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Note on Wind-Tunnel Measurements of Yawing Moment, Rudder Fixed and Free, on Models of Three Aircraft

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Summary.—Reasons for Enquiry.—In considering the lateral stability characteristics of an aircraft, values of the derivatives l_v and n_v with rudder free are needed. Since the effect on n_v of freeing rudders having different types of balance was not known quantitatively, measurements of n_v with rudders fixed and free were made on three aircraft having rudders with set-back hinge and horn balance.

Range of Investigation.—Yawing moments and rudder power were measured with rudder fixed and free on models of the Sunderland, Halifax and Lancaster. In some cases rolling moment and side force were measured, the latter quantity being useful for calculations of flat turning radii.

The tests include variations of rudder balance. The fin and rudder data have been compared with previous results for single and double fins and rudders.

Conclusions.—The effect on n_v of freeing the rudders is small for those rudders with set-back hinges or with shielded horn balance but large with unshielded horn balance ; n_v was more than doubled by freeing a rudder with a 9·5 per cent. unshielded horn. Any destabilising effect of freeing the rudder is likely to be greatest when the rudder is closely balanced by a geared tab, with no horn and little or no set-back of the hinge.

1. *Introduction.*—The lateral stability characteristics of an aircraft depend mainly on the derivatives l_v and n_v, and some criterion of the relation between l_v and n_v to give satisfactory stability is needed. In normal cruising flight the conditions to be assumed in considering l_v and n_v are probably considerably nearer those of rudder free than fixed. Many model tests have been made of n_v when the rudder is fixed but none at the Royal Aircraft Establishment with rudder free. It may be noted that the effect of freeing the rudders is almost entirely confined to n_v, since the fin and rudder contributions to l_v is usually not very large.

In order therefore, to provide data on the effect of freeing the rudder on n_v, yawing moment, and in some cases rolling-moment measurements were made with rudders fixed and free on models of the Sunderland, Halifax and Lancaster.

Rudder power and side force were also measured. Besides testing the standard rudders for these aircraft, the effects of modifications to the rudder balance were found.

2. *Details of Tests.*—The tests were made at 122 ft./sec. in the $11\frac{1}{2}$ ft. × $8\frac{1}{2}$ ft. wind tunnel at the Royal Aircraft Establishment during February, 1941. Details of the models are given in Tables 1, 2 and 3, and Figs. 1 to 6. The rudders when free were mass-balanced ; when the

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aerodynamic balance was changed the rudders were not re-balanced, since it was shown that the effect of the out-of-balance weight moments was negligible. Three fin and rudder units were tested on the Lancaster (Fig. 6). Two of those had shielded horn balance, and the third had an unshielded horn. The effect of adding the central fin shown in Fig. 5 was also measured.

Yawing moment with rudders fixed and free, rolling moment, side force and rudder power were measured at two values of C_L, 0·2 and 0·8, corresponding approximately to top speed and climb conditions.

3. *Results.*—The effect on n_v of freeing the rudder at $C_L = 0{\cdot}2$ is summarised in the following table :—

Aircraft	Type of balance and percentage balance*		Rudder fixed $n_v \times 10^3$	Rudder free $n_v \times 10^3$	Reference to Tables and Figures
Sunderland, Shorts	Set-back hinge	21·3	76·8	66·1	Tables 1 and 1(a). Figs. 2 and 7.
		24·8		61·0	
		28·0		62·9	
		32·0		66·4	
Halifax, Handley Page	Set-back hinge	23·8	49·5	42·0	Tables 2 and 2(a). Figs. 4 and 9.
		29·0		47·9	
Lancaster, A. V. Roe	Inset horn	14·5	53·7	49·9	Tables 3 and 3(a). Figs. 6 and 11.
	Inset horn	7·6	55·8	57·5	
	Unshielded horn	9·54	40·0	108·7	

* Percentage balance = Area of rudder ahead of hinge/Total area of rudder.

A table of the lateral stability derivatives measured for all three aircraft is given in Table 4.

It can be seen therefore that the effect of freeing the rudders on n_v is small when the rudders have a set-back hinge or a shielded horn balance, but when the horn is unshielded the effect is most marked, n_v being more than doubled by freeing the rudder with a 9·5 per cent. unshielded horn balance.

The effect of freeing the rudders can be expressed mathematically as follows.

$$n_v \text{ (rudder fixed)} = \left(\frac{\partial C_{nB}}{\partial \beta}\right) + a_1 \bar{V}'',$$

$$n_v \text{ (rudder free)} = \left(\frac{\partial C_{nB}}{\partial \beta}\right) + a_1 \left(1 - \frac{a_2}{a_1}\frac{b_1}{b_2}\right) \bar{V}'',$$

where C_{nB} denotes yawing moment with fin removed; a_1, a_2, b_1 and b_2 are the usual constants associated with the fin and rudder; β is angle of sideslip; and $\bar{V}''$ fin and rudder volume coefficient.

These equations do not strictly apply to single-fin tail units, since in this case a sidewash factor should be taken into account. They serve however to show the type of change which occurs due to freeing the rudders.

The directional stability with rudder free is increased when b_1/b_2 has a negative value, or since b_2 is always negative unless the rudder is overbalanced when b_1 is positive.

From the results of the present tests a_1, a_2, and b_1/b_2 have been determined from the yawing moment measurements. These values are given in Table 5 from which it can be seen that, while b_1/b_2 is small and positive for set-back hinge and shielded horn-balanced rudders it may be large and negative for unshielded horn-balanced rudders. The values of b_1/b_2 agree very well with the curves of Ref. 1.

It may be noted in passing that if, with rudders having no horn and little or no set-back of the hinge, a close balance (small $-b_2$) is obtained by means of a geared tab, b_1 is then likely to be negative and the positive value of b_1/b_2 may be large. There will be a considerable reduction of the n_v due to fin and rudder on freeing the rudder. In such cases, and where as often happens the body n_v is unstable, freeing the rudder may make the aircraft as a whole directionally unstable. Further experimental work on this point is needed.

REFERENCE

No.	*Author*	*Title, etc.*
1	Priestley	An Analysis of Model Hinge Moments on Set-back Hinge and Horn-balanced controls. A.R.C. 4536. January, 1940.

TABLE 1

Sunderland : Model Dimensions, etc.

Scale of model	1/12
Wing area S	11·6 sq. ft.
Wing span b	9·36 ft.
Mean chord $\bar{c}$	1·24 ft.
Aspect ratio	7·55
Dihedral	3 deg.
Wing setting to hull datum	6 deg. 9 min.
C.G. position	
Distance aft of leading edge root chord (measured parallel to chord).	0·646 ft.
Distance perpendicular to and above root chord	0·052 ft.
Tail unit details	
Tail plane setting to wing η_T	− 2 deg. 9 min.
Fin and rudder area S''	1·052 sq. ft.
Total rudder area	0·383 sq. ft.
Arm to C.G. l''	3·64 ft.
Fin and rudder volume $\left(= \frac{S''l''}{Sb}\right)$	0·0352
Rudder balance on Sunderland	28 per cent.
Other rudder balances tested	32 per cent., 24·8 per cent., 21·3 per cent.

$$\left(\text{Rudder balance} = \frac{\text{Area ahead of hinge}}{\text{Total rudder area}}\right)$$

The values of l_v and n_v quoted are a mean slope for the range $\beta = \pm 5$ deg., and not the slope at the origin.

TABLE 1(*a*)

Sunderland : Yawing Moment and Side Force Coefficients

$V = 122$ ft/sec

Condition	Angle of sideslip $\beta°$	$C_L = 0{\cdot}2$		$C_L = 0{\cdot}8$	
		$C_n \times 10^3$	C_Y	$C_n \times 10^3$	C_Y
No tail or fins and rudders	0	0	0	0	0
	2·5	−2·16	−0·0153	−2·35	−0·0170
	5·0	−3·62	−0·0362	−4·13	−0·0347
	10·0	−5·38	−0·0893	−5·76	−0·0848
With tail and fin and rudders					
Rudder fixed $\zeta = 0°$	0	0	—	0	—
	2·5	3·11	—	2·74	—
	5·0	7·19	—	6·81	—
	10·0	15·88	—	16·20	—
21·3 per cent balance rudders free	0	0	—	0	—
	2·5	2·53	—	2·35	—
	5·0	6·46	—	5·63	—
	10·0	13·76	—	14·38	—
24·8 per cent balance rudders free	0	0	—	0	—
	2·5	2·43	—	2·33	—
	5·0	5·80	—	5·61	—
	10·0	14·08	—	14·06	—
28 per cent balance rudders free (mass balanced)	0	0	—	0	—
	2·5	2·37	—	2·30	—
	5·0	6·20	—	6·08	—
	10·0	14·34	—	14·52	—
32 per cent balance rudders free	0	0	—	0	—
	2·5	2·51	—	2·14	—
	5·0	6·55	—	6·27	—
	10·0	15·00	—	15·35	—

Rudder Power

Condition	Rudder angle $\zeta°$	$C_L = 0{\cdot}2$	$C_L = 0{\cdot}8$
		$C_n \times 10^3$	$C_n \times 10^3$
21·3 per cent balance ($\beta = 0°$)	0	0	0
	10	−11·5	—
	15	−17·38	−17·14
24·8 per cent balance ($\beta = 0°$)	0	0	—
	15	−14·07	—
28 per cent balance ($\beta = 0°$)	0	0	0
	5	—	− 5·05
	10	—	− 9·94
	15	−13·52	−14·05
	20	—	−18·37
	25	—	−21·92
	30	—	−22·08
32 per cent balance ($\beta = 0°$)	0	—	—
	15	−13·77	—

TABLE 2

Halifax—Model Dimensions, etc.

Scale of model	1/10
Wing area S	12·5 sq ft
Wing span b	9·9 ft
Mean chord $\bar{c}$	1·262 ft
Aspect ratio	7·84
Dihedral	5·3 deg
Wing setting to body datum	5·0 deg
C.G. position	
Distance aft of leading edge root chord (measured parallel to chord)	0·55 ft
Distance perpendicular to and below root chord	0·021 ft
Tail unit details	
Tailplane setting to wing η_T	= −2·1 deg
Fin and rudder area S″	= 1·176 sq ft
Total rudder area	= 0·60 sq ft
Arm to C.G. l''	= 3·30 ft
Fin and rudder volume $\left(= \frac{S''l''}{Sb}\right)$	= 0·031
Rudder balances :—	23·8 and 29 per cent (Production balance)

$$\left(\text{Rudder Balance} = \frac{\text{Area ahead of hinge}}{\text{Total rudder area}}\right)$$

TABLE 2 (*a*)

Halifax : Yawing Moment, Rolling Moment and Side Force Coefficients

$V = 122$ ft/sec

Condition	Angle of sideslip $\beta°$	$C_L = 0·2$			$C_L = 0·8$		
		$C_n \times 10^3$	$C_l \times 10^3$	C_Y	$C_n \times 10^3$	$C_l \times 10^3$	C_Y
No tail or fins and rudders	0	0	—	0	0	—	0
	2·5	−1·34	—	−0·0069	−1·12	—	−0·0054
	5·0	−2·58	—	−0·0145	−2·31	—	−0·0119
	10·0	−4·04	—	−0·0334	−4·71	—	−0·0279
With tail and fins and rudders							
29 per cent balance rudder fixed $\zeta = 0°$	0	0	0	0	0	0	0
	2·5	1·95	−3·65	−0·0165	1·84	−3·52	−0·0114
	5·0	4·73	−7·41	−0·0326	3·68	−7·05	−0·0232
	10·0	9·05	−14·12	−0·0670	7·74	−14·55	−0·0486
Rudders mass-balanced and free	0	0	0	—	0	0	—
	2·5	2·13	−3·85	—	1·77	−3·30	—
	5·0	4·11	−7·56	—	3·49	−6·37	—
	10·0	8·72	−14·84	—	6·73	−13·76	—
24 per cent balance rudders free (not mass-balanced)	0	0	—	—	—	—	—
	2·5	1·98	—	—	—	—	—
	5·0	3·37	—	—	—	—	—
	10·0	7·07	—	—	—	—	—

TABLE 2 (*a*)—*contd.*

Rudder Power and Side Force Coefficients

(V = 122 ft/sec)

Condition	Rudder angle $\zeta°$	$C_L = 0{\cdot}2$		$C_L = 0{\cdot}8$	
		$C_n \times 10^3$	C_Y	$C_n \times 10^3$	C_Y
29 per cent. balance rudder .. ($\beta = 0°$)	0	0	0	0	0
	5	—	—	−4·40	0·0050
	10	−9·08	0·0198	−8·77	0·0154
	15	—	—	−13·56	0·0260
	20	−18·23	0·0398	−17·83	0·0415
	25	−21·02	0·0457	−20·08	0·0461
	30	−14·27	0·0313	−16·94	0·0393
($\beta = -10°$)	−15	3·55	—	5·41	—
	0	−9·33	—	−7·87	—
	15	−23·13	—	−21·05	—
($\beta = +10°$)	−15	—	—	18·41	—
	−10	+18·76	—	16·46	—
	0	9·05	—	7·74	—
	15	−5·12	—	−5·73	—
24 per cent. balance .. .. ($\beta = 0°$)	0	0	—	—	—
	10	−9·02	—	—	—
	20	−18·70	—	—	—

TABLE 3

Lancaster—Model Dimensions, etc.

Scale of model	1/12
Wing area S	9·00 sq ft
Wing span b	8·50 ft
Mean chord $\bar{c}$	1·06 ft
Aspect ratio	8·01
Dihedral	6 deg 46 min
Wing setting to body datum	4 deg
C.G. position	
Distance aft of leading-edge root chord (measured parallel to chord)	0·459 ft
Distance perpendicular to and below root chord ..	0·025 ft
Tail unit details	
Tailplane setting to wing η_T .. .. .. =	− 1·6 deg
Tailplane span .. .. =	2·75 ft

Fin and rudder details :—

	Large A.R. Fins and rudders	Small A.R. Fins and rudders with central fin	Small A.R. Fins and rudders no central fin	Rudders with unshielded horn
Fin and rudder area S''	0·772 ft²	0·832 ft²	0·574 ft²	0·694 ft²
Arm to C.G. l''	3·11 ft	3·07 ft	3·11 ft	3·11 ft
Rudder area	0·307 ft²	0·236 ft²	0·236 ft²	0·322 ft²
Rudder balance $= \dfrac{\text{Area of horn to hinge line}}{\text{Total area of rudder}}$	14·5%	7·6%	7·6%	9·54%
Fin and rudder volume $= \dfrac{S''l''}{Sb}$	0·0314	0·0334	0·0234	0·0282

TABLE 3 (*a*)

Lancaster : Yawing Moment, Rolling Moment and Side Force Coefficients

(V = 122 ft/sec)

Condition	Angle of sideslip $\beta°$	$C_L = 0·2$			$C_L = 0·8$		
		$C_n \times 10^3$	$C_l \times 10^3$	C_Y	$C_n \times 10^3$	$C_l \times 10^3$	C_Y
No tail or fins and rudders	0	0	0	0	0	0	0
	2·5	− 1·13	− 3·74	−0·0072	− 1·22	− 4·32	−0·0062
	5·0	− 1·66	− 7·64	−0·0149	− 2·48	− 7·79	−0·0131
	10·0	− 3·58	−15·13	−0·0329	− 4·71	−15·45	−0·0298
With tail and fins and rudders							
Large A.R. fins with inset horn-balanced rudders							
Rudders fixed $\zeta = 0°$	0	0	0	0	0	0	0
	2·5	2·39	− 4·64	−0·0168	1·80	− 4·38	−0·0150
	5·0	4·59	− 8·97	−0·0342	3·32	− 8·34	−0·0301
	10·0	9·25	−18·87	−0·0701	7·72	−16·98	−0·0651
Rudders free and mass-balanced	0	0	0	—	0	—	—
	2·5	1·87	− 4·78	—	1·97	—	—
	5·0	4·36	− 9·12	—	3·76	—	—
	10·0	8·12	−18·93	—	8·28	—	—
Small A.R. fins with inset horn-balanced rudders and central fin							
Rudders fixed $\zeta = 0°$	0	0	0	0	0	0	0
	2·5	2·50	− 4·39	−0·0169	1·74	− 3·97	−0·0150
	5·0	4·75	− 8·58	−0·0344	3·83	− 7·48	−0·0304
	10·0	9·50	−17·05	−0·0717	8·14	−15·15	−0·0665
Rudders free and mass-balanced	0	0	—	—	0	—	—
	2·5	2·59	—	—	1·94	—	—
	5·0	4·84	—	—	4·18	—	—
	10·0	9·91	—	—	9·83	—	—
Small A.R. fins and rudders without central fin							
Rudder fixed $\zeta = 0°$	0	0	0	0	0	0	0
	2·5	0·82	− 4·77	−0·0127	0·35	− 4·08	−0·0113
	5·0	1·36	− 8·27	−0·0260	0·80	− 7·89	−0·0229
	10·0	3·47	−17·52	−0·0540	2·31	−15·71	−0·0320
Rudder free and mass-balanced	0	0	—	—	0	—	—
	2·5	0·71	—	—	0·64	—	—
	5·0	1·78	—	—	1·49	—	—
	10·0	3·93	—	—	4·07	—	—
Fin and rudders with unshielded horn balance							
Rudder fixed $\zeta = 0°$	0	0	—	—	0	—	—
	2·5	1·73	—	—	1·33	—	—
	5·0	3·53	—	—	2·66	—	—
	10·0	7·67	—	—	5·76	—	—
Rudders free and mass-balanced	0	0	—	—	0	—	—
	2·5	4·69	—	—	4·00	—	—
	5·0	9·67	—	—	8·66	—	—
	7·5	12·58	—	—	12·10	—	—
	10·0	15·46	—	—	14·30	—	—

TABLE 3 (*a*) (*Contd.*)

Lancaster : Rudder Power

(V = 122 ft/sec)

Condition	Rudder angle $\zeta°$	$C_L = 0 \cdot 2$, $C_n \times 10^3$, Angle of sideslip $\beta = 0°$	$C_L = 0 \cdot 2$, $C_n \times 10^3$, $\beta = -10°$	$C_L = 0 \cdot 8$, $C_n \times 10^3$, $\beta = 0°$	$C_L = 0 \cdot 8$, $C_n \times 10^3$, $\beta = -10°$
Large A.R. fins and rudders	−25	—	7·11	—	9·38
	−20	—	—	—	6·63
	−15	—	3·06	—	4·62
	−10	—	− 0·89	—	0·74
	− 5	—	—	—	—
	0	0	− 9·44	0	− 7·57
	5	− 4·81	—	− 4·62	—
	10	− 8·97	−16·98	− 8·66	−15·59
	15	−11·94	−20·61	−11·90	−18·83
	20	−14·36	—	−14·36	—
	25	−16·96	−25·52	−16·62	−23·68
Small A.R. fins and rudders *with* central fin	−25	—	− 0·16	—	2·37
	−20	—	—	—	—
	−15	—	− 2·71	—	− 0·25
	−10	—	− 4·69	—	− 2·32
	− 5	—	—	—	—
	0	0	− 9·71	0	− 7·28
	5	− 2·57	—	—	—
	10	− 4·94	−13·99	− 4·51	−11·94
	15	− 6·84	−16·15	− 6·46	−13·82
	20	− 8·58	—	—	—
	25	−10·14	−19·70	− 9·88	−17·04
Without central fin	0	0	—	0	—
	5	− 2·61	—	—	—
	10	− 5·03	—	− 4·93	—
	15	− 7·20	—	− 6·83	—
	20	− 8·85	—	− 8·63	—
	25	−10·52	—	−10·27	—
Unshielded horn-balanced rudders	−25	—	8·42	—	11·21
	−20	—	—	—	—
	−15	—	4·18	—	—
	−10	—	0·69	—	3·04
	− 5	—	—	—	—
	0	0	− 8·12	0	− 5·86
	5	− 4·61	—	—	—
	10	− 9·04	−16·28	− 8·55	−14·32
	15	−11·84	−19·53	−11·91	−19·27
	20	−14·16	—	—	—
	25	−16·93	−21·43	−16·83	—

A.R. Abbreviation for Aspect Ratio.

TABLE 4

Values of Lateral Stability Derivatives, Rudders Fixed and Free

Condition	$C_L = 0{\cdot}2$				$C_L = 0{\cdot}8$			
	$n_v \times 10^3$	$l_v \times 10^3$	$\frac{\partial C_Y^*}{\partial \beta}$	$\frac{10^3 \partial C_n^*}{\partial \zeta^\circ}$	$n_v \times 10^3$	$l_v \times 10^3$	$\frac{\partial C_Y^*}{\partial \beta}$	$\frac{10^3 \partial C_n^*}{\partial \zeta^\circ}$
Sunderland (*Table* 1(*a*) *and Figs.* 7 *and* 8)								
No fin and rudder	−45·5	—	−0·382	—	−50·5	—	−0·394	—
With fin and rudder								
Rudder fixed $\zeta = 0^\circ$ ..	76·8	—	—	—	70·5	—	—	—
Free rudders								
21·3 per cent. balance ..	66·1	—	—	−66·0	59·5	—	—	−65·5
23·8 per cent. balance ..	61·0	—	—	−53·8	58·9	—	—	—
25 per cent. balance ..	62·9	—	—	−51·7	61·2	—	—	−53·6
32 per cent. balance ..	66·4	—	—	−52·6	63·6	—	—	—
Halifax (*Table* 2(*a*) *and Figs.* 9 *and* 10)								
No fins and rudders	−30·2	—	−0·162	—	−25·7	—	−0·130	—
With fin and rudder								
29 per cent. balance rudder								
fixed $\zeta = 0^\circ$	49·5	−84·5	−0·376	—	42·2	−80·8	−0·263	—
free	47·9	−87·4	—	−52	40·3	−74·3	—	−50·3
24 per cent. balance rudder								
free	42·0	—	—	−51·7	—	—	—	—
Lancaster (*Table* 3(*a*) *and Figs.* 11 *and* 12)								
No fins and rudders	−20·5	−86·5	−0·166	—	−27·0	−89·1	−0·146	—
With fins and rudders. Large A.R. fins with inset horn-balanced rudders								
Rudders fixed $\zeta = 20^\circ$ ..	53·7	−104·2	−0·388	—	39·6	−98·1	−0·344	—
Rudders free	49·9	−106·9	—	−53·1	44·2	—	—	−51·5
Small A.R. fins with inset horn-balanced rudders and a central fin								
Rudders fixed $\zeta = 20^\circ$ ..	55·8	−99·7	−0·391	—	41·9	−88·4	−0·346	—
Rudders free	57·5	—	—	28·8	46·2	—	—	−25·8
Small A.R. fins with inset horn-balanced rudders without central fin								
Rudders fixed $\zeta = 20^\circ$ ..	17·2	−101·5	−0·292	—	8·62	−92·0	−0·261	—
Rudders free	18·3	—	—	−29·4	15·9	—	—	−28·2
Fins and rudders with unshielded horn balance								
Rudders fixed $\zeta = 20^\circ$ ..	40·0	—	—	—	30·6	—	—	—
Rudders free	108·7	—	—	52·4	95·5	—	—	−49·1

* Angles in radians

TABLE 5

Values of a_1, a_2 and b_1/b_2 from Yawing Moment Measurements.—Sunderland

C_L	a_1	Rudder Balance							
		21·3 per cent.		24·8 per cent.		28·0 per cent.		32·0 per cent.	
		a_2	b_1/b_2	a_2	b_1/b_2	a_2	b_1/b_2	a_2	b_1/b_2
0·2	+3·49	+1·87	+0·155	+1·53	+0·294	+1·47	+0·258	+1·49	+0·208
0·8	+3·48	+1·86	+0·183	—	—	+1·52	+0·165	—	—

Halifax

C_L	a_1	Rudder Balance			
		24 per cent.		29 per cent.	
		a_2	b_1/b_2	a_2	b_1/b_2
0·2	+2·58	+1·71	+0·193	+1·66	+0·060
0·8	+2·18	—	—	+1·63	+0·040

Lancaster

C_L	Small A.R. fins (Shielded horn)			Large A.R. fins (Shielded horn)			Large A.R. fins (Unshielded horn)		
	a_1	a_2	b_1/b_2	a_1	a_2	b_1/b_2	a_1	a_2	b_1/b_2
0·2	+1·62	+1·23	−0·081	+2·38	+1·76	+0·102	+2·18	+1·87	−0·932
0·8	+1·76	+1·21	−0·256	+2·14	+1·69	−0·095	+2·08	+1·74	−1·09

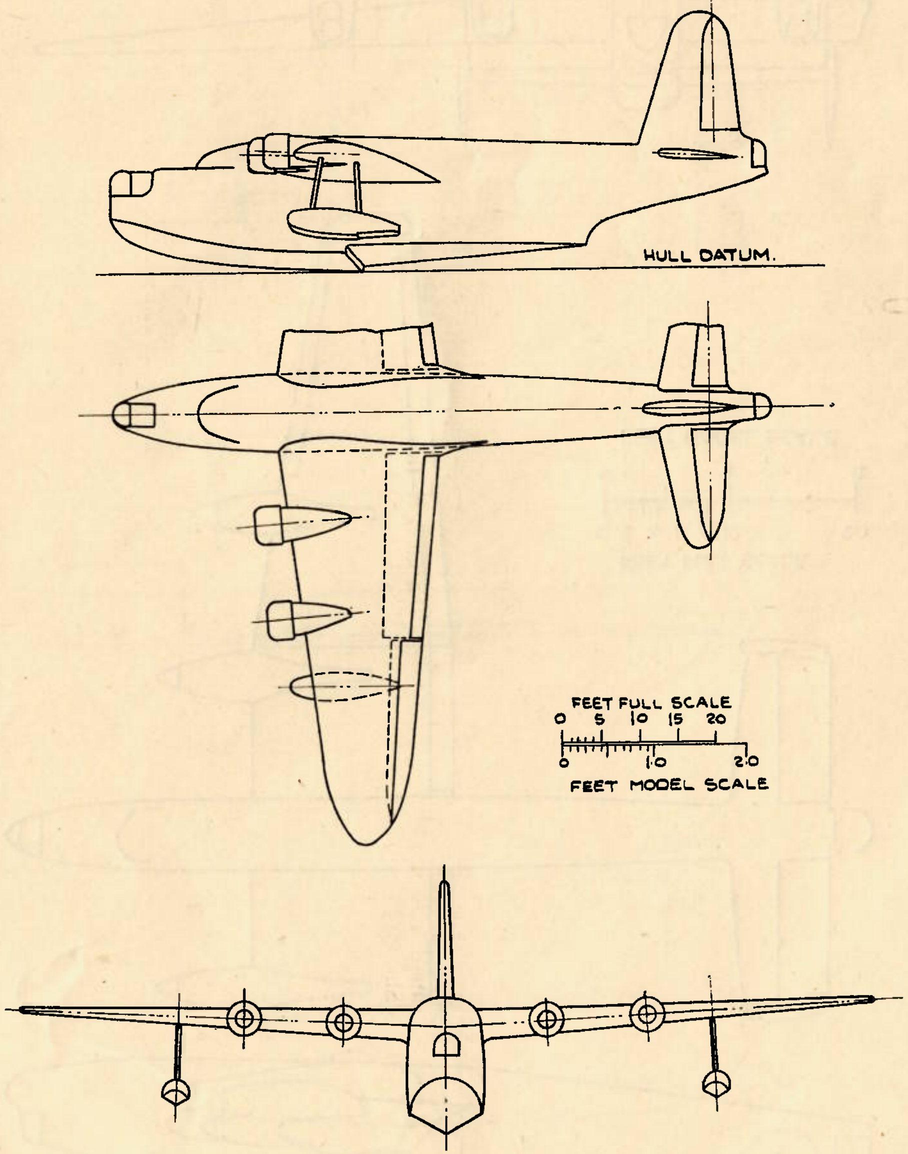

Fig. 1. General Arrangement of Sunderland Model.

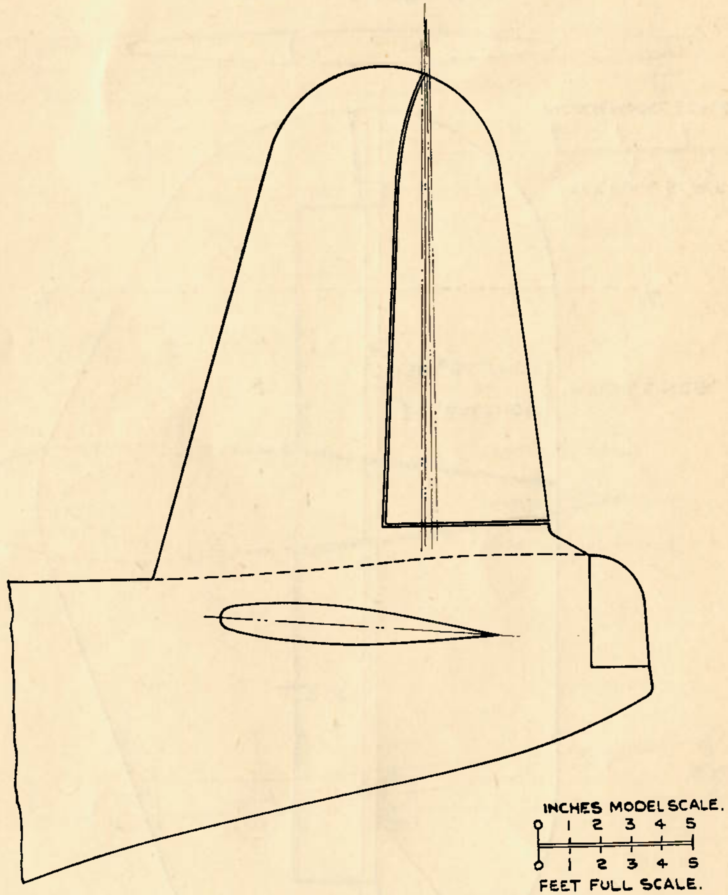

Fig. 2. General Arrangement of Sunderland Model-Tail Unit.

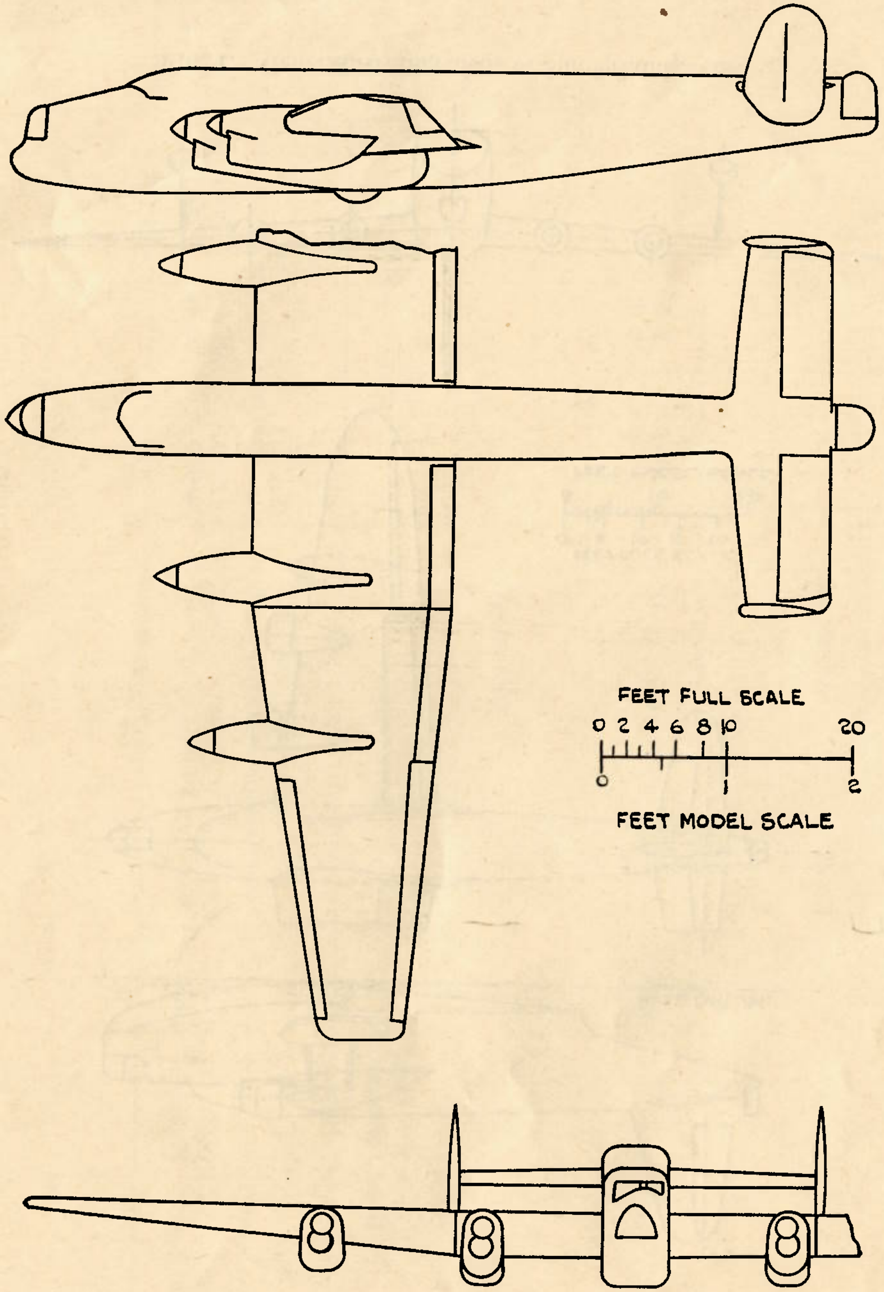

FIG. 3. General Arrangement of Halifax Model.

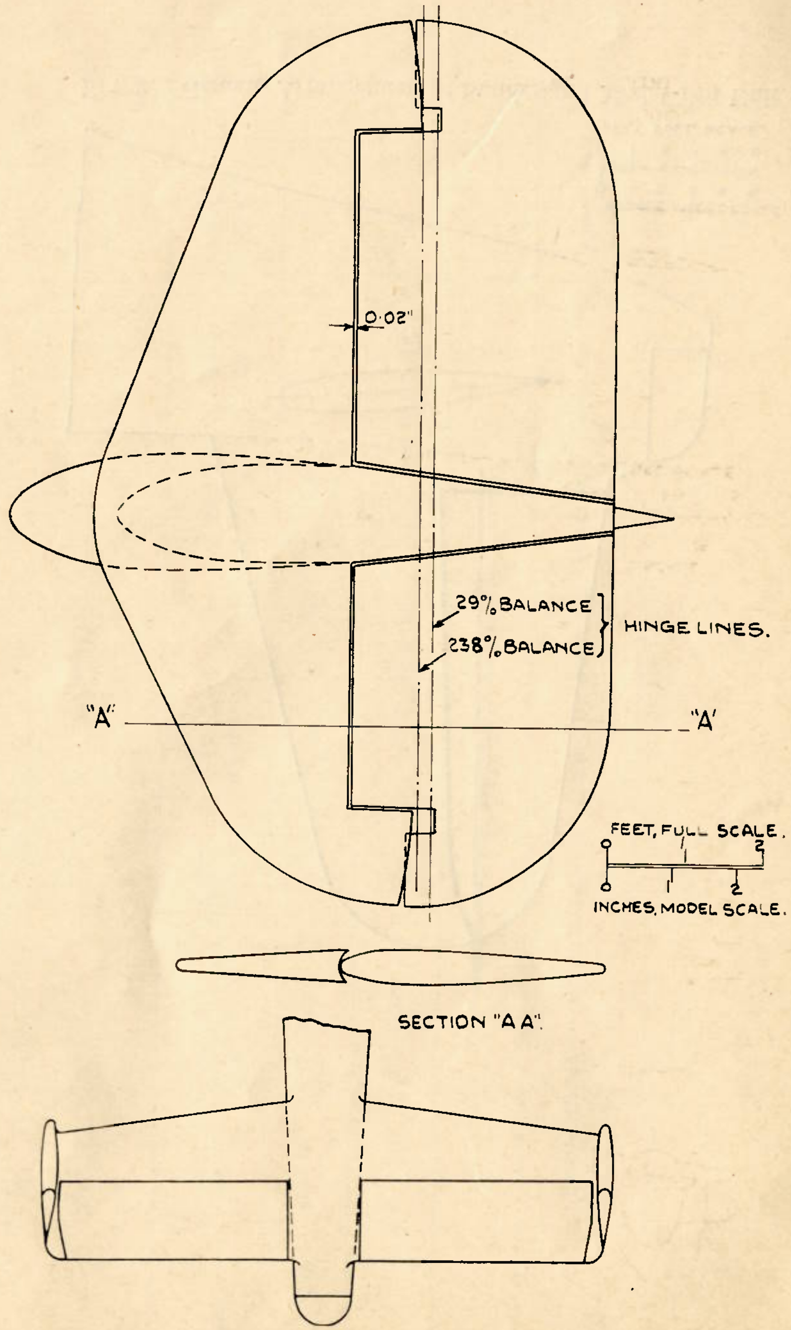

FIG. 4. Arrangement of Tail Unit—Halifax.

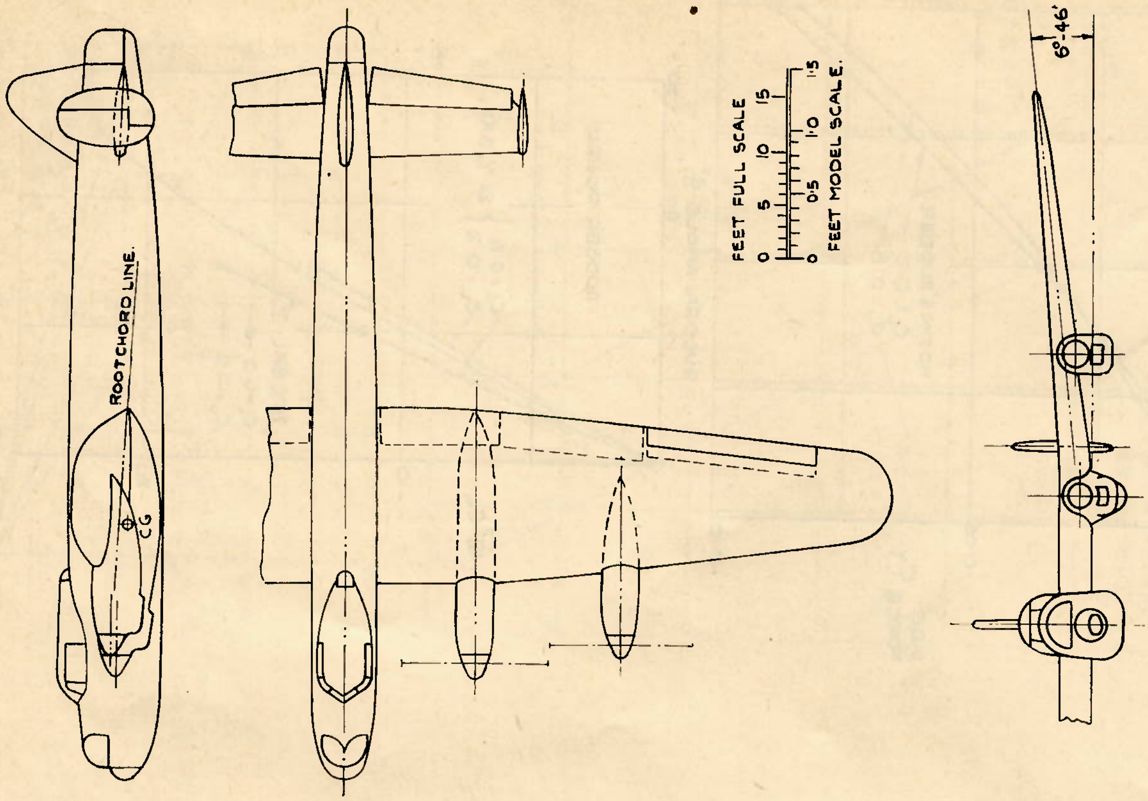

Fig. 5. General Arrangement of Lancaster Model.
(with small aspect ratio fins and rudders and central fin.)

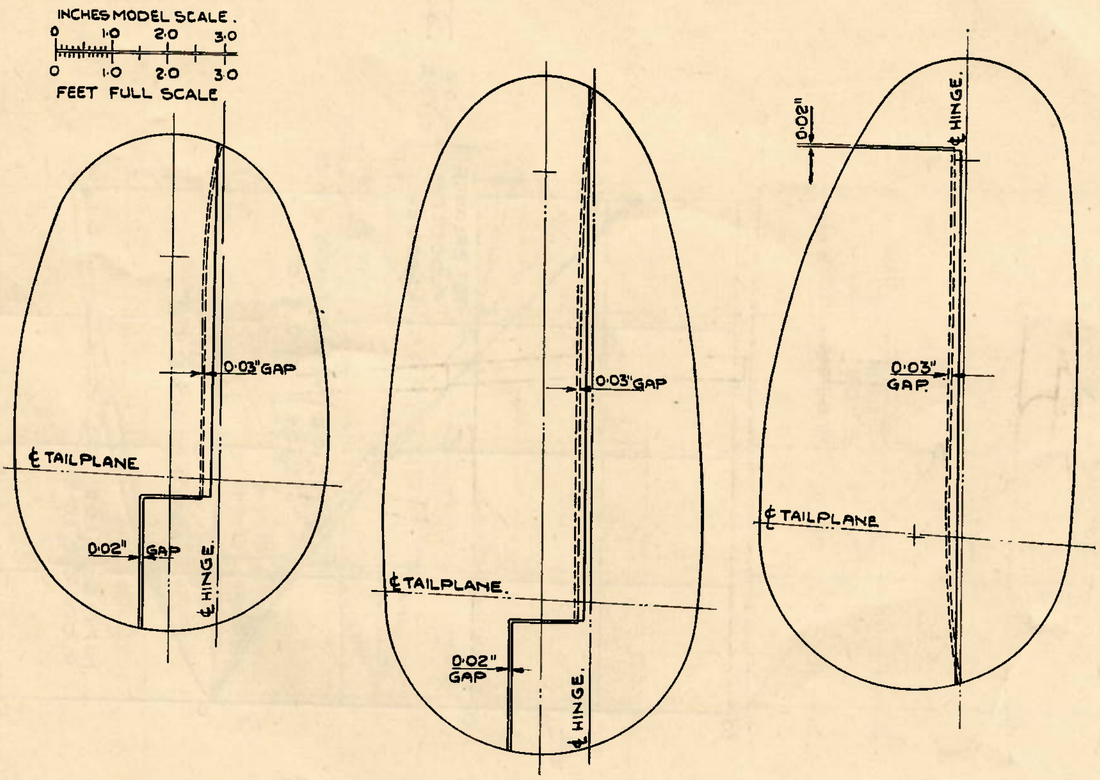

Fig. 6. Lancaster Fins and Rudders.

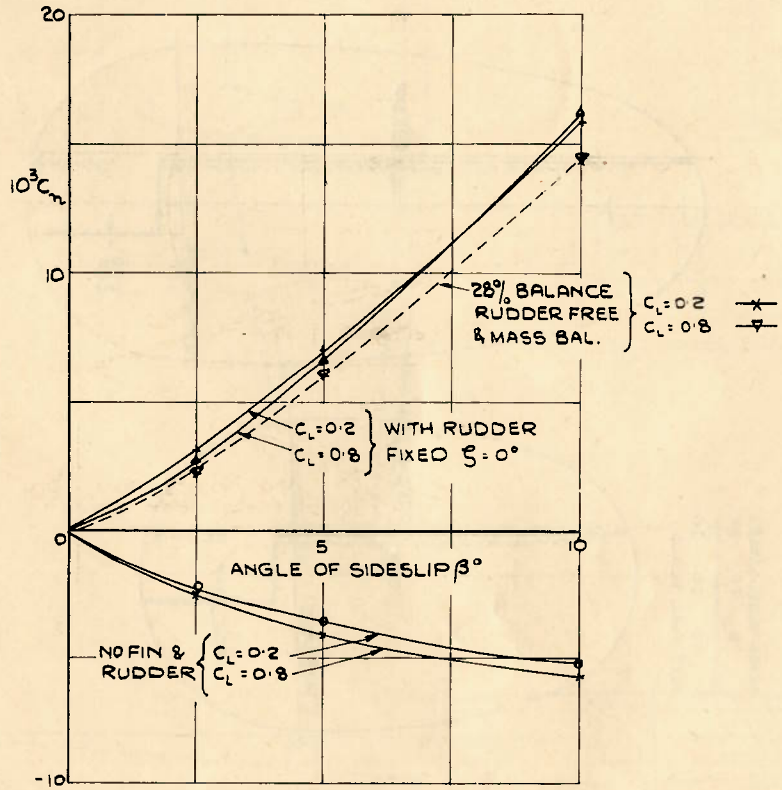

FIG. 7. Sunderland.—Yawing Moment Coefficients, Rudder Fixed and Free.

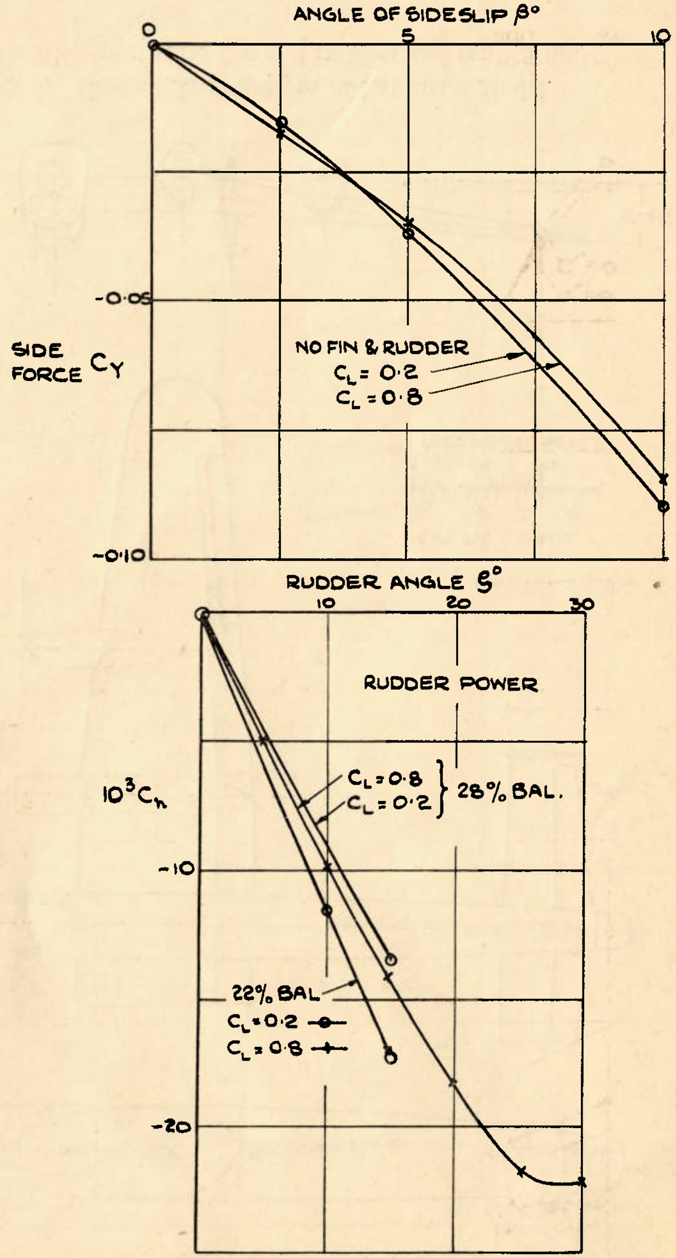

FIG. 8. Sunderland.—Side Force and Rudder Power.

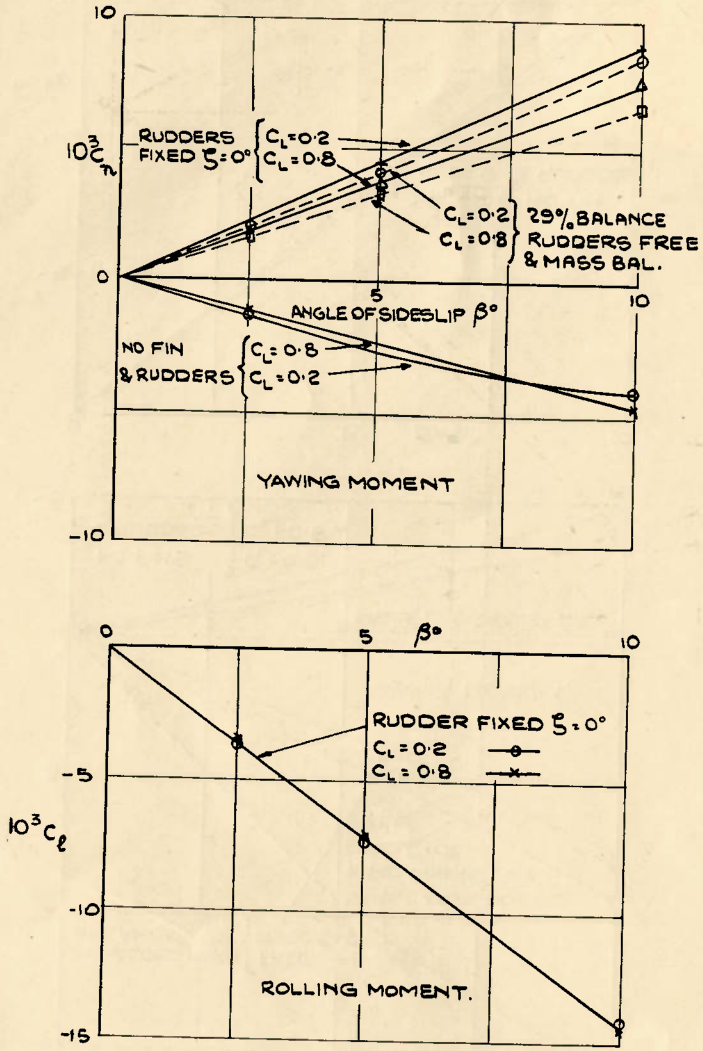

FIG. 9. Halifax.—Yawing and Rolling Moment Coefficients, Rudders Fixed and Free.

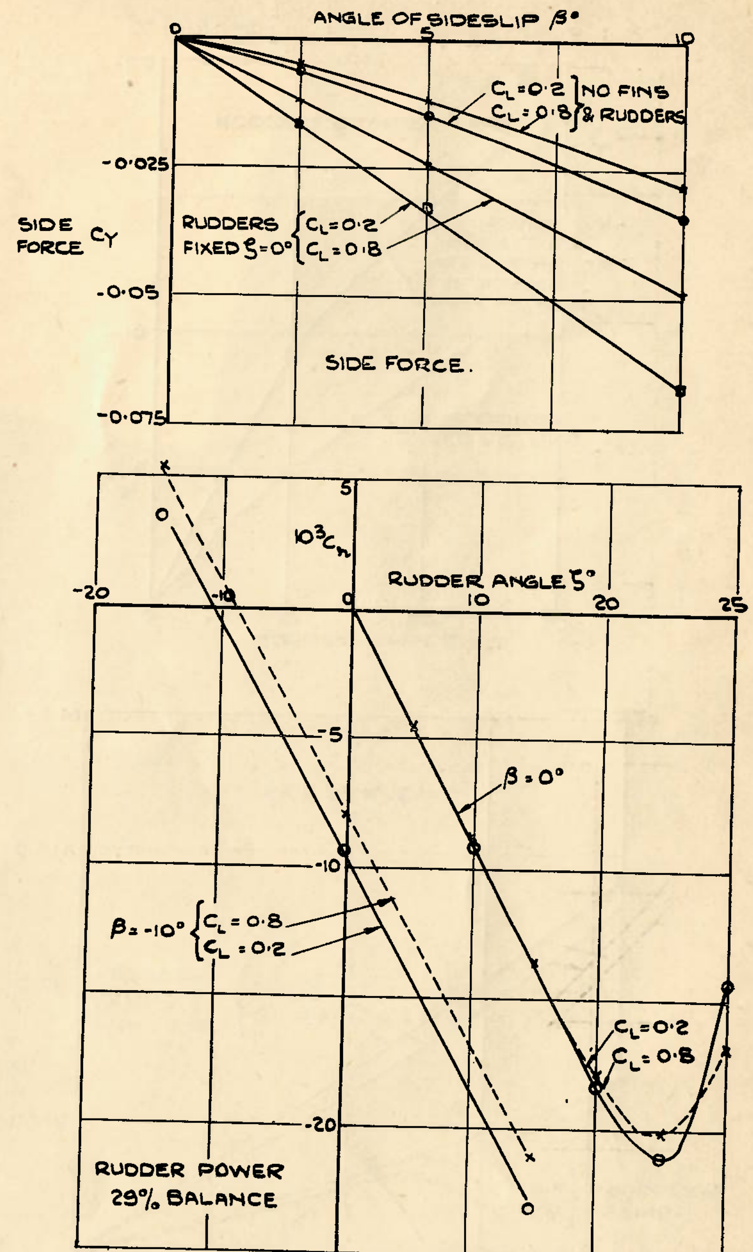

FIG. 10. Halifax.—Side Force and Rudder Power.

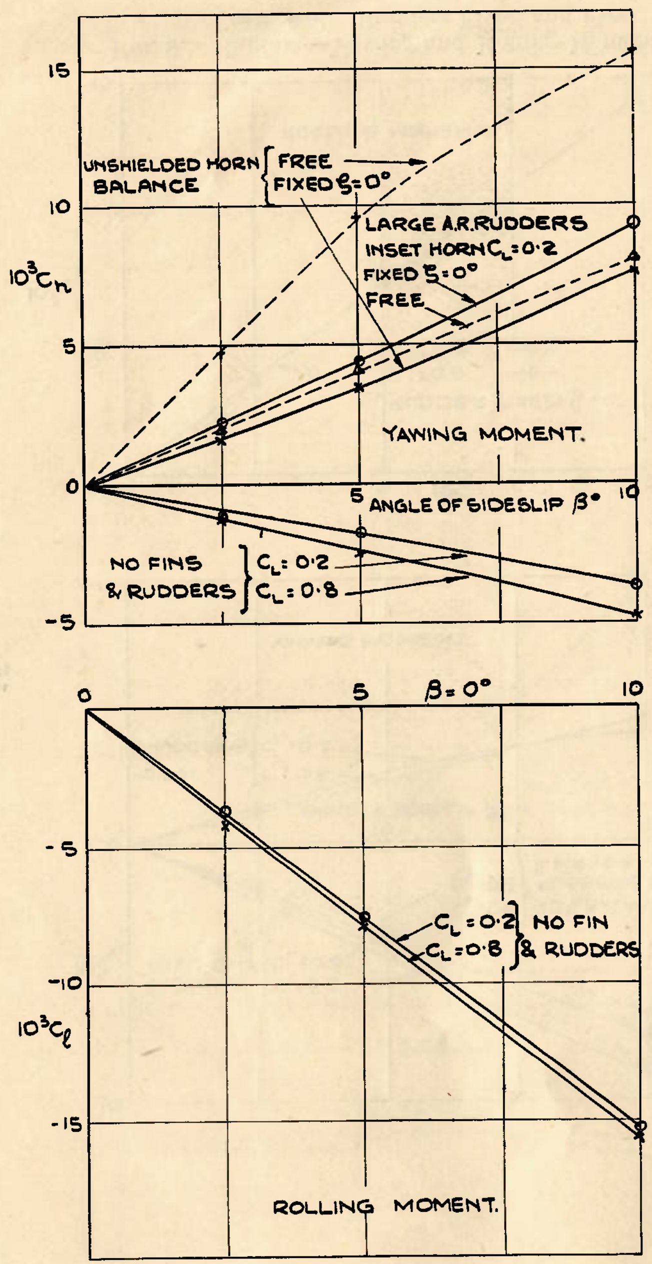

FIG. 11. Lancaster.—Yawing and Rolling Moment Coefficients

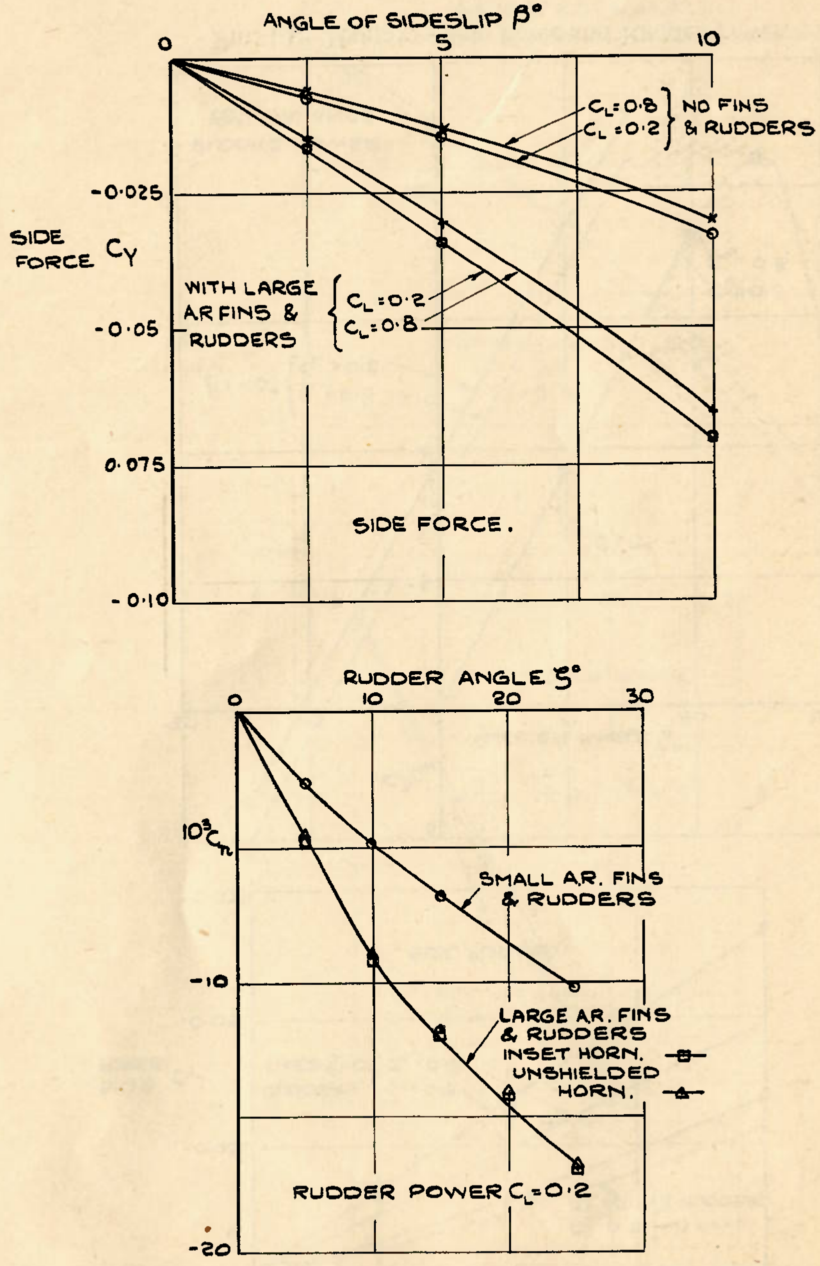

FIG. 12. Lancaster.—Side Force and Rudder Power.

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