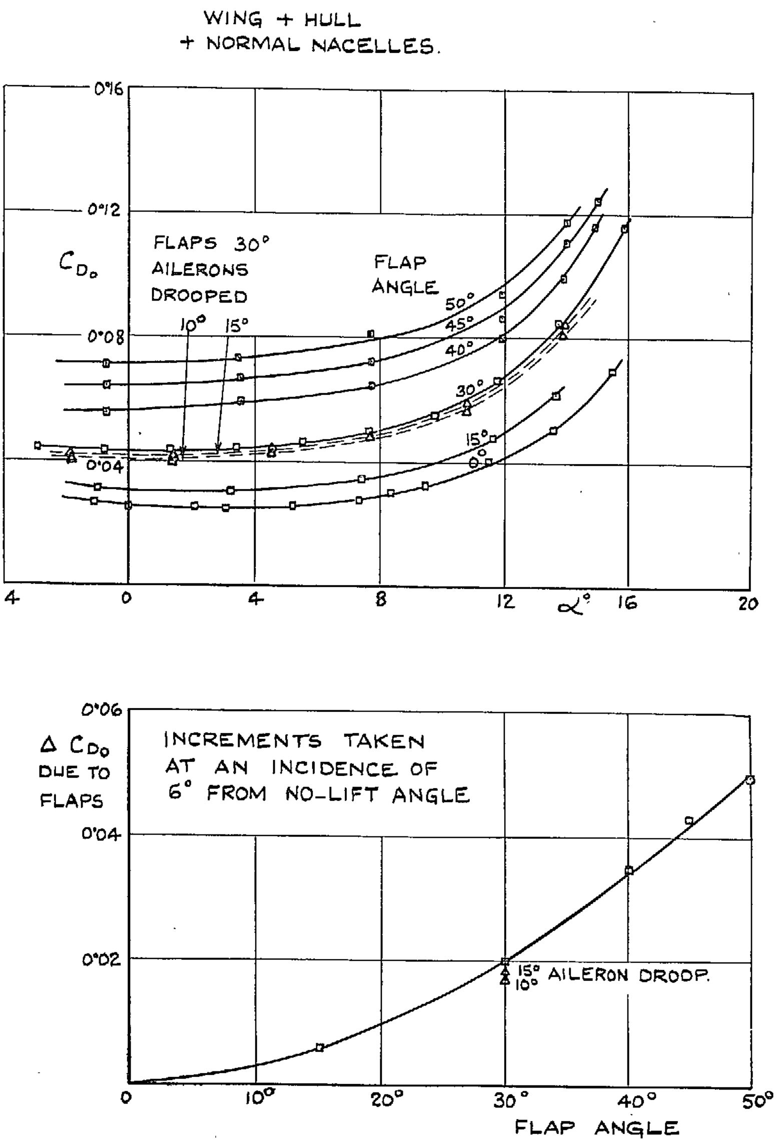

FIG. 6. Drag Due to Flaps.

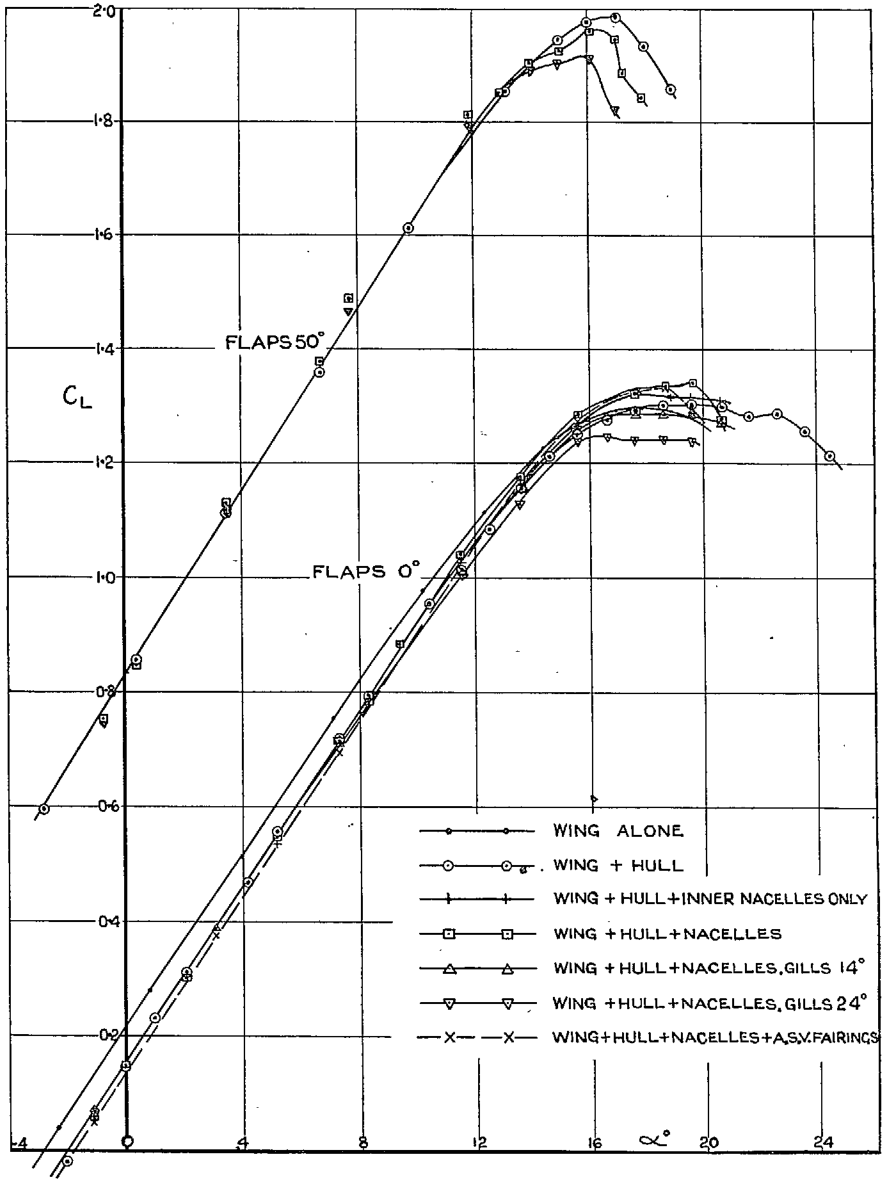

FIG. 7. Lift with Normal Nacelles.

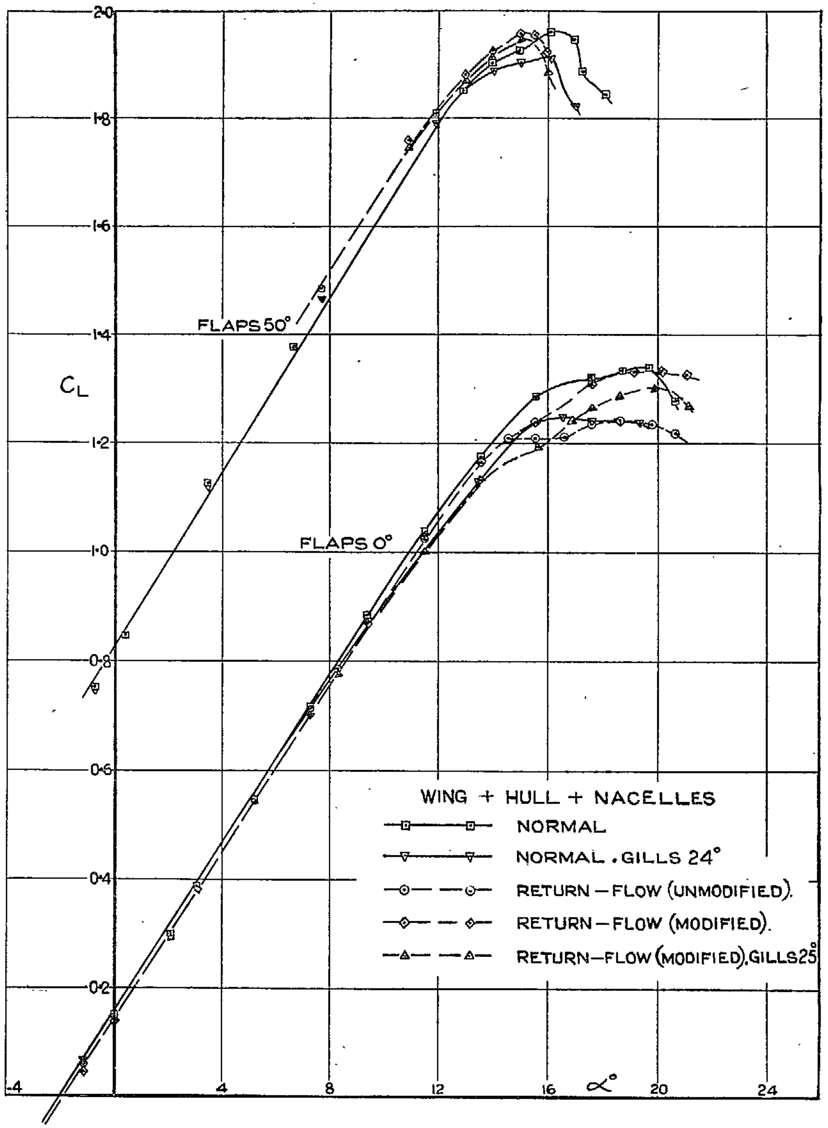

FIG. 8. Effect of Return-flow Nacelles on Lift.

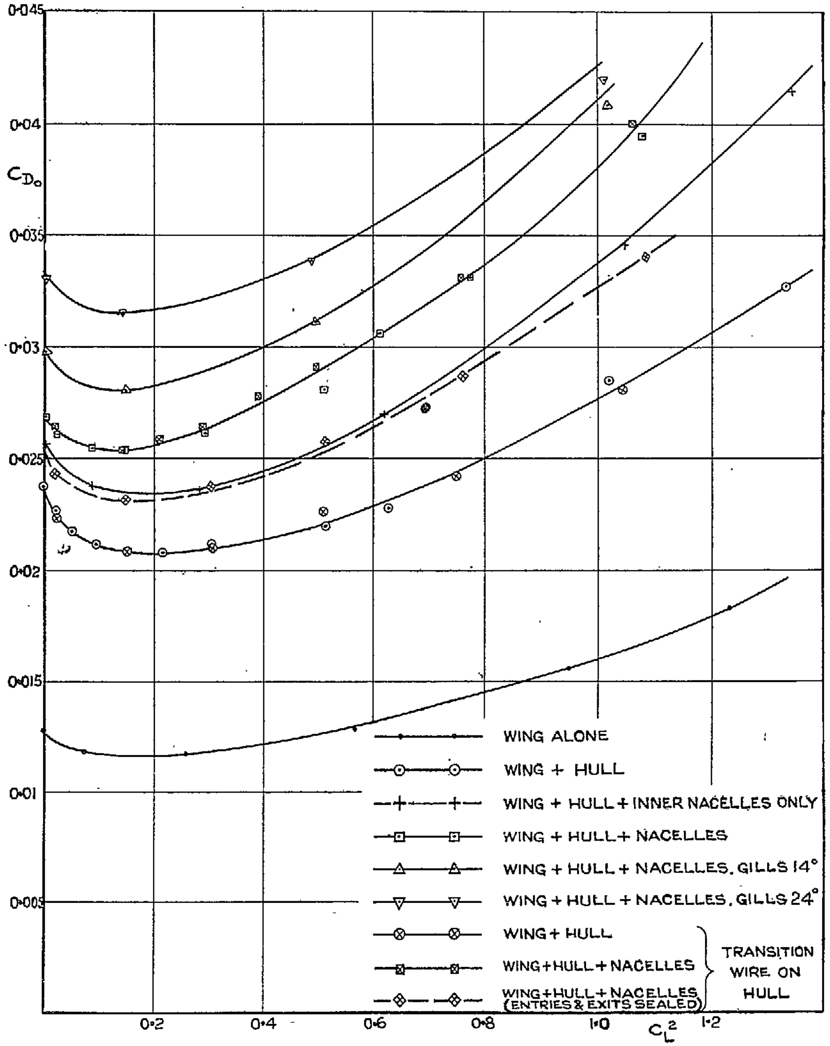

FIG. 9. Drag with Normal Nacelles—Flaps 0 deg.

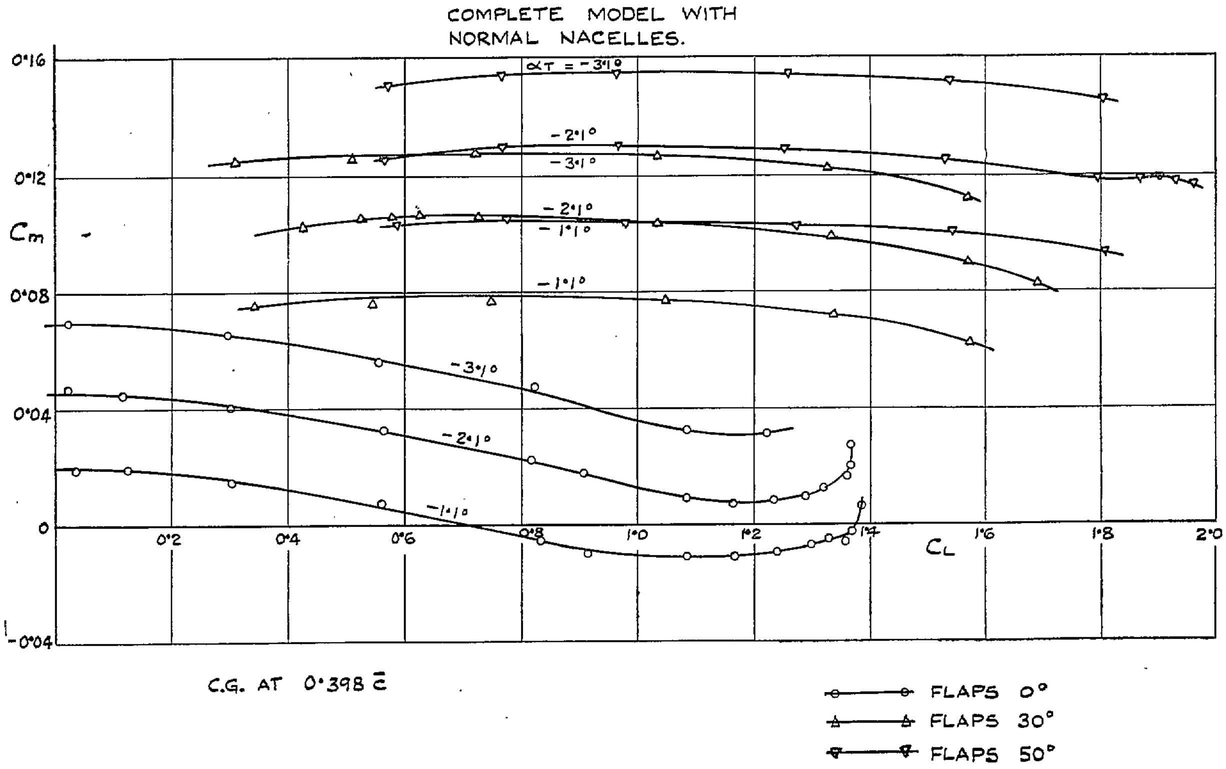

FIG. 10. Pitching Moment Due to Flaps: C_m against C_L.

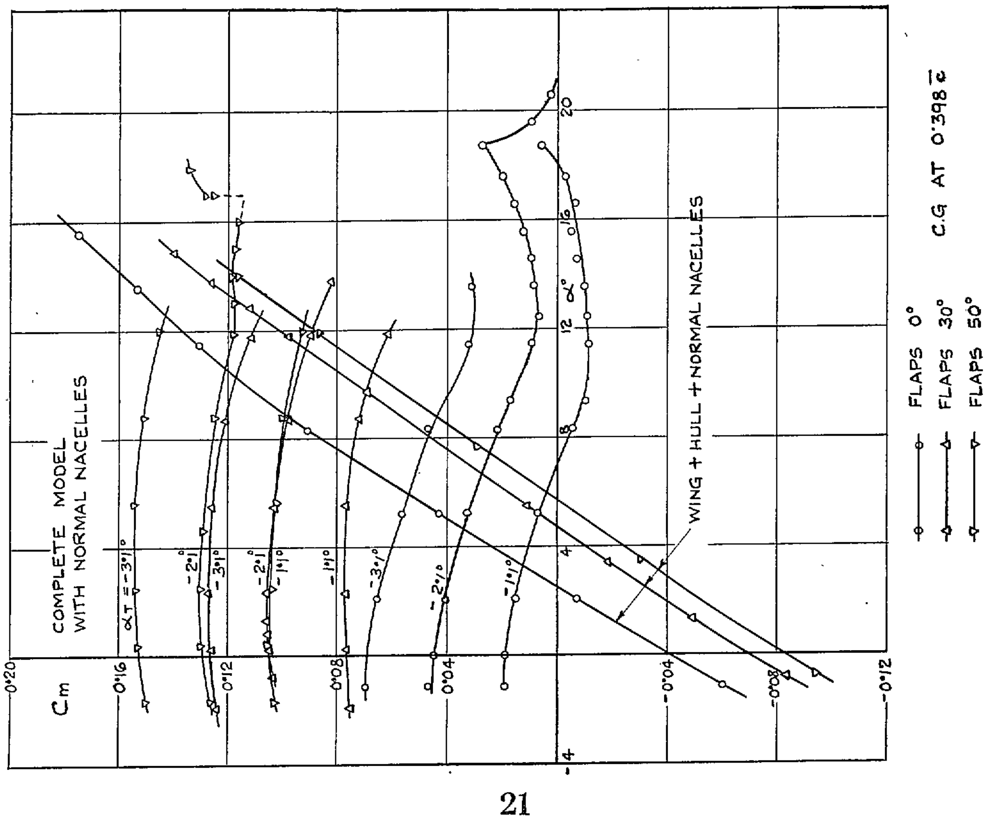

FIG. 11. Pitching Moment Due to Flaps: C_m against α.

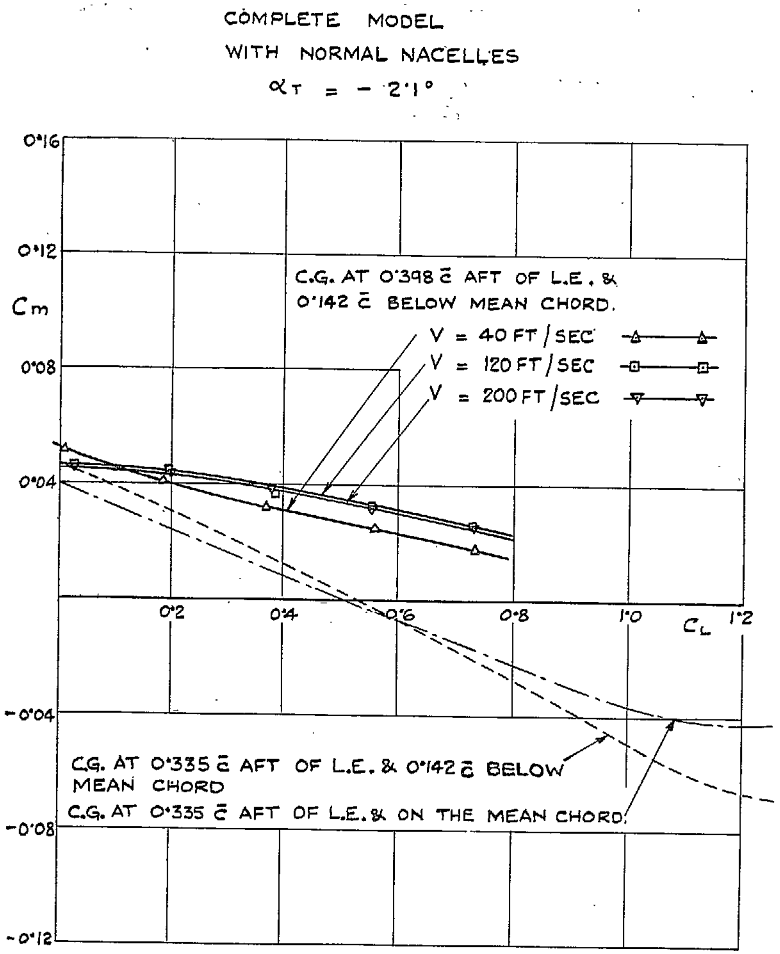

FIG. 12. Scale Effect and Effect of C.G. Position on Pitching Moment: Flaps 0 deg.

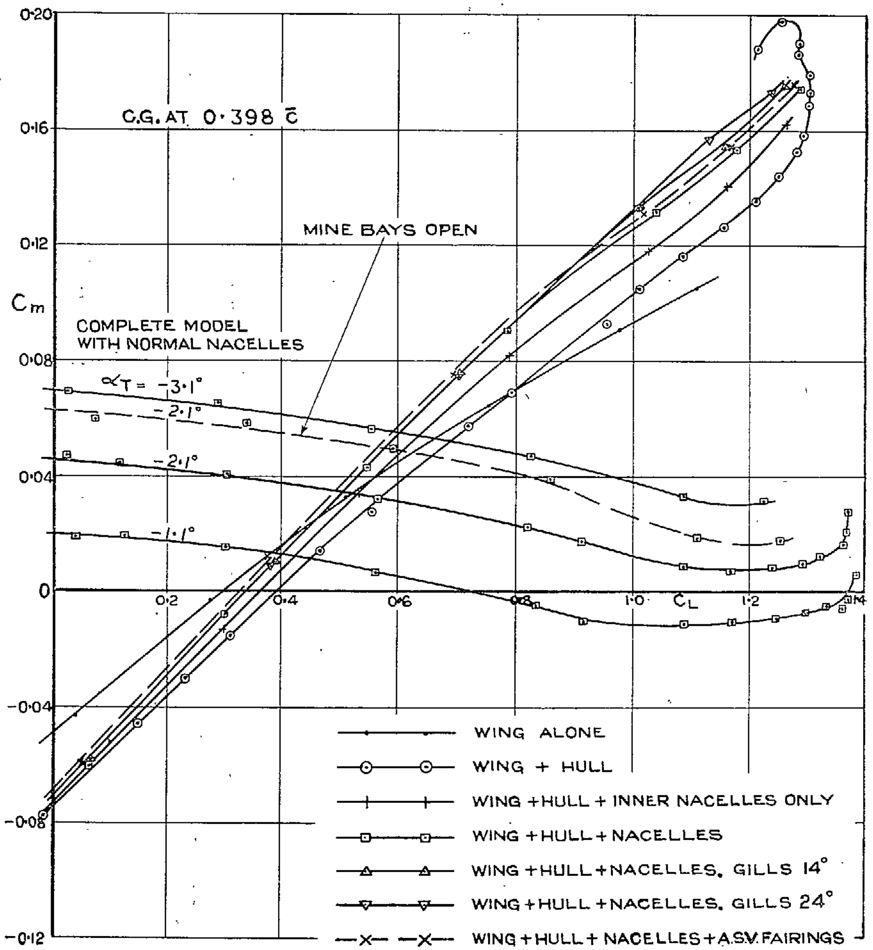

FIG. 13. Analysis of Pitching Moments with Flaps 0 deg.

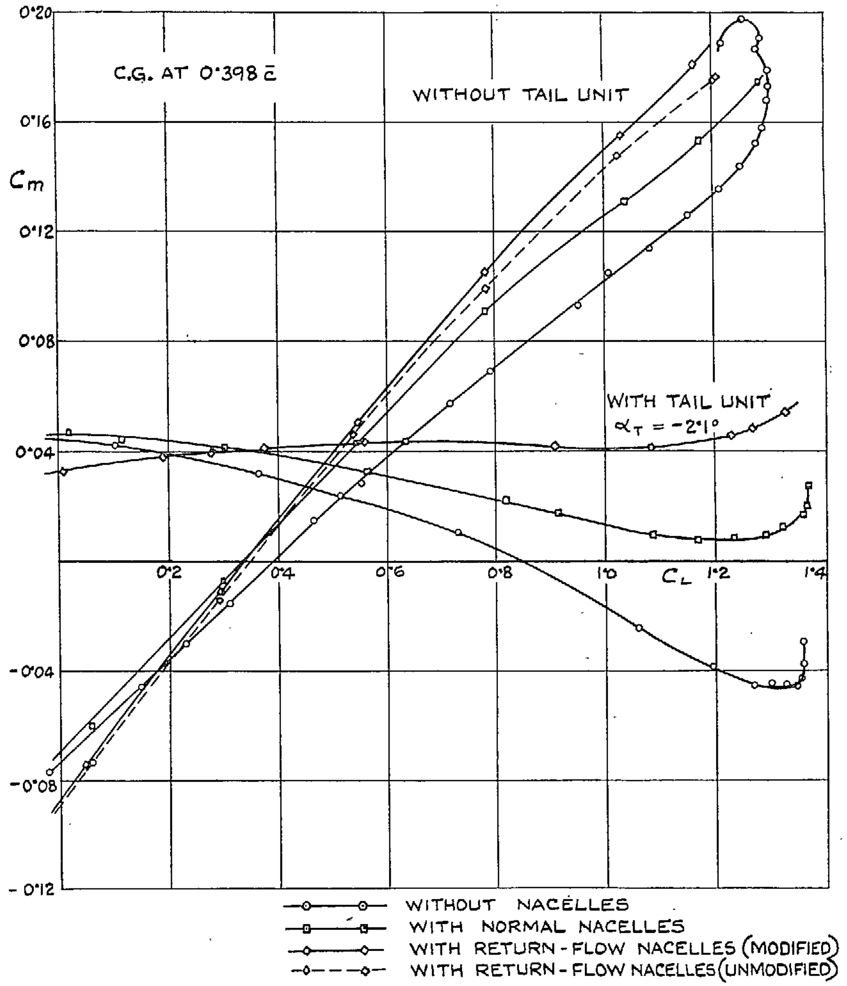

FIG. 14. Effect of Nacelles on Pitching Moment C_m against C_L: Flaps 0 deg.

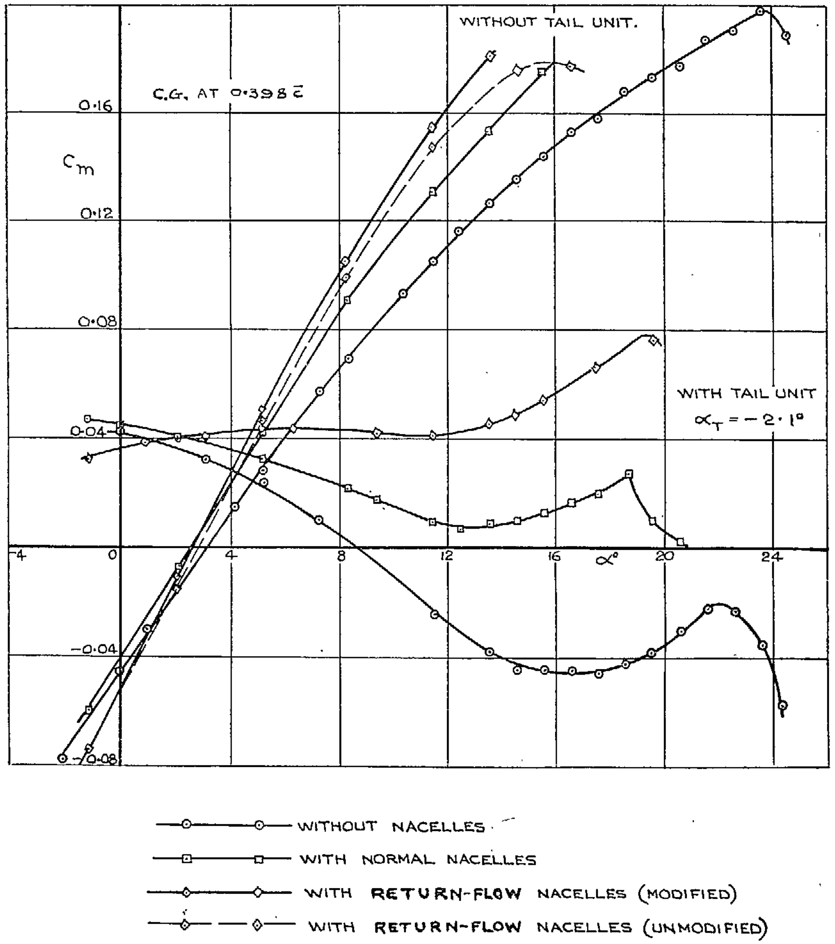

Fig. 15. Effect of Nacelles on Pitching Moment C_m against α: Flaps 0 deg.

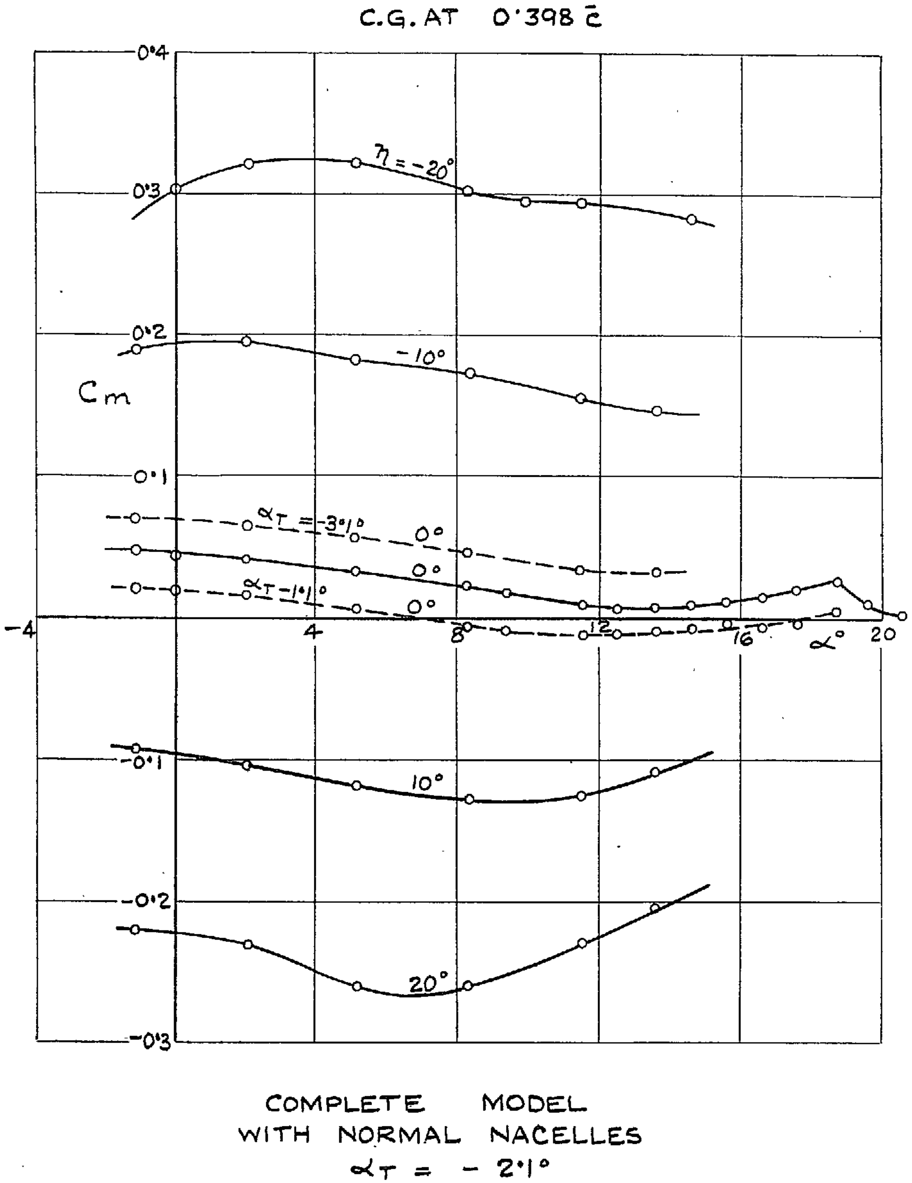

FIG. 16. Pitching Moment Due to Elevators.

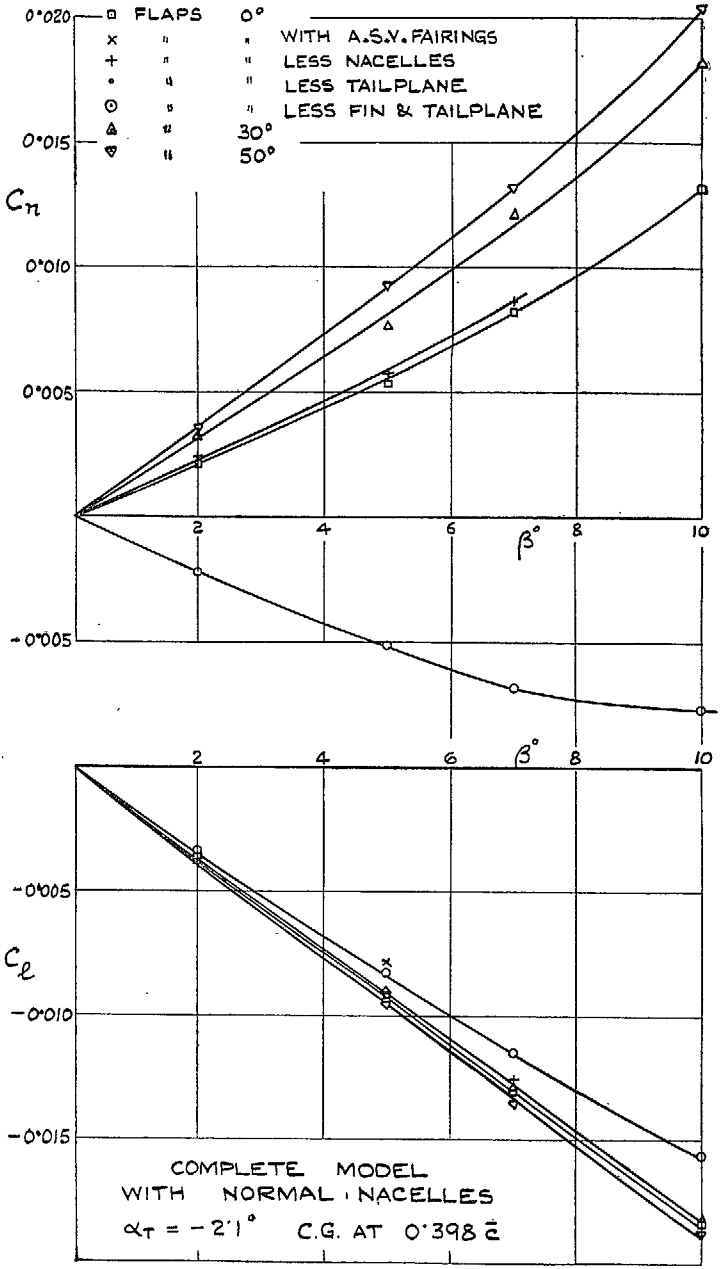

FIG. 17. Yawing and Rolling Moments: α = 7 deg.

(95501) Wt. 14/806 K.5 1/51 Hw.

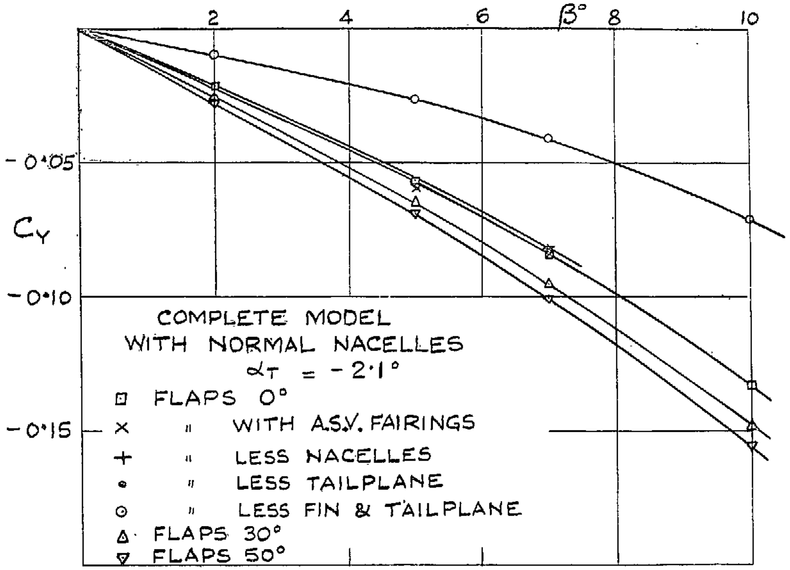

FIG. 18. Side-Force—$\alpha = 7$ deg.

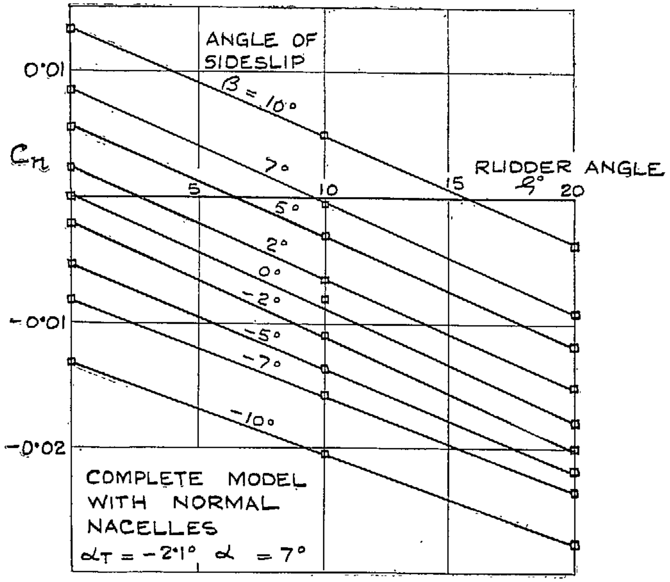

FIG. 19. Yawing Moment Due to Rudder.

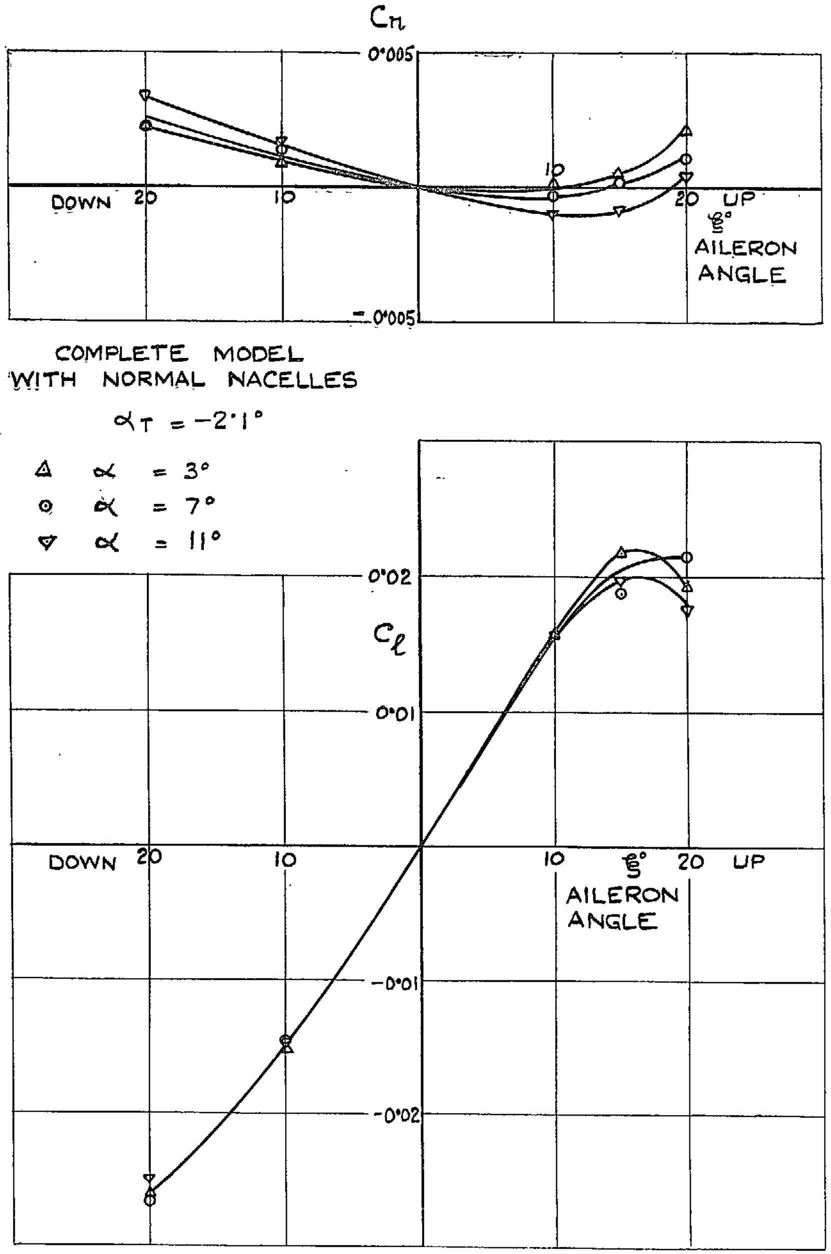

FIG. 20. Yawing and Rolling Moments Due to One Aileron.

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