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Summary.—An analysis has been made of the full-scale measured drag and lift performance data available on the *Sunderland, Solent, Shetland, Sealand, Saro* E.6/44 and *Princess* boat seaplanes, which all have hulls of fairly orthodox length/beam and fineness ratios but with different degrees of aerodynamic fairing.

The drag coefficient and profile drag show progressive decreases from the order of 0·033 to 0·018 and from 1·5 lb to 0·33 lb per 100 lb of all-up weight respectively, the best seaplane being the *Princess*. The value of the extra-to-induced drag coefficient k_z at 1·1 is generally good for all the aircraft and extends up to a C_L of the order of 1·0.

This drag reduction is caused by improvement in hull design, reduction of drag with change of propulsion unit from propeller reciprocating to propeller turbine and turbine jet, and also with increase of size. The hull drag is of the order of 0·22 of the total profile drag for all the aircraft but the ratio of the turbulent skin-friction drag of the idealised wing, hull and tail unit to the actual profile drag, increases to 0·73 for the *Princess* from 0·4 for the *Sunderland.*

Further drag reductions would be possible if full use were made of recent methods of reducing hull air drag still further by detail fairing and increase of length-to-beam ratio.

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1. *Introduction.*—This report presents some collected data on the full-scale air drag of various British seaplanes, all of which may be described as being of good orthodox design of the period dating from the late 1930's to 1950. By orthodox design is meant that the aircraft are all high-wing monoplanes and have hull forms which have a plan fineness ratio of the order of 6 to 7, based on the ratio of the length between the bow and the aft step and the maximum beam. They also have beam loadings up to the maximum developed for this form of hull, but vary in size from all-up weights of 10,000 to 320,000 lb. The aim of the report is to demonstrate the order of air drag achieved with these seaplanes.

The full-scale achievement is illustrated by analysing the drag characteristics in the form

$$C_D = C_{D0} + \frac{kC_L^2}{\pi A}$$

with correction for slipstream wherever possible, and also by analysing the lift characteristics in terms of the lift coefficient, C_L, and wing incidence.

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* M.A.E.E. Report F/Res/265, received 23rd April, 1956.

From these basic lift and drag results some analyses of the drag efficiency and, where relevant, lift efficiency of the aircraft have also been made, in terms of the criteria:

(*a*) cleanness efficiency

(*b*) drag efficiency

(*c*) hull drag ratio

(*d*) profile drag at 100 ft/sec per 100 lb of all-up weight

(*e*) maximum lift/drag ratio.

These have all been corrected for slipstream effects wherever possible, and the drags referred to in the various ratios and efficiencies are those at a speed of 100 ft/sec.

Cleanness efficiency is defined as the ratio of the drag of the idealised aircraft to the actual profile drag, where the idealised aircraft drag consists of the skin friction and pressure drags of the wings, hull and tail unit only, and assumes that the skin-friction drag is that for smooth turbulent conditions over these wetted surfaces. No allowance is made for surface roughness, air leaks, control gaps, cabins, nacelles, wing-tip floats, etc. This criterion is in effect a measure of the efficiency with which the drag of the aircraft has been reduced, accepting the necessity for the basic size and dispositions of the wing, hull and tail unit.

Drag efficiency is defined as the ratio of the drag of the idealised wing to the actual profile drag, where the idealised wing drag is the skin friction and pressure drag of the gross wing area and span. This criterion may be considered as a measure of the penalty paid in departing from an ideal flying wing as defined by the actual wing design. It is, therefore, a measure, although possibly a debatable one, of the efficiency with which all drag extra to that of the wing has been reduced.

The hull drag ratio is defined as the ratio of the profile drag of the hull to the total profile drag, where the profile drag of the hull has been estimated, using wind-tunnel data, and does not take account of roughness, leaks, turrets, etc. This ratio is of use in demonstrating the contribution to total profile drag made by the conventional form of boat-seaplane hull designed largely for high capacity and high water clearance.

The profile drag at 100 ft/sec is selected as a measure of the total profile drag which is commonly used, and it is given in terms of 100 lb of all-up weight to give a measure of the cost in profile drag per unit of all-up weight. This is then independent of the induced drag which depends directly on aspect ratio, a separate variable.

The lift/drag ratio is a measure of the total drag, profile and induced, incurred for the total weight moved and is a major term determining range and economic efficiency.

These data have all been based where possible on the cruise speed conditions of Reynolds number.

Finally, there is a short discussion of these results in relation to the trends in boat-seaplane design.

2. *Aircraft Test Data.*—Aircraft for which reasonably comprehensive measurements of performance and drag were found to be available were the *Sunderland* Mk. 2, *Shetland* Mk. 1, *Solent* N.J. 201, *Sealand* Mk. 1, *Saro* E.6/44 and the *Princess*, and these are the aircraft considered in this report.

Of these aircraft, Marine Aircraft Experimental Establishment reports already existed for the first four and the last and are given in Refs. 1 to 6. The information on the *Saro* E.6/44 and the *Princess* drag characteristics has been taken from the measurements made in the course of co-operative trials between M.A.E.E. and the design firm, Saunders-Roe.

Information on the nature of the tests, data available and drag analyses is given so that some idea of the general scope and accuracy of the work may be assessed. A short discussion is also given on particular points relevant to the individual aircraft.

For some of the aircraft, the data are not very complete, either because specific tests were not made to obtain drag and lift performance (*e.g.*, the *Sunderland* and *Shetland*) or because tests were not completed before they were stopped on the aircraft concerned (*e.g.*, *Saro* E.6/44 and *Princess*). Where necessary, original data has been amended, and where possible extended.

3. *Sunderland* (Ref. 1).—3.1. *Introduction.*—The *Sunderland* is a high-wing boat seaplane powered by four reciprocating engines driving propellers and is used for marine reconnaissance duties. It is the earliest of the designs considered in this analysis and the first monoplane flying boat to go into military service in this country. The maximum all-up weight is, at the time of writing, of the order of 62,500 lb in temperate conditions, which is equivalent to a wing loading of $37 \cdot 1$ lb/ft^2 and beam loading $C_{\Delta 0} = 1 \cdot 03$. A civil version is in service in many parts of the world which is essentially the same aeroplane, less turrets and military equipment.

A general arrangement sketch and photographs of the Mark II *Sunderland* are given in Figs. 1 and 2, and aerodynamic data in Table 1.

3.2. *Data Available.*—Performance data were obtained in the course of level speed and fuel consumption measurements made at M.A.E.E. on *Sunderland* II T.9083 for a weight range of 43,000 to 57,000 lb at 2,100 ft. For these tests the midship gun hatches were open, bomb doors closed and the engine cooling gills closed.

Lift-attitude data were taken from measurements made on the *Sunderland* III J.M. 681 at a weight of 50,000 lb in the same flight configuration as for the fuel consumption tests, using visual observations of a sensitive field clinometer.

3.3. *Method of Analysis.*—No torque meters were fitted, and therefore engine powers were estimated from data supplied by the engine manufacturers and corrected for altitude by the methods of Refs. 8 and 9. Propeller propulsive efficiencies were derived from the manufacturers' data sheets.

No corrections were made for slipstream in the original analysis when estimating values of the drag coefficient.

Some revisions of the aerodynamic efficiency results of Ref. 1 have been made, using more recent information, and a slipstream correction estimated.

3.4. *Results and Discussions.*—The drag results are shown in Fig. 3 and lift results in Fig. 4. The former have been expressed by

$$C_D = C_{D0} + \frac{k}{\pi A} C_L^2$$

where

$$C_{D0} = 0 \cdot 0318$$

and

$$k = 1 \cdot 14$$

for C_L values up to $1 \cdot 0$. With correction for slipstream, a possible value of C_{Dz} would be $0 \cdot 030$, and of k_z about $1 \cdot 10$.

The results of the drag analysis in terms of the 'ideal' standards are as tabulated below:

Aerodynamic Efficiencies of Sunderland (based on $V/\nu = 1{\cdot}525 \times 10^6$, *i.e.*, on a speed of 250 ft/sec at 5,000 ft).

	$\text{Drag}/\frac{1}{2}\rho V^2 S$	Drag at 100 ft/sec (lb)
Measured profile drag:		
(*a*) Without slipstream correction	0·0318	639
(*b*) With estimated slipstream correction	0·030	603
Estimated profile drag of idealised seaplane:		
Wings (gross)		160
Wings (net)		142
Hull		78
Tail unit		29
Total		249
Cleanness efficiency	0·41	
Drag efficiency	0·26	
Hull drag ratio	0·20	
(Assuming hull drag = 1·6 × idealised drag)*		
$100D_{100}/W$	0·96	
Maximum L/D	13·0	

The lift/attitude curve is plotted in Fig. 4 and shows good agreement between the measured and theoretical slopes.

These results indicate that the *Sunderland* is reasonably clean for a military aircraft and also has a good value of the induced-drag factor k. Data, although limited, are self-consistent. The civil version without turrets and gun hatches would be expected to be cleaner, with a cleanness factor of, say, 0·42, with no slipstream correction.

4. *Shetland* (Refs. 2 and 3).—4.1. *Introduction.*—The *Shetland* was a four-engined high-wing boat seaplane designed for long-range reconnaissance duties. It was powered by four reciprocating engines driving propellers and was equipped with the usual turrets fore and aft. At the time of its first flight it was the largest aeroplane built, its original design all-up weight being 120,000 lb. The aircraft was never produced for service use, although a very promising type technically, but certain limited aerodynamic test data were obtained in prototype trials. A drag analysis is given here which created considerable interest at the time of original publication because it showed up the drag of a boat seaplane in such a favourable light.

The hull form and aircraft lay-out are orthodox for the time, and there is very little step fairing, as is shown by the general arrangement sketch of Fig. 5. Aerodynamic data are given in Table 2. Tail and bow turrets are represented by fairings on the first prototype.

4.2. *Data Available.*—Data for the calculation of drag characteristics are taken from level flight fuel consumption tests made at M.A.E.E. over a range of steady speeds. The aircraft was fitted with torque meters on the two starboard engines only. All runs were made with the engine cooling gills closed. No attitudes were measured.

4.3. *Method of Analysis.*—The powers of the two starboard engines were calculated from the torque-meter readings and engine speeds; the power of each port engine was assumed to equal the mean of the two starboard engines. This is reasonable as all the engines were run at the same r.p.m. and boost, and variation in power between the two starboard engines as calculated from the torque-meter readings was of the order of ± 3 per cent, which is within the accuracy of the instruments.

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* Ref. 14.

Thrusts of the propellers were estimated from data supplied by the manufacturers.

Values of the drag coefficient calculated in the usual way were then corrected for the effect of slipstream by the method of Ref. 11.

An estimate was also made of the total profile drag of the *Shetland* by the standard techniques of the time (Ref. 3).

4.4. *Results and Discussion.*—The drag of the *Shetland* as illustrated in Fig. 6 can be expressed in the form

$$C_D = C_{D0} + \frac{k}{\pi A} C_L^2,$$

where $C_{D0} = 0 \cdot 025$

and $k = 1 \cdot 13$

for C_L up to the order of $1 \cdot 0$, the highest value tested. The effect of the slipstream corrections is also shown in Fig. 6, the drag relationship becoming

$$C_{Dx} = C_{Dz} + \frac{k_z C_L^2}{\pi A}$$

where $C_{Dz} = 0 \cdot 0235$

and $k_z = 1 \cdot 13$.

These results are confirmed by a similar analysis of separate flight data obtained by the design firm using different propellers, the comparable results being

$$C_D = 0 \cdot 024 + \frac{1 \cdot 0 C_L^2}{\pi A}$$

without slipstream correction, and

$$C_{Dx} = 0 \cdot 0235 + \frac{1 \cdot 0 C_L^2}{\pi A}$$

with slipstream correction.

Details of the drag synthesis and also of the aerodynamic efficiencies are tabulated below:

Aerodynamic Efficiencies of Shetland (based on $V/\nu = 2 \cdot 45 \times 10^6$, *i.e.*, on a speed of 400 ft/sec at 2,000 ft).

	Drag/$\frac{1}{2}\rho V^2 S$	Drag at 100 ft/sec (lb)
Measured profile drag:		
(*a*) C_{D0}	0·0250	
(*b*) C_{Dz}	0·0235	738
Estimated profile drag of idealised seaplane:		
Wings (gross)		235
Wings (net)		215
Hull		102
Tail unit		51
Total		368
Cleanness efficiency	0·50	
Drag efficiency	0·32	
Hull drag ratio (assuming hull drag 1·6 × idealised drag)	0·22	
$100 D_{100}/W$	0·75	
Maximum L/D	16·0	

Aerodynamic Drag Synthesis of the Shetland (R.A.E. Estimate, Ref. 3)—(Based on $V/\nu = 2{\cdot}45 \times 10^6$).

Item	Drag at 100 ft/sec (lb)	
Wings		
Profile	215	
Roughness (0·0015 in.)	32	
Control gaps	11	
Total wing		258
Body		
Profile	102	
Roughness (0·0015 in.)	13	
Cabin	5	
Nose-turret fairing	7	
Tail-turret fairing	20	
Total body		147
Tail		
Profile	51	
Roughness (0·0015 in.)	9	
Control gaps	13	
Total tail		73
Power plant		104
Miscellaneous		
Floats	43	
Steps and chines	45	
Interferences, leaks and minor fittings	52	
Radio	4	
		144
Total profile drag		726
C_{Dz} estimated		0·0232
C_{Dz} measured in flight		0·0235

For comparative purposes a cleanness ratio* has been calculated in Ref. 3 for the *Lancaster* II and compared with those of the *Sunderland* and *Shetland* in the following table, all being based on a common Reynolds number of $1{\cdot}8 \times 10^6 \times$ length (Ref. 3).

Aircraft	Flight result C_{Dz}	Idealised aircraft C_{Dz} at $V/\nu = 1{\cdot}8 \times 10^6$	A* Cleanness ratio	Wing loading w_s lb/ft^2
Shetland I (S = 2,636 sq ft)	0·0235	0·0178	0·76	49·3
Sunderland II (S = 1,687 sq ft)	0·030	0·0176	0·59	33·3
Lancaster II (S = 1,297 sq ft)	0·0294	0·0136	0·46	50·0

* This idealised aircraft drag is the actual drag of the wings, body, tail and tip floats, *i.e.*, the total measured drag less engines, nacelles, turrets, ailerons and other external excrescences.

Finally, comparative values of the induced-drag factor k_z were calculated for other aircraft of the same period and are tabulated below:

Aircraft	*Shetland* I	*Sunderland* II	*Lancaster* II	*Tudor* I	*Hastings* I
k_z	1·12	1·11	1·0 at $C_L^2 = 0$ 0·625 at $C_L^2 = 0·8$	1·35	1·27

The profile-drag coefficient value of 0·0235 was considerably less than that of the *Lancaster* and *Sunderland* and this was thought to be because the effect of accessory sources of drag such as turrets and engine nacelles was much smaller on a larger aircraft than a smaller one. This assumes that the sizes of the nacelle installations and turrets in particular are fairly constant, which is fairly correct for the cases considered.

The cleanness ratios show clearly that, whatever the reason, the *Shetland* is much superior in cleanness to the contemporary landplane chosen for comparison, and indeed to the *Sunderland* and *Solent,* despite the fact that the hull form was not one designed for particularly low drag.

The extra-to-induced drag is very low, as in the case of the *Sunderland,* and considerably lower than the values found for contemporary low-wing landplanes.

5. *Solent* (Ref. 4).—5.1. *Introduction.—Solent* N.J. 201 is a civil version of a *Seaford,* a military flying-boat developed directly from the *Sunderland* by increasing the capacity of the hull but retaining the same wing. Turrets were removed from *Seaford* N.J. 201 and replaced by nose and tail fairings. Later marks of the *Solent* are aerodynamically identical, but the Mark II has Hercules 633 engines and the Mark III Hercules 733 engines *Solent* aircraft are still in use for civil passenger transport services in various parts of the world and the all-up weight has been increased to the order of 82,000 lb, compared with 60,000 lb to 62,000 lb for the *Sunderland.* This corresponds to

$$w_s = 48·6 \text{ lb/ft}^2$$

$$C_{\Delta 0} = 1·18 .$$

Further relevant data of *Solent* N.J. 201 are given in Table 3 and a general-arrangement sketch and photographs in Figs. 7 and 8 respectively.

5.2. *Data Available.—Tests Made.*—Performance measurements were made in level flight with zero, one-third and full flap, and in climbing flight with zero flap and full flap, for the specific purpose of measuring lift and drag for airworthiness test requirements.

An automatic observer was installed, which included torque meters for all the engines and fuel meters for each pair of engines. Attitudes were observed visually with an inclinometer.

Tests were made at set values of r.p.m. and boost in level flight and at set values of r.p.m., boost and speed in climbing flight.

Glides were made at selected speeds with the throttles fully closed and the propellers allowed to windmill. Rates of climb and descent were obtained from original and final altimeter readings, a constant rate being assumed.

5.3. *Method of Analysis.*—The power of the engines was calculated from the torque-meter readings and engine speeds, mean values being taken for the four engines over the total time for each test. The propeller efficiencies were estimated from the manufacturers' data. The all-up weight for each run was taken as the all-up weight at take-off, less the amount of fuel used at the middle of the run.

The drag data were corrected for slipstream by the method of Ref. 11, except in the case of flaps down when the method is not applicable.

5.4. *Results and Discussion.*—Results of the drag-lift relationship obtained from the equations $C_D = C_{D0} + \{k/(\pi A)\}C_L^2$ and $C_{Dx} = C_{Dz} + \{k_z/(\pi A)\}C_L^2$ are plotted in Figs 9 and 10 and tabulated below:

Condition of aircraft	C_{D0}	C_{Dz}	k	k_z
Level flight, no flaps	0·033	0·031	1·30	1·30
Level flight, 1/3 flap	0·033	—	1·26	—
Climbing flight, no flaps	0·032	0·030	1·04	0·95
Climbing flight, full flap	0·055 (approx.)	—	1·05	—
Level flight, full flap	0·045 (approx.)	—	1·11	—

Results of the glide tests were unsatisfactory, perhaps because of the high and variable drag of the windmilling propellers, and are not quoted. The results with full flap are very few and the values given for drag must be regarded as of the correct order only. The lift results are given in Figs. 11 and 12 in the form of lift against attitude curves.

Results of the aerodynamic efficiency calculations are tabulated below, the idealised data being based on Refs. 12 and 13.

Aerodynamic Efficiencies of Solent (based on $V/\nu = 1{\cdot}525 \times 10^6$; cruise configuration).

	Drag/$\frac{1}{2}\rho V^2S$	Drag at 100 ft/sec (lb)
Measured profile drag:		
(*a*) C_{D0}	0·033	662
(*b*) C_{Dz}	0·031	622
Estimated profile drag of idealised Seaplane:		
Wings (gross)		159
Wings (nett)		141·5
Hull		82·5
Tail unit		38
Total		262
Cleanness efficiency	0·42	
Drag efficiency	0·26	
Hull drag ratio (assuming hull drag = 1·6 × idealised drag)	0·21	
$100D_{100}/W$	0·76	
Maximum L/D	12·0	

The drag results show that the drag coefficient varies linearly with C_L^2 for C_L up to about 1·2 in level and climbing flight, no flaps, and up to C_L of the order of 1·5 with 1/3 flap out. The value of the profile-drag coefficient uncorrected for slipstream is the same in level and climbing flight and also with 1/3 flap extended at the same lift coefficient, indicating that one-third flap is a very efficient condition for take-off, climb and slow or loitering-speed requirements.

The value of the profile-drag coefficient is fairly high but this is because of the size of the hull, rather than because the aircraft is aerodynamically inefficient. A comparison of *Solent* drag characteristics with those of the *Sunderland* is interesting, because the *Solent* has the same wing as the *Sunderland* but bigger engines and also a somewhat larger hull to cope with a larger pay load and all-up weight. Despite this the *Solent* profile-drag coefficient at 0·031 is very close to that of the *Sunderland* (corrected for slipstream) and the cleanness efficiency is better.

The induced-drag factor k, which measures the rate of increase of total drag associated with lift, is higher than would be expected for an aircraft with small interference losses, but is of the same order as that normally found in contemporary landplanes (*see* Section 4). It is, however, considerably reduced in the climb, much more than would be expected because of slipstream, for which the calculated effects are shown in Fig. 9.

It is evident that the slipstream quickly cleans up most, if not all, of the interference losses reflected in the level-flight value of k. That this cleaning up is present is also indicated by the lift curves of Fig. 11, there being evidence of very considerable improvement of the lift slope in the presence of the extra slipstream. By comparison with the *Sunderland* with the same wing there is a loss of induced-drag efficiency, k for the latter being $1 \cdot 14$ in level flight.

6. *Sealand* (Ref. 5).—6.1. *Introduction.*—The *Sealand* amphibian is a small twin-engined propeller-driven boat seaplane of 9,100 lb all-up weight, designed for operation from land and sheltered water, and is in both civil and military use. It is the lightest of the seaplanes considered in this report and illustrates, therefore, the possible effect of size on the contribution to overall drag of the hull of a boat seaplane. The hull itself is of orthodox design, in the *Sunderland* tradition, with a mildly faired step.

A general arrangement sketch is given in Fig. 13 and photographs in Fig. 14. Aerodynamic data are given in Table 4. At maximum all-up weight the wing loading is $25 \cdot 8$ lb/ft^2 and hull beam loading $C_{\Delta 0} = 0 \cdot 985$.

6.2. *Data Available.*—The tests analysed consisted of two series of partial climbs done at 2,000 ft with and without 15-deg of flap, with take-off power and propeller pitch levers in the fully fine position, and also glides made both with zero and 15-deg of flap from 2,500 to 2,000 ft with the engine throttles closed. Torque meters were not available for the engines.

6.3. *Method of Analysis.*—The power has been assessed using data supplied by the engine manufacturer which apply to the bare engine only. These have been corrected for thrust estimation purposes by making an allowance for the increased back pressure caused by fitting a manifold. The propeller efficiencies were also obtained from manufacturers' design charts.

Corrections to drag for slipstream have been made to the flaps-up performance by the method of Ref. 11.

6.4. *Results and Discussion.*—The lift and drag coefficients are plotted in Figs. 15 to 18. Fig. 15 gives the results for climbing and gliding flight without flaps, and also for the climb condition showing the effect of correcting for slipstream. Fig. 16 gives the effect of flap on drag.

The lift results are plotted for the zero-flap condition in Fig. 17 and for 15-deg flap in Fig. 18.

The values obtained for the profile-drag coefficient and the induced-drag factor are tabulated below:

Flap (deg)	Power	Drag equation
0	Take-off	$C_D = 0 \cdot 037 + \dfrac{1 \cdot 33 C_L^2}{\pi A}$
0	Take-off corrected for slipstream	$C_{Dx} = 0 \cdot 0345 + \dfrac{1 \cdot 15 C_L^2}{\pi A}$
15	Take-off	$C_D = 0 \cdot 047 + \dfrac{1 \cdot 55 C_L^2}{\pi A}$
0	Nil—propellers windmilling ..	$C_D = 0 \cdot 057 + \dfrac{1 \cdot 76 C_L^2}{\pi A}$
15	Nil—propellers windmilling ..	$C_D = 0 \cdot 071 + \dfrac{1 \cdot 64 C_L^2}{\pi A}$

An analysis has been made of the possible components of the total profile drag based on a cruise speed of 200 ft/sec at 2,200 ft, the results being as tabulated below:

Component Drags of Sealand

Component:	Drag at 100 ft/sec (lb)
Idealised wing profile drag	33·2
Idealised tail profile drag	11·8
Idealised hull profile drag	22·0
Total	67·0
Power plant	12
Hull steps, chines and turned up tail	8·4
Floats	4
Wheels	5
Cabin	3
Radio	1
Roughness and control gaps	16
Interference	3
Miscellaneous	5
Drag unaccounted for	20·6
Total drag (measured)	145·0

In this table the idealised wing, tail and hull drags used, based on Refs. 12 and 13, are the same idealised figures used for the drag criteria. For drag syntheses the effects of steps and so on have been added separately as shown above.

The aerodynamic efficiencies are as follows:

Aerodynamic Efficiencies of Sealand (based on a speed of 200 ft/sec at 2,200 ft, the cruise configuration).

	Drag/$\frac{1}{2}\rho V^2 S$	Drag at 100 ft/sec (lb)
Measured profile drag:		
(*a*) C_{D0} (take-off power)	0·037	
(*b*) C_{Dz}	0·0345	145
Estimated profile drag of idealised seaplane:		
Wings (gross)		48
Wings (net)		33
Hull		22
Tail unit		12
Total		67
Cleanness ratio	0·47	
Drag efficiency	0·33	
Hull drag ratio (hull drag estimated as 1·6 × idealised drag)	0·24	
$100D_{100}/W$	1·59	
Maximum L/D	14·0	

The total profile-drag coefficient of the aircraft, 0·0345, corrected for slipstream, which is appropriate to the cruise condition, appears rather high in absolute value, but most of it can be accounted for in the normal manner and the cleanness efficiency of 0·47 is in fact quite good.

The effect of the slipstream is fairly large (7 per cent), as would be expected, since full take-off power was used in obtaining the test results.

The drag unaccounted for in the estimate is of the order of 14 per cent and is similar to that obtained on other piston-engined aircraft.

The figures show a large increase in profile-drag coefficient in the glide condition compared with the climb condition, which increase is almost certainly because of the drag of windmilling propellers. There is also a fairly large increase of drag coefficient with 15-deg of flap, both in the climb and glide conditions.

The value of the induced-drag factor k_z is good for the cruise condition, 1·15, and that of k reasonable, 1·33, in the climb with full slipstream. This increase in the climb case is fairly characteristic, but may be exaggerated in the case of the *Sealand* because of some possibly asymmetric flow separation from the wing centre section which is only present at very high thrust coefficients and attitudes. There is little sign of such flow separation in cruising flight up to a C_L of 1·0, when a good $C_D/C_L{}^2$ linear relationship holds.

The lift results also demonstrate no adverse qualities, either in the climb or glide case with either of the two flap positions.

7. *Saro E*.6/44 (Refs. 17 and 18).—7.1. *Introduction.*—The *Saro* E.6/44 was a high-wing single-seater boat seaplane with jet propulsion, designed for fighter duties from advanced water bases. It was the first jet-propelled boat-seaplane design and first flew in 1947. For various reasons, mainly linked with the end of the 1939–1945 war, it did not go into production for general service, although it was for its time a promising aircraft technically, both on the water and in the air. It is of particular interest because of the successful solution of the problem of compromise between high air speed, high water speed and high water stability for a small aircraft (16,500 lb all-up weight) with an orthodox hull shape.

The aircraft proved to have a low drag form, and it was unfortunate that it was not possible to take advantage of the unique opportunity offered to obtain good quantitative data.

A general arrangement sketch of the aircraft is given in Fig. 19 and photographs in Fig. 20. Aerodynamic data are given in Table 5. At 16,500 lb the wing loading was $w_s = 40$ lb/ft² and beam loading $C_{\Delta 0} = 1 \cdot 03$.

7.2. *Data Available.*—The only air performance data available are those obtained in the course of contractors' trials at Saunders-Roe, Ltd., and given in Ref. 17. Jet thrust measurements were not made on these tests. Further data were obtained on the aircraft in a take-off and landing configuration, *i.e.*, floats down, but flaps up, for the purposes of a comparison between model and full-scale water performance, and these have also been given. They are the more accurate because done with thrust-calibrated engines for research purposes in conjunction with M.A.E.E.

7.3. *Method of Analysis.*—The engine thrusts for the drag analysis made in Ref. 17 were based on manufacturers' brochure figures. This engine performance was plotted in terms of the non-dimensional curves of $V/\sqrt{T}$ against $N/\sqrt{T}$ for different altitudes and hence the thrusts used in flight were deduced from the speed, V, engine r.p.m., N, and ambient temperature T. If the brochure thrust data are correct, the estimated drag figures should be correct to within $\pm$ 2 per cent.

The rise of drag due to compressibility, which occurs above $M = 0 \cdot 7$, was calculated from dive tests using the energy method of analysis (Ref. 17).

The thrust calculations for the take-off and landing configuration (Ref. 18), were based on experimentally determined curves of gross thrust against tail-pipe pitot pressure and mass flow against $\frac{\sqrt{(\text{compressor inlet velocity head})}}{\text{compressor intake pitot pressure}}$, the full-scale data for which were obtained by full instrumentation recorded on an automatic observer.

7.4. *Results and Discussion.*—The drag results are plotted in Fig. 21 for the aircraft with no flaps, floats up and floats down respectively. The range of C_L is very small for the floats-up case but the general C_D/C_L^2 shape is thought justified by results for the floats-down case.

Results can be expressed as

$$C_D = 0 \cdot 0245 + 1 \cdot 10 C_L^2/\pi A \text{ floats up}$$

$$C_D = 0 \cdot 041 + 1 \cdot 10 C_L^2/\pi A \text{ floats down,}$$

assuming the same aspect ratio.

The effects of compressibility on drag are shown in Fig. 22 (C_{D0} against Mach number with floats up). The drag rise probably starts at the wing, rather than the hull, because of the high thickness/chord ratio of 14 to 12 per cent and because there is no sweepback.

The lift-attitude characteristics with floats down, the only ones available, are plotted in Fig. 23. These include a component of thrust, as obtained in level flight tests.

The analysis of the aerodynamic efficiencies is as follows:

*Aerodynamic Efficiencies of E.*6/44 (based on $V/\nu = 1 \cdot 87 \times 10^6$, *i.e.*, on a speed of 200 knots at 15,000 ft).

	$\text{Drag}/\frac{1}{2}\rho V^2 S$	Drag at 100 ft/sec (lb)
Total profile drag measured (clean)	0·0245	123
Idealised wing profile drag (gross)		40·9
Idealised wing profile drag (net)		31·8
Idealised hull profile drag		25·8
Idealised tail profile drag		14·8
Idealised total		72·4
Cleanness efficiency	0·59	
Drag efficiency	0·33	
Hull drag ratio (assuming hull drag = 1·6 × idealised drag)	0·34	
$100 D_{100}/W$	0·75	
Maximum L/D	12·0	

For a fighter aircraft with jet propulsion the drag coefficient is fairly high. This is partly the result of a fairly small wing (wing loading 40 lb/ft^2) and partly the result of the use of a fairly large hull. The hull size is probably smaller than would be used for propeller propulsion because intake clearance from the sea was achieved efficiently by the bow intakes. However, it is by no means as small as could be obtained by the use of a long fine hull with much higher beam loading and lower air drag, nor was the step fairing very efficient because of the worry at that time concerning stability at high water speeds. It is, however, a clean design, as is demonstrated by its good value of cleanness ratio, 0·58.

8. *Princess* (Ref. 6).—8.1. *Introduction.*—The *Princess* is a high-wing boat seaplane powered with ten propeller-turbine engines, designed for long-range transport of passengers. The ten engines are arranged as an outer single and two inner coupled pairs on each wing, the former driving single and the latter contra-rotating propellers. It had a design all-up weight at the time of testing of 320,000 lb and a wing span of 219 ft 6 in. with the wing-tip floats retracted and is

the largest aircraft considered in this report. Three in all were built but have subsequently been 'cocooned' for the future, pending the delivery of more powerful and economical engines. Before this happened, 96 hours 50 minutes of flying was done between August, 1952 and June 1954 at the contractors, Saunders-Roe, in conjunction with M.A.E.E., during which time the basic performance was measured to provide a basis for development of the design. The results demonstrate the very considerable progress made to date on the reduction in full-scale air drag of British boat seaplanes.

A general arrangement drawing is given in Fig. 24 and photographs in Fig. 25. The main aerodynamic and hydrodynamic data are given in Table 6. Other information is given in Refs. 6 and 21.

The hull is a figure-of-8 section superimposed on a Vee planing bottom, the main step being faired in plan-form and elevation. The hull design was developed as a result of comprehensive tests to decide on the best compromise between air drag and water stability, making use of the extensive knowledge gained in the course of systematic research and development work on hull drag (Refs. 20 and 21).

Analyses of the results of these full-scale performance measurements involved the determination of the power of free turbines and incompletely calibrated engines and the estimation of propeller efficiencies and slipstream effects of contra-rotating propellers at high T_c values. The accuracy of the results may not, therefore, be as high as could be desired, scatter of individual points being within $\pm$ 5 per cent of the mean value, but it is quite adequate for comparison with the results of the other flight tests in this report and also to demonstrate the high aerodynamic cleanness of this aircraft.

8.2. *Data Available.*—Lift and drag performance was measured in level flight and climbs between sea level and 30,000 ft at speeds between 120 and 250 knots I.A.S., in partial climbs at 19,000 ft., and in a descent from 30,000 ft at a constant speed of 220 knots I.A.S. to investigate Mach-number effects briefly. These tests were all made with flaps and floats retracted. The position error was measured by the aneroid method over the speed range 130 to 245 knots I.A.S. at 300 ft at a mean weight of 250,000 lb.

All measurements were recorded on automatic observers except for attitude, which was observed visually. It was only possible to use torque meters to measure shaft horsepower on the single engines, *i.e.*, the outermost engine in each wing, and jet pipe thrusts on one single and one coupled pair of engines. Compressor delivery pressures and r.p.m. were, however, measured on all ten engines.

8.3. *Method of Analysis.*—The shaft horsepowers delivered by the single engines fitted with torque meters were plotted non-dimensionally in terms of

$$\frac{\text{shaft horsepower}}{(\text{air-intake total pressure})\ (\text{air-intake temperature})^{1/2}}$$

against

$$\frac{\text{compressor delivery static pressure}}{\text{air-intake total pressure}}$$

The shaft power of the coupled engine was deduced from this calibration, knowing the compressor delivery static pressure and air-intake total pressures. These values were reduced by 2 per cent when estimating propeller thrusts to allow for a consistent discrepancy in pressure ratio, which ratio appeared to be too large at high values of r.p.m. or of air mass flow near the ground.

The jet thrusts of the calibrated jet pipes were also plotted non-dimensionally in terms of

$$\frac{\text{jet thrust}}{\text{air-intake total pressure}}$$

against the same compressor pressure ratio as for shaft power, and the overall jet thrust deduced from this second measured parameter. The jet thrusts were about 10 per cent of the total thrusts and small errors unimportant.

Propeller propulsive efficiencies were estimated from the manufacturers' performance estimates.

Power for auxiliary services (*e.g.*, pressurisation) has been allowed for in calculations of the drag coefficient.

The drag coefficients have been corrected to zero slipstream conditions, using the results of special wind-tunnel tests given in Ref. 23. These C_D corrections closely resemble those given in Ref. 11 for C_L values less than 0·4 but are higher for values of C_L greater than this by about 0·001.

The lift coefficients have similarly been corrected for slipstream by the method of Ref. 11.

8.4. *Results and Discussion.*—The air-drag results are plotted in Fig. 26 in terms of C_D against $C_L{}^2$ and the lift results in Fig. 28 in terms of C_L against wing incidence.

The corrected C_D values (Fig. 27) vary linearly with $C_L{}^2$ up to a C_L of about 0·65, the approximate cruising value, *i.e.*,

$$C_{D_x} = 0 \cdot 0179 + \frac{1 \cdot 12}{\pi A} C_L{}^2$$

but increase more rapidly above that value up to the maximum C_L measured of about 1·0.

Without slipstream correction the drag relationship becomes

$$C_D = 0 \cdot 0188 + \frac{1 \cdot 16}{\pi A} C_L{}^2 \text{ for } T_c = 0 \cdot 05$$

$$C_D = 0 \cdot 0197 + \frac{1 \cdot 25}{\pi A} C_L{}^2 \text{ for } T_c = 0 \cdot 10 \, .$$

In this relation the aspect ratio has been taken as 9·18 as against an anticipated value of 9·62 if there had been no air leaks at the tip float to wing-tip junction.

Insufficient results were obtained to show whether the drag increased due to compressibility above a Mach number of 0·55 at a C_L of 0·285.

The slope of the lift curve corrected for slipstream is

$$\alpha_{\text{wing}} = -\, 1 \cdot 4 + 10 \cdot 7 C_L \text{ deg}$$

and holds for a measured C_L range of 0·3 to 1·0. Without slipstream correction,

$$\alpha_{\text{wing}} = -\, 1 \cdot 4 + (10 \cdot 7 - 11 \cdot 8 T_c) C_L \text{ deg,}$$

the lift slopes being 0·098 and 0·104 at $T_c = 0 \cdot 05$ and 0·10, respectively.

Analysis of the aerodynamic efficiencies is as follows:

Aerodynamic Efficiencies of Princess (based on a speed of 507 ft/sec at 33,000 ft).

	Drag/$\frac{1}{2}\rho V^2 S$	Drag at 100 ft/sec (lb)
Measured profile drag:		
(*a*) C_D at $T_c = 0 \cdot 05$	0·0188	
C_D at $T_c = 0 \cdot 10$	0·0197	
(*b*) $C_{D\,z}$	0·0179	1070
Estimated profile drag of idealised seaplane:		
Wings (gross)		496
Wings (net)		466
Hull		174
Tail unit		150
Total		790
Cleanness ratio	0·74	
Drag efficiency	0·46	
Hull drag ratio	0·21	
(hull drag estimated at 1·25 × idealised drag)*		
$100 D_{100}/W$	0·34	
Maximum L/D (cruise T_c, 0·05)	19·0	

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* *See* Ref. 20.

It is of interest that the cleanness ratio based on the gross surface area of the seaplane (*i.e.*, including tip floats and nacelles) is 0·8.

The cleanness efficiency shows that the *Princess* is aerodynamically the cleanest aircraft built to date in this country, and this result is reflected in the high value of $(L/D)_{\max}$ of 19. The effects of slipstream are fairly severe with the high values of T_c available even with the present engines, and this is particularly noticeable at high powers at low speeds, *e.g.*, in the climb, when it also affects longitudinal stability adversely.

It is likely that improvements in the wing-tip to float junction, control-gap sealing and in detail hull fairing known to be still possible, would reduce the drag further.

An interesting result is that this high cleanness efficiency is achieved with a large hull Reynolds number, which demonstrates that the low values of skin-friction coefficient pertaining to Reynolds numbers of the order of 10^8 can be achieved in practice.

9. *Discussion.*—A summary of the drag results for all the aircraft is given in Table 7 and an analysis in Figs. 29 and 30. The various drags and efficiencies have been related to one another by the size of the seaplane, this being defined in terms of $W^{1/3}$. The change of wing loading and profile-drag coefficient with size is shown in Fig. 29 and that of the drag ratios in Fig. 30. A short summary of the various efficiencies is tabulated below, where k_z is included as a measure of the extra-to-induced drag efficiency.

Aircraft	k_z	Cleanness efficiency	Drag efficiency	$\frac{\text{Hull drag}}{\text{Total drag}}$	$\frac{100D_{100}}{W}$	$W^{1/3}$
Sunderland ..	1·10	0·41	0·26	0·20	0·96	39·6
Solent	1·30	0·42	0·26	0·21	0·76	43·4
Shetland ..	1·13	0·50	0·32	0·22	0·57	50·7
Sealand ..	1·15	0·47	0·33	0·24	1·59	21·0
E.6/44	1·10*	0·59	0·33	0·34	0·75	25·5
Princess ..	1·16	0·73	0·46	0·21	0·34	68·4

All these results are as for no slipstream present.

It will be seen from the table that all the extra-to-induced drag factors (k_z values) are good with the exception of the *Solent* though even this is reasonable. The fairly high value is probably a result of the high-wing body combination, combined with the fact that there is little increase of hull pressure drag with increasing incidence up to a wing C_L of the order of 1·0.

Similarly the cleanness values are all fairly good and that for the *Princess* particularly so. It is also noticeable that the extra-to-wing drag, as measured by the drag efficiency, is progressively less with later date of design, although the hull drag as a proportion of the total drag remains fairly constant.

The profile drag per unit weight of aircraft, a better measure of profile-drag reduction than the lift/drag ratio, which depends on aspect ratio, is by far the smallest for the *Princess*, for reasons best seen from an analysis in terms of aircraft size.

The effect of size on drag, both with respect to cleanness and to total drag per unit of wing area or of all-up weight, has long been debated. From a simple dynamic scale point of view, scale varies as $W^{1/3}$ and one would expect wing loading to be linearly proportional to this for similar aircraft. Wing loading directly affects the values of coefficients and aerodynamic efficiencies dependent on wing area, namely $C_{D\,z}$, cleanness efficiency and hull drag ratio. Fig. 29 shows that in practice w_s varies almost linearly with $W^{1/3}$ for the seaplanes analysed, the exception being the E.6/44 which has a proportionally much higher wing loading of 40 as against a scale

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* Assumed k_z for this aircraft.

25 lb/ft^2. If the drag coefficients were scaled proportionally to the scale wing loadings for the relevant aircraft sizes, the value for the E.6/44 would be of the same order as for the *Princess*, and the *Shetland* a little higher. In fact, it would appear that with the cleanness of the *Princess* and scale wing loadings all the drag coefficients would be of the same order, *i.e.*, 0·018. The use of more refined hulls of high length/beam ratio could decrease the hull drag contribution by say another 15 per cent. The very low value of drag coefficient for the E.6/44 is, of course, largely due to it being jet propelled and hence having much lower nacelle-wing drag. Similarly, the reciprocating-engined aircraft will have a higher drag than the turbine-engined aircraft.

The variation of the various efficiencies with aircraft size can be more readily appreciated from Fig. 30 than from the table. Faired curves have been drawn through the values of some of the aerodynamic efficiencies in this figure, but these are only to help to make the general picture clearer. This plot emphasises the gains in aerodynamic cleanness with improvement in hull design and with replacement of reciprocating by turbine-propeller and turbine-jet engines. There is no loss with large size as was expected at one stage, which indicates that smooth turbulent conditions are as easily achieved at high as at low Reynolds numbers.

The ratio of the total drag to the gross-wing ideal drag is again good for the *Princess* but that for the E.6/44 is no better than that for the *Sealand* and *Shetland*, largely because of the small wing area for the size of seaplane. This is shown up by the ratio of hull to total drag, all the seaplanes being of the order of 0·22 except the E.6/44 which is 0·34. There is, however, a tendency for the hull drag ratio to decrease with the size of aircraft.

Finally, the profile drag per 100 lb of all-up weight gives what may be regarded as the final measure of profile-drag reduction for a given all-up weight (this could alternatively be plotted as C_{Dz}/w_s). There is a pronounced decrease with increase of size but some of this is due to the greater cleanness of the larger aircraft. This parameter is also sensitive to increases in all-up weight so that the more fully developed aircraft such as the *Solent* show up well in this respect.

An overall improvement could probably be achieved for all the aircraft considered if the optimum hull length/beam ratio were used, thereby reducing the total hull drag on account of both greater cleanness and smaller size for the same hydrodynamic qualities. The hull drag of the *Princess*, for example, might be reduced by about 15 per cent and the cleanness ratio improved to the order of 0·80 and C_{Dz} reduced to 0·017. With the advent of jet propulsion for high-speed transport, the immediately achievable C_{Dz} would be about 0·015 for similar types of boat seaplanes (Ref. 24).

10. *Conclusions*.—The full-scale lift and drag characteristics of the British seaplanes considered show both a pronounced increase in efficiency of aerodynamic fairing and a reduction of overall drag coefficient with successive designs. These improvements culminate in the results for the *Princess*, which is by far the best aircraft on all the bases examined, with $C_{Dz} = 0{\cdot}018$ at $w_s = 64$ lb/ft^2 and a cleanness efficiency of 0·73. It is further notable that the extra-to-induced drag is low, the mean value of k_z being 1·1.

All the aircraft considered are of the high-capacity boat-seaplane type and have orthodox hull shapes apart from various improvements in detail fairing, particularly of the steps and chines. The lowest drag hull, the *Princess*, has an estimated 1·25 times the drag of the equivalent body of revolution. Improvements in step design and increase of length/beam ratio with future aircraft should reduce this to about 1·1 and, where capacity allows, size can also be reduced with no loss of hydrodynamic performance. Further reduction of drag with jet propulsion makes possible an immediate C_{Dx} of 0·015 for this type of aircraft.

The actual value of C_{Dx} varies from 0·033 for the smallest to 0·018 for the largest aircraft considered and the total profile drag from 1·5 to 0·033 lb at 100 ft/sec per 100 lb of all-up weight. This very large decrease of total profile-drag coefficient is in part due to size, and in part due to the fact that the larger seaplanes had, on the whole, the most advanced hull forms. The *Sealand* with the highest drag has a cleanness and drag efficiency comparable with those of the *Shetland* which has half the profile-drag coefficient.

The E.6/44 has a low drag coefficient for its size, demonstrating the gains due to jet propulsion, and a high cleanness value, despite the basically high-drag hull form.

The cleanness efficiency increases from 0·41 for the *Sunderland* class to 0·73 for the *Princess*, being 0·59 for the E.6/44.

The drag efficiency increases from 0·26 for the *Sunderland* class to 0·46 for the *Princess* being of the order of 0·33 for the rest.

The hull drag is a fairly constant proportion of the total profile drag for all the aircraft considered. Taken in conjunction with the increase of cleanness and drag efficiency this indicates that there is a considerable reduction of drag other than in the hull itself, as is illustrated particularly in the cases of the *Princess* and E.6/44.

The maximum lift/drag ratio includes the effect of aspect ratio, this helping the *Princess* and *Sealand* and penalising the E.6/44. Its value increases from 12 for the *Sealand* and for the *Sunderland* class through 16 for the *Shetland* to 19 for the *Princess*.

LIST OF SYMBOLS AND DEFINITIONS

Aerodynamic Efficiencies

Cleanness efficiency $= \dfrac{\text{Profile drag of idealised aircraft}}{\text{Actual total profile drag}}$ *

Drag efficiency $= \dfrac{\text{Profile drag of idealised wing}}{\text{Actual total profile drag}}$ *

Hull drag ratio $= \dfrac{\text{Hull drag}}{\text{Actual total profile drag}}$ *

Profile drag/weight ratio $= \dfrac{\text{Profile drag at 100 ft/sec}}{\text{All-up weight/100}}$ *

$= \dfrac{100 D_{100}}{W}$ lb per 100 lb of all-up weight.

Maximum $\frac{\text{lift}}{\text{drag}}$ without slipstream $= \frac{1}{2}\left(\dfrac{\pi A}{k_z C_{D\,z}}\right)^{1/2}$

The idealised aircraft drag is estimated on the basis of smooth turbulent skin friction and pressure drag of the hull wings (net) and tail unit only.

The idealised wing drag is estimated on the basis of the gross wing.

The hull drag is estimated in terms of the smooth turbulent skin friction and pressure drag of the equivalent body of revolution of the same surface area times the factor for drag of steps, chines, etc.

C_D = Drag$/\frac{1}{2}\rho V^2 S$

$C_{D\,x}$ = Drag without slipstream$/\frac{1}{2}\rho V^2 S$

$C_{D\,0}$ Drag coefficient at zero lift, with slipstream

$C_{D\,z}$ Drag coefficient at zero lift, without slipstream

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* All drags are corrected to eliminate the effects of slipstream, and refer to a speed of 100 ft/sec.

LIST OF SYMBOLS AND DEFINITIONS—*continued*

C_L	$= L/\frac{1}{2}\rho V^2 S$
S	Wing area (gross)
V	Forward speed
ρ	Air density
A	Aspect ratio
k k_z	Extra-to-induced drag factor defined by: $C_D = C_{D0} + \frac{k}{\pi A} C_L^2$ with slipstream $C_{Dz} = C_{Dz} + \frac{k_z}{\pi A} C_L^2$ without slipstream
W	Maximum all-up weight
D_{100}	Profile drag in lb at 100 ft/sec
$C_{\Delta 0}$	Beam loading
	$= W/\rho_w b^3$
ρ_w	Density of water
b	Beam of hull
w_s	Wing loading

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TABLE 1

Aerodynamic Data—Sunderland

Wings	
Gross area	1,687 sq ft
Net area	1,488 sq ft
Span	112·8 ft
Mean chord	15·7 ft
Aspect ratio	7·5
Wing section	Gottingen 436 (Mod.)
Thickness/chord ratio at tip	0·09
Thickness/chord ratio at root	0·2
Flap type	Gouge
Flap angle	26 deg
Wing surface area	3,060 sq ft
Wing loading at maximum all-up weight, 58,000 lb	39·0 lb/ft^2
(based on net area) at 60,000 lb	40·4 lb/ft^2
(based on gross area) at 62,500 lb	37·1 lb/ft^2
Sweepback normal to aerofoil datum	4° 0′
Wing setting to datum	6° 15′
Hull	
Length overall	85 ft 8 in.
Forebody length	32·94 ft
Afterbody length	29·18 ft
Forebody length/beam ratio	3·37
Afterbody length/beam ratio	3·01
Beam	0·79 ft
Surface area	2,800 sq ft
Beam loading, $C_{\Delta 0}$, at maximum all-up weight, 58,000 lb	9·97
at 60,000 lb	1·00
at 62,500 lb	1·03
Main step fairing ratio (*Sunderland* V)	6 : 1
Height	17·75 ft
Tail unit	
Tailplane area	205 sq ft
Tailplane span	35·75 ft
Tailplane section	R.A.F. 30
Total fin area	136·2 sq ft
Fin span	15·1 ft
Fin section	R.A.F. 30
Propellers	
Sunderland I, II and III	
Type	De Havilland constant-speed
Diameter	12·75 ft
Number of blades	3
Sunderland V	
Type	Hamilton A5/158
Diameter	12·08 ft
Number of blades	3
Engines	
Type	Pegasus (*Sunderland* I, II and III) Pratt Whitney Wasp (*Sunderland* V)
Number	4

TABLE 2

Aerodynamic Data—Shetland

Wings	
Gross area	2,636 sq ft
Net area	2,410 sq ft
Span	150 ft
Mean chord	17·53 ft
Aspect ratio	8·56
Wing section	Gottingen 436 (Mod.)
Thickness/chord ratio at root	0·2
Thickness/chord ratio at tip	0·1
Flap type	Handley Page
Flap area	314·8 sq ft
Flap area/net wing area	0·1305
Flap angle (maximum down)	50 deg
Wing loading at maximum all-up weight (130,000 lb)	
based on gross area	49·5 lb/ft^2
based on net area	53·9 lb/ft^2
Sweepback of $\frac{1}{4}$-chord line	10·4 deg
Wing incidence to hull datum	6° 37′
Wash-out	Nil
Hull	
Length overall	110 ft
Forebody length	43·75 ft
Afterbody length	41·66 ft
Forebody length/beam ratio	3·5
Afterbody length/beam ratio	3·3
Beam	12 ft 6 in.
Height	39 ft
Beam loading $C_{\Delta 0}$, at maximum all-up weight, 130,000 lb	1·038
at 120,000 lb	0·96
Step depth unfaired	13·5 in.
Tail unit	
Tailplane area	410 sq ft
Tailplane span	45·5 ft
Tail section	R.A.F. 30
Fin and rudder area	242 sq ft
Fin section	R.A.F. 30
Propellers	
Type	De Havilland constant-speed
Diameter	15 ft
Number of blades	4
Activity factor	89
Engines	
Type	Centaurius VII or XI
Number	4

TABLE 3

Aerodynamic Data—Solent

Wings

Gross area	1,687 sq ft
Net area	1,488 sq ft
Span	112·8 ft
Mean chord	14·97 ft
Aspect ratio	7·54
Taper ratio	2·6
Wing section	Gottingen (Mod.)
Flap type	Gouge
Flap area	286 sq ft
Flap increase in wing area	$\frac{1}{3}$ deflection = 34·6 sq ft $\frac{2}{3}$ deflection = 50·2 sq ft
Flap angle, maximum	25 deg
Wing loading at 78,000 lb, based on net area	52·4 lb/ft²
Sweepback normal to aerofoil datum	4·0 deg
Setting to datum	6° 9′
Wash-out	Nil

Hull

Length overall		89·6 ft
Forebody length		36·1 ft
Afterbody length		34·8 ft
Forebody length/beam ratio		3·35
Afterbody length/beam ratio		3·23
Beam maximum		10·75 ft
Beam at step		10·27 ft
Wetted area		2,890 sq ft
Beam loading, $C_{\Delta 0}$	based on maximum beam, 72,000 lb	0·906
	82,000 lb	1·03
	84,000 lb	1·06
	based on beam at step, 72,000 lb	1·03
	82,000 lb	1·18
	84,000 lb	1·21
Step fairing ratio, in terms of step depth		1 : 3·5
Step depth unfaired		12·79 in.

Tail unit

Tailplane area, excluding elevators and tabs	163·5 sq ft
Elevator area, including tabs	102·3 sq ft
Tailplane span	42·43 ft
Tailplane section	R.A.F. (Mod.)
Fin area, excluding rudder	112·82 sq ft
Rudder area, including tabs	82·18 sq ft

Propellers

Type	De Havilland
Diameter	12·75 ft
Number of blades	4

Engines

Type	Hercules 637
Number	4

TABLE 4

Aerodynamic Data—Sealand

Wings	
Gross area	353 sq ft
Net area	316 sq ft
Span	59 ft
Mean chord	5·83 ft
Aspect ratio	9·86
Wing section	AD.6
Thickness/chord ratio at root	0·20
Thickness/chord ratio at tip	0·0785
Flap angle: Take-off	15 deg
Flap angle: Landing	30 deg
Flaps, inner	26·3 sq ft
Flaps, outer	38·3 sq ft
Wing surface area	706 sq ft
Wing loading at maximum all-up weight (9,100 lb) based on net area	28·8 lb/ft^2
Sweepback	Nil
Wing incidence: L.E./T.E. chord to hull datum	6° 0′
L.E./T.E. chord to keel datum	2° 16′
Hull	
Length overall	42·17 ft
Forebody length	18 ft 3 in.
Afterbody length	14 ft 7 in.
Forebody length/beam ratio	3·48
Afterbody length/beam ratio	2·84
Beam	5 ft 3 in.
Height	8·5 ft
Beam loading, $C_{\Delta 0}$, at maximum all-up weight (9,100 lb)	0·985
Wetted area	671 sq ft
Step fairing	3½ : 1
Tail unit	
Tailplane area gross	62·3 sq ft
Tailplane mean chord	3·82 ft
Tailplane span	16·33 ft
Tailplane section	A.D.4
Thickness/chord ratio at root	0·125
Thickness/chord ratio at tip	0·125
Fin area gross	45·2 sq ft
Fin mean chord	5·6 ft
Propellers	
Type	De Havilland hydromatic constant-speed
Diameter	7 ft 6 in.
Number of blades	3
Engines	
Type	Gipsy Queen
Number	2

TABLE 5

Aerodynamic Data—E.6/44

Wings	
Gross area	415 sq ft
Net area	322 sq ft
Span	46 ft
Mean chord	108·4 in.
Aspect ratio	5·1
Taper ratio	0·47
Wing section	Goldstein (Mod.)
Thickness/chord ratio at tip	0·12
Thickness/chord ratio at root	0·14
Flap angle: Landing	75 deg
Flap angle: Take-off	33 deg
Wing loading at maximum all-up weight (16,500 lb) based on net area.	51·2 lb/ft^2
Sweepback	3·0 deg
Setting to datum	4·5 deg
Hull	
Length overall	50 ft
Forebody length	22·75 ft
Afterbody length	18·83 ft
Forebody length/beam ratio	3·61
Afterbody length/beam ratio	2·99
Beam	6·3 ft.
Height	8·75 ft
Gross surface area	928 sq ft
Beam loading, $C_{\Delta 0}$, at maximum all-up weight, 16,500 lb	1·032
Step depth unfaired	9·0 in.
Arc	1·3
Step fairing	3 : 1
Wetted surface	913 sq ft
Tail unit	
Tailplane area	81·25 sq ft
Tailplane span	16·00 ft.
Thickness/chord ratio (mean)	0·115
Fin mean chord	7·2 ft
Fin area	79·2 sq ft
Fin span	16·25 ft
Fin thickness/chord ratio (mean)	0·12
Total surface area	107·62 sq ft
Engines	
Type	Metropolitan-Vickers–F2/4A Axial-flow jet turbine
Number	2

TABLE 6

Aerodynamic Data—Princess

Wings	
Gross area (excluding floats)	5,019 sq ft
Net area (excluding floats)	4,711 sq ft
Floats plan area	99 sq ft
Span (floats up)	219 ft 6 in.
Span (floats down)	209 ft 6 in.
Mean chord	23·33 ft
Aspect ratio, excluding float	9·74
including float	9·62
Taper ratio	2·73
Wing section, basic and root	Goldstein developed
Wing section, tip	4415 (Mod.)
Thickness/chord ratio at tip	0·15
Thickness/chord ratio at root	0·18
Flap type	slotted
Flap angle, fully down	45 deg
Flap span, total	92·83 ft
Flap chord/local wing chord	0·212
Flap area, total	570 sq ft
Wing loading at	
320,000 lb* based on net area	67·9 lb/ft^2
315,000 lb based on net area	66·8 lb/ft^2
320,000 lb based on gross area	63·9 lb/ft^2
315,000 lb based on gross area	62·9 lb/ft^2
Wash-out, wing top only	2 deg
Setting to hull datum	4° 30′
Hull	
Length overall	148 ft 0 in.
Forebody length	59·4 ft
Afterbody length	61·4 ft
Forebody length/beam ratio	3·56
Afterbody length/beam ratio	3·69
Beam	16·67 ft
Height	24·25 ft
Beam loading $C_{\Delta 0}$ at maximum all-up weight 320,000 lb	1·079
at 315,000 lb	1·063
Main-step fairing (in elevation)	6 : 1
(in planform)	2 : 1
Wetted surface area	6,912 sq ft
Gross surface area	7,325 sq ft
Step depth unfaired	1·36 ft
Tail unit	
Tailplane area gross	1,103 sq ft
Tailplane mean chord	14 ft 4 in.
Tailplane span	77 ft 2 in.
Tailplane section	Goldstein (developed)
Thickness/chord ratio at tip	0·12
Thickness/chord ratio at root	0·152

---

* Maximum all-up weight.

TABLE 6—*continued*

Tail unit—continued	
Fin and rudder mean chord	18 ft 1 in.
Fin and rudder section	Goldstein (developed)
Fin and rudder area	569 sq ft
Thickness/chord ratio at root	0·149
Thickness/chord ratio at tip	0·113
Total rudder area	111 sq ft
Propellers	
Type	De Havilland
Diameter	16 ft 6 in.
Number of blades	4
Engines	
Type	Bristol Proteus 600 single 610 coupled
Number	2 single 4 double

TABLE 7

Summary of Drag Analysis

Aircraft	*Sunderland*	*Shetland*	*Solent*	*Sealand*	*Saro* E.6/44	*Princess*
W lb	62,500	130,000	82,000	9,100	16,500	320,000
C_{D0}	0·0318	0·025	0·033	0·037	0·0245	0·0188
k	1·14	1·13	1·30	1·33	1·1	1·16
D_{100} (profile) lb	603	738	622	145	123	1,070
C_{Dz}	0·030	0·0235	0·031	0·0345	0·0245	0·0179
k_z	1·10	1·13	1·30	1·15	1·1	1·12
$w_s$lb/ft^2	37	49·5	49	26	40	64
A	7·5	8·6	7·5	9·9	5·1	9·2
$(L/D)_{\max}$	13	16	12	14	12	19
Cleanness efficiency $\frac{\text{Ideal}}{\text{Total}}$	0·41	0·50	0·42	0·47	0·59	0·73
Drag efficiency $\frac{\text{Ideal Wing}}{\text{Total}}$	0·26	0·32	0·26	0·33	0·33	0·46
Hull drag ratio $\frac{\text{Drag Hull}}{\text{Total}}$	0·20	0·22	0·21	0·24	0·34	0·21
D_{100}/W	0·0096	0·0057	0·0076	0·0159	0·00745	0·00337
$W^{1/3}$	39·6	50·7	43·4	21·0	25·5	68·4

(73271) Wt. 53/2293 K. 7 7/59 Hw.

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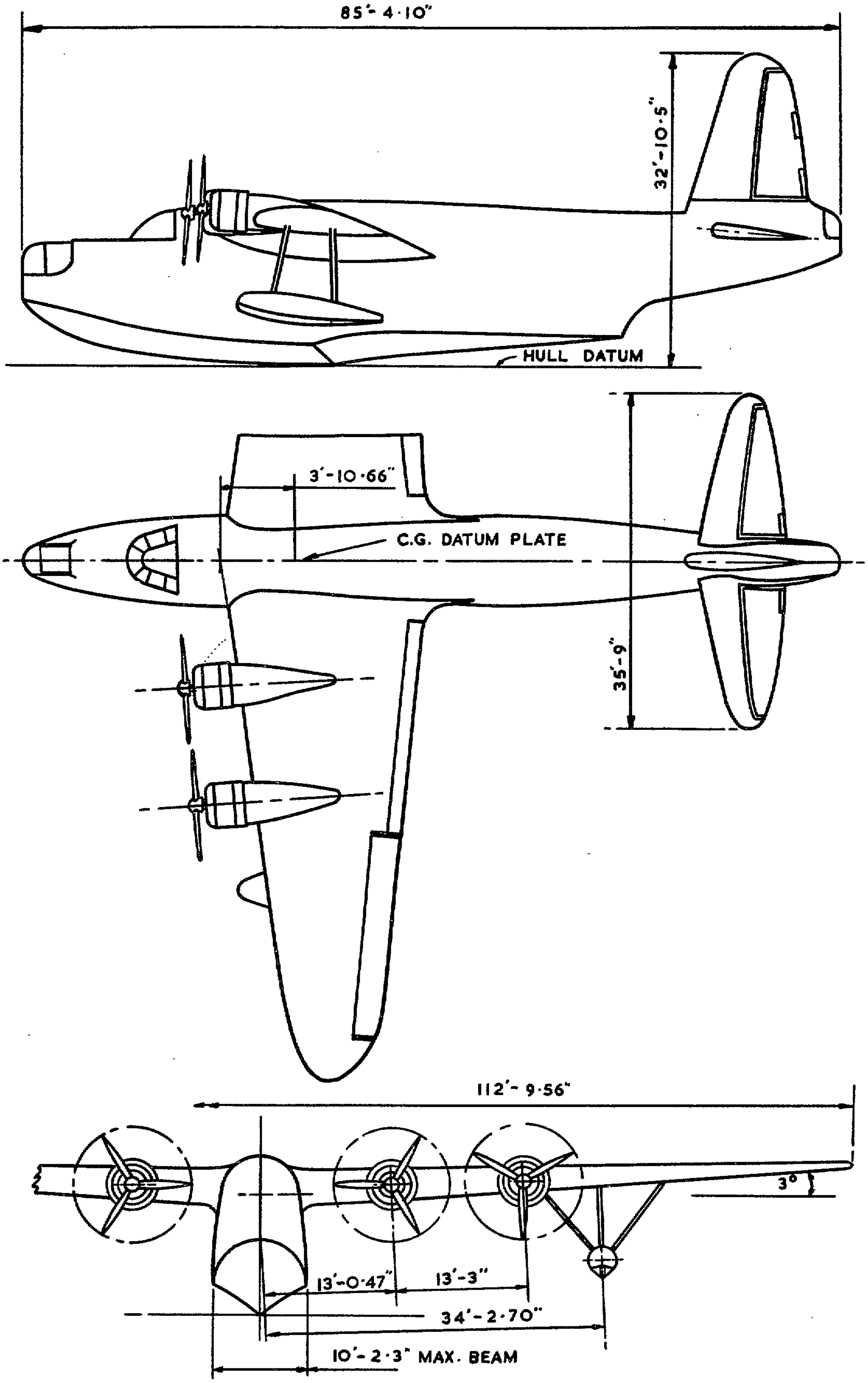


FIG. 1. GENERAL ARRANGEMENT SKETCH OF SUNDERLAND Mk. 5

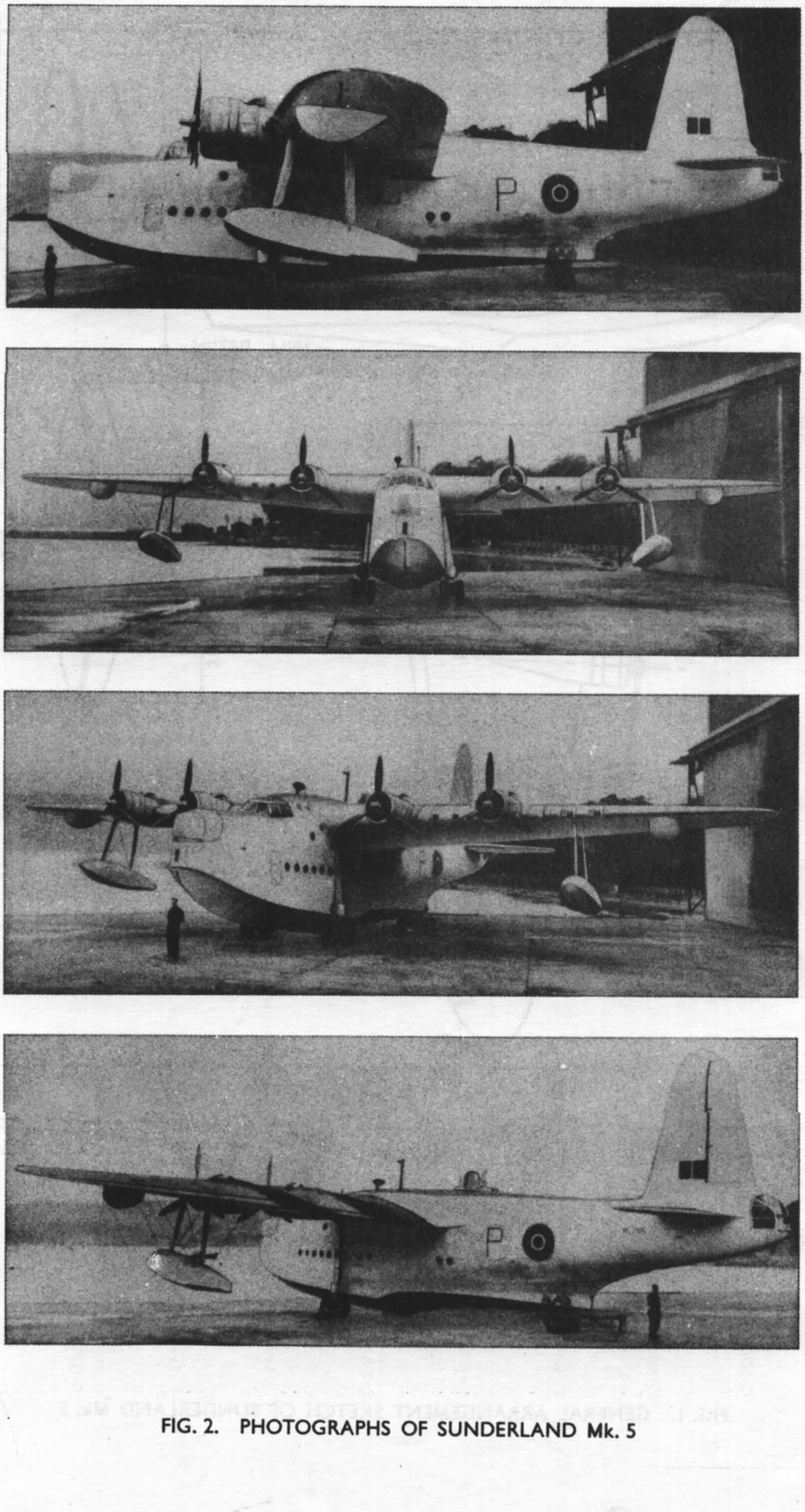


FIG. 2. PHOTOGRAPHS OF SUNDERLAND Mk. 5

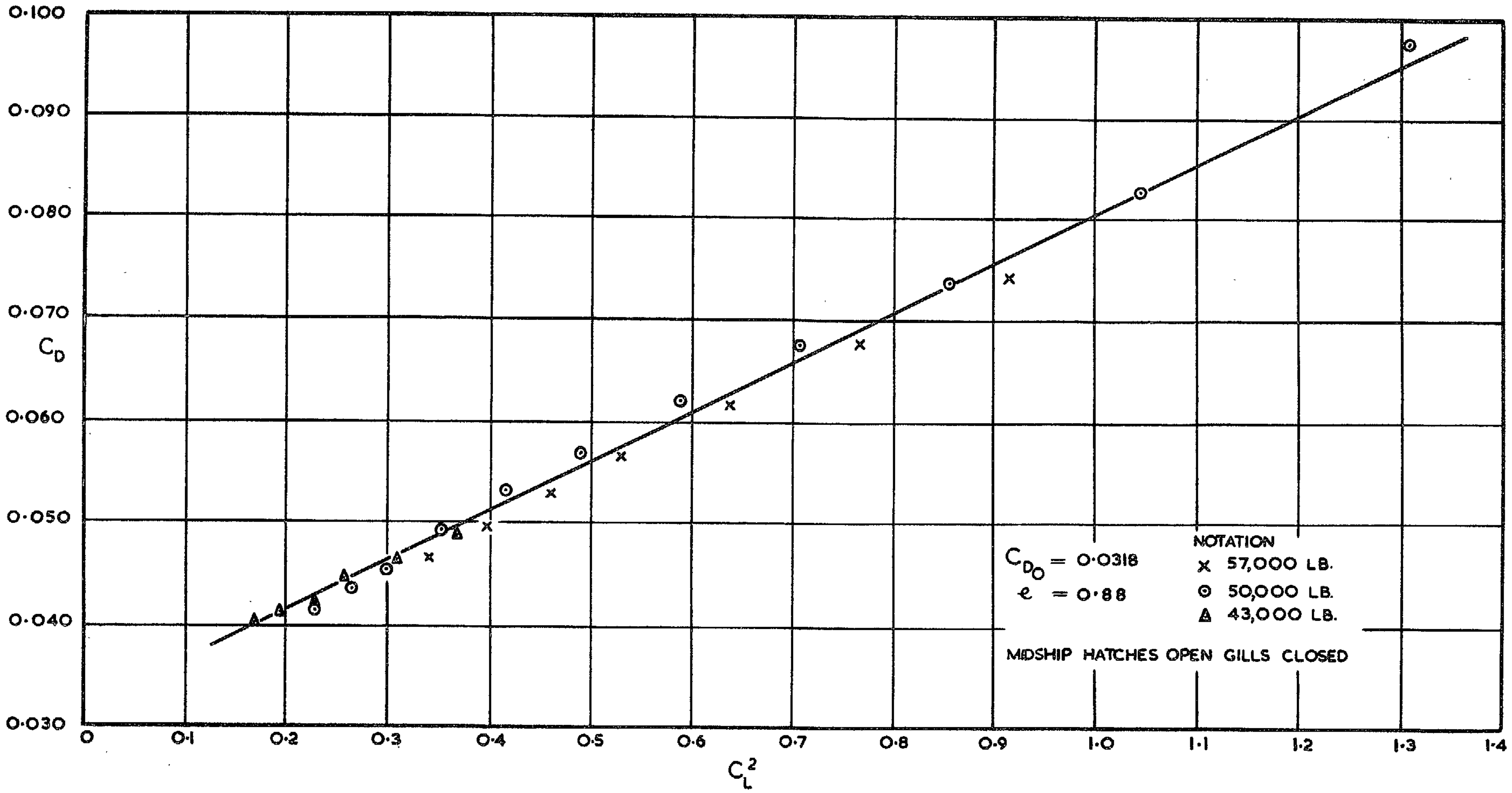


FIG. 3. DRAG OF SUNDERLAND IN LEVEL FLIGHT

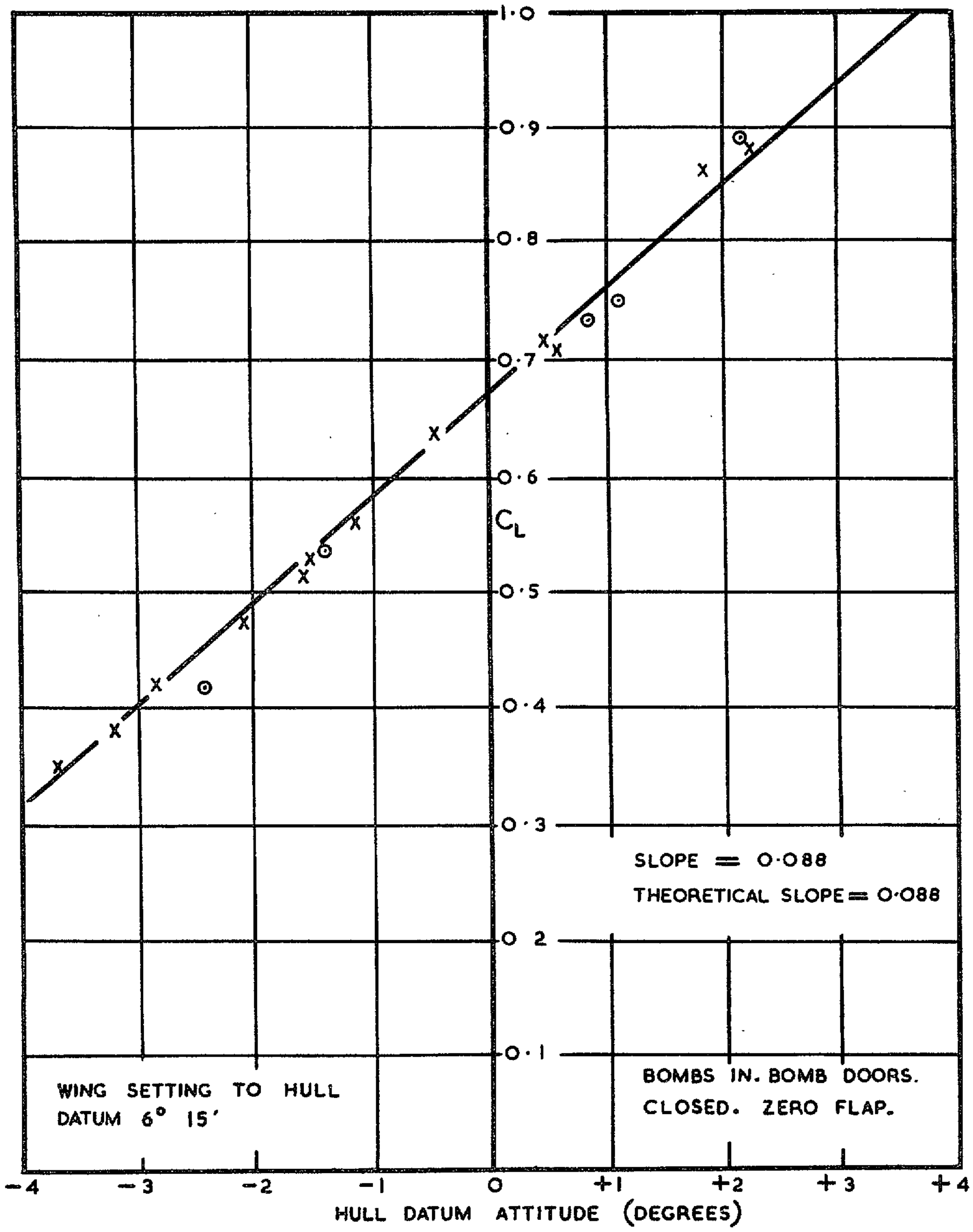


FIG. 4. LIFT OF SUNDERLAND IN LEVEL FLIGHT

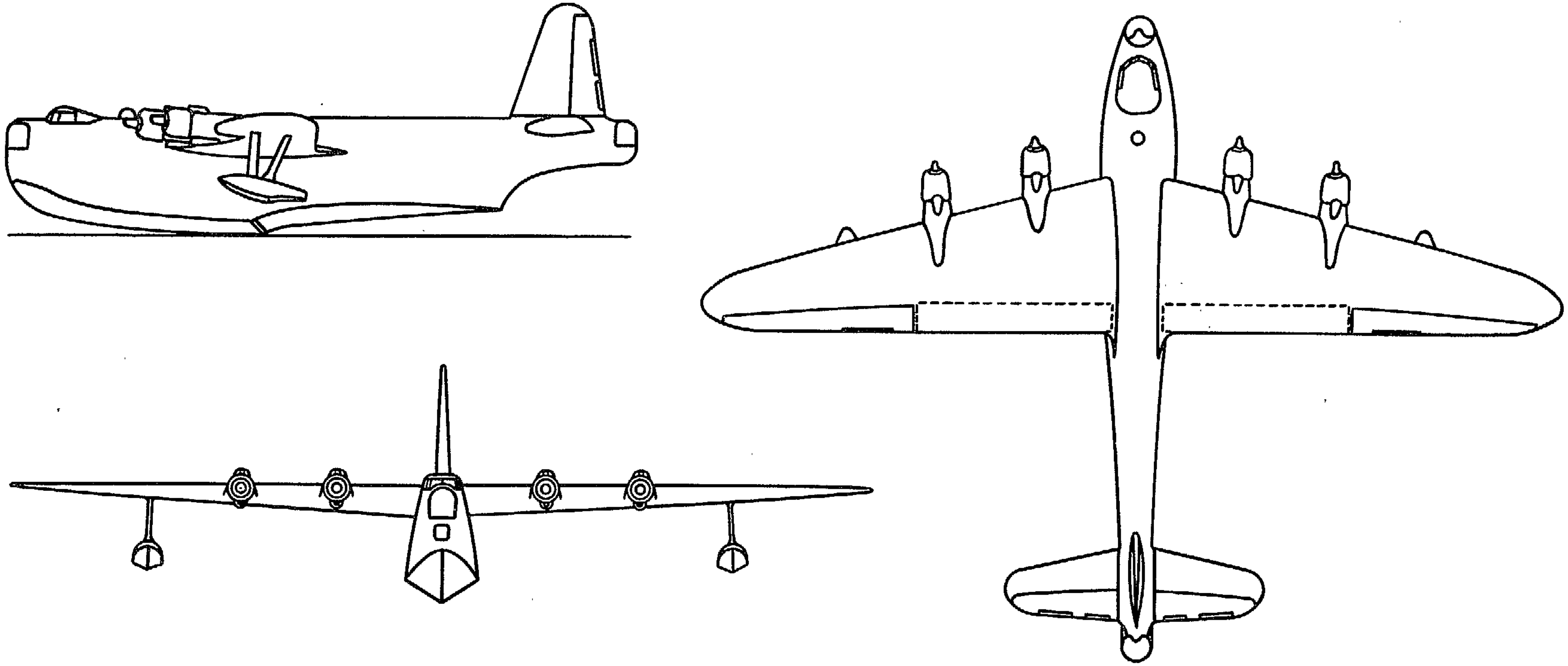


FIG. 5. GENERAL ARRANGEMENT SKETCH OF SHETLAND I

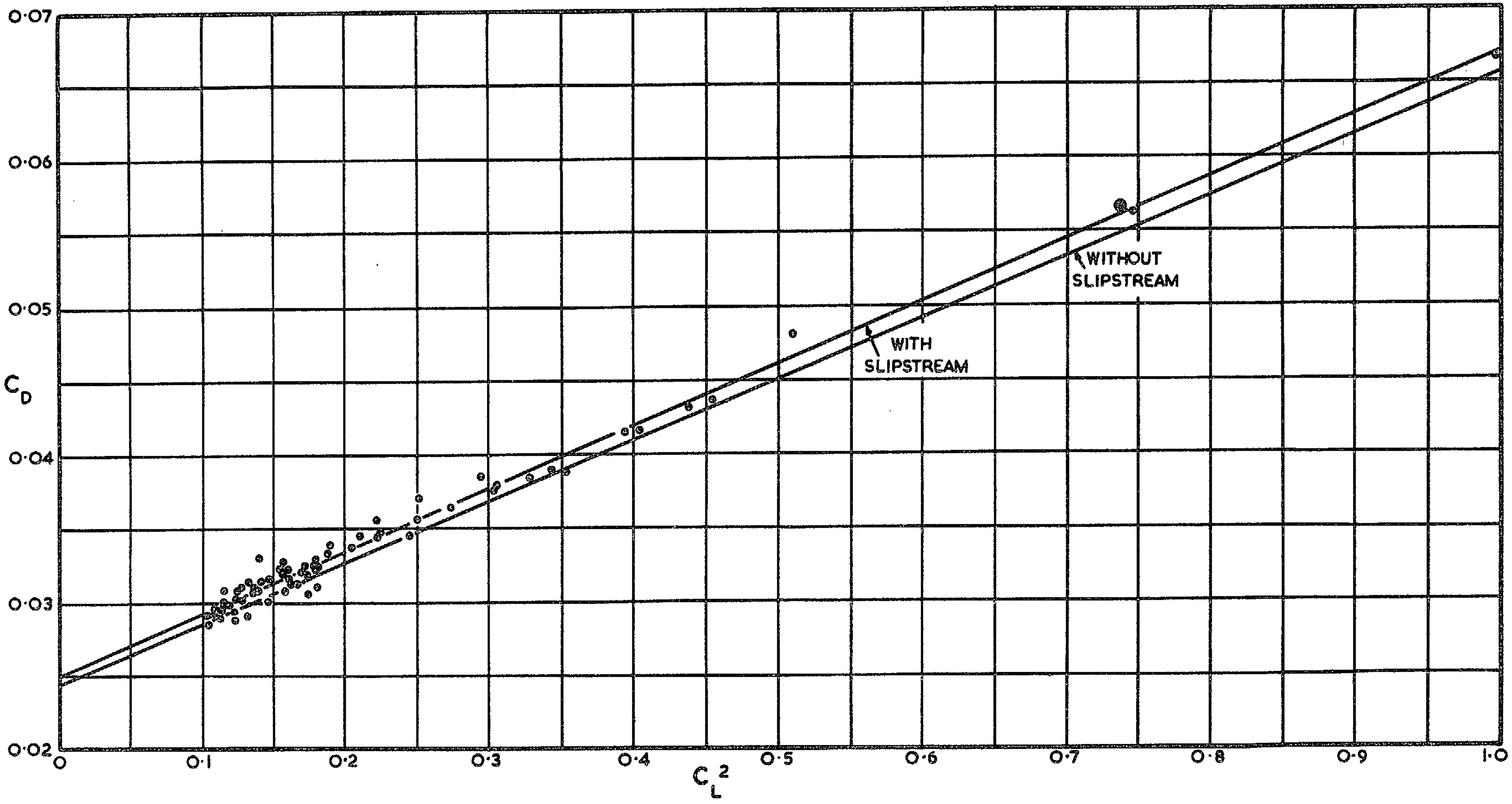


FIG. 6. DRAG OF SHETLAND IN LEVEL FLIGHT

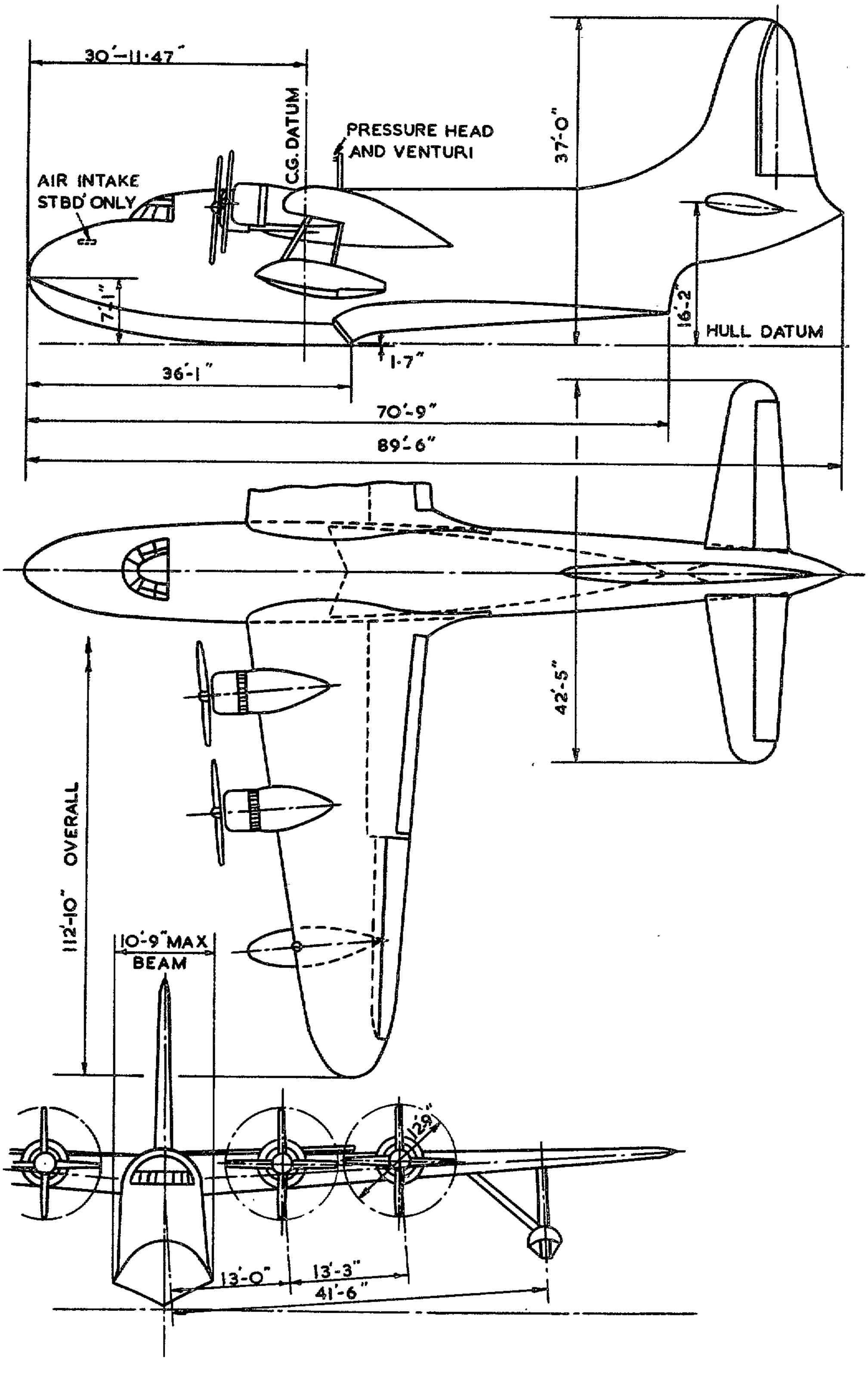
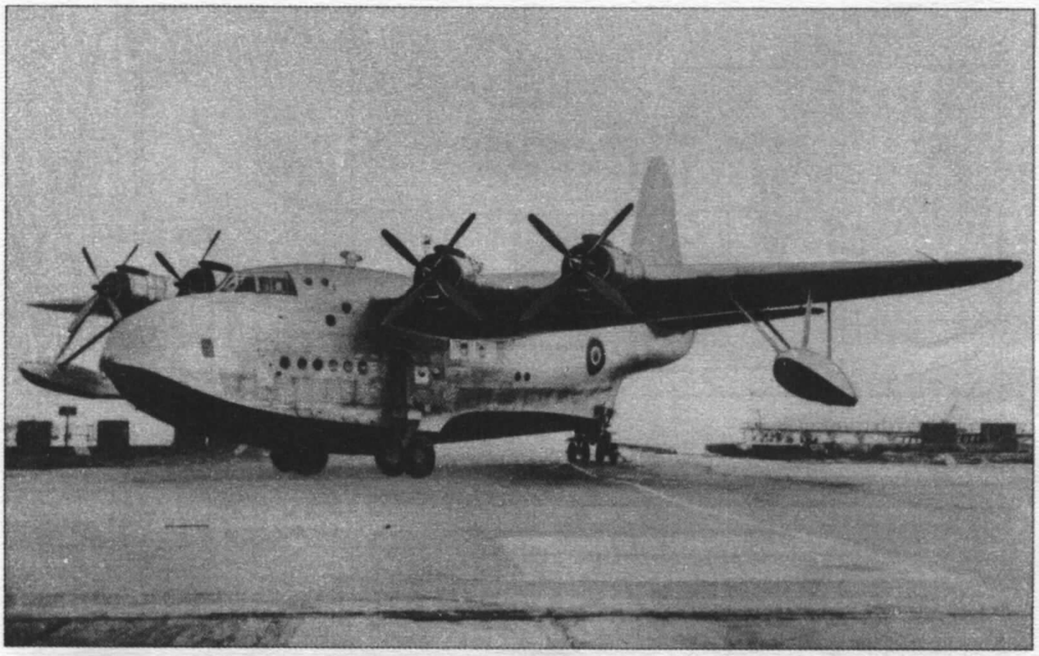


FIG. 7. GENERAL ARRANGEMENT SKETCH OF SOLENT



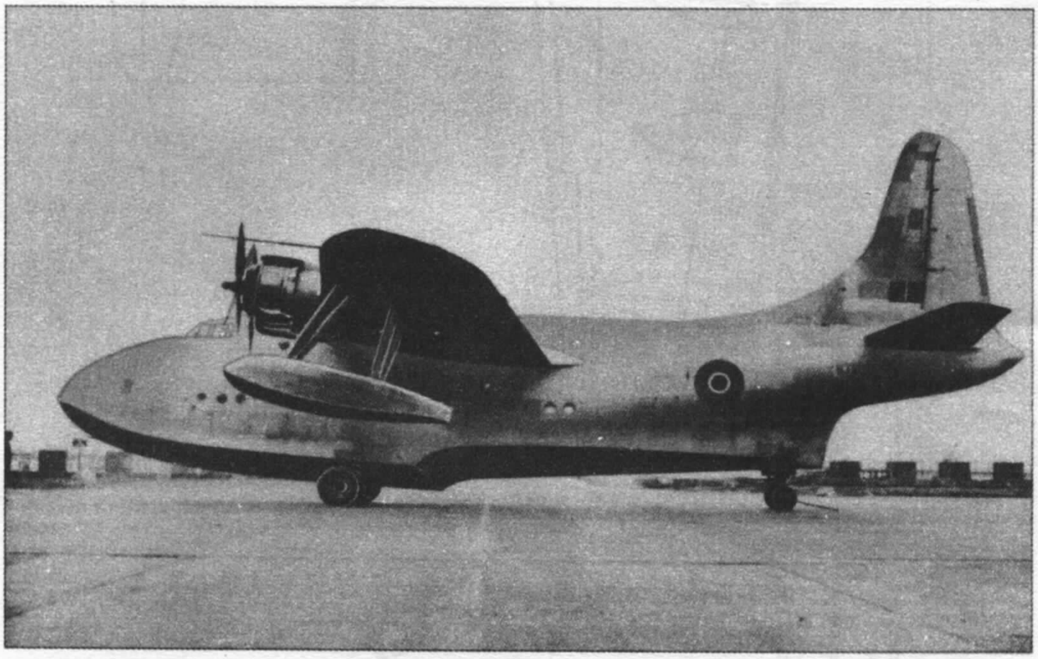


FIG. 8. PHOTOGRAPHS OF SOLENT

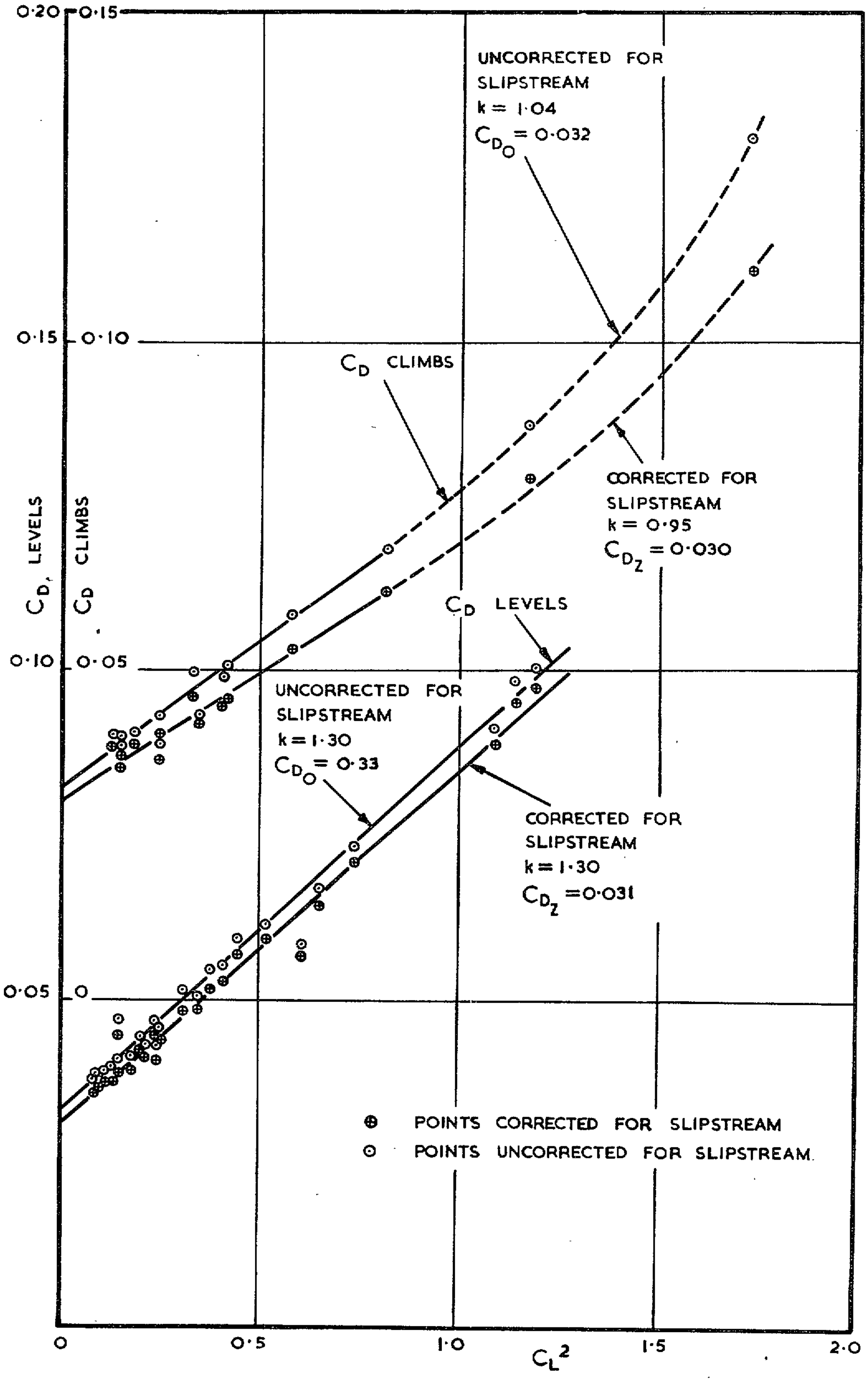


FIG. 9. DRAG OF SOLENT WITH ZERO FLAP

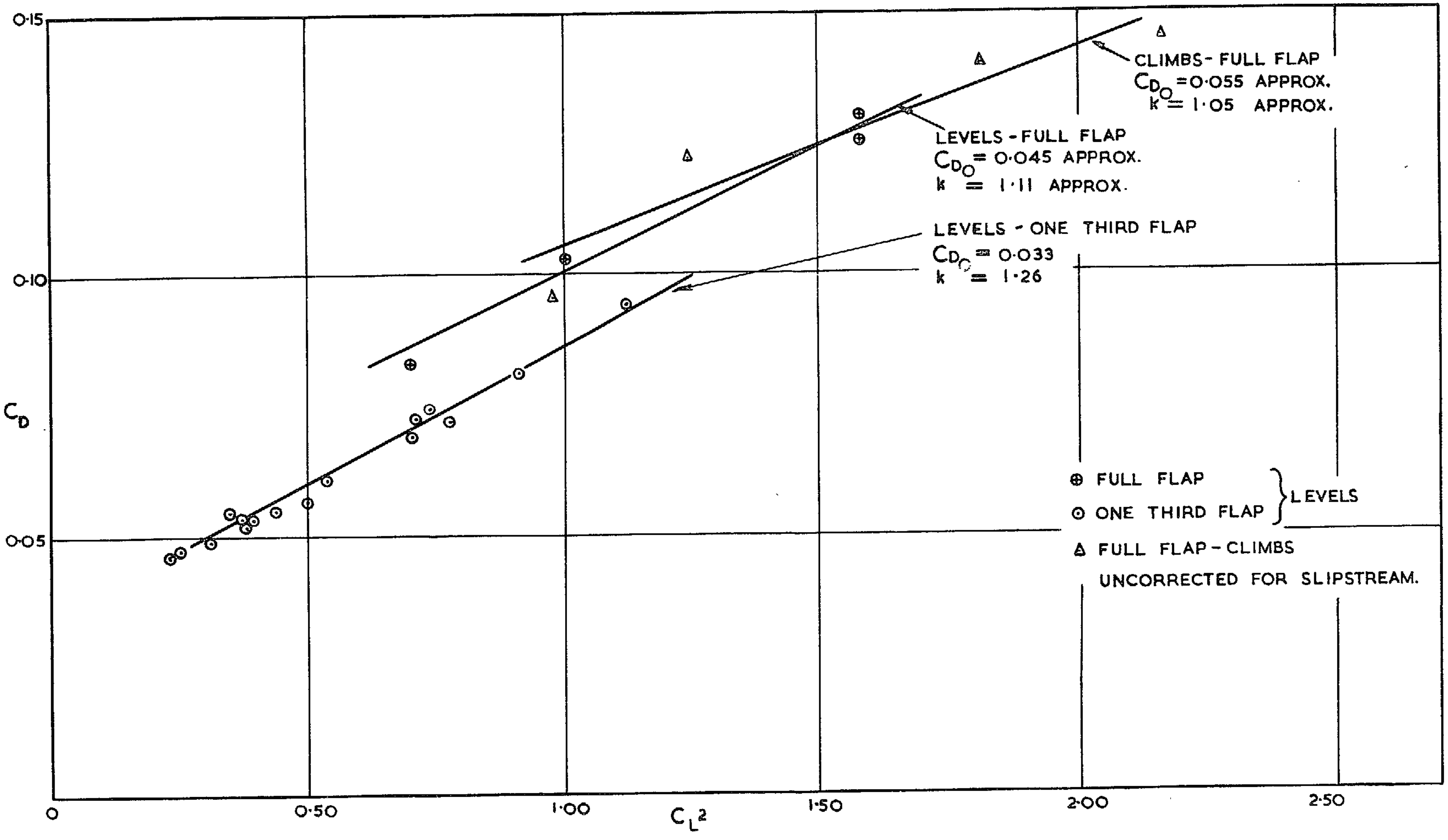


FIG. 10. DRAG OF SOLENT WITH FLAPS

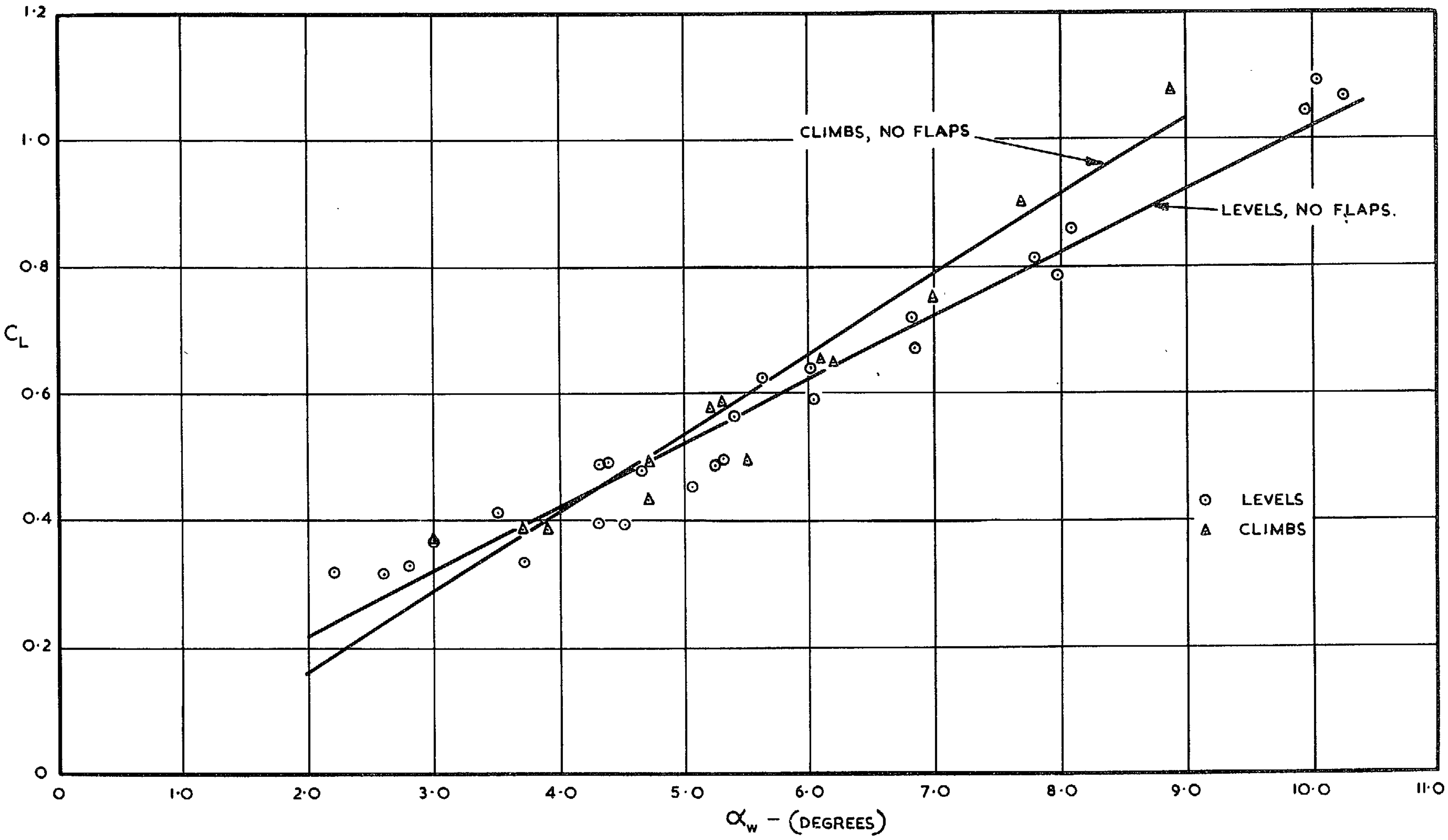


FIG. 11. LIFT OF SOLENT WITH ZERO FLAP

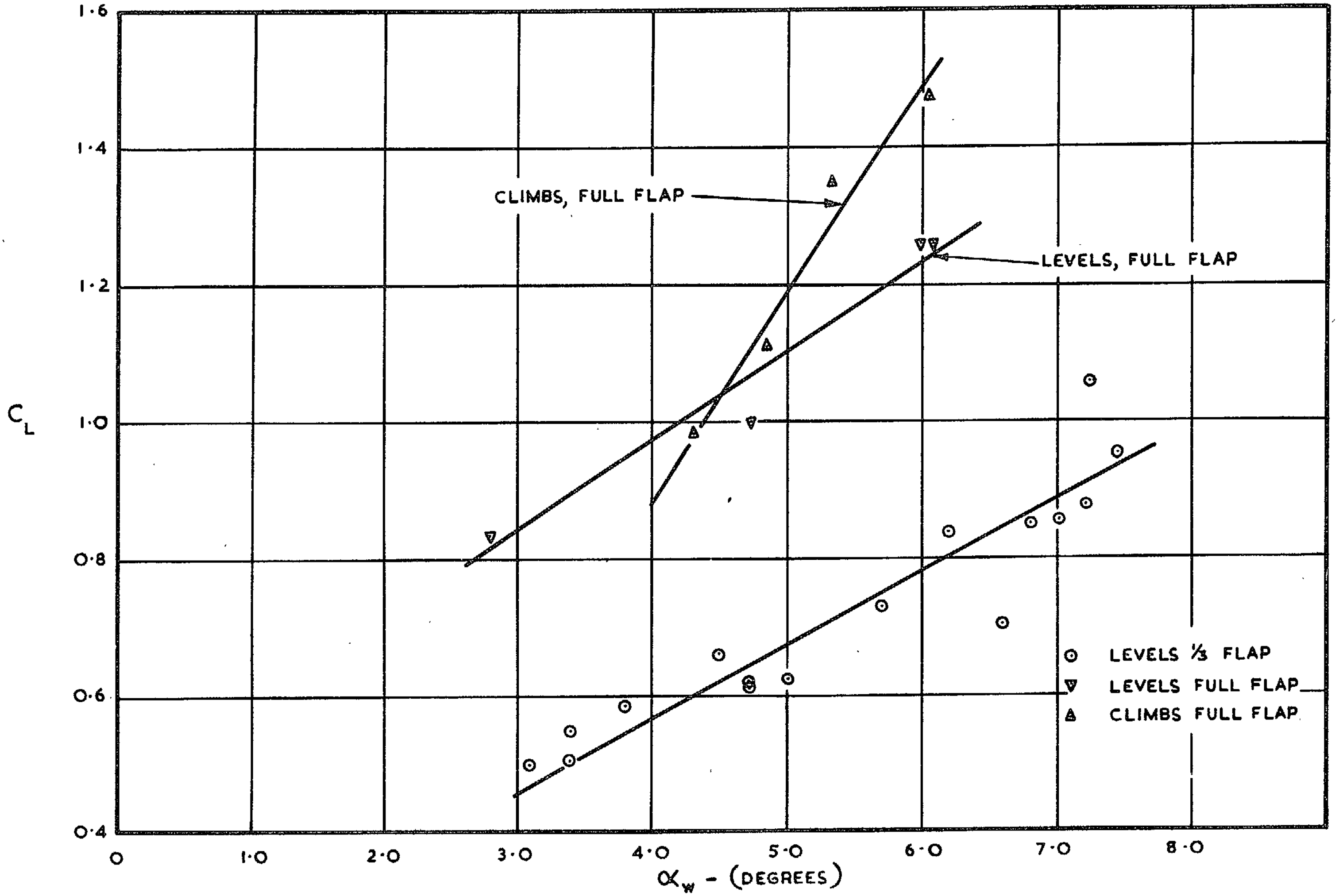


FIG. 12. LIFT OF SOLENT WITH FLAPS

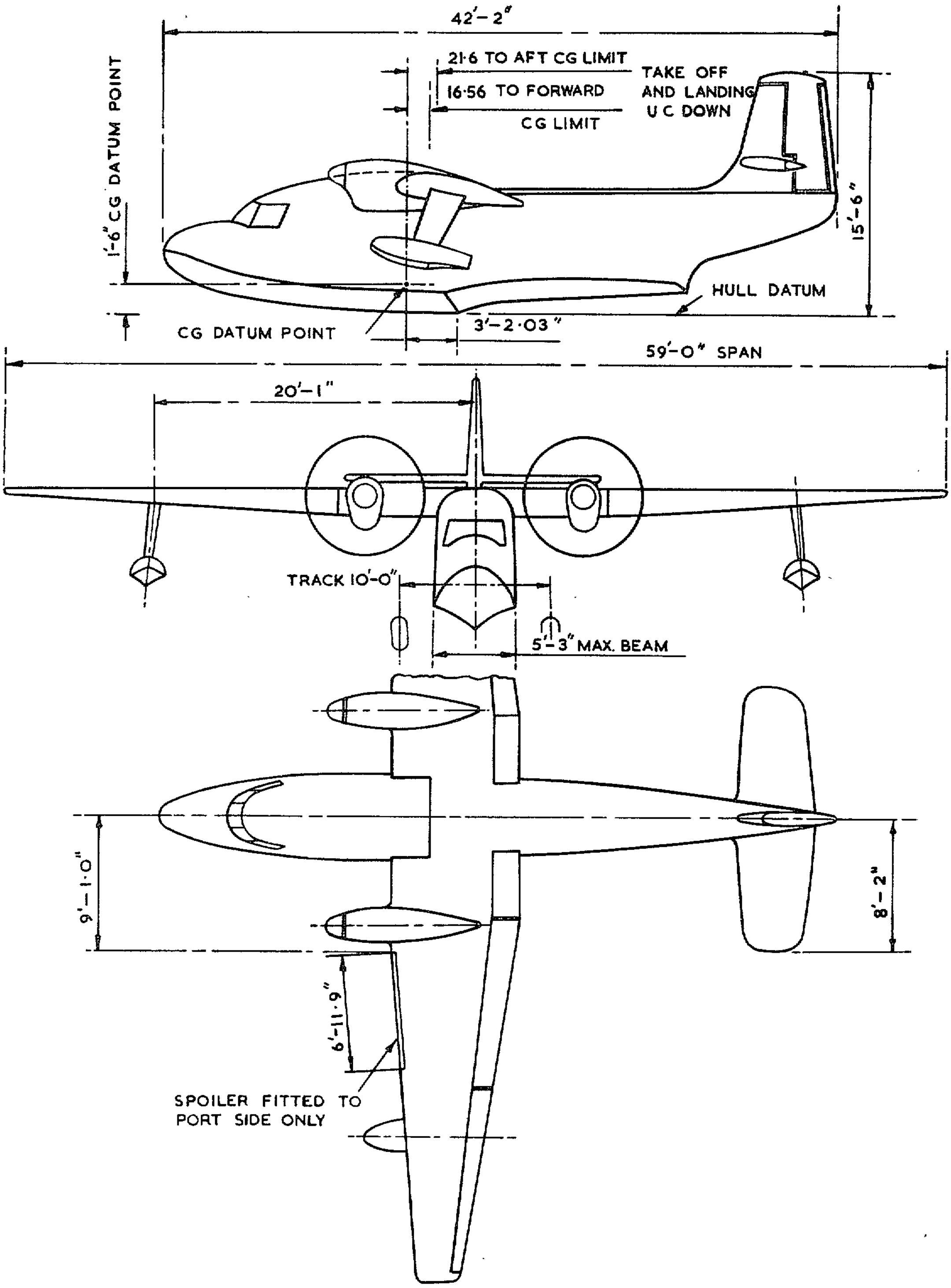


FIG. 13. GENERAL ARRANGEMENT SKETCH OF SEALAND

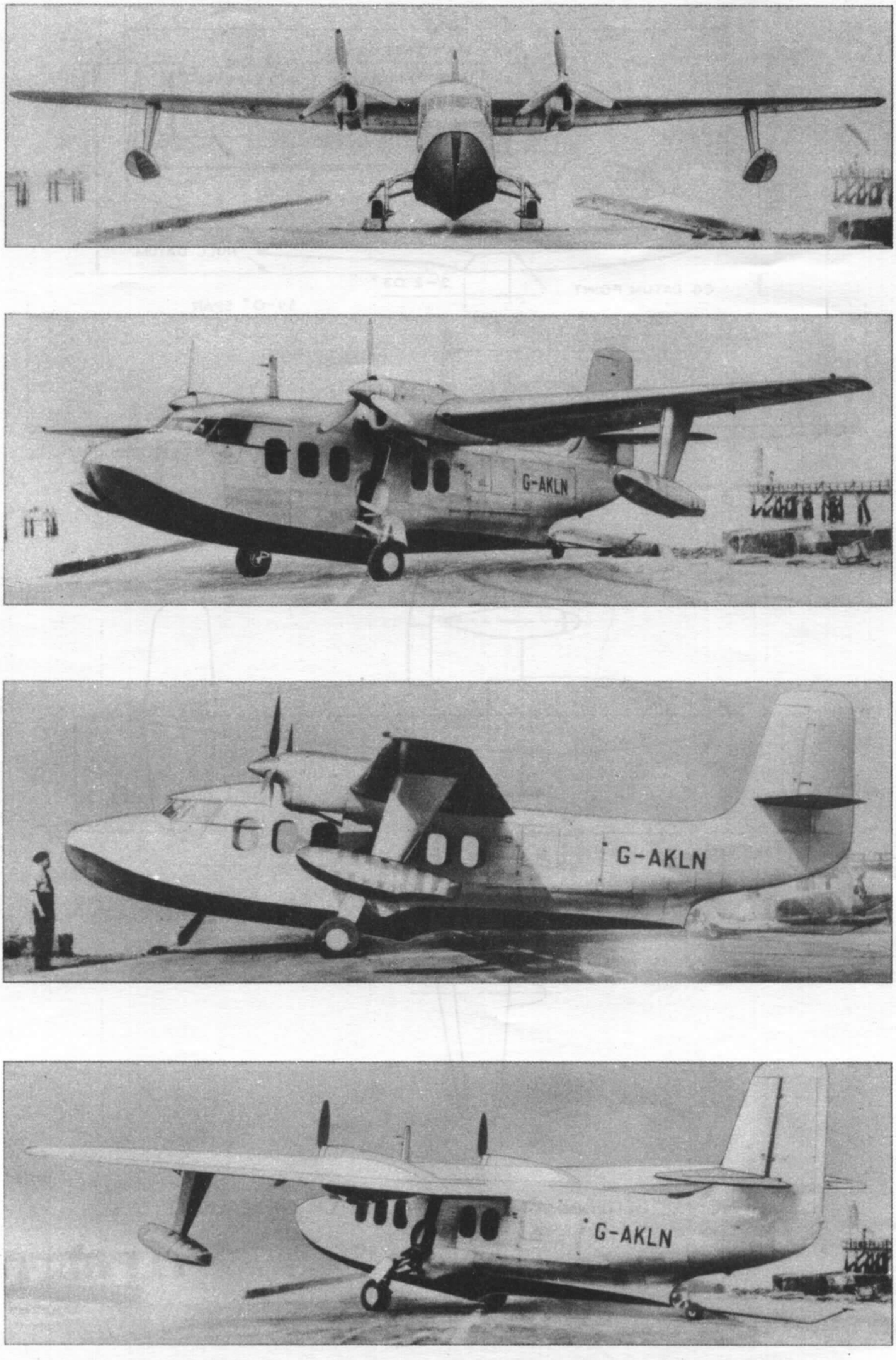


FIG. 14. PHOTOGRAPHS OF SEALAND

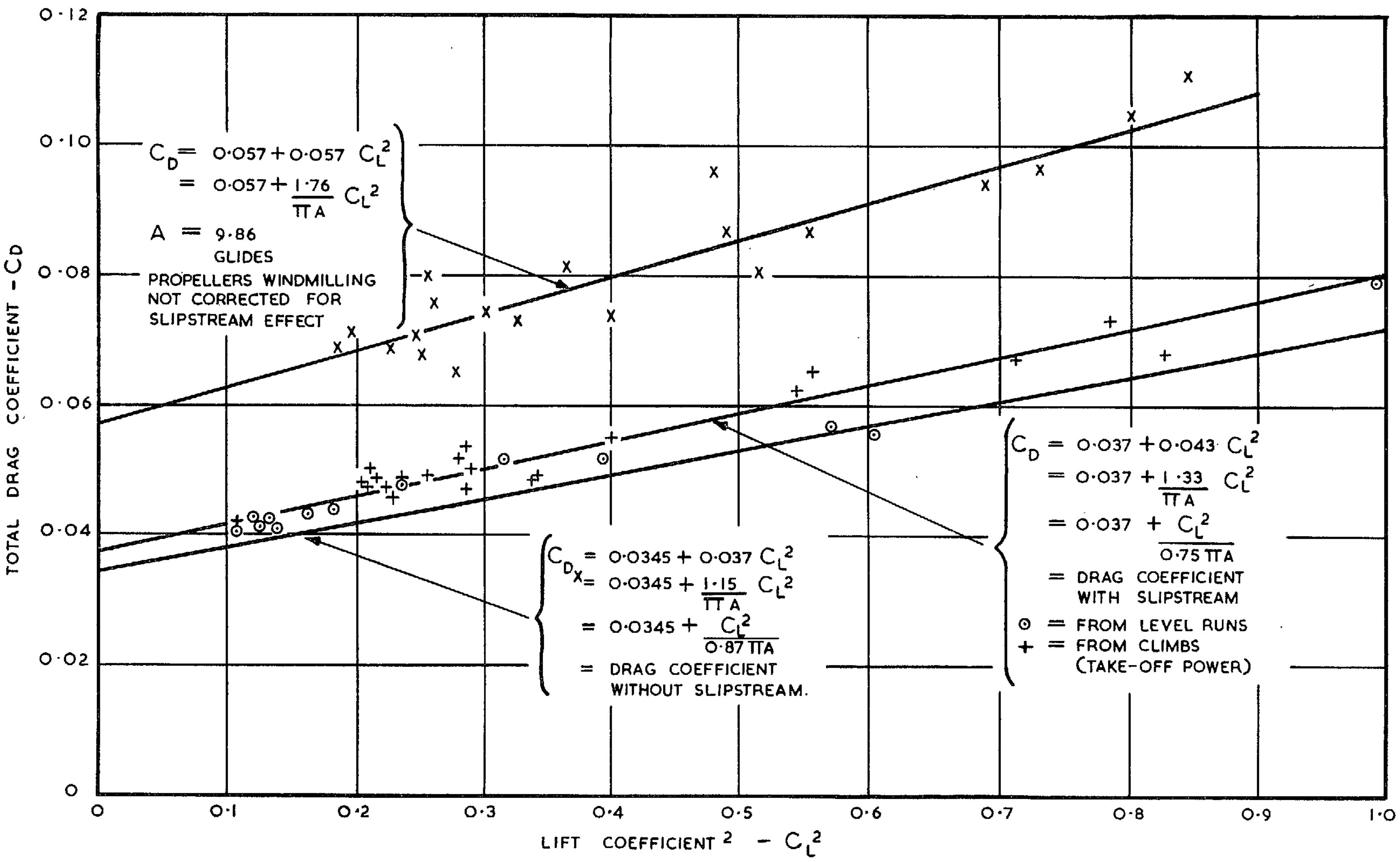


FIG. 15. DRAG OF SEALAND WITH ZERO FLAP

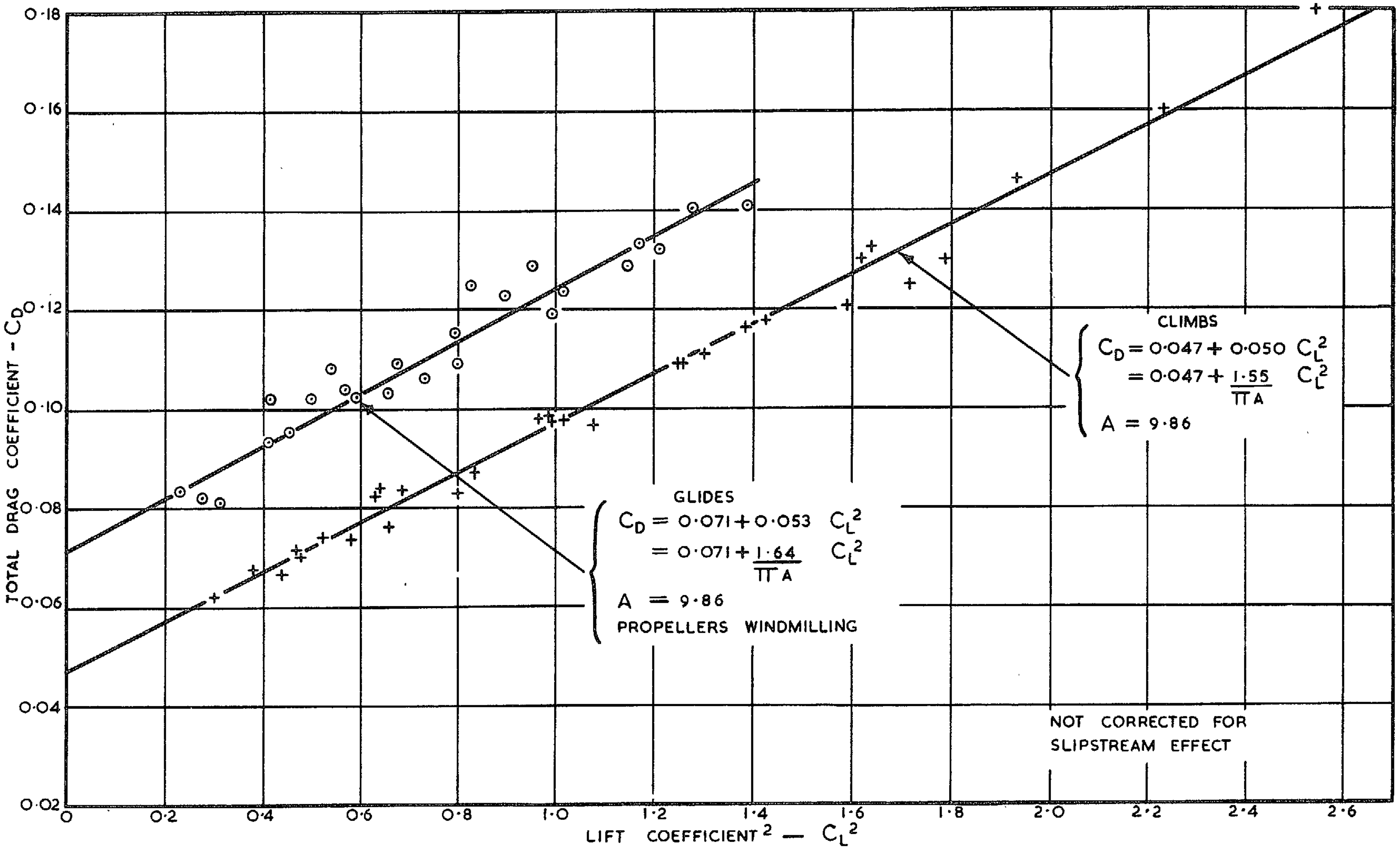


FIG. 16. DRAG OF SEALAND WITH 15° FLAP

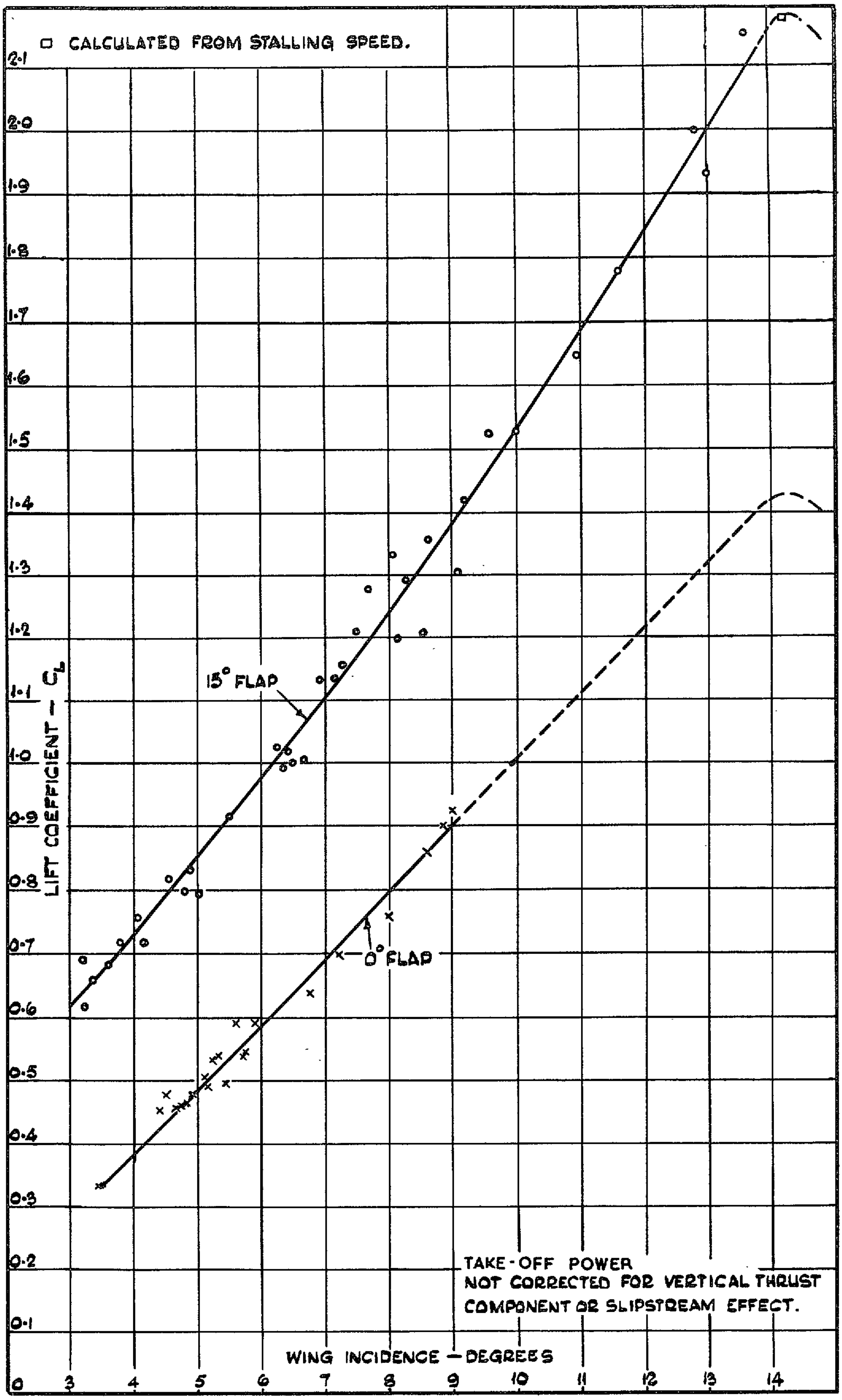


FIG. 17. LIFT OF SEALAND IN CLIMBS

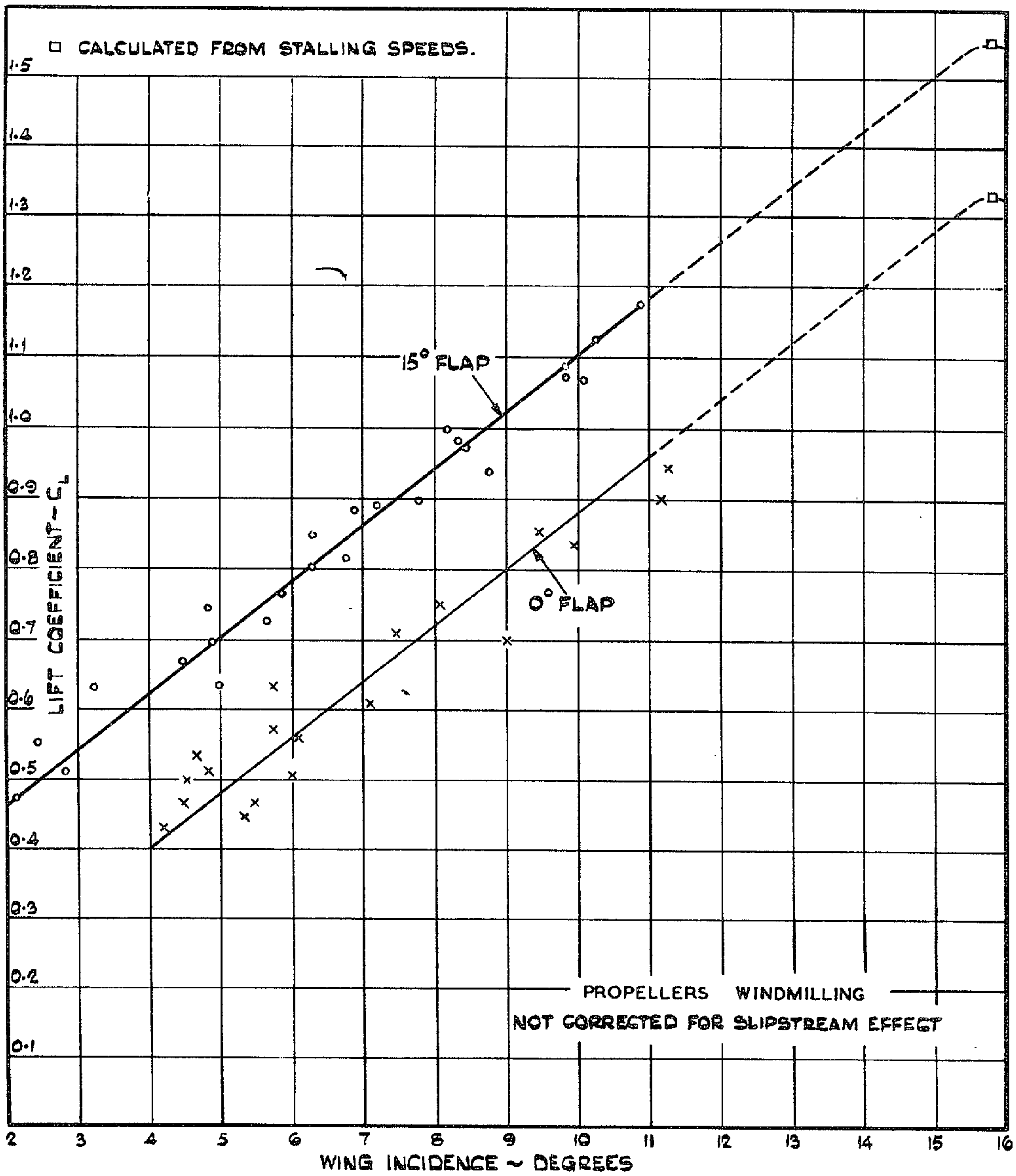


FIG. 18. LIFT OF SEALAND IN GLIDES

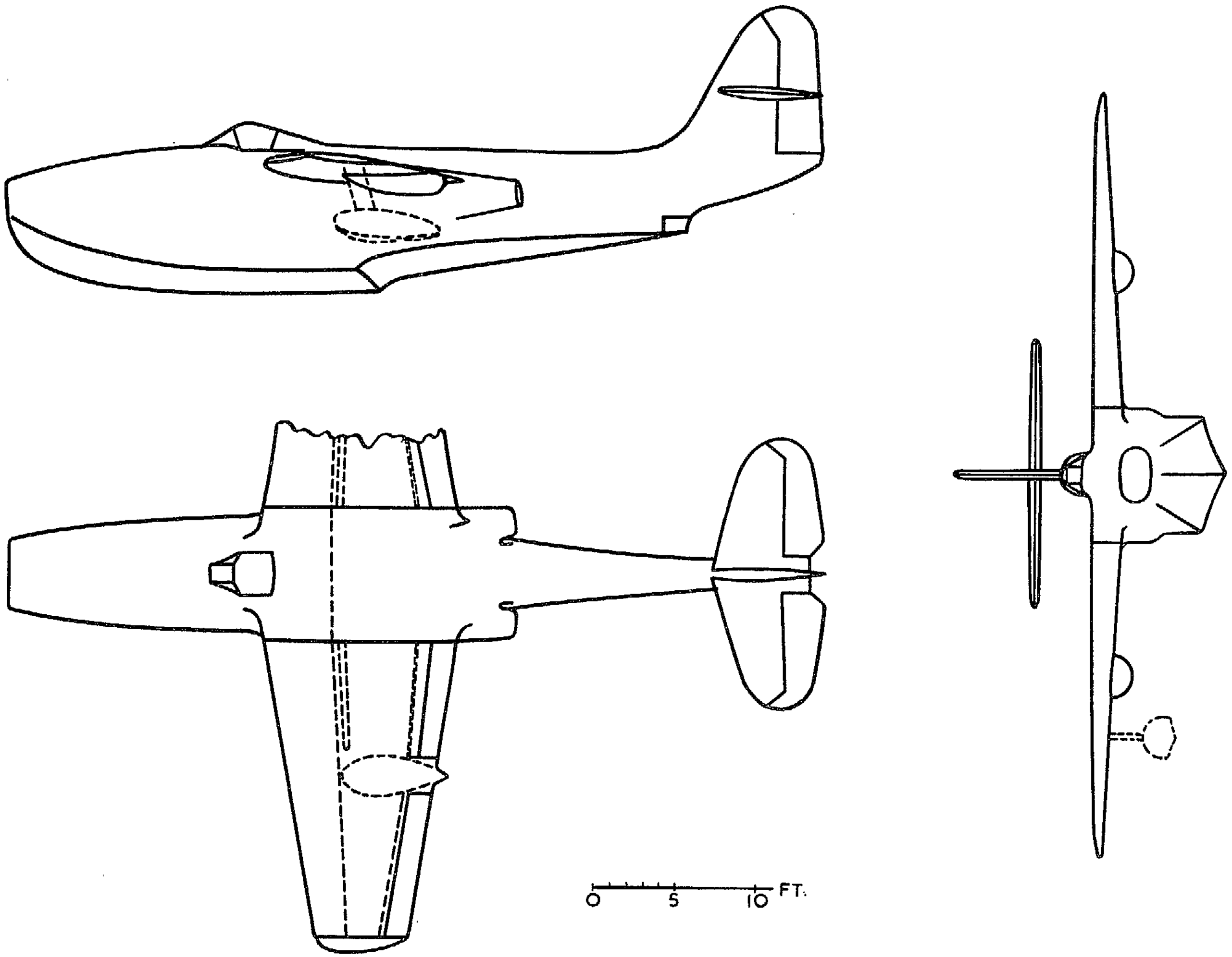


FIG. 19. GENERAL ARRANGEMENT SKETCH OF SARO E6/44

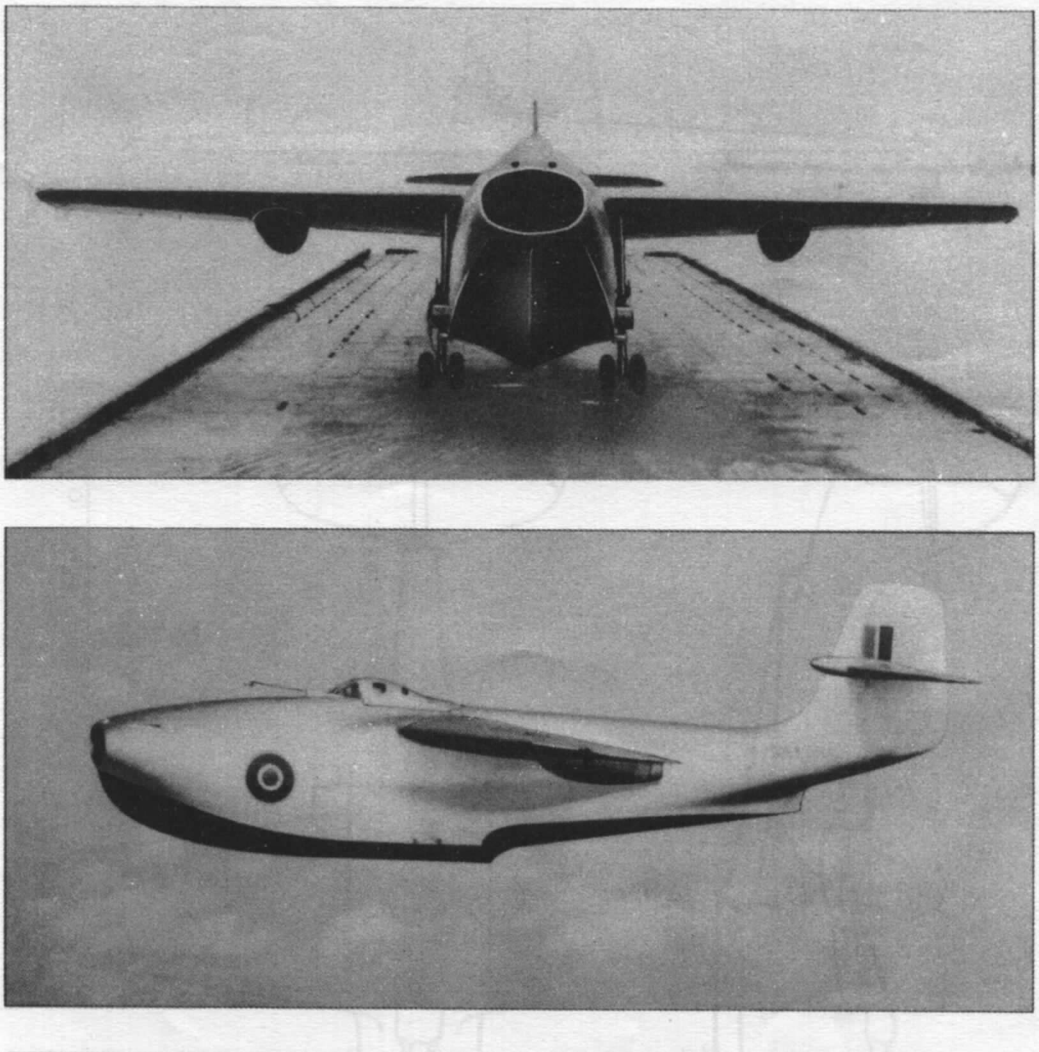


FIG. 20. PHOTOGRAPHS OF SARO E6/44

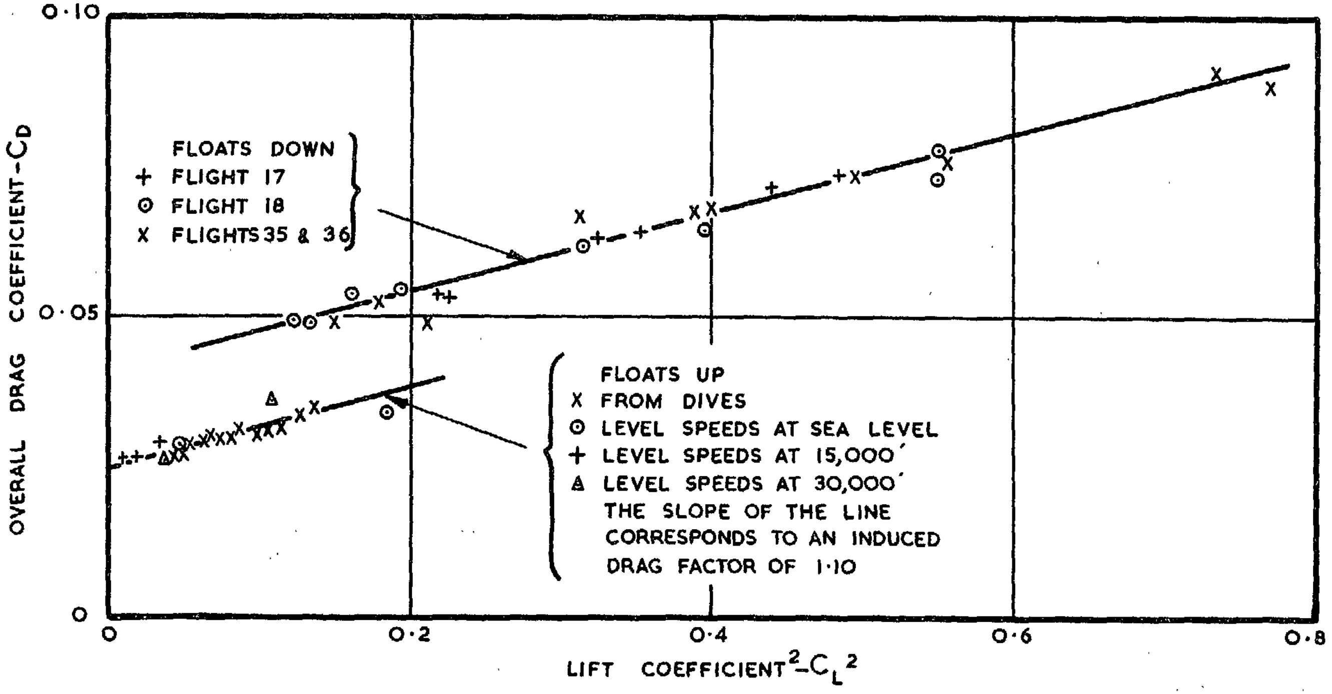


FIG. 21. DRAG OF SARO E6/44 IN LEVEL AND CLIMBING FLIGHT WITH ZERO FLAP

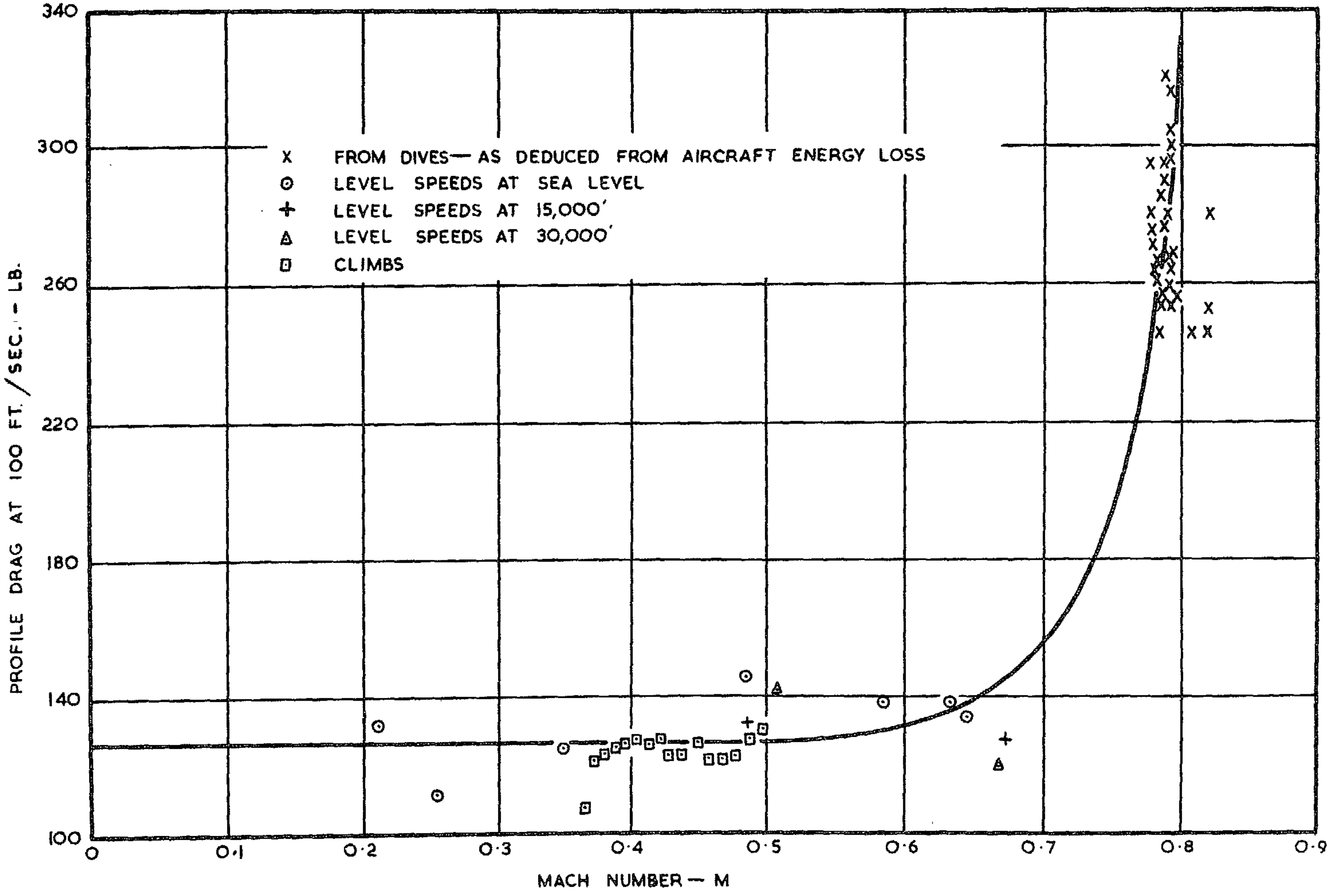


FIG. 22. DRAG OF SARO E6/44 : EFFECT OF MACH NUMBER

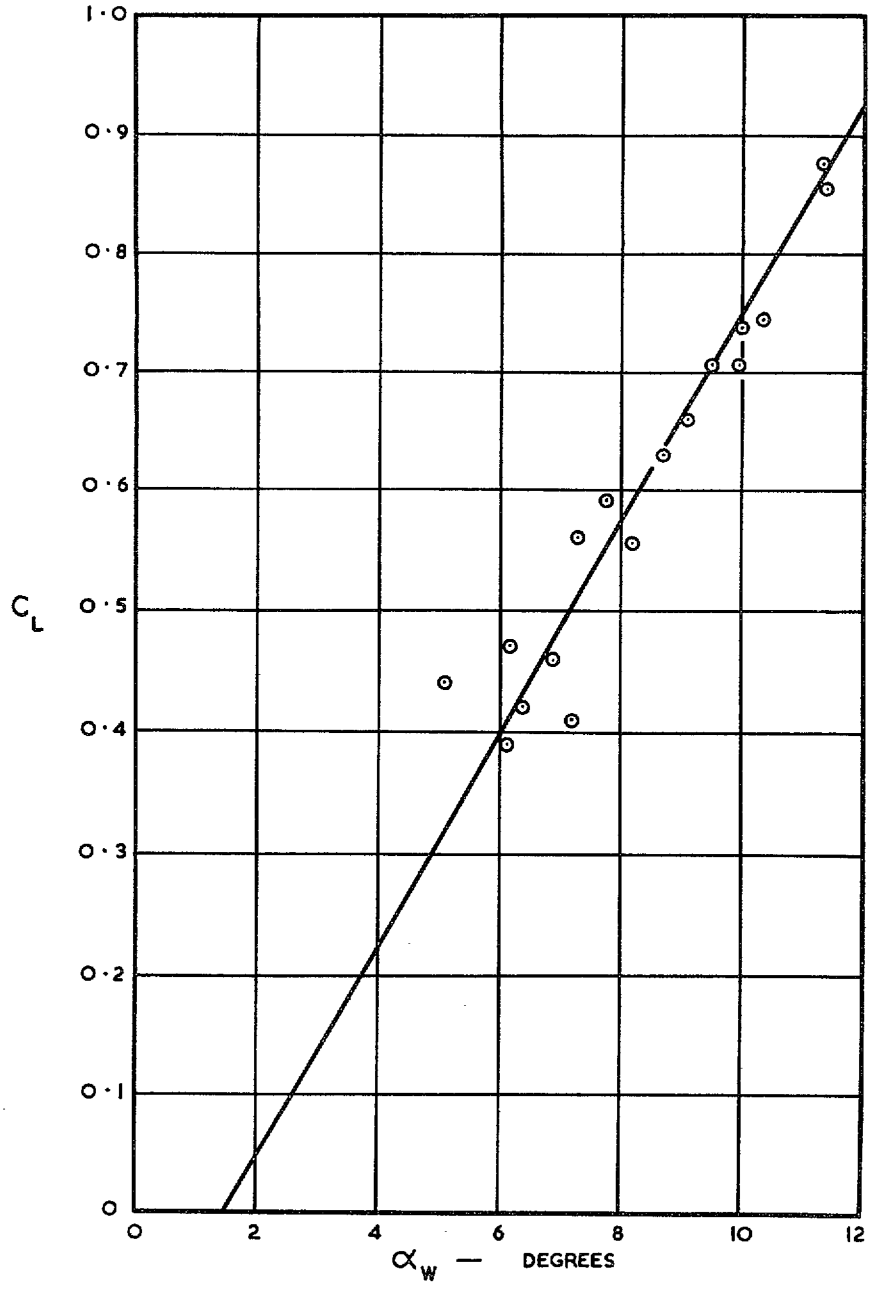


FIG. 23. LIFT OF SARO E6/44 WITH ZERO FLAP

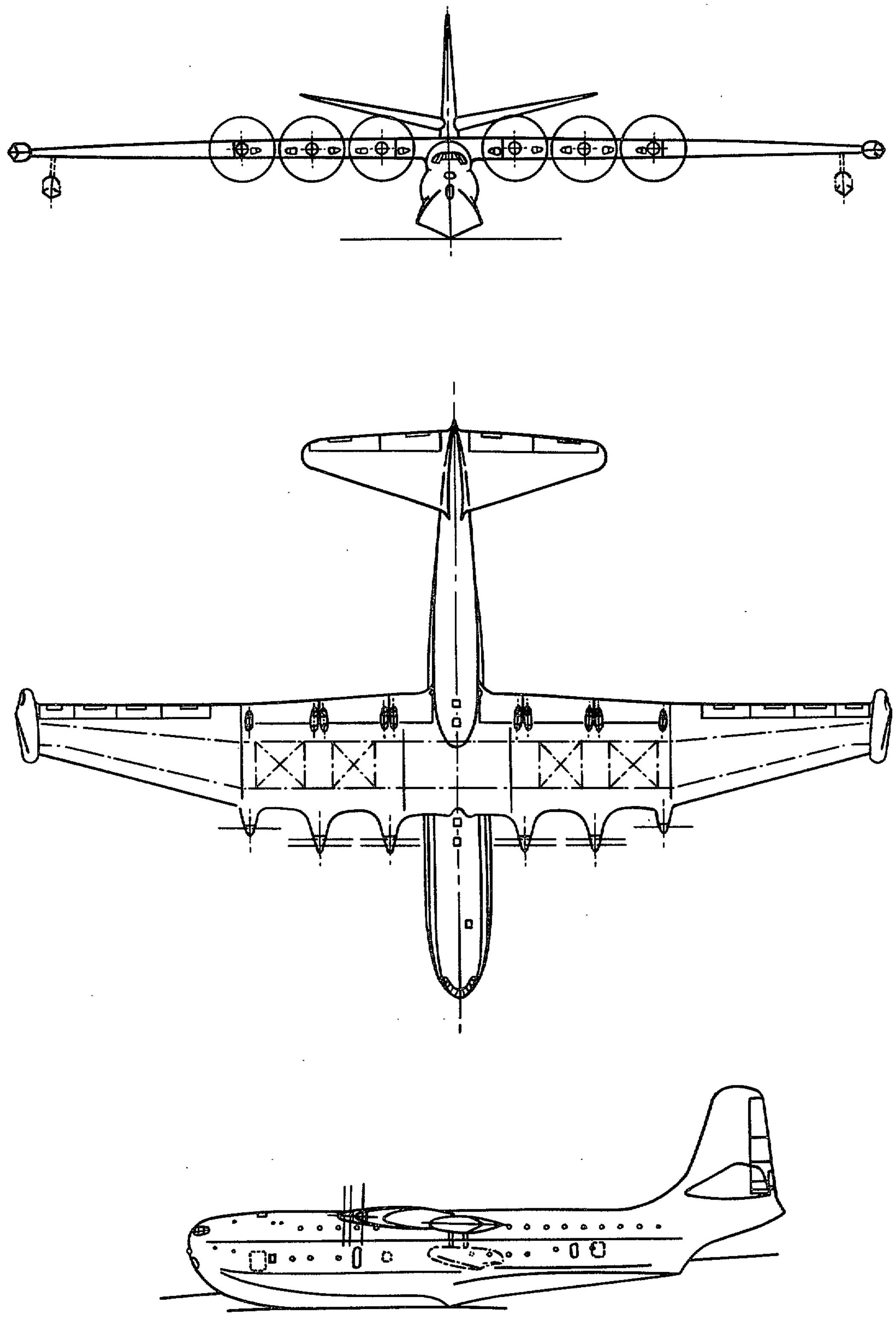


FIG. 24. PRINCESS GENERAL ARRANGEMENT

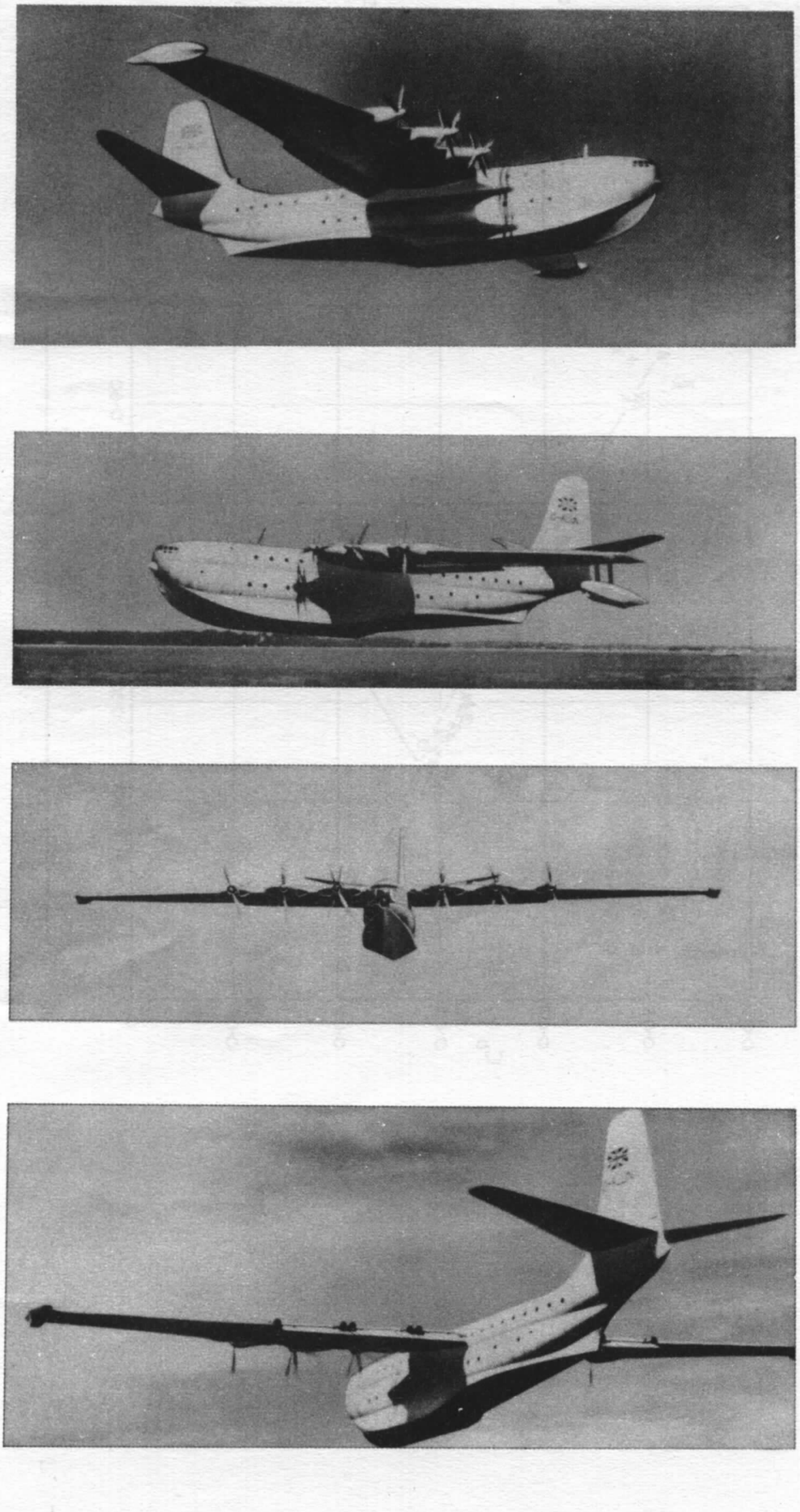


FIG. 25. PHOTOGRAPHS OF PRINCESS

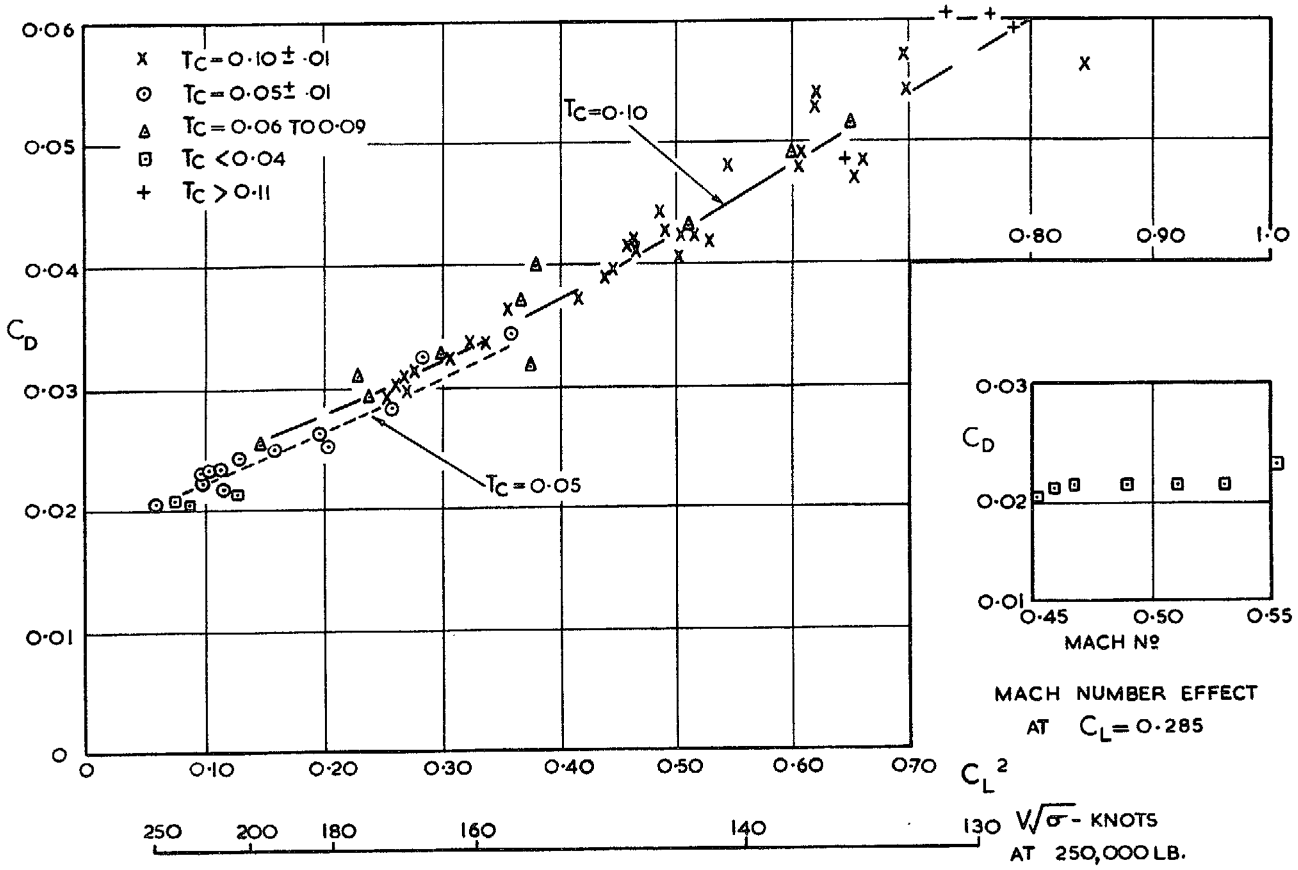


FIG. 26. DRAG OF PRINCESS WITH ZERO FLAP WITHOUT SLIPSTREAM CORRECTIONS

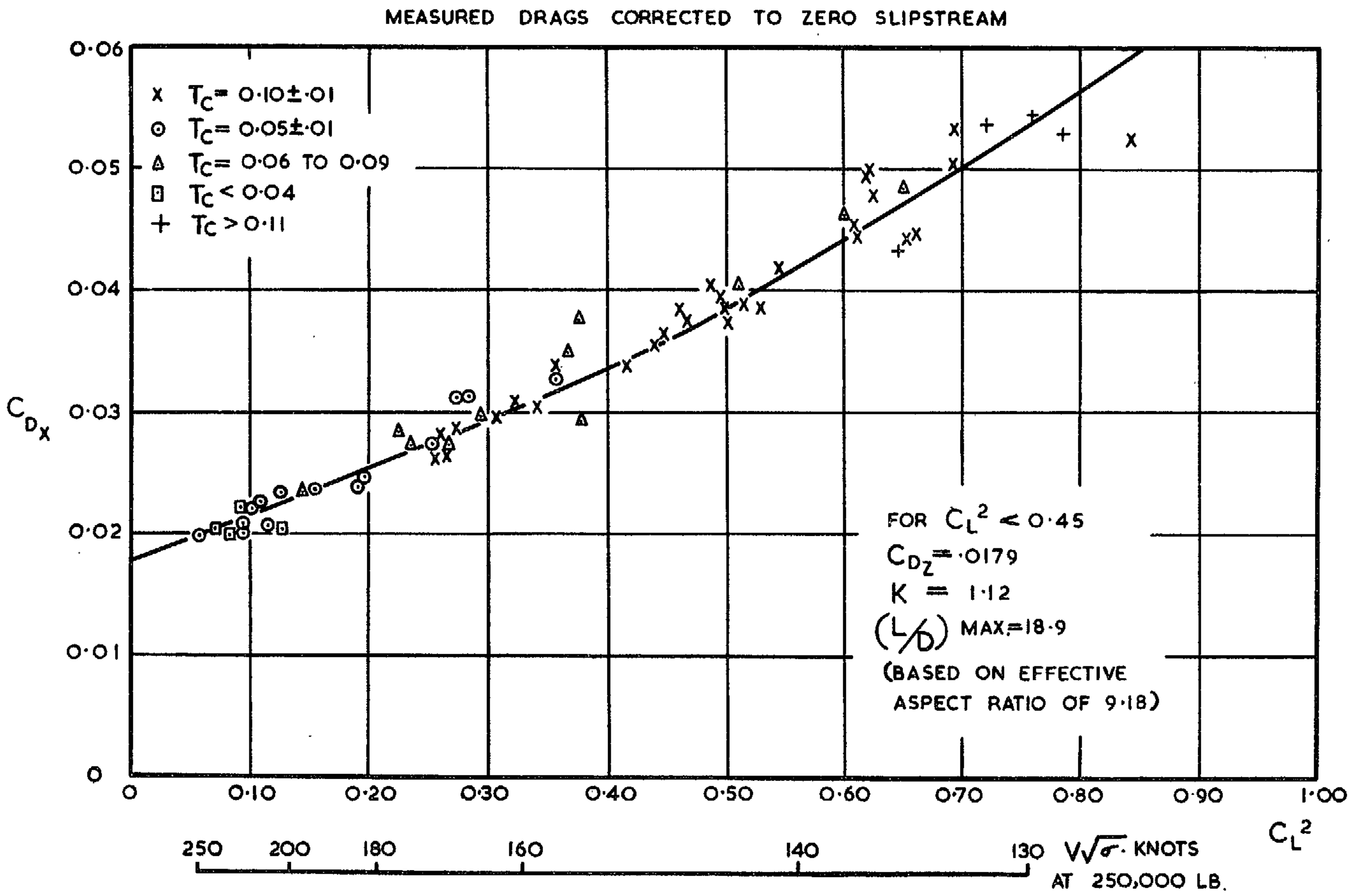
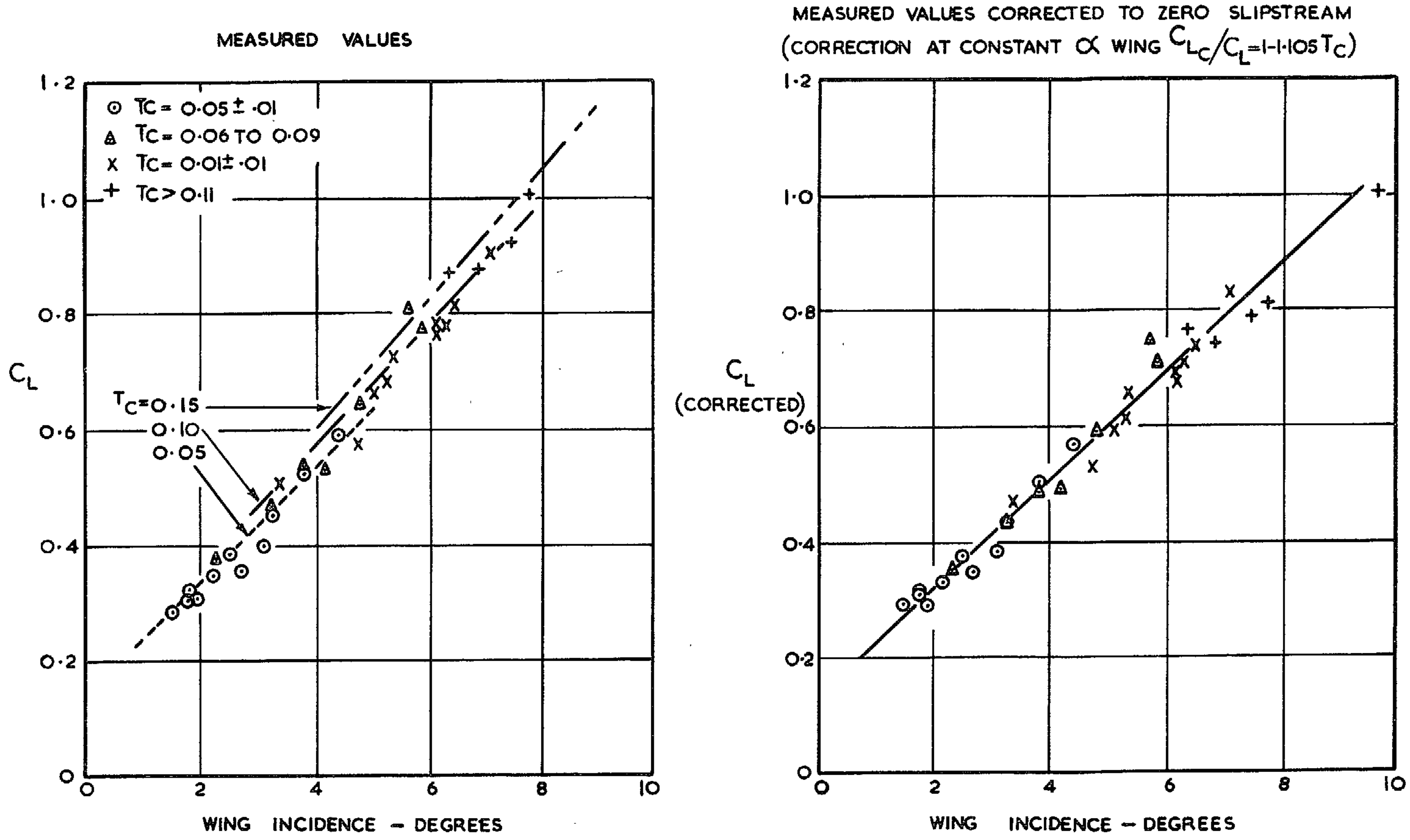


FIG. 27. DRAG OF PRINCESS IN LEVEL FLIGHT WITH ZERO FLAP WITH SLIPSTREAM CORRECTIONS



FLOATS RETRACTED

FIG. 28. LIFT OF PRINCESS WITH ZERO FLAP

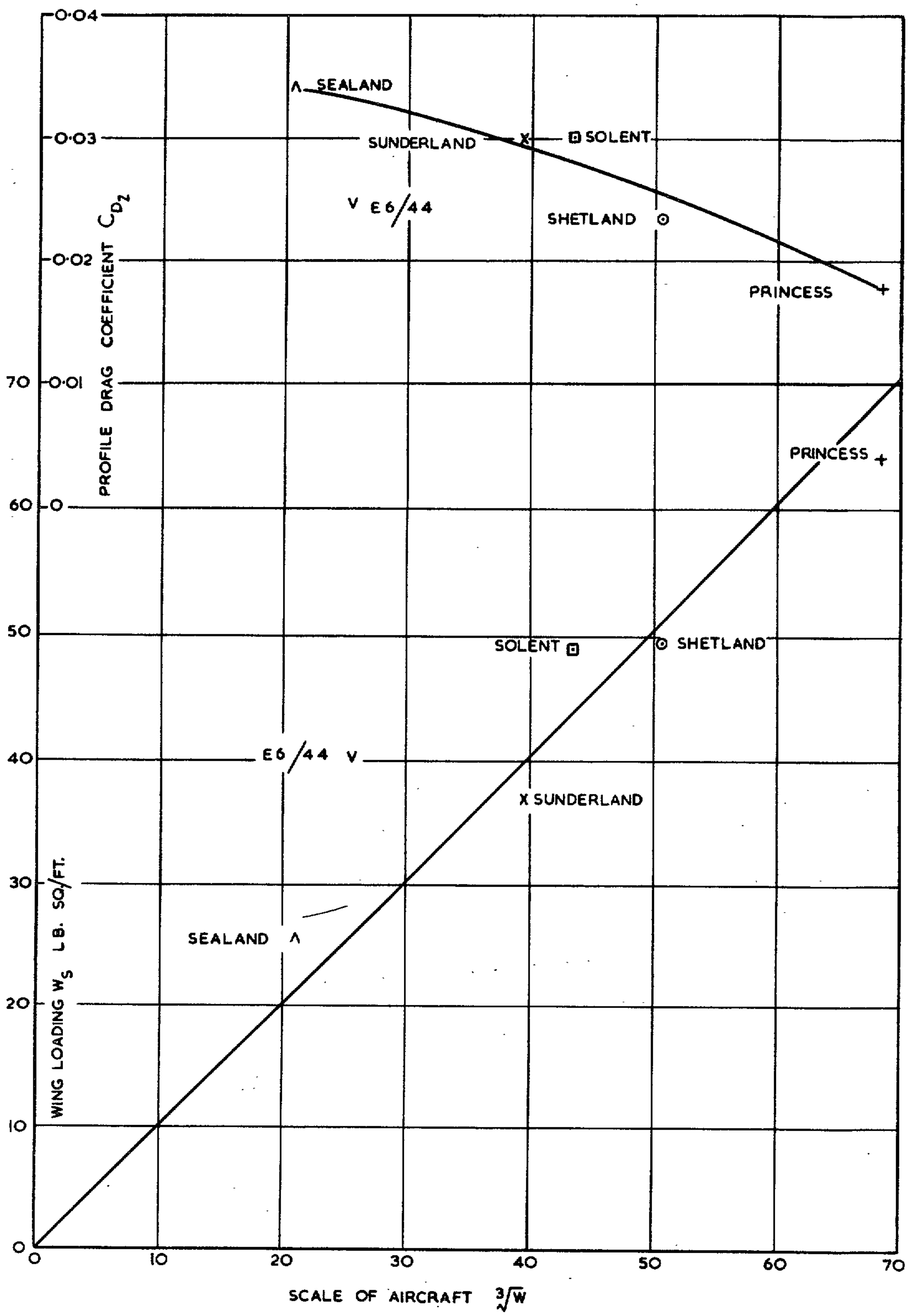


FIG. 29. CHANGE OF PROFILE DRAG COEFFICIENT AND WING LOADING WITH SIZE OF BOAT SEAPLANE

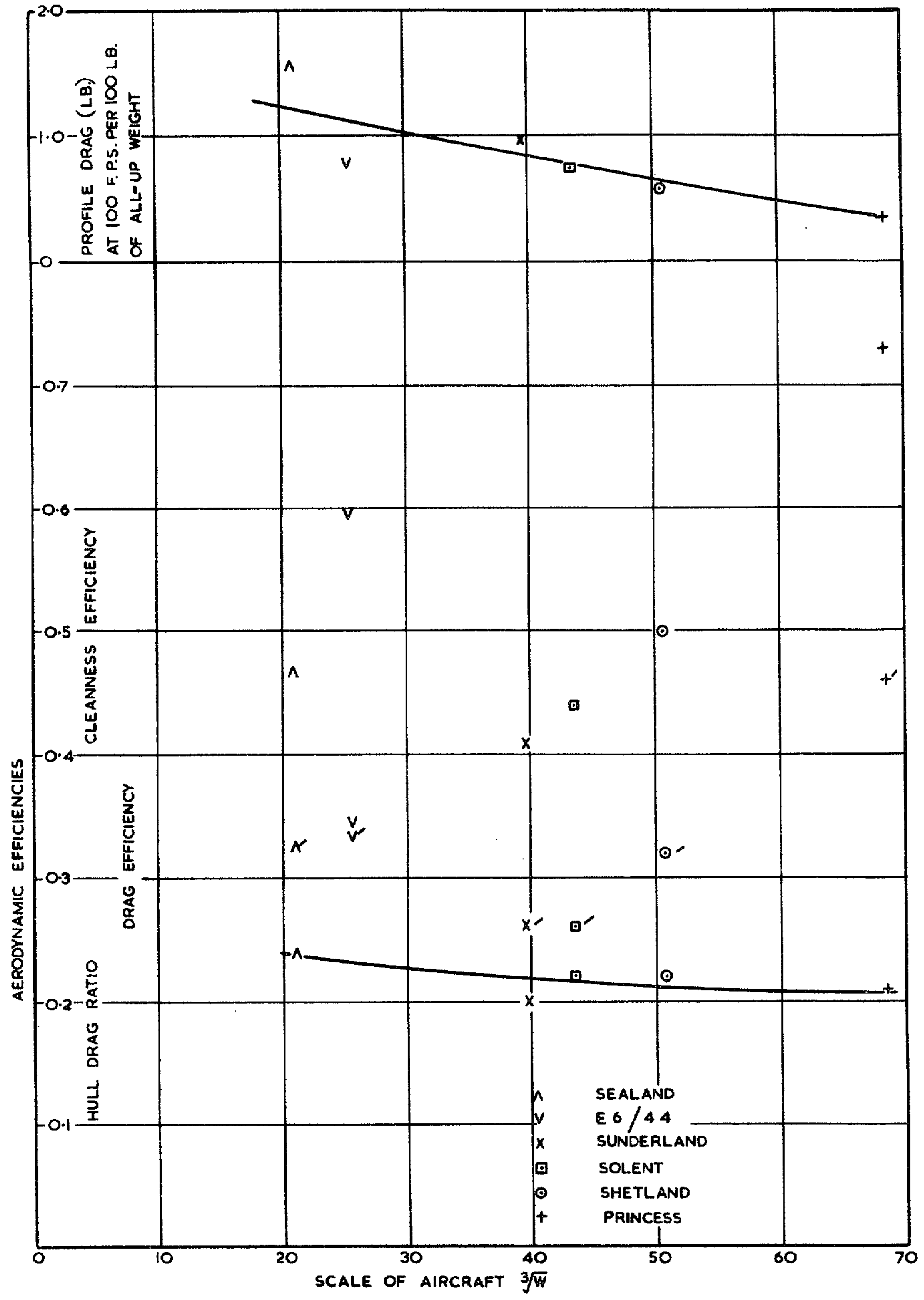


FIG. 30. CHANGE OF AERODYNAMIC EFFICIENCIES WITH SIZE OF BOAT SEAPLANE

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