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By

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Summary.—Tank tests were required to find out whether the water characteristics of a hull with a main step, faired in both planform and elevation, were comparable with those of a hull with a conventional Vee or transverse step. Stability diagrams and spray and resistance characteristics were obtained over a large range of loadings ($C_{\Delta 0} = 0{\cdot}616$ to $C_{\Delta 0} = 1{\cdot}440$).

The fully faired step offers more possibility of designing a longitudinally stable flying boat hull than does the conventional transverse or Vee step, but a hull with such a step is 5 to 10 per cent. less efficient hydrodynamically except at high speed. In order to avoid running too fine at high speed, it is recommended that the centre of gravity should not be more than $0{\cdot}46b$ ahead of the apex of the step.

The modification to the step planform makes little difference to the main spray characteristics, but increase in all-up-weight reduces wing, tailplane and propeller clearances.

The effect of increase in load on the porpoising stability characterictics is to raise both limits, with a tendency for the upper limit to rise more rapidly, but less regularly, than the lower limit. The free-to-trim attitudes also rise with increase in all-up-weight.

The planing efficiency of the hull increases with increase of load, especially at high speeds. There is evidence of a second resistance hump at high speeds and also of a critical variation of planing efficiency with attitude under similar conditions.

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1. *Introduction.*—The airdrag of the main step of a conventional flying boat hull is 20 to 25 per cent. of the total hull drag. The step is necessary, however, to reduce the water drag sufficiently to enable the boat to take-off and also to give good porpoising stability characteristics. Attempts have been made to reduce the airdrag by fairing the main step, without harming the water characteristics [1, 2, 3]. Such a fairing can reduce the step drag to the order of 10 per cent. of the total without loss of porpoising stability. So far, these fairings have been restricted to fairing the step depth, the step planform being either transverse or Vee with an included angle of greater than 120 deg. For convenience this type of fairing will be called a " fairing in elevation ".

It has been found[4] that a step faired in planform as well as elevation (defined as a fully faired step) has less airdrag than the conventional type step with an acceptable fairing in elevation. Messrs. Short Bros. have developed such a step and have incorporated it in an experimental hull based on the Shetland[5].

This report gives the results of stability and resistance tests made on the experimental hull in the Royal Aircraft Establishment Seaplane Tank between January and November, 1944.

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2. *Porpoising Tests.*—A $\frac{1}{10}$th scale dynamically similar model was constructed, utilising an existing wing, and the same values of the lift due to slipstream were used as in earlier tests on the conventional hull[6, 7]. The effects of slipstream were not otherwise represented.

Fig. 1 shows a general arrangement drawing of the flying boat with the experimental hull, with the lines of the conventional hull superimposed on them. The lines and offsets of the experimental hull are given in Fig. 2. Table 1 gives the general particulars of the flying boat.

2.1. *Original Hull Lines.*—Stability tests were made on the original form of experimental hull with a fully faired step to cover the following conditions : (1) take-off, with flaps up, at 120,000 lb, 130,000 lb and 140,000 lb and (2) landing, flaps up, at 77,000 lb all-up-weight.

For the take-off cases the c.g. was in the position given in Table 1. Stability diagrams for the conventional and experimental hulls over the range of take-off conditions are shown in Figs. 5, 6 and 7.

The experimental hull exhibits the same stability characteristics over the range tested. At speeds between 50 and 65 knots the hull is unstable on disturbance at all running attitudes. This instability is very gentle and is equally easy to start or stop. As the speed increases, the stability improves until there is a very wide stable range at take-off speeds. These characteristics are in direct contrast to those of the conventional hull which, at all-up-weights of 120,000 lb and 130,000 lb is very stable below 85 knots but above this speed has a very much reduced stable region. In previous tests on a flying boat incorporating a step of similar planform[8], it had also been found that the faired planform step gave better high speed stability characteristics than the same hull with a transverse step. At a speed of 93 knots the conventional hull, when running at low attitudes, will trim back on disturbance and patter about a higher attitude. The steady running attitude (undisturbed) is outside the limits of the porpoising and so it is possible to draw alternative limits, shown by heavy broken lines, to include the steady running attitude in the stable region whilst excluding the higher attitudes (after disturbance) about which the model patters. At an all-up-weight of 140,000 lb the stability of the conventional hull also becomes poor at low speeds, there being an all-attitude unstable region between 60 and 70 knots.

The free-to-trim attitudes of the two hulls agree closely over the range considered, although the hump attitude of the experimental hull is half a degree higher than that of the conventional hull at an all-up-weight of 120,000 lb.

The results for the landing case are given in Fig. 8 and show similar tendencies to those shown in the take-off cases. The hump attitude of 9 deg. is, however, unusually high for such a light loading, being nearly 2½ deg. higher and also occurring at a speed 10 knots higher than in the case of the experimental hull.

2.2. *Modifications to Improve the Porposing Stability.*—The first modifications were made on the assumption that the characteristic medium speed porpoising of the experimental hull was caused by inadequate afterbody ventilation. First the step fairing in elevation was removed and the hull tested under conditions representing a take-off, flaps up, at 120,000 lb all-up-weight. Fig. 9a shows that the unstable band between 45 and 65 knots was unaffected by this modification, but the upper limit at speeds greater than 70 knots has been raised considerably. At a speed of 72 knots, free-to-trim, the boat trims back about 4 deg. after disturbances and patters about a mean attitude of 7 deg.

The heel-to-heel angle was next increased by 1 deg. and then the step depth at the keel was increased to 10 per cent. of the maximum beam. Neither of these modifications made any appreciable difference to the water stability, but increasing the heel-to-heel angle increased the hump attitude by 1 degree.

Observations of the waterflow, made whilst the boat was porpoising, showed that the water tended to lick round the sides of the afterbody and wet the hull sides near the rear step. On the assumption that this interference was a possible cause of the medium speed porpoising, it was decided to weaken the afterbody by decreasing the beam in the neighbourhood of the rear step so as to increase the afterbody water clearance. This modification proved entirely successful in eliminating the medium speed unstable region, but the hump attitude increased 2 deg. above that of the original form, and at a speed of 31 knots the counter was intermittently sucked down and the boat oscillated between attitudes of 11 and 13 deg. Photographs of the extreme positions are shown in Fig. 10.

Modifications were now made to break down these suctions. The rear step was first lowered to its original position. This did not affect the suction forces but it did lower the lower limit 2 deg. at 50 knots without altering the upper limit, Fig. 9b. Further attempts to break down the suction forces by strengthening the afterbody were unsuccessful in that those modifications which broke down the suction, caused all-attitude instability on disturbance at speeds in the neighbourhood of 50 knots. A complete list of the modifications tried and their effects is given in Table 3.

Finally, the rear turret had to be replaced by a faired counter which gave increased clearance from the rear step spray and roach. This modification was successful in eliminating the suction forces without altering the stability at any other speed.

2.3. *Final Experimental Hull. Step Faired in Planform Only.*—This hull (mod. 11) differs from the original experimental hull in that the step is faired in planform only, the step depth at the keel increased to $0 \cdot 10$ maximum beam, the afterbody narrowed in planform and its deadrise altered towards the rear step, and the rear turret replaced by a faired counter. The alteration of the afterbody deadrise was unintentional. The offsets of the new rear fuselage are given in Fig. 13.

The porpoising stability was ascertained for take-offs, flaps up, at 120,000 lb, 140,000 lb, 160,000 lb and 180,000 lb all-up-weight in order to explore the possible limitation of loading on stability. The results are shown in Figs. 14 and 15. This hull form is extremely stable, the upper limit rising beyond the trim range for all-up-weights greater than 120,000 lb. The lower limit rises steadily with increase in all-up-weight, rising about 1 deg. for each 20,000 lb increase in load. The stability limits for the weight range considered are shown superimposed in Fig. 16a. The free-to-trim attitudes rise steadily with increase in load and the hump trim varies from 11 deg. at 120,000 lb all-up-weight to 13 deg. at 180,000 lb all-up-weight. This hump trim is high, even bearing in mind the relatively high $C_{\Delta 0}$, and probably will be reduced by the effects of slipstream.

2.4. *Final Experimental Hull. Step Fully Faired.*—A step fairing in elevation based on that used on the original experimental hull having a fairing ratio of $5 \cdot 8 : 1$ at the keel was added to the final experimental hull. The fairing becomes complex at the beginning of the step and, in transverse section, the fairing is slightly convex in this region in order to eliminate the hard chine line. The lines of this fairing are shown by the broken lines in Fig. 17. The stability limits for a take-off, flaps up, at 130,000 lb all-up-weight are shown in Fig. 18. A region of all-attitude instability was introduced between 45 and 55 knots and, at speeds above 80 knots, the boat would trim back when disturbed and patter about a higher attitude. Observation showed that, during porpoising at speeds between 45 and 55 knots, water ran round the fairing near the position of maximum beam. The shape of the fairing in this region was therefore altered so that the transverse sections were now concave but the fairing at the keel line was unaltered. The offsets and lines of this new fairing are given in Fig. 17.

This modified fairing was reasonably successful and was tested in conditions representing take-offs, with flaps up, at 120,000 lb, 140,000 lb, 160,000 lb and landing at 77,000 lb all-up-weight. The results are shown in Figs. 19 and 20.

In all the take-off cases the lower limits were unaltered by the addition of the fairing, but the upper limits were lowered considerably. At 120,000 lb all-up-weight the take-off upper limit came down abruptly at a speed of 50 knots, leaving a stable range of only 1 deg. At 65 knots the upper limit was again high, but above this speed came down steadily until the stable range at take-off speeds was reduced to about 4 deg. The upper limit porpoising takes the form of a patter on disturbance.

With increase in all-up-weight the upper limit at the hump rose rapidly and was not found at 160,000 lb all-up-weight. At speeds above the hump, the upper limit also rose with increase in loading but the rise, whilst greater than that of the lower limit for the same increase in loading, is not so regular. The stability limits have been superimposed in Fig. 16b. Under conditions of high speed high attitude porpoising, the blister licked round the afterbody chines and completely enveloped the counter (Fig. 11).

The stability limits for the landing case were exceptionally good, the upper limit not being found. At a speed of 82·5 knots, however, the boat had two steady running positions when trimmed above 3·5 deg. attitude. The smaller of the attitudes was the trim taken up when the boat was accelerated from rest, after running for a second or so in this position Fig. 12a, the blister flicked inwards and enveloped the rear of the hull, Fig. 12b, the boat then trimmed back 2 to 3 deg. and ran steadily about the second attitude. On disturbance, the boat settled down to run steadily about the lower of the two running attitudes and after a short while resumed the higher running position. As has been noted above, porpoising on disturbance generally occurred when the blister licked round the afterbody chines; this exception was probably due to the far forward position of the centre of gravity with respect to the point of the step. This caused the boat to pitch forward on hitting the water and to settle down about the lower running attitude before the suction round the afterbody developed sufficiently to cause the boat to trim back. The hump angle was rather high for the light loading, but no signs of interference were present.

3. *Spray Characteristics.*—Photographs of the main spray characteristics of the original experimental and conventional hulls are mounted side by side in Figs. 21 and 22. These show the spray formations at all-up-weights of 120,000 lb and 140,000 lb and cover a range of speeds in the neighbourhood of the hump. In all cases the boat was trimmed by the estimated thrust and air-moments due to slipstream.

At 120,000 lb all-up-weight the spray characteristics are nearly identical except that (1) at 41·3 knots the leading edge of the blister is not inclined so far aft in the case of the experimental hull, (2) at 51·6 knots the blister from the experimental hull is further below the tailplane than in the case of the conventional hull. This is probably because, owing to the planform of the step, the blister leaves the forebody planing bottom further forward relative to the tailplane.

At 140,000 lb all-up-weight, the differences in spray characteristics between the hulls are accentuated. The experimental hull is still slightly the cleaner at 31 knots, and at 41 knots the tailplane clearance is greater in the case of the experimental hull, even though the running attitude is $\frac{1}{2}$ deg. higher than the conventional hull. At 52 knots, however, the experimental hull still trims $\frac{1}{2}$ deg. higher and the tailplane is splashed whilst that of the conventional hull is clear of spray.

At low speeds the forebody spray formations will apply equally well to the conventional and experimental hulls as they have identical forebodies and low speed free-to-trim attitudes. Fig. 23 shows front quarter views of the spray formations for a speed range of 21 to 62 knots at an all-up-weight of 130,000 lb. The propeller clearance is least at speeds in the neighbourhood of 20 knots, when spray may be sucked into the propeller discs. The tailplane clearance appears to be a minimum at 52 knots.

In the case of the final experimental hull photographs of the spray characteristics at the free-to-trim attitudes were taken during the stability tests. No quantitative measurements were made, but from visual observation, it appeared that the clearances of the tailplane and wings were least at speeds between 31 and 62 knots. Figs. 24 and 25 show the spray formations over this range of speeds for landing at 77,000 lb all-up-weight and take-offs at 120,000 lb, 140,000 lb and 160,000 lb all-up-weight. The differences in the spray characteristics at a given speed for an increase in load are slight. The general tendency is for the blister clearance to decrease as the load increases and at the same time for the leading edge of the blister to be thrown out more perpendicularly to the hull.

4. *Resistance and Pitching Moment Tests.*—The tests were made with a $\frac{1}{19}$th scale pine model of the hull. During the tests the model was screened from the airflow. The load-on-water under any set of conditions was obtained by subtracting the calculated airlift (including the effects of slipstream) for the appropriate condition from the all-up-weight. The values of the airlift are the same as were used for the tests on the conventional hull and are shown in Fig. 3.

4.1. *Original Experimental Hull.*—The hull was tested over a considerable range of loadings (100,000 lb to 150,000 lb) and the results are shown in Figs. 26 to 30.

At all loads there is a tendency for local peaks to occur in plots of drag against attitude under conditions of high speed and attitude. This effect has been noted before in model tests[9], although it has not yet been ascertained whether these local peaks are solely due to the conditions of model testing or whether they also occur full scale.

From the pitching moment curves it appears that, beyond the hump, the boat becomes more difficult to trim as the all-up-weight increases. This would be noticeable full scale as a loss in elevator effectiveness[10]. In the table below the slope of the pitching moment curve at the free-to-brim attitude (as given by the curve) is tabulated for a range of all-up-weights and speeds.

All-up-weight (lb)	slope of pitching moment curve at free-to-trim (lb ft/deg.)				
	51·6 kt.	61·9 kt.	72·2 kt.	82·5 kt.	92·8 kt.
100,000	54,000	48,000	54,000	70,000	40,000
120,000	50,000	45,000	40,000	47,000	37,000
130,000	105,000	60,000	55,000	35,000	50,000
140,000	160,000	65,000	56,000	35,000	50,000
150,000	150,000	80,000	80,000	80,000	95,000

The take-off times and distances have been calculated for a range of all-up-weights (Table 4). The running attitudes used were those of the resistance model corrected for the effects of slipstream until a running attitude of 5 deg. was reached when the trim was assumed to remain constant until take-off. The experimental hull takes slightly longer to take-off.

4.2. *Comparison of the Planing Efficiencies of the Conventional and Original Experimental Hulls.*—The efficiency of the hull is measured by the ratio of the water resistance to load-on-water (R/Δ). In Figs. 31 to 33 R/Δ is plotted against hull attitude over a range of speeds and all-up-weights. Analysis shows that the results can be considered in two parts:—

(a) Speeds up to 80 knots.
(b) Speeds above 80 knots.

Below 80 knots the R/Δ curves for the conventional hull have a fairly well defined minima at an attitude of about 6 deg. The experimental hull, however, has no well defined minimum R/Δ being almost constant until the hull attitude exceeds 5 deg. The experimental hull is 5 to 10 per cent. less efficient than the conventional hull under conditions of maximum efficiency, and the difference becomes greater with increase of attitude.

Above 80 knots the efficiencies of both hulls decrease rapidly with increase in speed. This deterioration has been noticed in full scale tests on the Sunderland[11]. Both hulls have very well defined minima, those of the conventional hull occurring at a greater attitude and being more clearly defined. In general the experimental hull is the more efficient at these speeds.

4.3. *Effect of All-up-weight on the planing Efficiency of the Original Experimental Hull.*—Fig. 34 shows R/Δ plotted against attitude for take-offs at the extremes of the weight range tested (100,000 to 150,000 lb). There is a tendency for the hull to become more efficient at the heavier loadings, particularly at high speeds, and at a given speed the minima of the curves become less well defined as the load increases.

4.4. *Final Experimental Hull. Step Fully Faired.*—Tests were made on a screened drag model at all-up-weights of 120,000 lb and 140,000 lb in order to check the values previously obtained on the original form. Except in the neighbourhood of the hump, the resistance measurements obtained, Figs. 35, 36, checked very closely. This was to be expected in the absence of afterbody interference or immersion, as the forebody was unaltered. There was, however, a very rapid increase in drag at high speeds and attitudes, especially at an all-up-weight of 140,000 lb. This increase in drag was probably due to the water not being separated efficiently from the afterbody by the fully faired step. Photographs were taken, Fig. 37, of the waterflow in the neighbourhood of the step and afterbody for a range of attitude at a speed of 92·8 knots.

At a hull attitude of 7 deg., the water follows the fairing and wets the afterbody. The spray obscuring the rear of the afterbody does not, in general, touch it, but it was found impossible to position the camera so that the whole of the afterbody and step fairing was unobscured by spray. From Fig. 36 it can be seen that the angle at which afterbody wetting occurred was coincident with the beginning of the drag hump. The tests were repeated with the fairing in elevation removed, but the values of the water drag remained the same, and little difference was made to the afterbody wetting.

Analysis of the pitching moment curves showed that the hump trim, as obtained from the pitching moment curves, was nearly 2 deg. less than that of the dynamic model. Normally, the running attitudes given by the resistance model are greater than those of the dynamic model as the trimming moments due to the airstructure are not represented. In this case, this generalisation only held at speeds greater than about 60 knots.

Fig. 38 shows the variation of draught with incidence over a range of speeds for take-offs, flaps up, at 120,000 lb and 140,000 lb all-up-weight. These results were obtained in order to facilitate a more complete drag analysis of the hull which, however, is beyond the scope of this report.

5. *Discussion.*—The original reason for the adoption of the extreme Vee Step was to decrease the airdrag of the flying boat hull without harming the water stability. The initial tests showed that, although the hull was unstable at speeds in the neighbourhood of the hump, the stability at high speeds was very good, in fact serious instability was only present when the step was unduly faired in elevation. It follows that the afterbody was very efficiently ventilated probably because the air following the hull side, just above the chines, tends to follow the faired planform of the step with a minimum of eddying. The airdrag of this form of step is less than that of the conventional Vee Step for probably the same reason. The effect of variation in the step planform on general hydro-dynamic characteristics is to be explored more systematically in a further series of tests.

The instability encountered at speeds between 45 and 65 knots was probably due to inadequate clearance between the afterbody and the forebody wake in the neighbourhood of the rear step and not to bad ventilation as was thought at first. At the speeds considered, there was full chine immersion at the step, and, owing to the step planform, the flow in the neighbourhood of the maximum beam left the forebody relatively further forward than in the case of the conventional step. The result was that the wake interfered with the rather bluff afterbody of the original design when the boat was disturbed. Fining down the afterbody in the neighbourhood of the rear step cured this interference. It would seem that, in order to ensure adequate stability at speeds in the neighbourhood of the hump with faired planform steps it is advisable to use either a nomal afterbody of about 3 to 3·5 beams length with a pointed rear step and fine lines, or to use a shorter (2·5 beams length) afterbody with the rear step similar in planform to the main step. In the latter case either the increased hump trim will have to be accepted or the afterbody angle will have to be reduced.

In view of the good afterbody ventilation attributes of this type of step, it may be possible to reduce the step depth below the value of 10 per cent. maximum beam normally recommended to ensure adequate water stability.

The elliptical planform step shows itself capable of being well faired in elevation although care must be taken with the fairing near the position of maximum beam as the stability in the neighbourhood of the hump seemed to vary critically with the shape of the fairing in this position. With the fairing tested the high speed upper limit porpoising takes the form of a patter, but it is not anticipated that this form of porpoising will be dangerous full scale. The fact that there is very little change of attitude during a patter, coupled with the fact that this form of instability normally only occurs at normal attitudes at speeds near the flying region, will make this type of porpoising difficult to detect full scale. Full scale runs at steady speed will also probably fail to show this form of instability because if the boat is bounced clear of the water, it will probably fly off.

Both upper and lower limits rise with increase in all-up-weights with the upper limit showing a tendency to rise at a slightly greater rate than the lower limit. This effect is most noticeable at speeds in the neighbourhood of the hump, and has also been noticed in the course of full scale tests on the Sunderland III[10]. This tendency for the stable region to widen with increase of weight is in direct contrast to previous tank tests on the conventional hull in which the limits closed at the hump at the maximum weight tested (140,000 lb). This tendency for the limits to meet at the hump has been noticed in previous tank tests at high overloads[12], but has not yet been confirmed full scale.

For this particular step form it would seem that, in order to prevent the running attitude becoming too fine at high speeds, the centre of gravity should not be more than about $0 \cdot 46b$ forward of the step.

Tests in a compressed-air wind tunnel[4] have shown that the fully faired step has less air drag than any other combination of step form and fairing tested, with the exceptions of a conventional Vee step with either a straight or convex fairing in elevation. From the hydrodynamical point of view neither of the latter two fairings are practicable, unless the fairings are made retractable or artificial ventilation is used as there is not sufficient discontinuity at the step to break the water flow cleanly away from the afterbody.

The water drag analysis shows that the experimental hull is 5 to 10 per cent. less efficient than the conventional hull at low and medium speeds but is more efficient at speeds in the neighbourhood of the flying region. There is a general tendency for the hull efficiencies to improve with increase in load, but except at high speeds the improvement in efficiency is not great. Full scale tests on the Sunderland III[11] have shown that there is a tendency for a second drag hump to occur at high speeds and this is shown in the present results. The full scale results, however, do not show the critical variation of λ with attitude (λ is approximately equal to R/Δ), owing to an insufficient range of attitude being covered at high speed.

The pitching moment curves obtained for the final lines of the experimental hull show large differences between the hump trims of the dynamic and resistance models, and these differences are in the opposite direction to what would be expected normally. The model was retested unscreened but the hump trim was only about $\frac{1}{2}$ deg. higher.

Apart from the change in hump trim, the water drags at high speeds and attitudes may be optimistic as visual observation showed that the blister did not cling so closely to the hull sides and counter of the resistance model as in the case of the dynamic model.

6. *Conclusions.*—1. The faired planform step offers more possibility of designing a longitudinally stable flying boat hull than does the conventional transverse or Vee step.

2. Except at high speed, the conventional type hull is slightly more efficient hydrodynamically than the experimental hull. The afterbody wetting at high speeds and attitudes appears to be independent of the step fairing.

3. It is recommended that, in the case of this particular step form, the centre of gravity should not be more than $0 \cdot 46b$ in front of the step.

4. There is little difference in the spray characteristics of the experimental and conventional hulls.

5. The experimental hull is probably the best all-round type of hull with regard to air and water drag and porpoising stability that can be designed without resorting to artificial means of improving the water stability and drag characteristics, *e.g.*, without using air lubrication, step ventilation, retractable fairings or hydrofoils.

6. Increasing the all-up-weight raises both the limits and the free-to-trim curves of the experimental hull and also, in this case, widens the stable region slightly.

7. Increase in all-up-weight increases the planing efficiency of the hull, especially at high speeds. There is evidence of a second resistance hump at high speeds and also of the critical variation of the planing efficiency of the hull with attitude under similar conditions.

SYMBOLS AND DEFINITIONS

b	Maximum beam of planing bottom.
w	Density of sea-water (64 lb/cu ft).
Δ	Load on water.
C_{Δ}	Beam loading Δ/wb^3.
R	Water resistance (lb).
α	Attitude (deg.).
η	Elevator angle.
Afterbody angle	The angle between the afterbody keel and the forebody keel at the main step.
Heel-to-heel angle	The angle between the forebody keel at the main step and the line joining the points of the main and rear steps.
Deadrise angle	The angle between the horizontal and the line joining the keel and chine, on a section normal to the keel datum.
Fairing ratio	The ratio of the distance the step fairing extends along the afterbody to the step depth. This does not take into account the actual shape of the fairing which is defined separately.

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TABLE 1

Particulars of the Flying Boat

Wing

Span	150·3 ft	Wing Setting	6° 38′ to hull datum
Gross Area	2636 sq ft	Dihedral	4° 30′
Mean Chord	17·46 ft	Sweepback	10° 24′ at quarter-chord line
Aspect Ratio	8·61	Section	Gottingen 436 (modified)

Tailplane

Gross area	407 sq ft	Arm (c.g. to quarter-chord point)	52·5 ft
Span	45·15 ft	Dihedral	6°

Engines

4 Centaurus VII rated at 2,400 H.P. each (Take-off rating)

Propellers : hydromatic 15 ft 9 in. diameter
4 blades solidity 0·112

Hull

Maximum beam (*b*)	12·5 ft
Forebody length	46·69 ft = 3·74*b*
Afterbody length	39·56 ft = 3·17*b*
Counter length	23·17 ft = 1·86*b*
Angle of forebody keel to datum	2° 38′
Angle of deadrise beginning of step (st : 18)	22·6°
Stepdepth at keel original hull	1·08 ft = 8·6% *b*
Stepdepth at keel final hull	1·23 ft = 9·9% *b*
Afterbody keel angle (final form)	7° 18′ to forebody keel
Heel to Heel angle	9° 6′ to forebody keel

c.g. position (relative to hull datum and point of step)

Aft (Take-off case)	0·46 *b* 5·79 ft in front,	1·29 *b* 16·1 ft above
Forward (Landing case)	0·575 *b* 7·19 ft in front,	1·29 *b* 16·1 ft above

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TABLE 2

Wing and Beam Loadings over a Range of Weights

All-up-weight (lb)	$C_{\Delta 0}$	Wing Loading lb sq ft
77,000	0·616	29·3
120,000	0·960	45·6
130,000	1·040	49·5
140,000	1·120	53·2
150,000	1·200	57·1
160,000	1·280	60·9
180,000	1·440	68·5

TABLE 3

List of Modifications

Modification Number	Modification	Effect
1	Removal of step fairing	Raises upper limit above 60 knots. No effect 45 to 60 knots unstable band
2	Afterbody heel to heel angle increased 1 deg	Hump attitude increased 1 deg. No change in stability
3	Step depth increased to 10 per cent at keel	No effect
4	Afterbody fined down . .	Intermittent suction present at 31 knots. Stability now excellent
5	As 4, but rear step in original position	Stability not materially altered but intermittent suction still present at 31 knots
6	Breaker step fitted to rear turret	No effect
7	As 6, afterbody dead rise reduced to 15 deg. near rear step	Suction eliminated, but hump instability now present
8	As 6, afterbody dead rise reduced to 25 deg. in neighbourhood of rear step	No effect—result as for 6
9	Afterbody beam increased slightly in neighbourhood or rear step. Otherwise as 5	Suction eliminated, but hump instability now present
10	As 5, but rear step lowered to reduce heel to heel angle by 1 deg.	Unstable at hump speeds. Suction eliminated
11	As 5, but rear turret replaced by faired counter	Suction eliminated. Stability excellent
12	5·8 : 1 fairing fitted, based on original fairing	All attitude instability present at hump and high speeds
13	Fairing reduced in neighbourhood of maximum beam	Stability acceptable

TABLE 4

All-up-weight	Experimental Hull		Conventional Hull	
(lb)	Time (sec)	Distance (yd)	Time (sec)	Distance (yd)
120,000	52	1,480	48	1,390
130,000	74	2,200	68	2,060
140,000	116	3,570	96	2,920

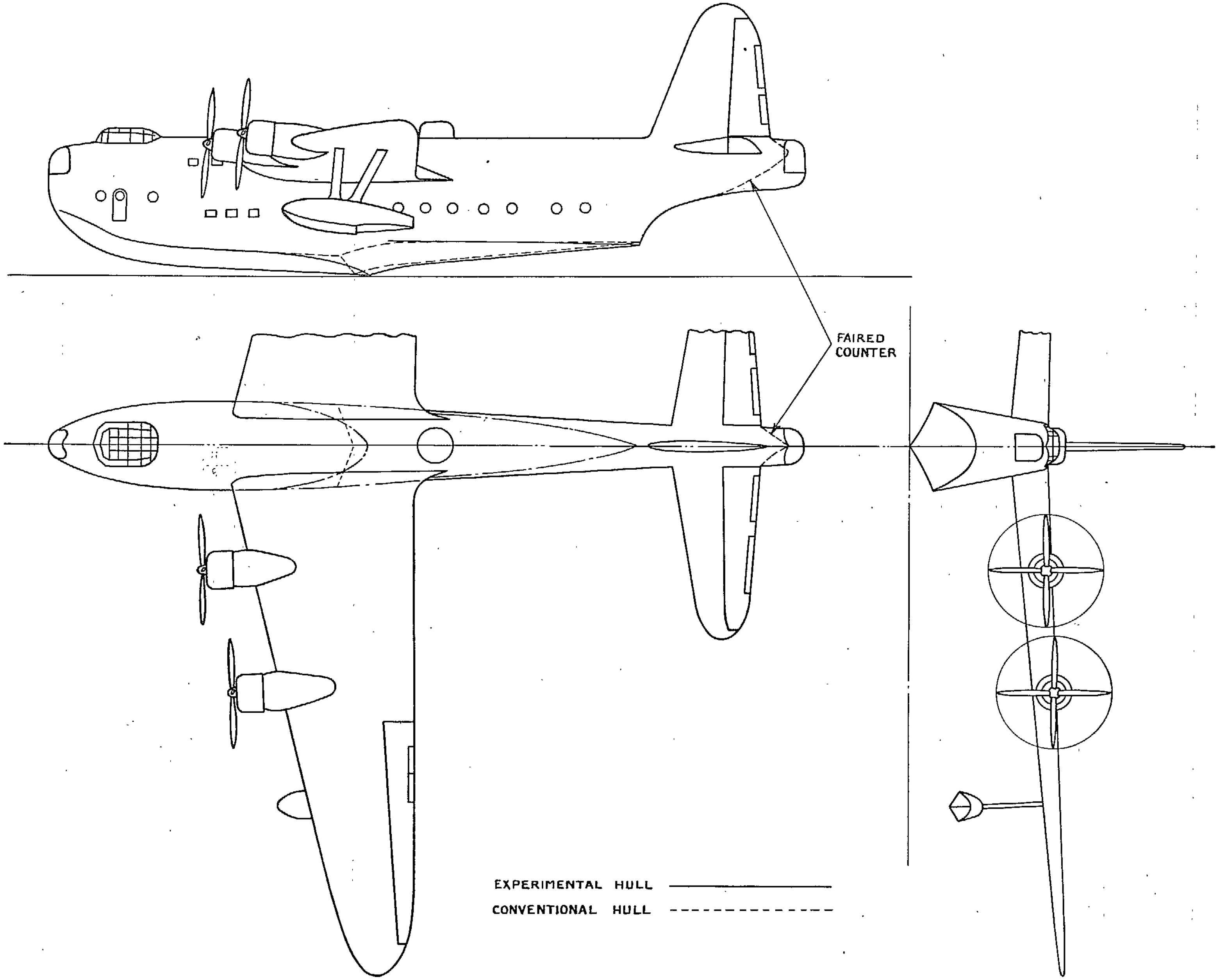
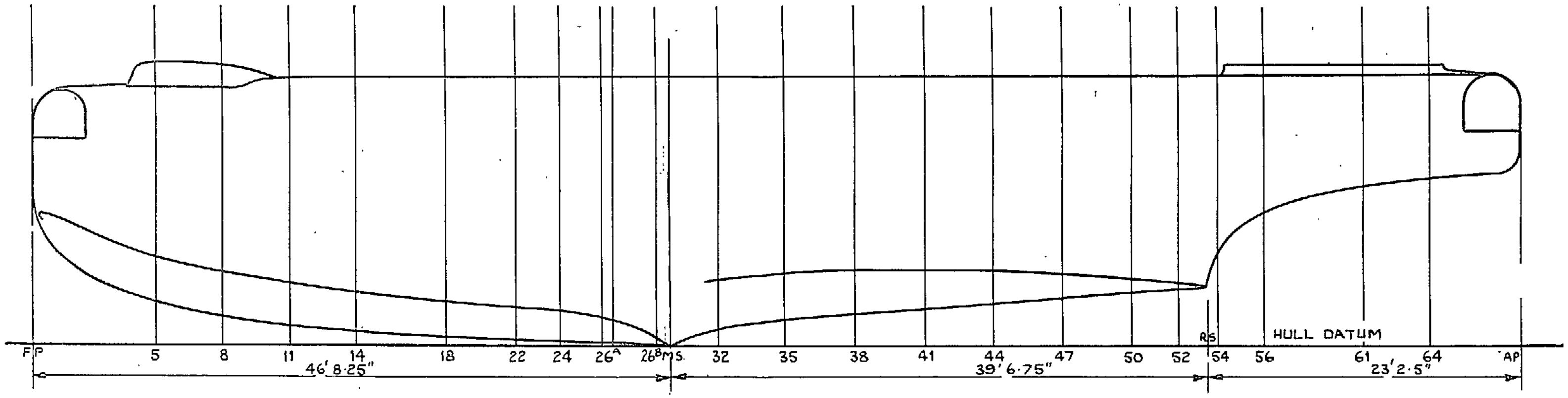
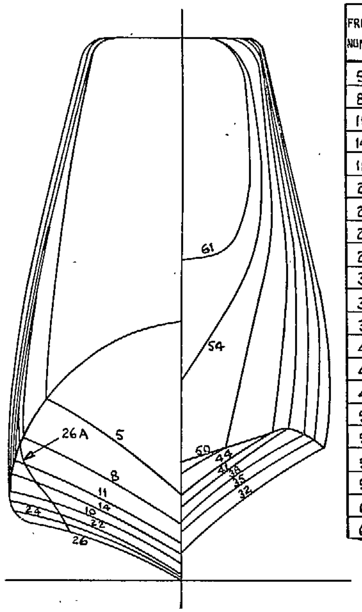
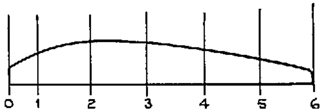


FIG. 1. General arrangement of flying boat



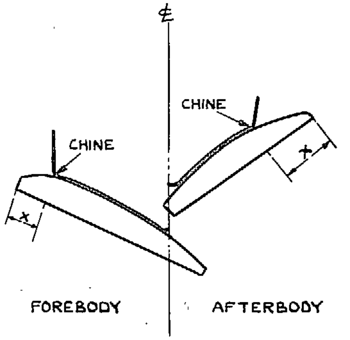


FRAME NUMBER	DISTANCE OF FRAMES FROM FORD. PERP	KEEL ABOVE DATUM	CHINE ABOVE DATUM	MAX. BEAM ABOVE DATUM	MAX HALF BEAM	HALF BEAM AT CHINE	X ON PLANING BOTTOM CURVE	HALF BREADTHS AT WATERLINES (COLUMNS HEADED BY HEIGHT OF WATERLINES ABOVE DATUM)											FRAME NUMBER
								1' 0"	2' 0"	3' 0"	4' 0"	6' 0"	8' 0"	10' 0"	12' 0"	14' 0"	16' 0"	18' 0"	
5	107·50	38·94	78·94	78·94	57·98	57·98	12·98	—	—	—	—	—	56·76	54·90	52·70	50·10	46·75	41·86	5
8	167·50	24·87	61·24	61·24	68·08	68·08	20·70	—	—	—	—	67·42	65·72	63·65	61·06	57·75	53·21	46·71	8
11	227·50	17·02	51·35	51·35	72·72	72·72	31·86	—	—	—	—	71·93	70·19	67·59	64·16	59·96	54·89	48·94	11
14	287·50	12·28	45·24	45·24	74·57	74·57	37·90	—	—	—	74·50	73·62	71·78	68·73	64·52	59·33	53·67	48·04	14
18	367·31	7·92	38·75	44·30	73·95	73·88	44·50	—	—	—	73·92	73·40	71·61	67·81	62·83	57·23	51·58	45·93	18
22	429·12	5·08	33·63	56·15	72·92	70·00	53·00	—	—	70·80	72·60	72·58	70·17	66·28	61·22	57·03	49·96	44·31	22
24	467·12	3·33	29·25	62·00	71·40	62·50	62·50	—	—	65·40	70·25	71·30	69·10	65·21	60·25	54·62	48·97	43·32	24
26A	511·00	1·31	21·50	67·85	69·52	47·00	82·25	—	48·25	56·13	66·00	69·50	67·63	64·00	—	—	—	—	26A
26B	552·75	-0·61	5·00	73·10	67·50	14·38	118·75	20·68	32·25	44·75	58·63	67·45	65·95	62·63	—	—	—	—	26B
32	604·5	13·25	58·75	79·45	64·20	62·13	23·13	—	—	—	—	64·33	63·52	60·85	56·52	—	45·37	—	32
35	664·5	20·84	61·88	89·13	59·95	58·00	48·38	—	—	—	—	59·38	59·87	58·34	54·82	—	43·27	—	35
38	724·5	26·05	64·50	103·52	53·32	53·00	59·13	—	—	—	—	54·25	55·21	54·92	52·52	—	42·23	—	38
41	784·5	31·26	65·13	118·10	50·78	47·00	66·63	—	—	—	—	47·85	49·80	50·77	49·53	45·91	40·65	—	41
44	844·5	36·46	64·00	132·0	46·48	40·38	77·50	—	—	—	—	41·25	43·70	46·02	46·21	43·70	39·08	—	44
47	904·5	41·67	61·75	144·0	42·55	32·00	90·25	—	—	—	—	33·25	36·61	40·52	42·55	41·30	37·51	—	47
50	964·5	46·88	58·13	155·0	38·99	20·45	106·87	—	—	—	—	22·60	27·30	33·86	38·49	38·73	35·94	—	50
52	1004·5	50·35	55·38	168·0	36·91	9·88	120·75	—	—	—	—	12·31	19·04	28·30	35·41	36·91	34·90	—	52
54	1044·5	85·22	—	172·0	35·10	—	—	—	—	—	—	—	6·00	20·42	32·00	35·10	33·85	—	54
56	1084·5	118·31	—	180·0	—	—	—	—	—	—	—	—	—	—	28·14	33·53	32·80	—	56
61	1171·25	140·79	—	182·0	—	—	—	—	—	—	—	—	—	—	—	30·62	30·85	—	61
64	1230·25	147·40	—	184·0	29·87	—	—	—	—	—	—	—	—	—	—	28·56	29·75	—	64



STATION	0	1	2	3	4	5	6
DISTANCE	0	12·16	36·49	60·81	85·14	109·46	133·78
HEIGHT	8·48	14·54	19·11	18·52	15·95	11·33	5·47

OFFSETS OF PLANING BOTTOM CURVE



DIMENSION X GIVEN IN COLUMN 8 OF TABLE

METHOD OF LAYING OUT THE PLANING BOTTOM

FIG. 2. Lines and offsets of original experimental hull

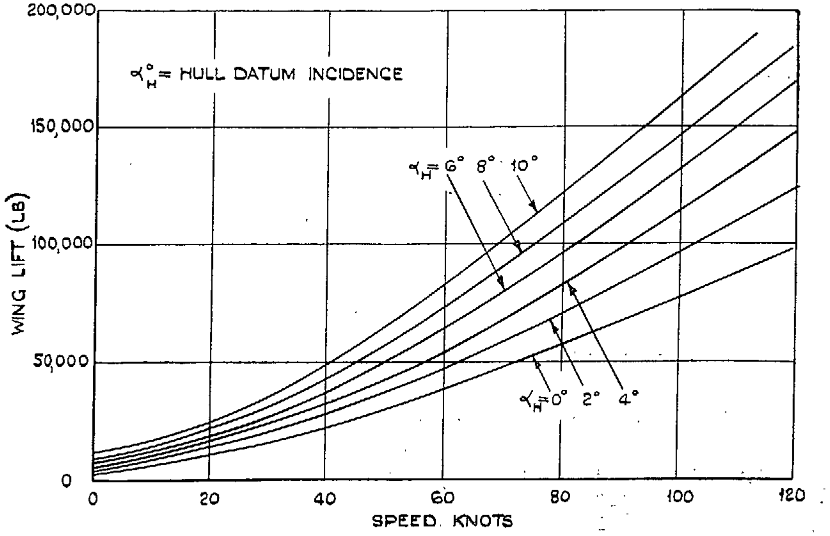


FIG. 3. Estimated wing lift, including slipstream lift and vertical component of thrust

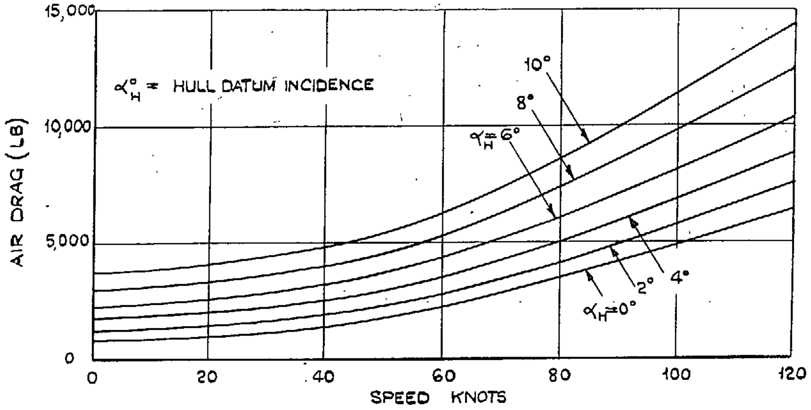


FIG. 4. Estimated air drags with flaps up, slipstream drag included but nacelle drag excluded

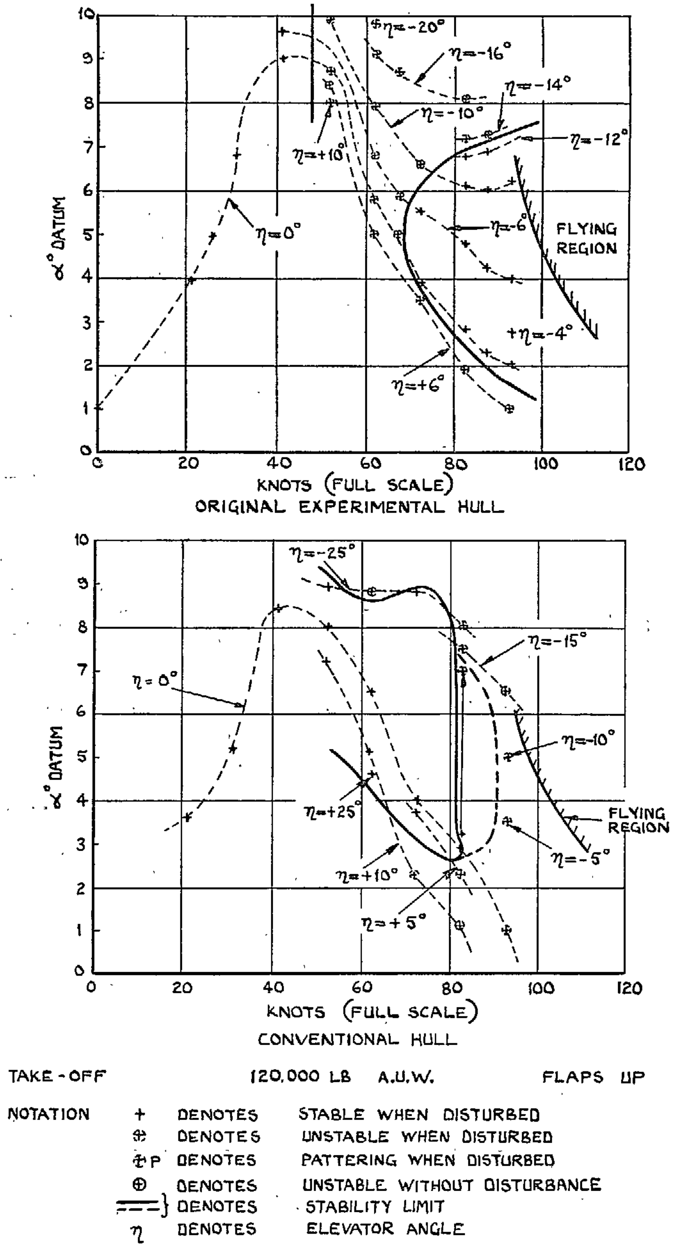
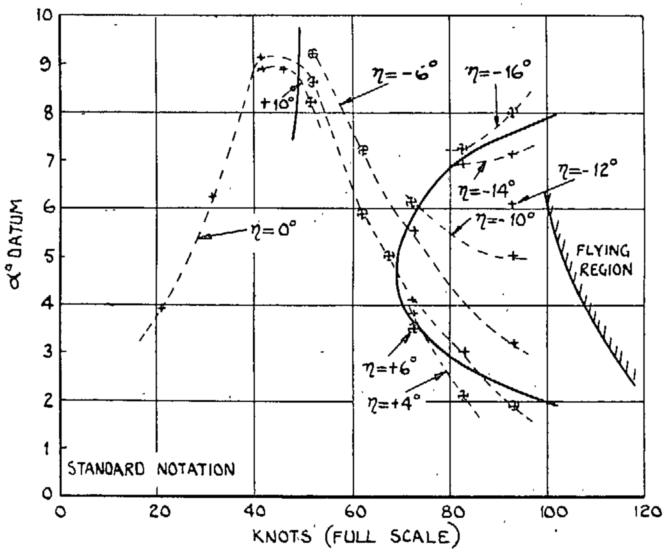
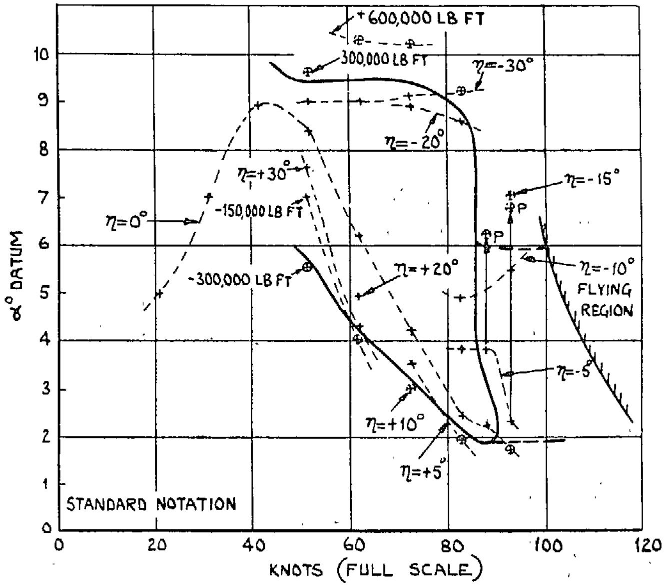


FIG. 5. Comparison of the water stability of the conventional and original experimental hulls



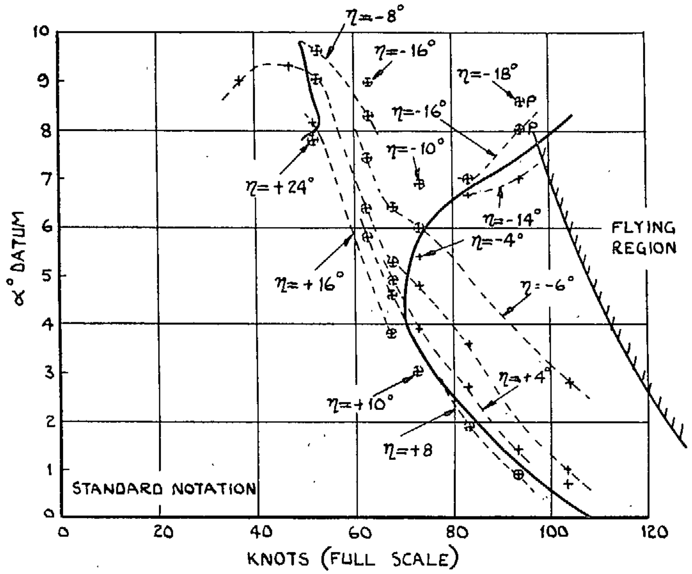
ORIGINAL EXPERIMENTAL HULL



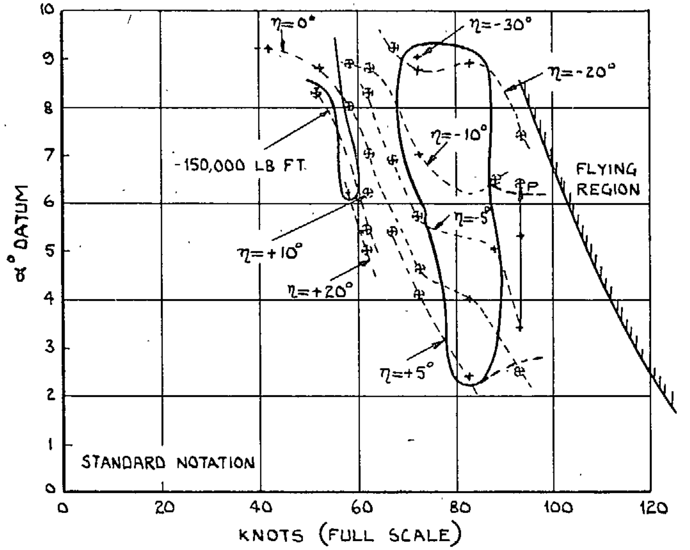
CONVENTIONAL HULL

TAKE-OFF 130,000 LB A.U.W. FLAPS UP

FIG. 6. Comparison of the water stability of the conventional and original experimental hulls



ORIGINAL EXPERIMENTAL HULL



CONVENTIONAL HULL

TAKE-OFF 140,000 LB A.U.W. FLAPS UP

FIG. 7. Comparison of the water stability of the conventional and original experimental hulls

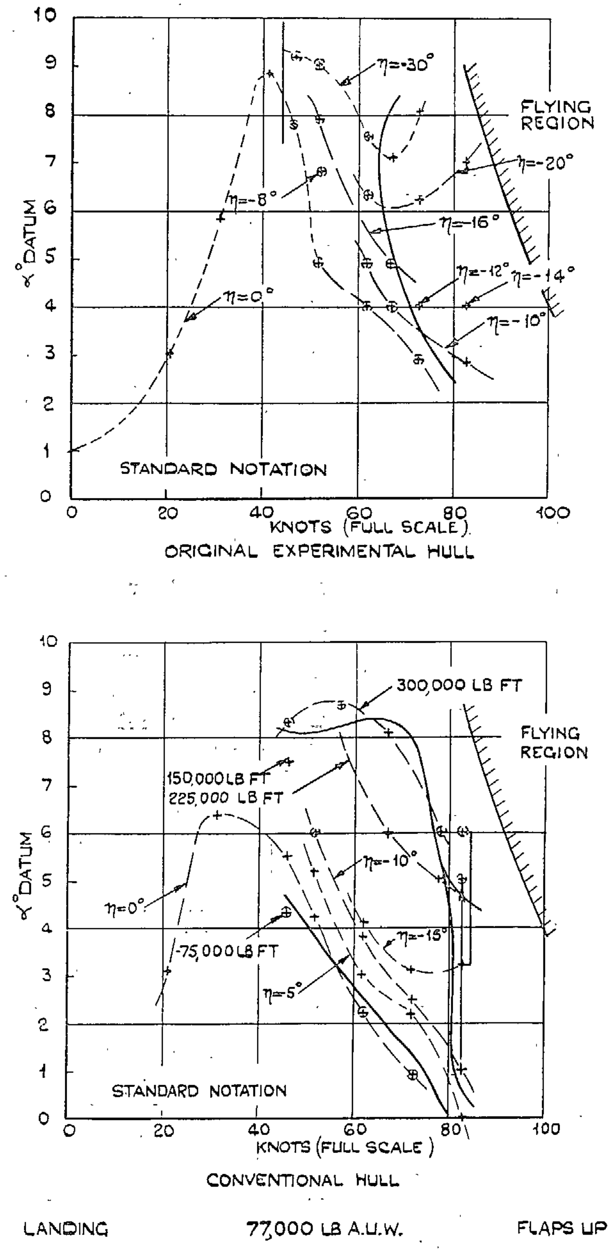


FIG. 8. Comparison of the water stability of the conventional and original experimental hulls

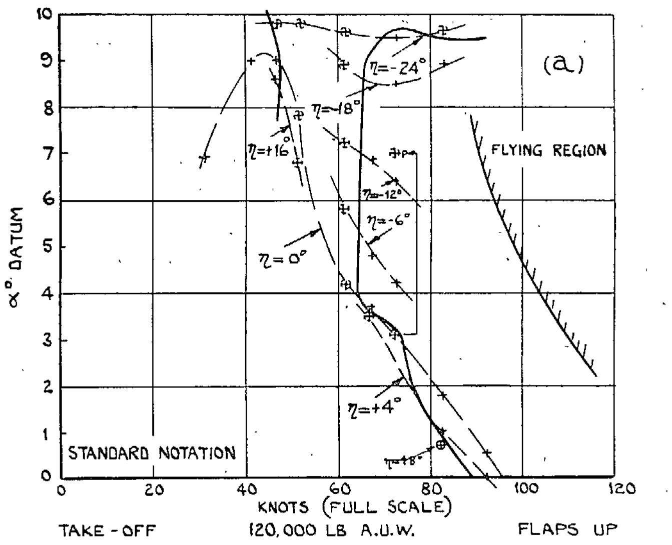


FIG. 9a. Original experimental hull—step fairing removed

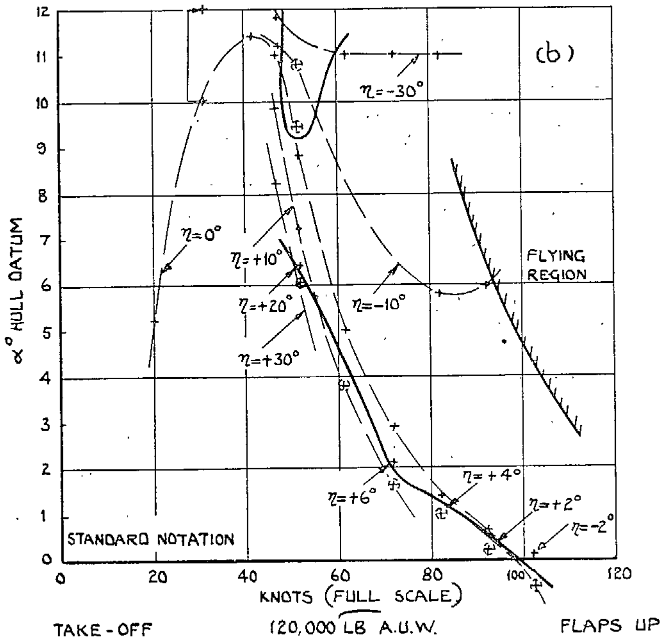
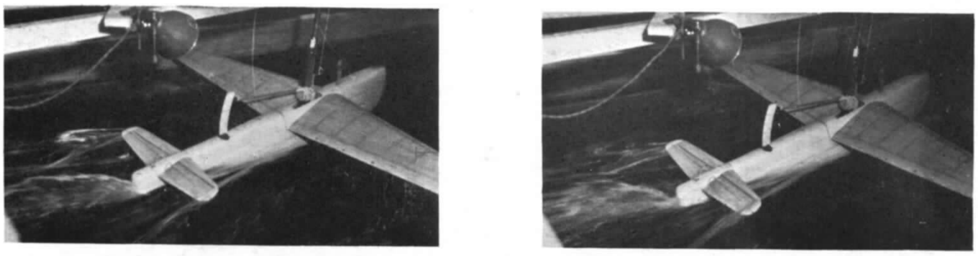


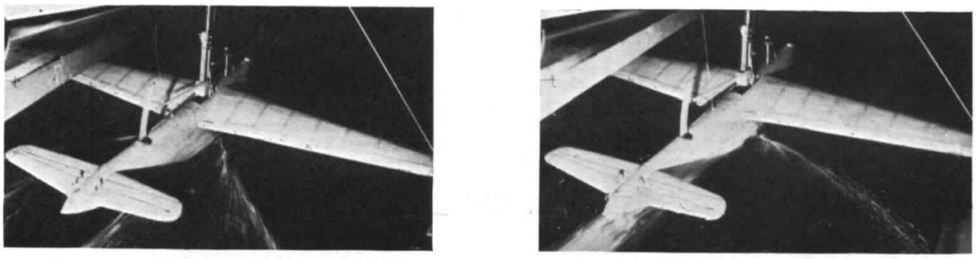
FIG. 9b. Original experimental hull with step fairing removed, step deepened to 10 per cent. maximum beam, and afterbody fined down



NO SUCTION PRESENT ATTITUDE 11·0° SUCTION PRESENT ATTITUDE 12·9°

SPEED 31·0 KNOTS TAKE OFF 120,000 LB. A.U.W.

FIG. 10. Experimental hull Mod. 4

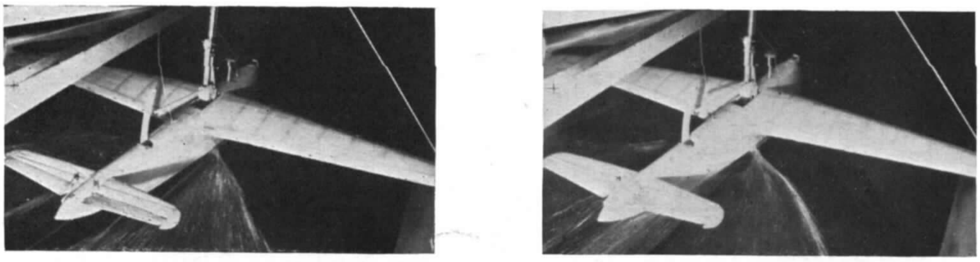


ELEVATOR – 6° ATTITUDE 2·3° ELEVATOR – 8° ATTITUDE 6·0°

AFTERBODY CLEAR SPRAY LICKING ROUND AFTERBODY CHINES

SPEED 92·8 KNOTS TAKE OFF 120,000 LB. A.U.W.

FIG. 11. Experimental hull—final lines

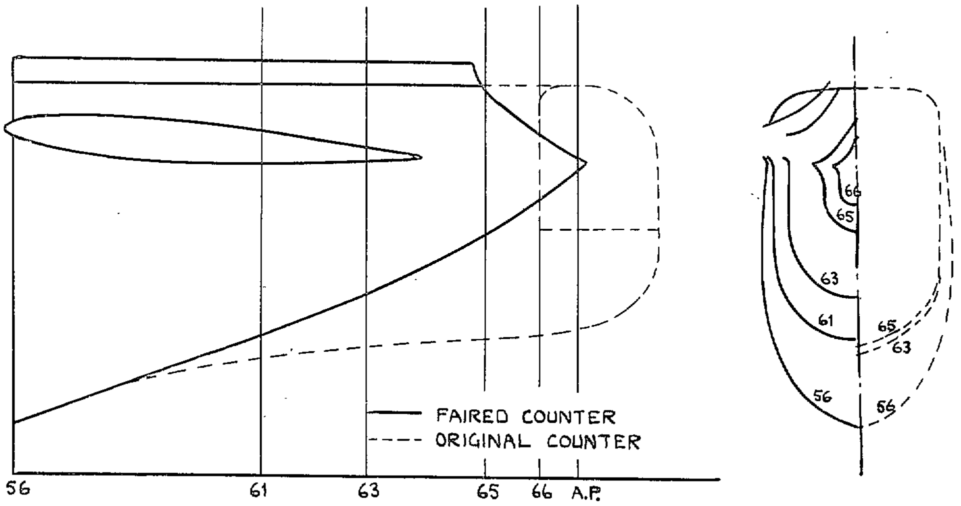


ELEVATOR – 16° ATTITUDE 3·8° ELEVATOR – 16° ATTITUDE 6·2°

NO AFTERBODY INTERFERENCE AFTERBODY INTERFERENCE

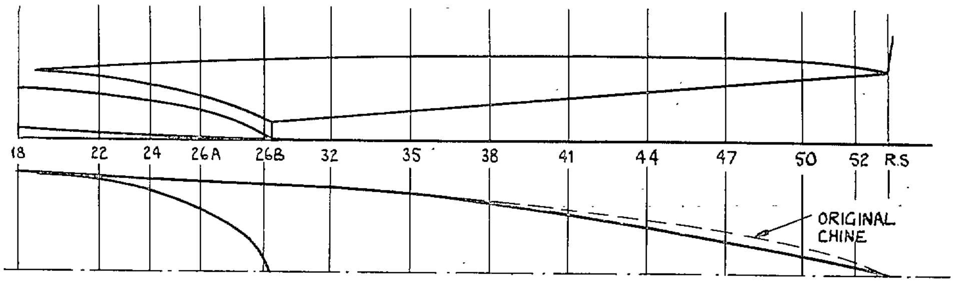
SPEED 82·5 KNOTS LANDING 77,000 LB A.U.W. FLAPS UP

FIG. 12. Experimental hull—final lines



STATION	DISTANCE FROM F.P.	TO P. ABOVE DATUM	KEEL ABOVE DATUM	HALF BREADTHS AT WATER LINES					HEIGHT AT BUTTOCKS.				
				144″	168″	192″	216″	228″	6″	12″	18″	24″	30″
56	1084·5	238·5	118·31	28·14	33·53	32·80	—	29·71	238·28	237·51	236·10	233·95	—
61	1171·25	238·5	149·10	—	27·53	29·76	28·88	24·88 26·43	237·53 149·81	235·66 151·90	232·35 155·48	228·61 161·58	226·88
63	1208·75	238·5	163·34	—	13·79	—	24·14	8·82	164·58	229·37 166·90	223·76 171·54	220·50 182·63	218·82
65	1251·75	234·49	185·78	—	—	11·30	9·44	2·00	220·40 187·32	213·55 193·17	—	—	—
66	1269·75	220·91	197·55	—	—	—	2·90	—	200·40	—	—	—	—
A.P.	1284·0	212·15	207·85	—	—	—	—	—	—	—	—	—	—

FIG. 13a. Faired counter



STATION	18	22	24	26A.	26B	32	35	38	41	44	47	50	52	R.S.
DISTANCE FROM F.P.	367·31	429·12	467·12	511·00	552·75	604·5	664·5	724·5	784·5	844·5	904·5	964·5	1004·5	1035·0
KEEL HEIGHT	7·92	5·08	3·33	1·31	-0·61	16·84	21·85	26·86	31·67	36·88	41·89	46·93	50·35	53·0
CHINE HEIGHT	—	56·05	57·19	58·33	59·85	60·99	62·70	63·35	64·41	64·98	63·46	60·42	57·00	53·0
CHINE ½ BREADTH (AFTERBODY)	—	70·87	69·54	68·40	67·07	64·79	59·66	53·39	45·22	35·34	25·27	14·25	6·46	0

FIG. 13b. Afterbody lines

N.B.—Offsets have been scaled from model and have not been faired full scale. Step depth is approx. constant and equals 14·82 in. Keel radii are as for original form and planing bottom curve at the same position at keel. Forebody is unaltered.

FIG. 13. Final experimental hull

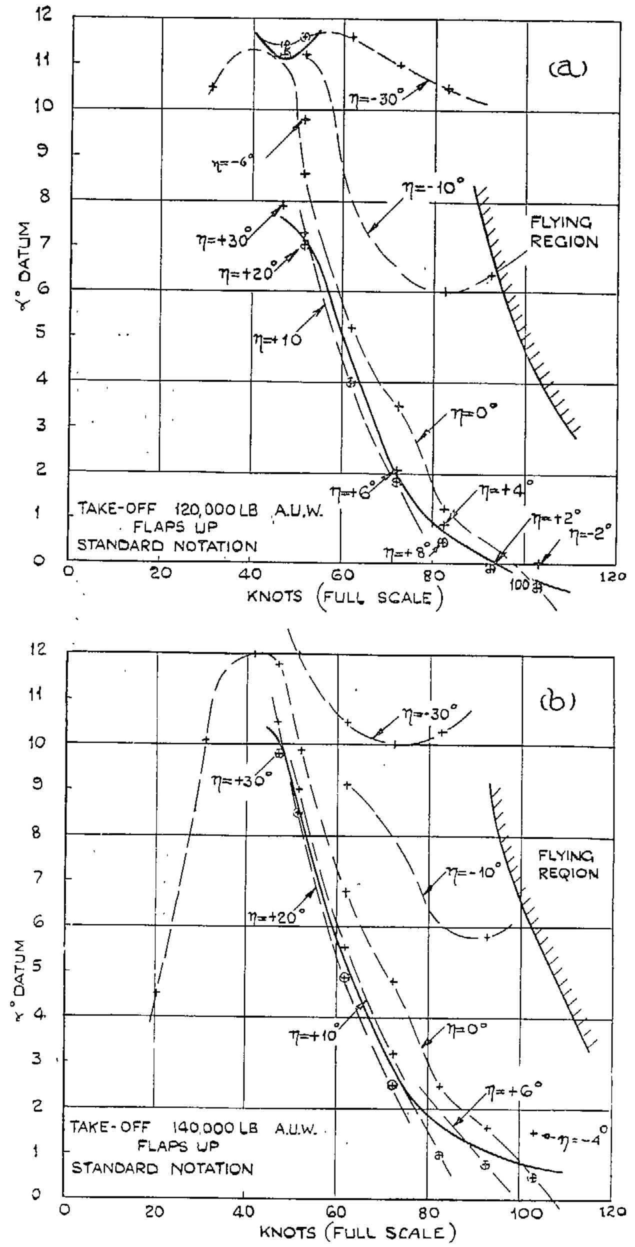


FIG. 14. Stability diagrams for take-offs at 120,000 lb and 140,000 lb all-up-weight. Final experimental hull. Step faired in planform only

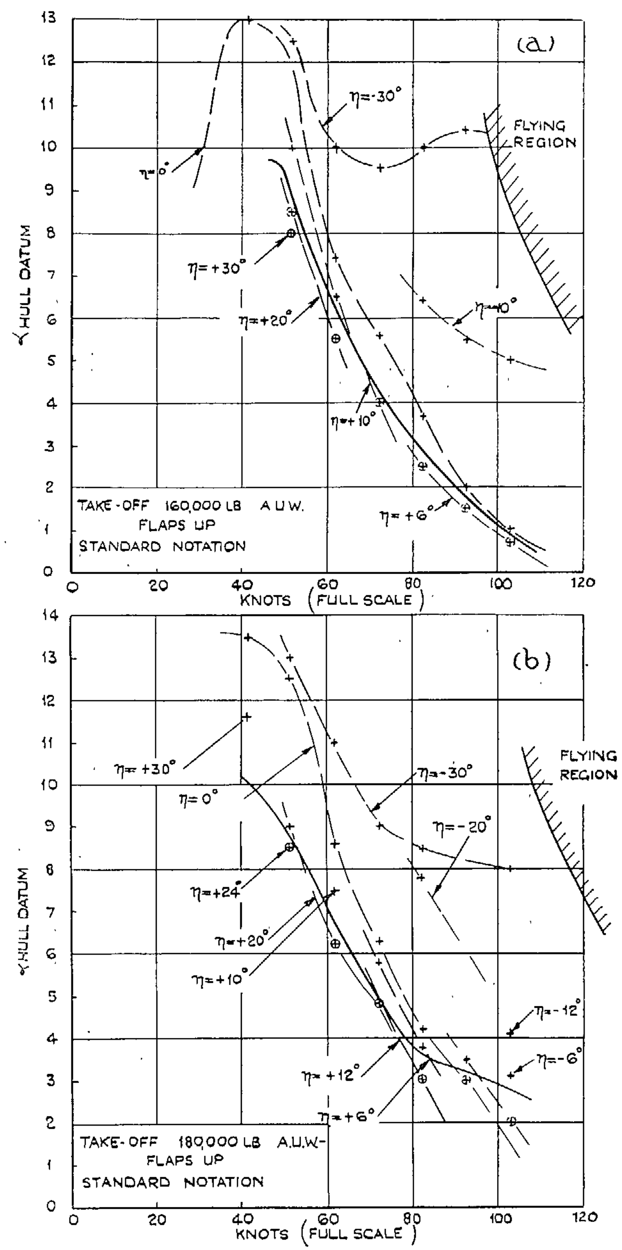
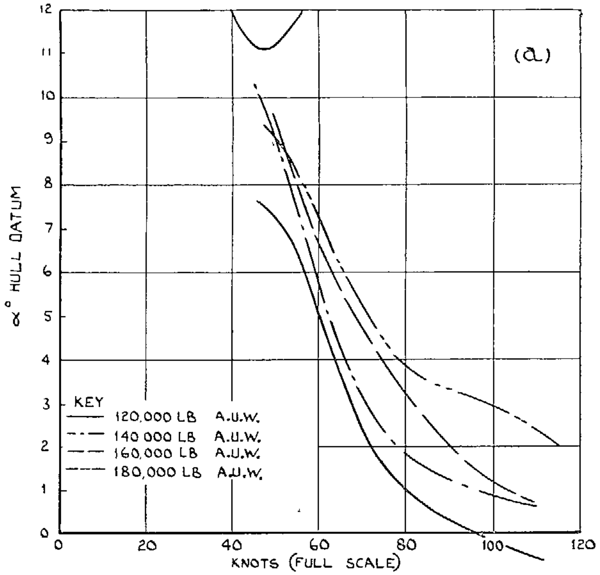
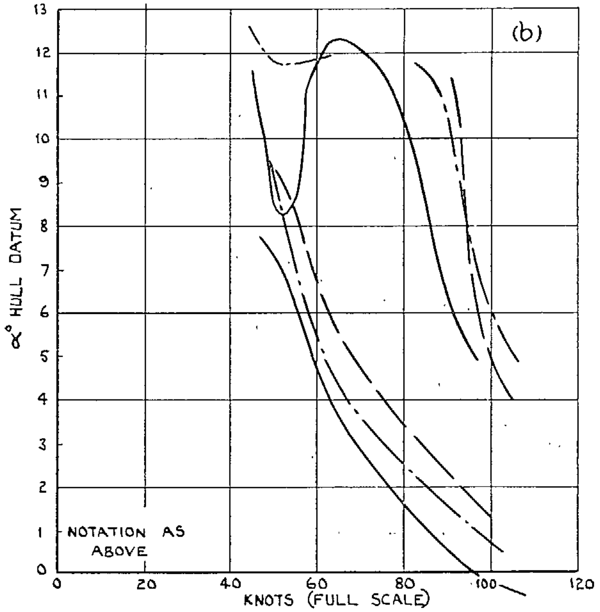


FIG. 15. Stability diagrams for take-offs at 160,000 lb and 180,000 lb. all-up-weight. Final experimental hull. Step faired in planform only

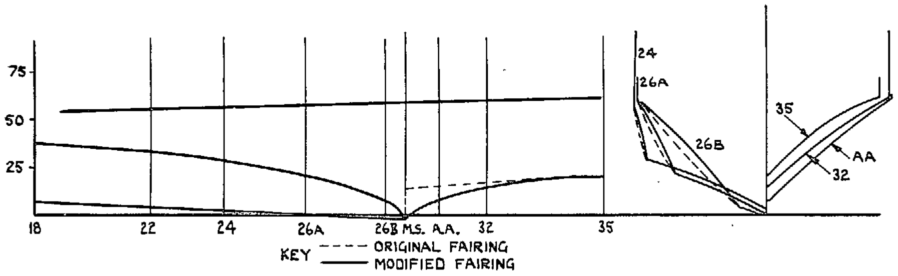


STEP FAIRED IN PLANFORM ONLY



STEP FULLY FAIRED

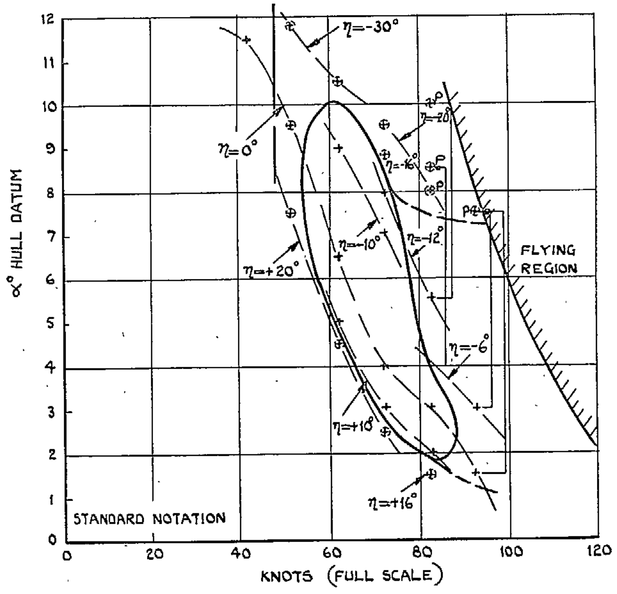
FIG. 16. Effect of increase of weight on the stability limits. Final experimental hull



STATION	DIST. FROM F.P.	KEEL HEIGHT	CHINE HEIGHT		CHINE ½ WIDTH		BUTTOCKS.					
			F'B'DY	AFT'B'DY	F'B'DY	AFT'B'DY	12"	24"	36"	48"	60"	66"
18	367·31	7·92	38·75	—	73·88	—	—	—	—	—	—	—
22	429·12	5·19	33·63	56·05	70·00	—	—	—	—	—	—	—
24	467·12	3·36	29·25	57·19	62·50	69·54	—	—	—	—	—	45·90
26A	511·00	1·22	21·50	58·33	47·00	68·40	—	—	—	27·36	49·21	55·89
26B	552·75	-0·61	5·00	59·85	14·38	67·07	—	17·88	31·45	44·65	55·04	—
M.S.	560·25	-0·95	—	—	—	—	—	—	—	—	—	—
A.A.	579·25	8·02	—	60·38	—	65·93	16·30	29·49	39·67	48·68	57·40	—
32	604·50	15·26	—	60·99	—	64·79	25·27	35·26	44·66	52·35	59·53	—
35	664·50	21·26	—	62·20	—	59·66	33·88	43·26	51·09	57·84	—	—

N.B. OFFSETS HAVE NOT BEEN FAIRED FULL SCALE

FIG. 17. Lines of original and modified step fairing



TAKE-OFF 130,000 LB FLAPS UP

FIG. 18. Final experimental hull—original step fairing

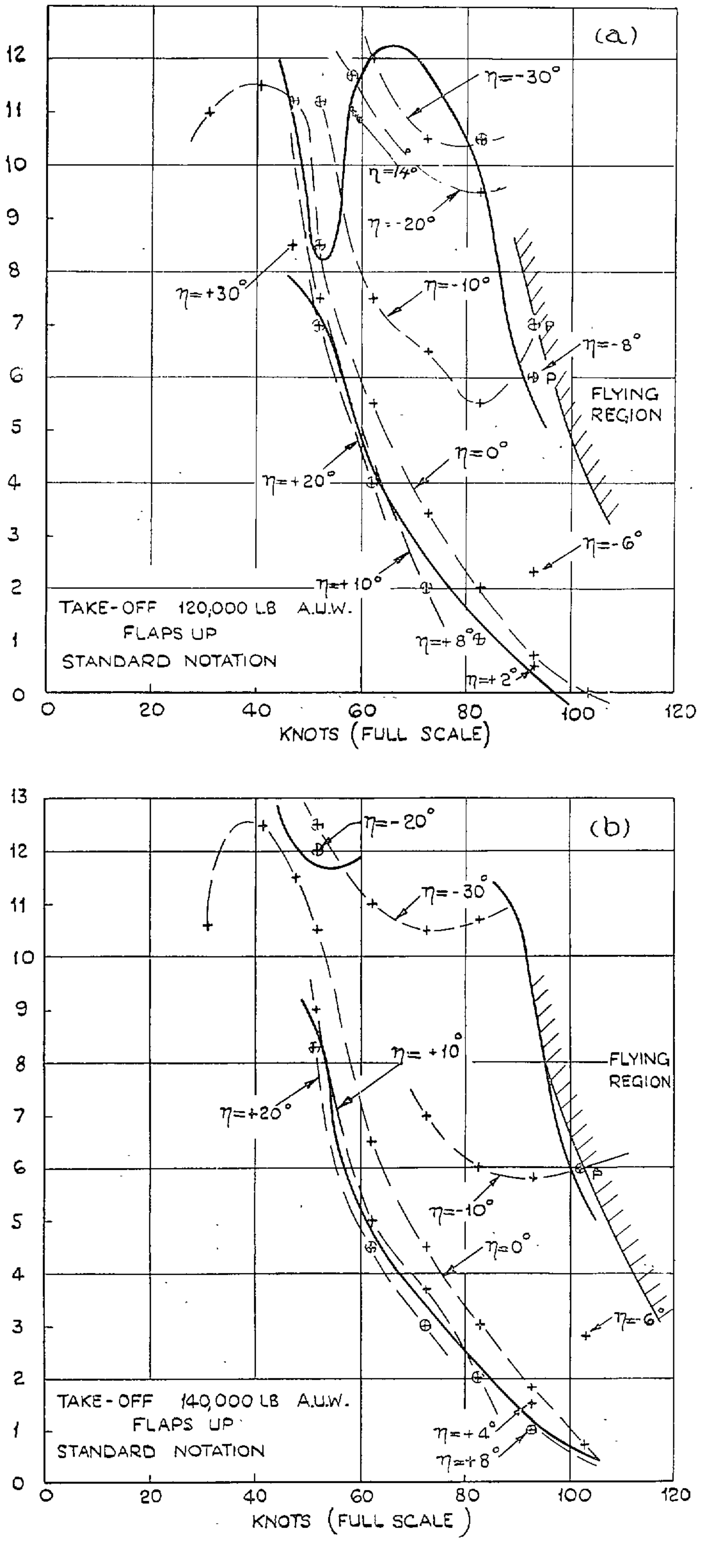


FIG. 19. Stability diagrams for take-offs at 120,000 lb and 140,000 lb all-up-weight. Final experimental hull. Step fully faired

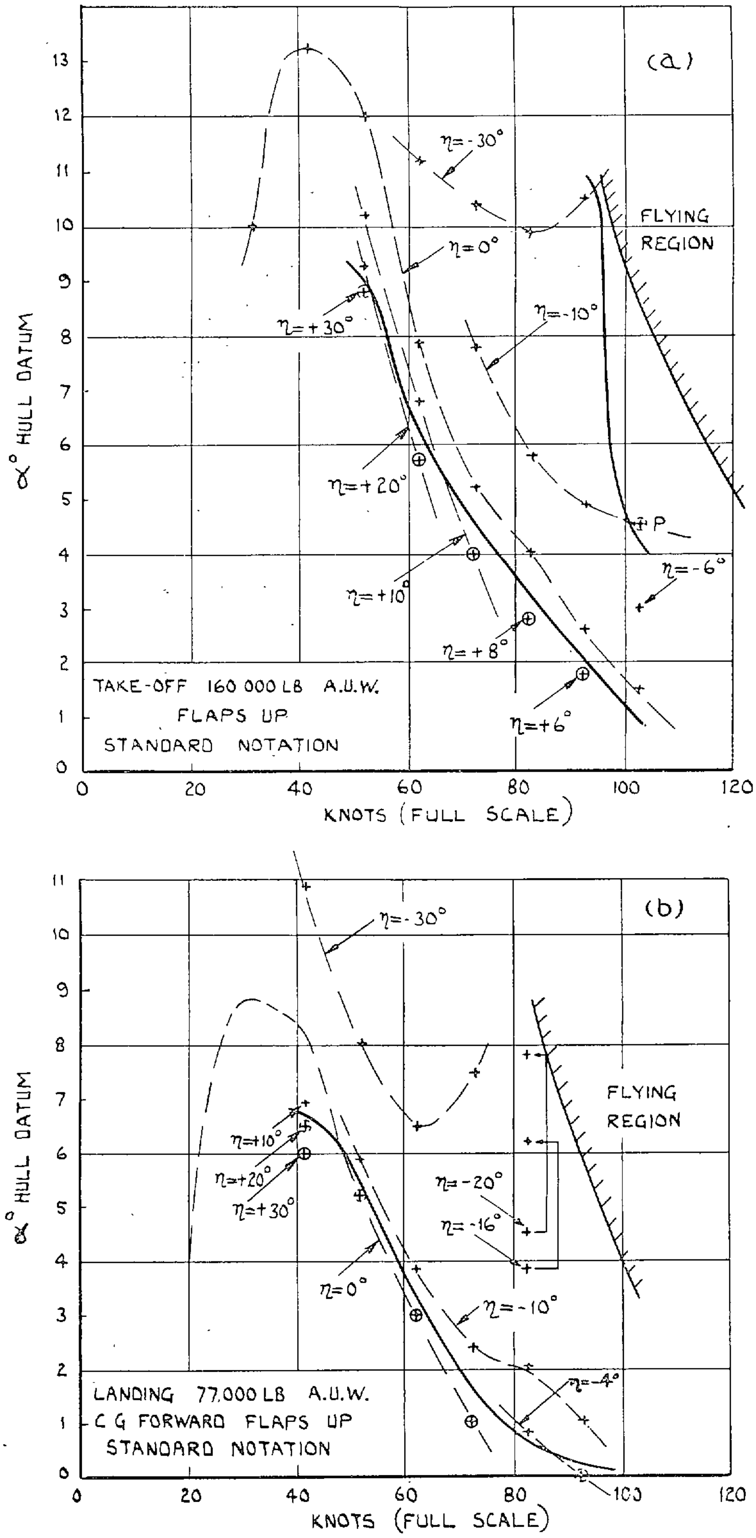
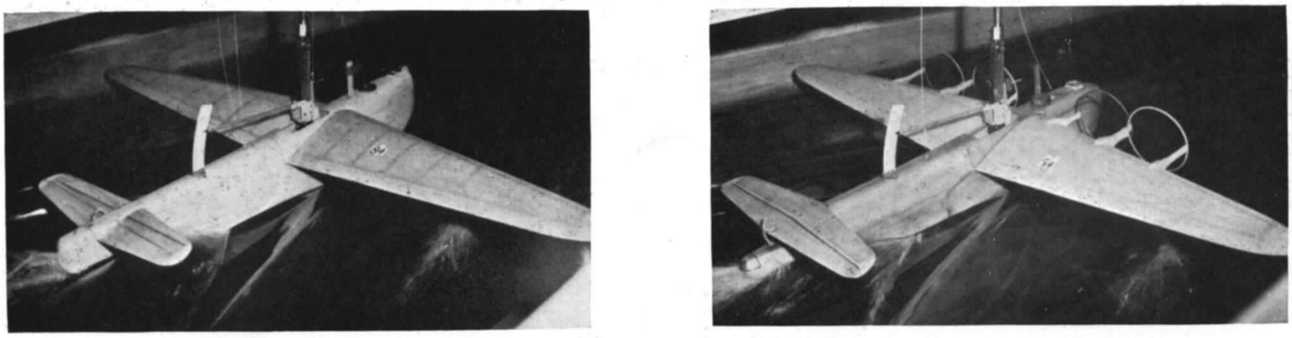
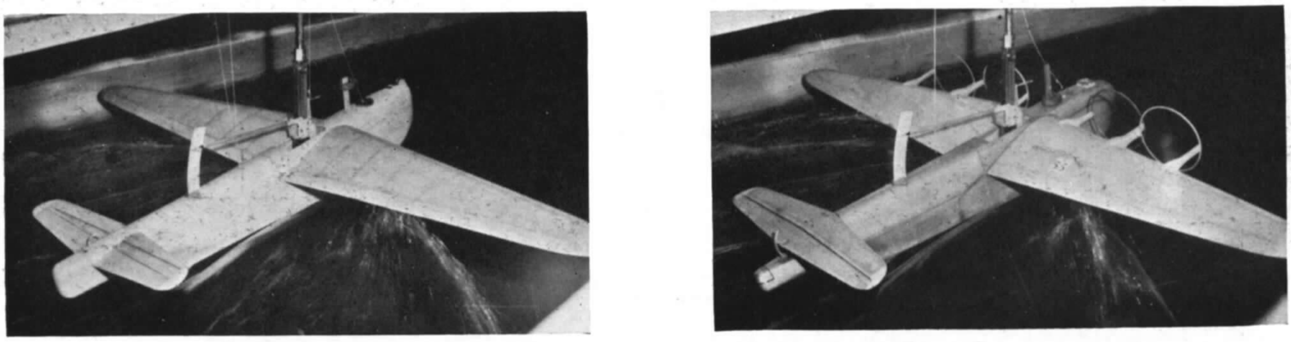


FIG. 20. Stability diagrams for a take-off at 160,000 lb all-up-weight and a landing (c.g. forward) at 77,000 lb all-up-weight. Final experimental hull. Step fully faired

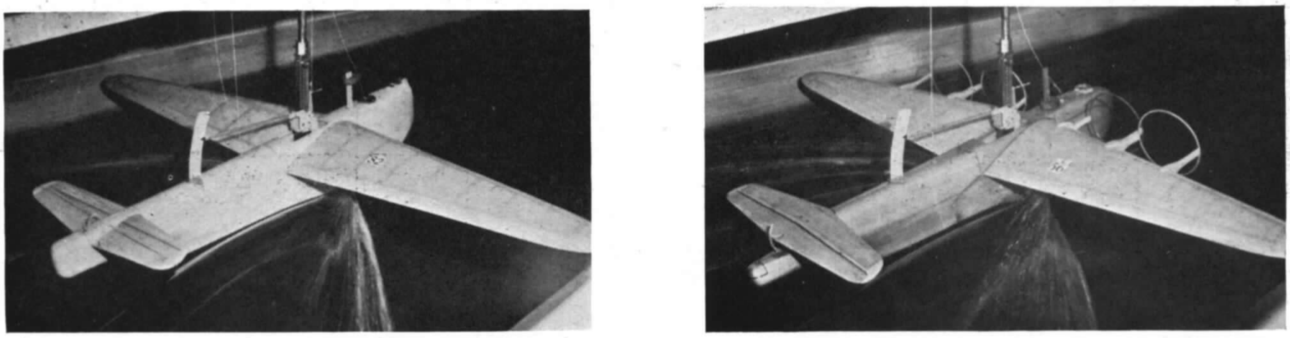
EXPERIMENTAL HULL CONVENTIONAL HULL



SPEED 31·0 KNOTS



SPEED 41·3 KNOTS



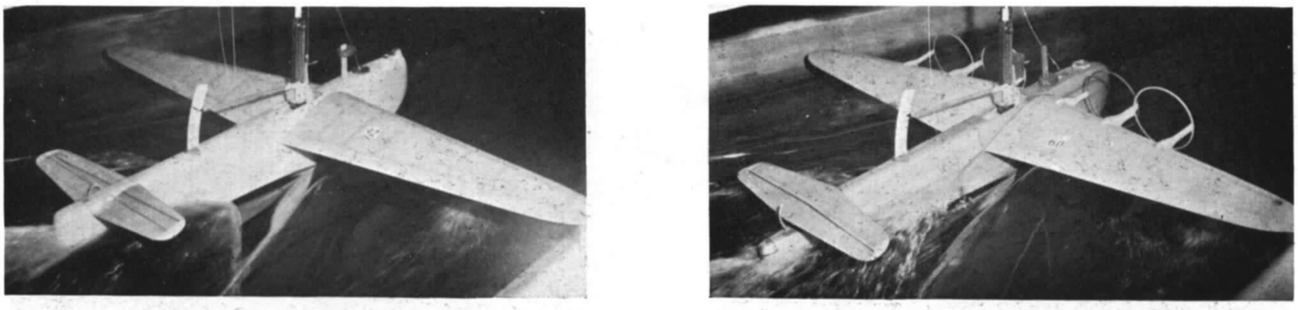
SPEED 51·6 KNOTS

ELEVATOR NEUTRAL TRIMMED BY THRUST MOMENT

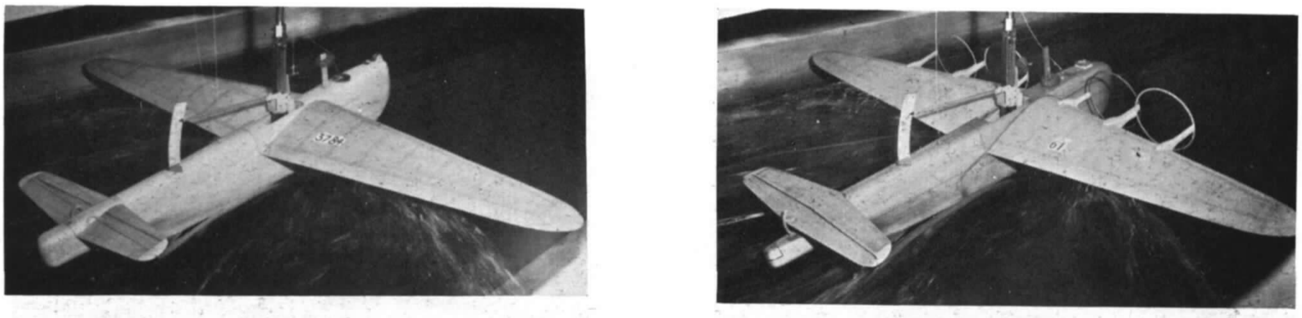
TAKE OFF 120,000 LB. A.U.W. FLAPS UP

FIG. 21. Comparison of main spray characteristics. Original experimental and conventional hulls

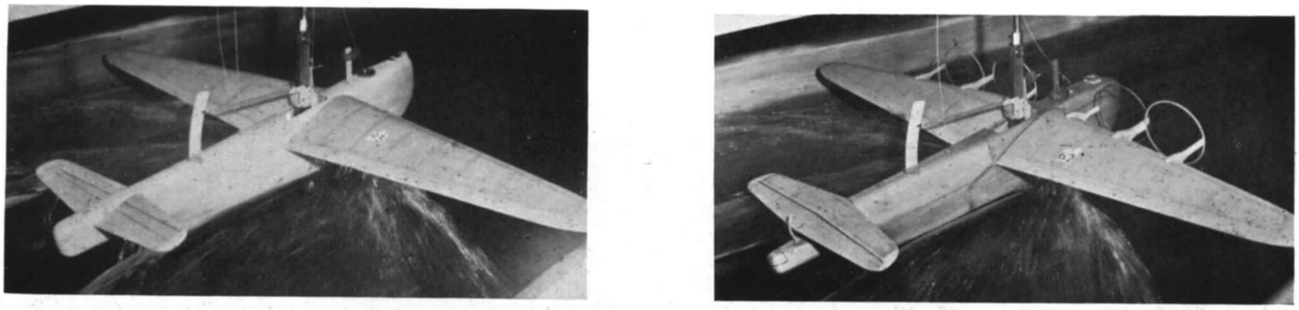
EXPERIMENTAL HULL CONVENTIONAL HULL



SPEED 31·0 KNOTS



SPEED 41·3 KNOTS

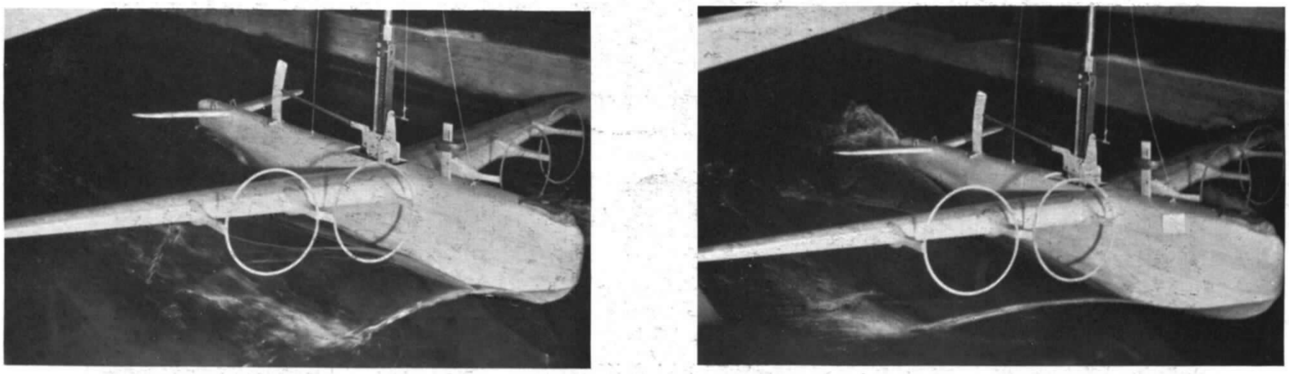


SPEED 51·6 KNOTS

ELEVATOR NEUTRAL TRIMMED BY THRUST MOMENT

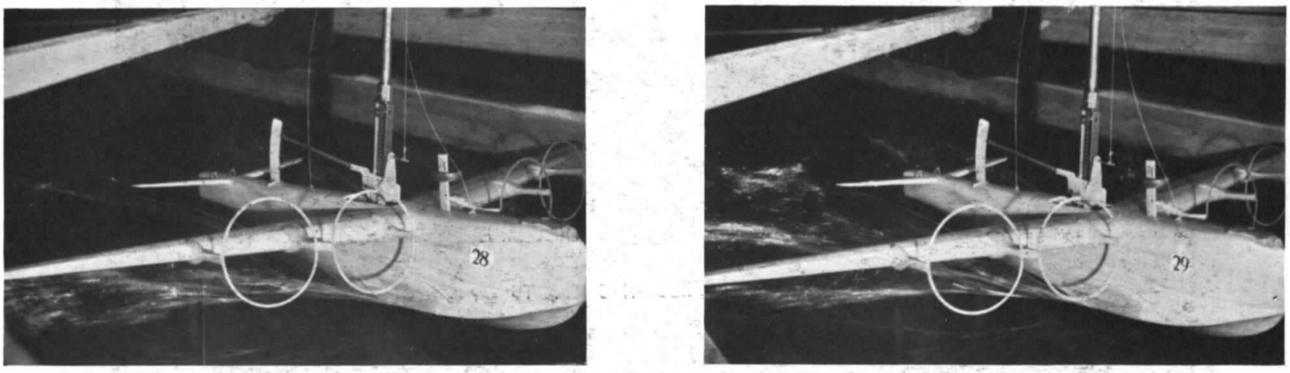
TAKE OFF 140,000 LB A.U.W. FLAPS UP

FIG. 22. Comparison of main spray characteristics. Original experimental and conventional hulls



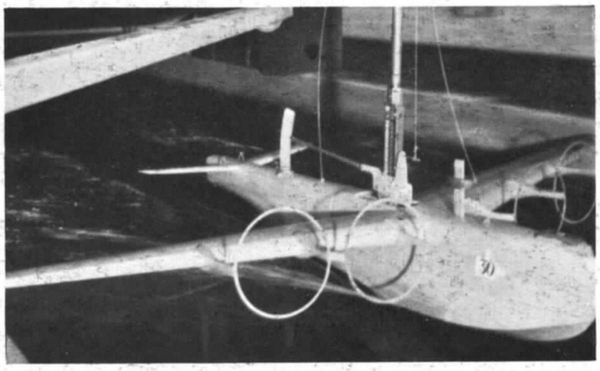
SPEED 2·06 KNOTS ATTITUDE 4·6°

SPEED 31·0 KNOTS ATTITUDE 7·4°



SPEED 41·3 KNOTS ATTITUDE 10·1°

SPEED 51·6 KNOTS ATTITUDE 8·7°



SPEED 61·9 KNOTS ATTITUDE 5·2°

TAKE OFF 130,000 LB A.U.W. FLAPS UP

FIG. 23. Forebody spray characteristics. Original experimental hull

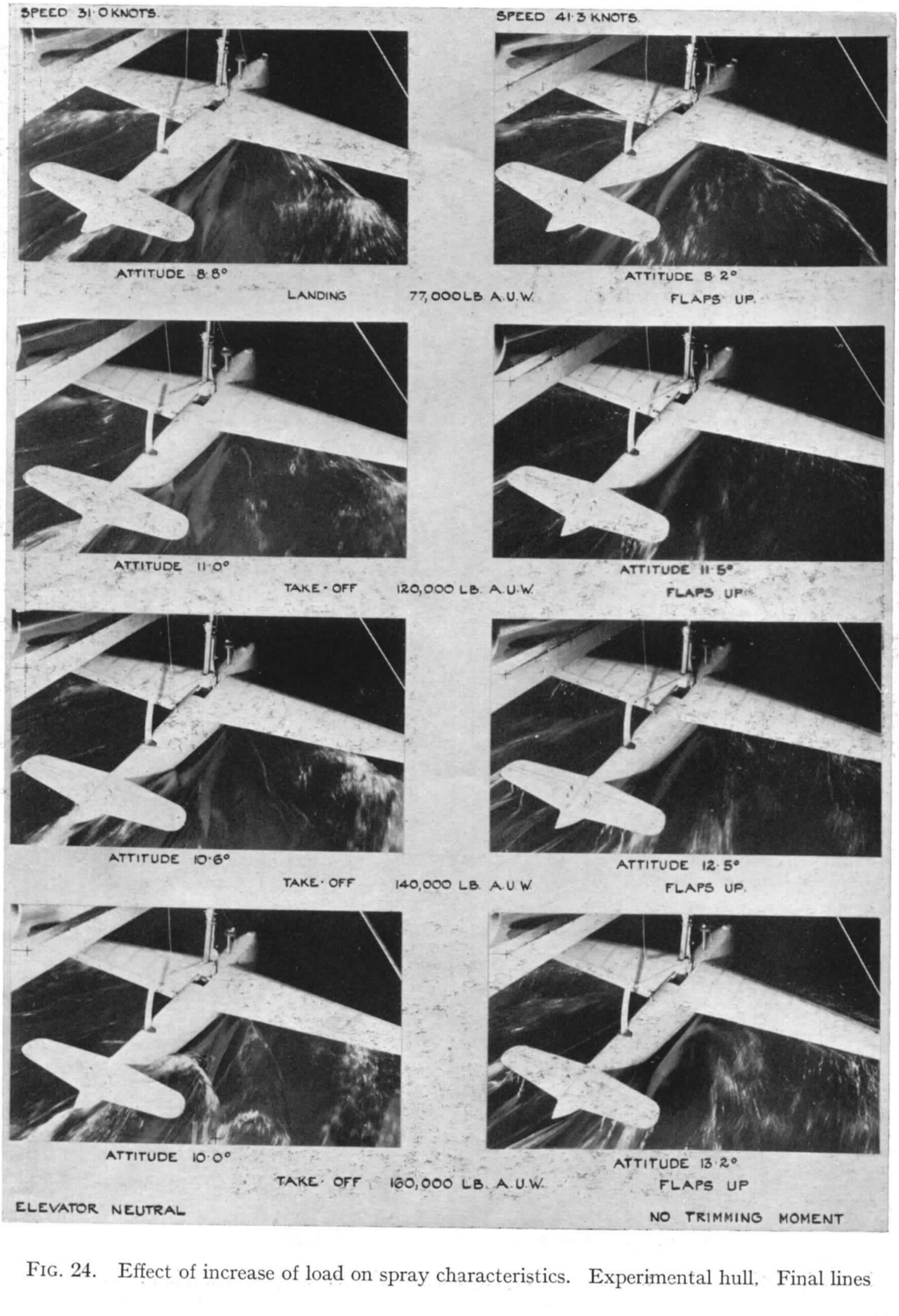


FIG. 24. Effect of increase of load on spray characteristics. Experimental hull. Final lines

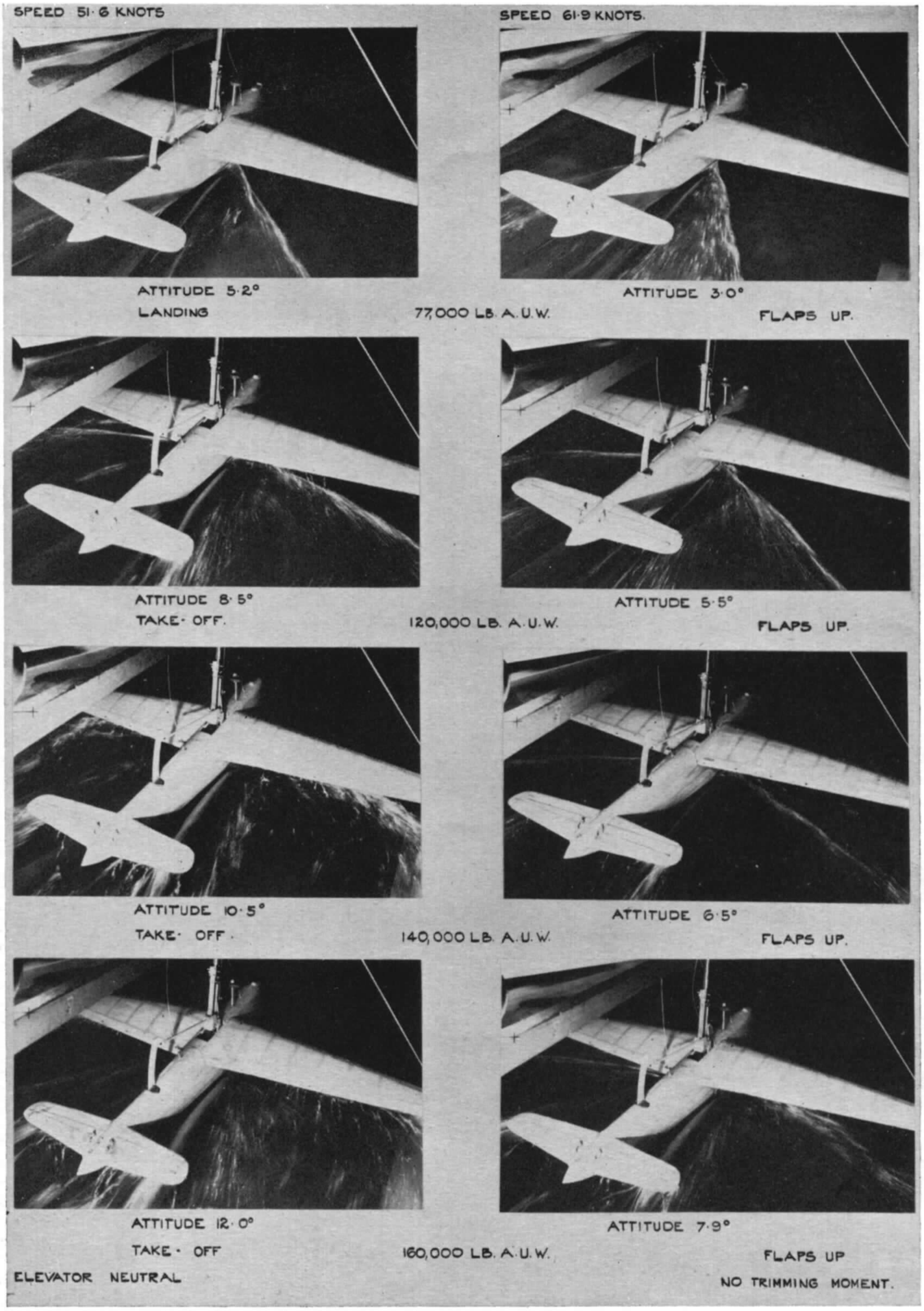


FIG. 25. Effect of increase of load on spray characteristics. Experimental hull. Final lines

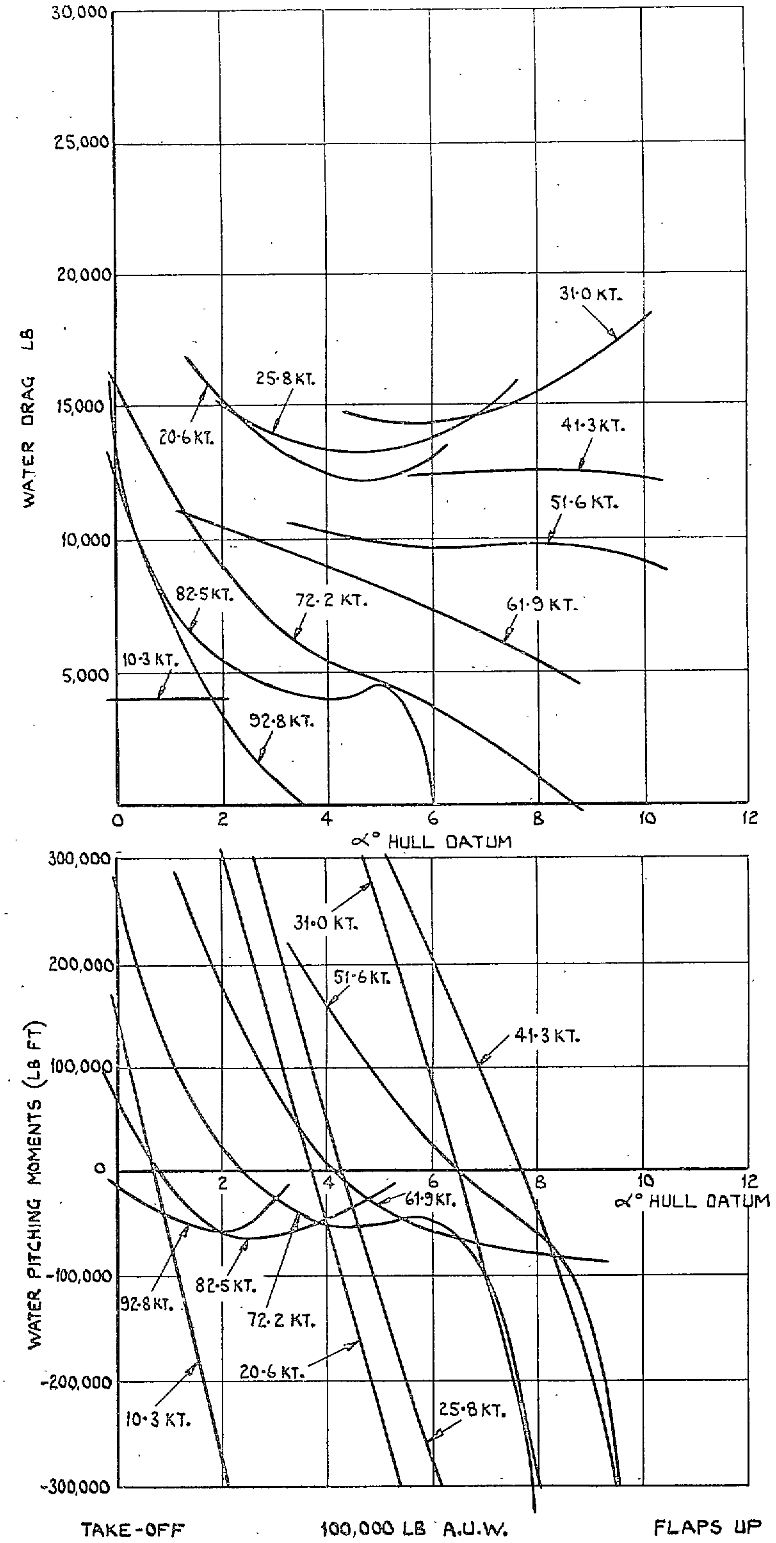


FIG. 26. Water drags and pitching moments. Original experimental hull

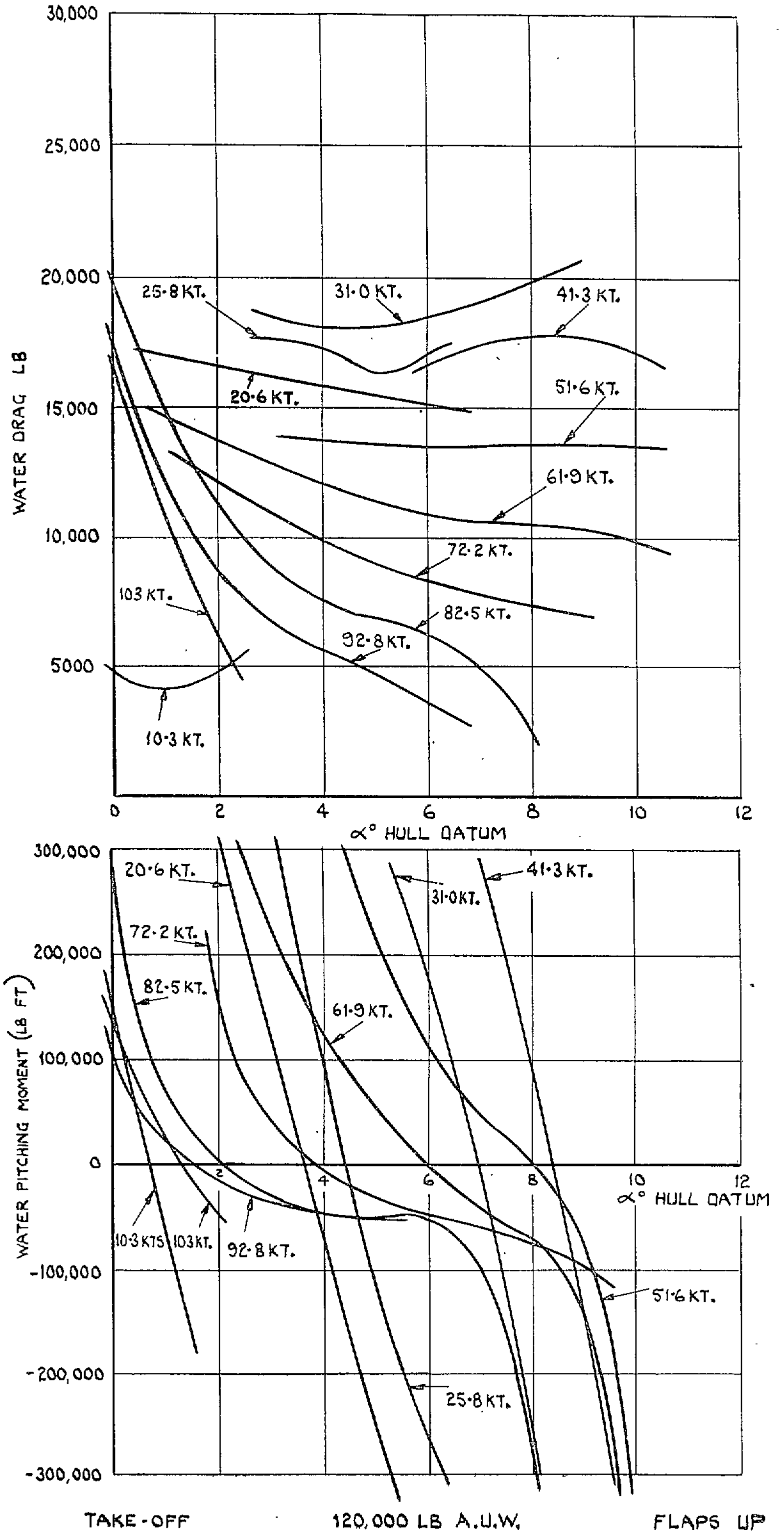


Fig. 27. Water drags and pitching moments. Original experimental hull

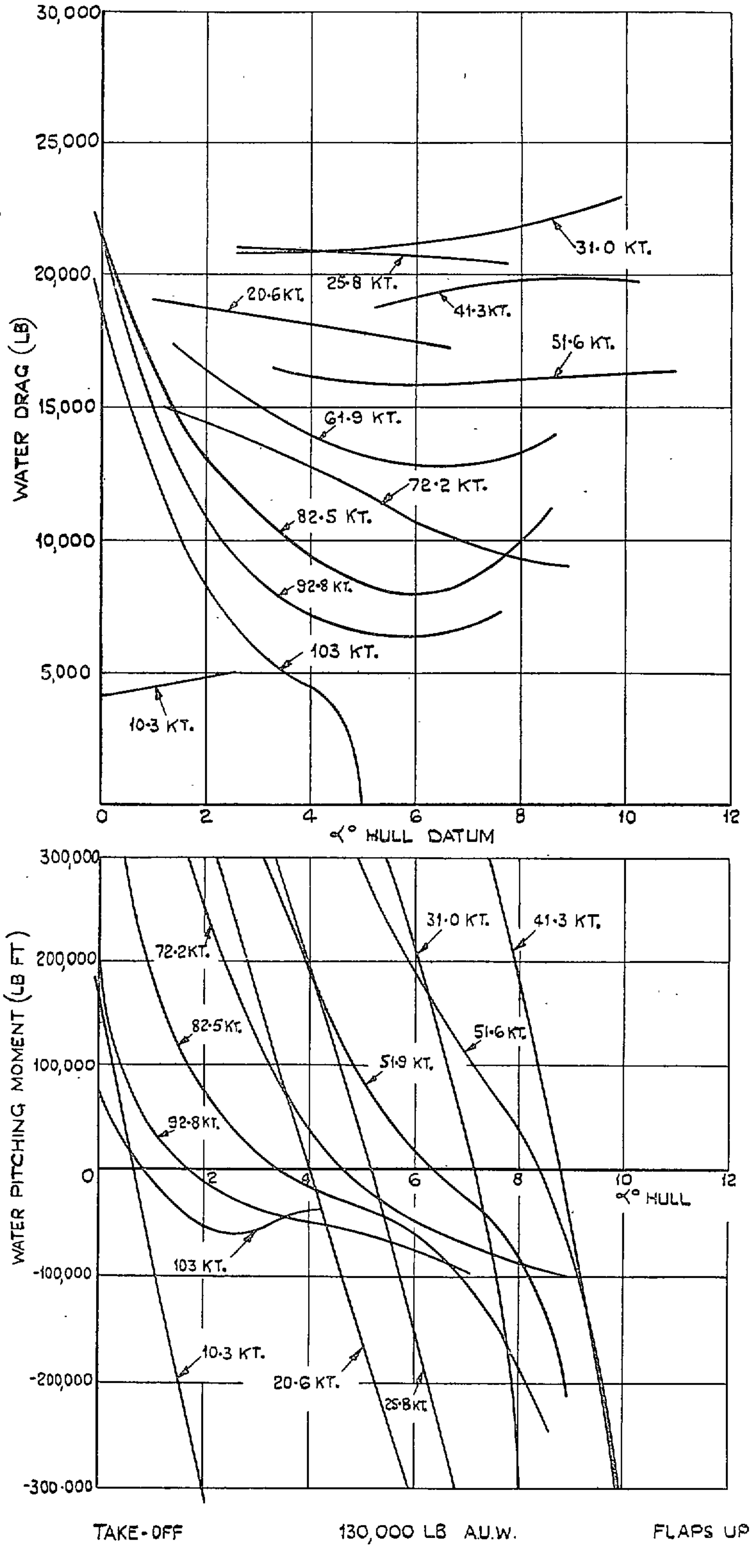


Fig. 28. Water drags and pitching moments. Original experimental hull

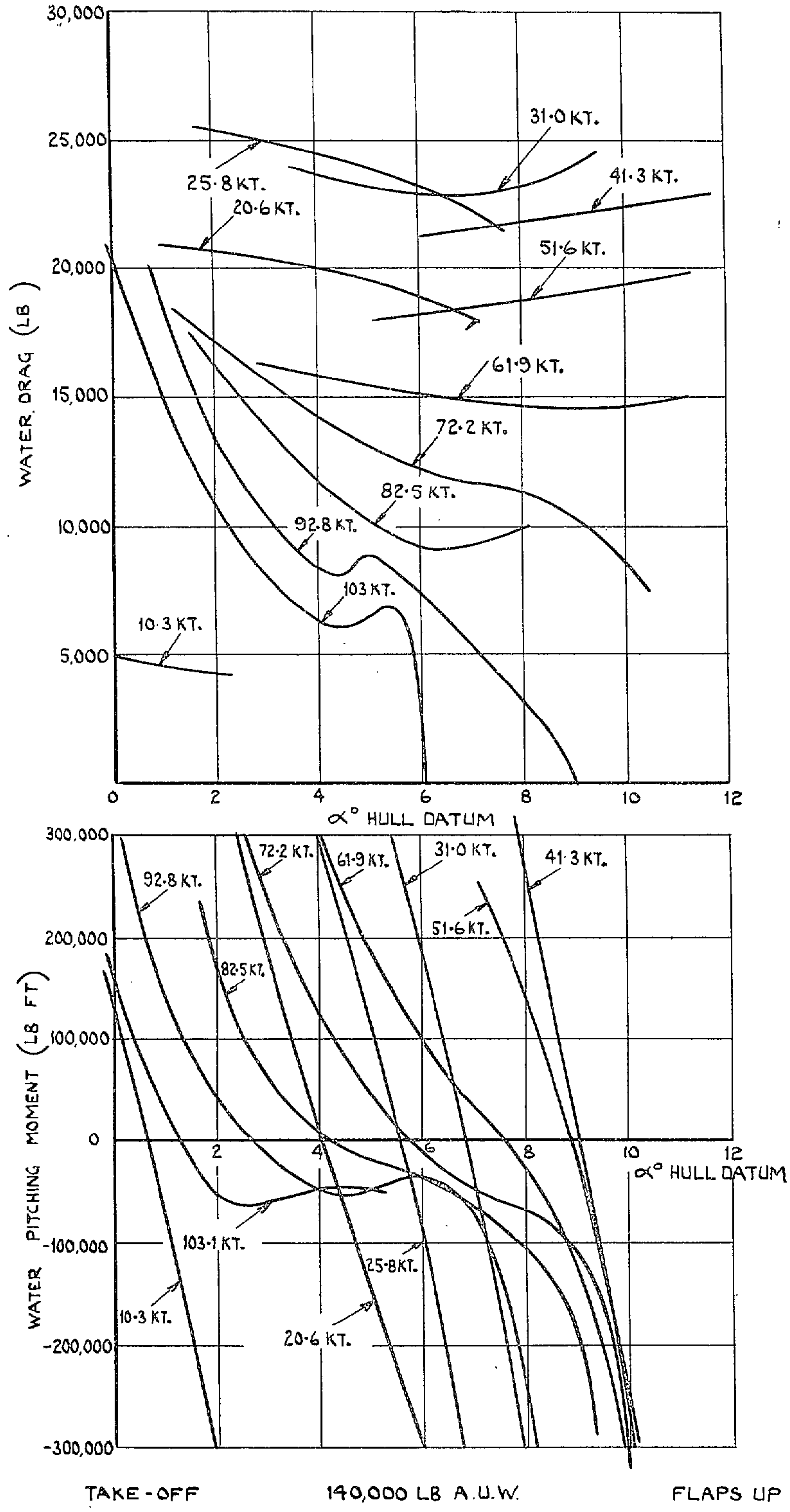


FIG. 29. Water drags and pitching moments. Original experimental hull

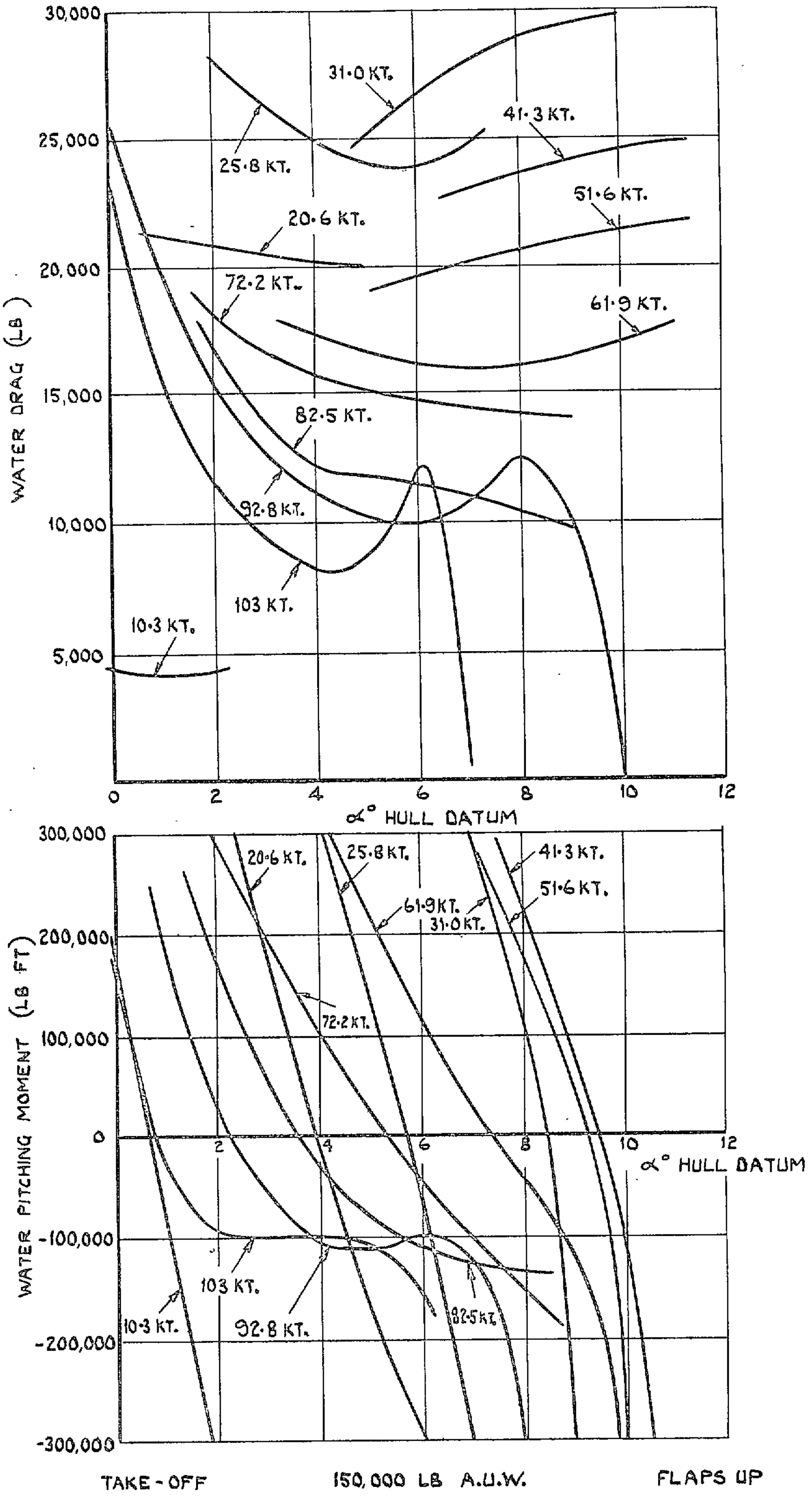


FIG. 30. Water drags and pitching moments. Original experimental hull

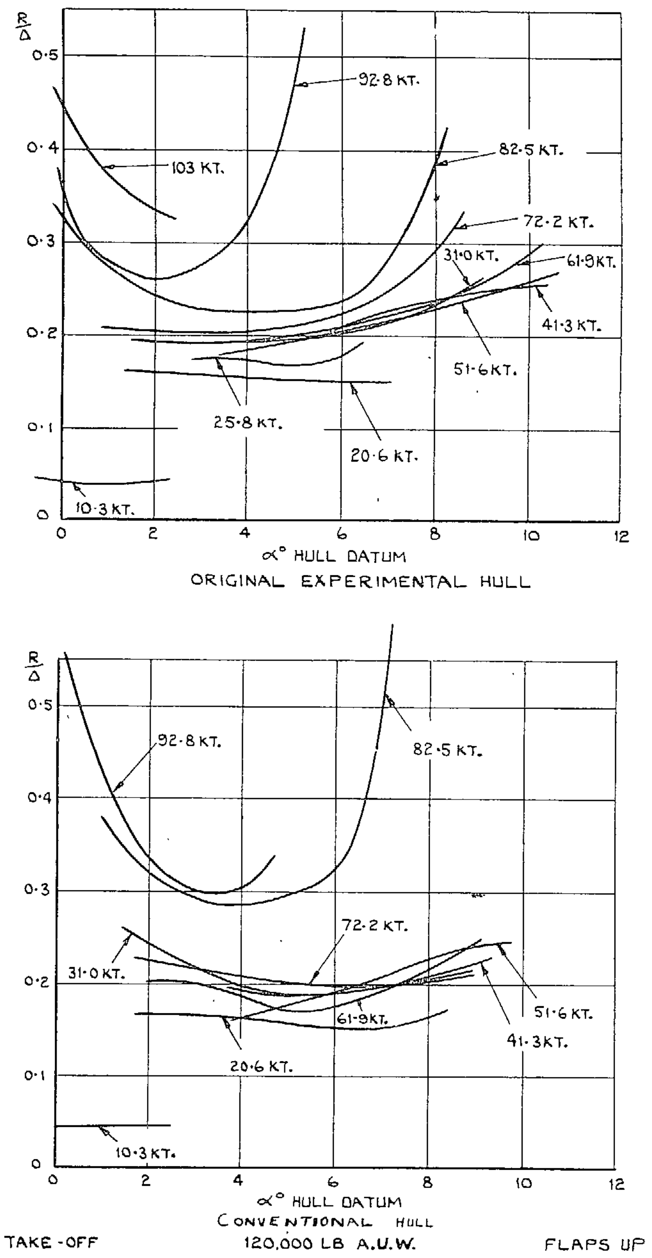


FIG. 31. Comparison of the efficiencies of the experimental and conventional hulls

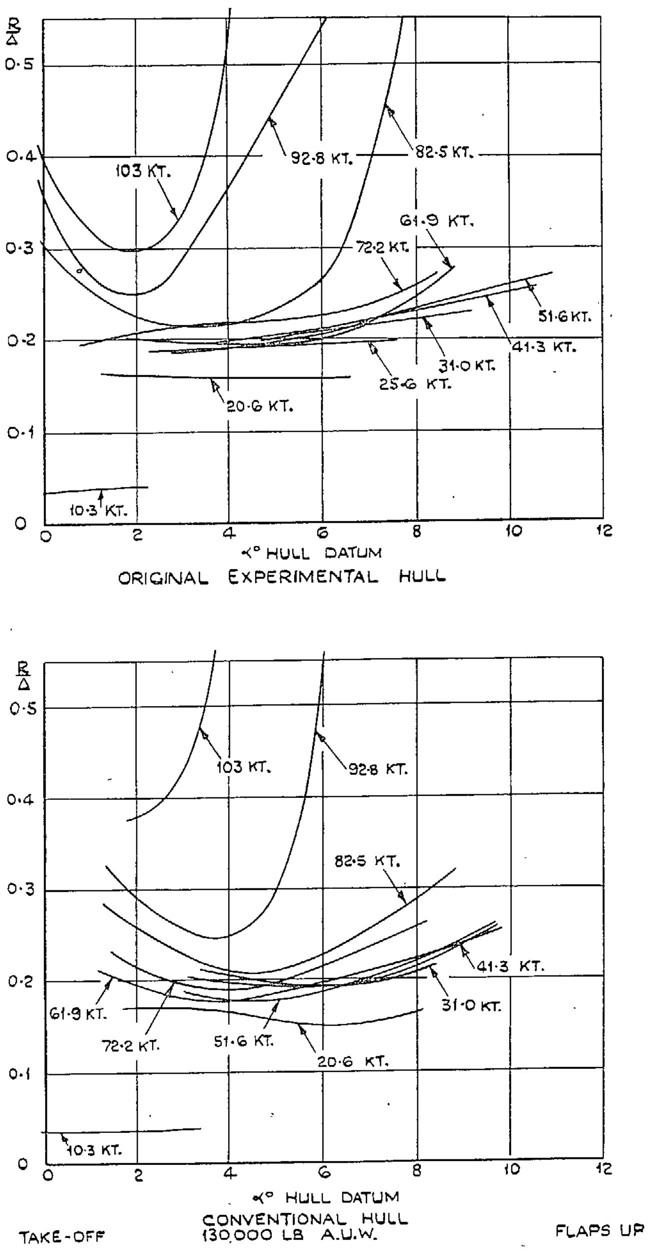
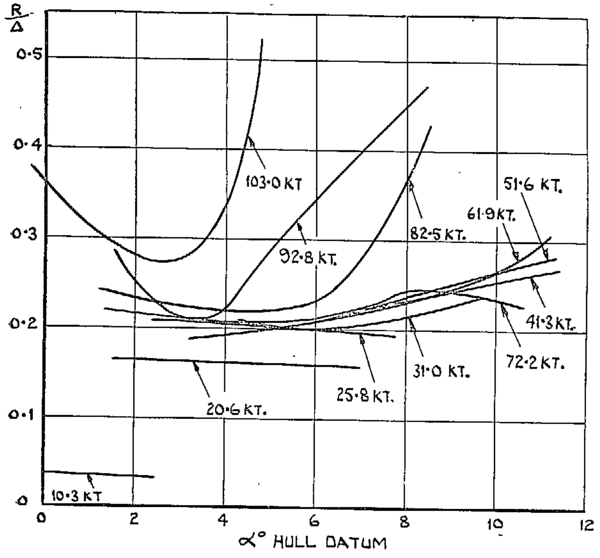
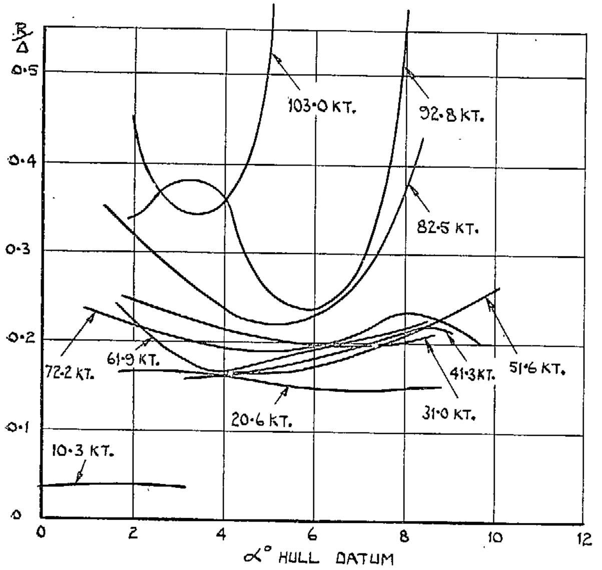


FIG. 32. Comparison of the efficiencies of the experimental and conventional hulls



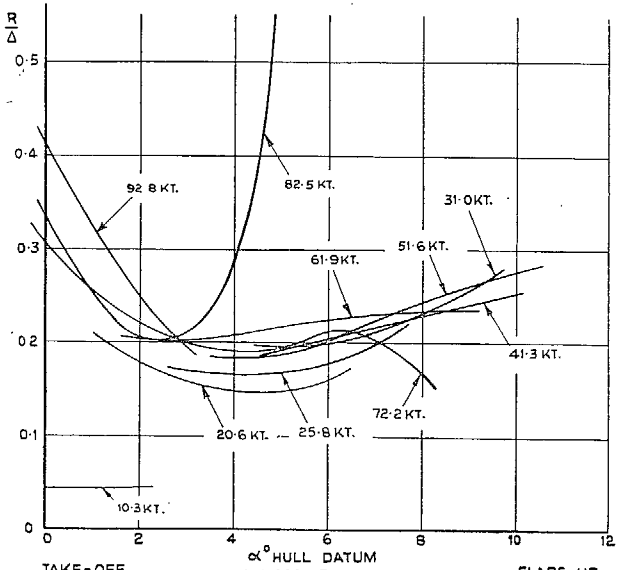
ORIGINAL EXPERIMENTAL HULL



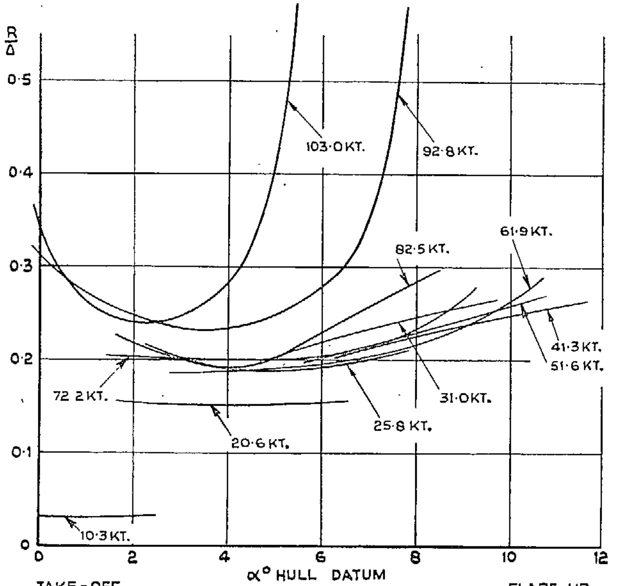
CONVENTIONAL HULL

TAKE OFF 140,000 LB A.U.W. FLAPS UP

FIG. 33. Comparison of the efficiencies of the experimental and conventional hulls



TAKE-OFF 100,000 LB A.U.W. FLAPS UP



TAKE-OFF 150,000 LB A.U.W. FLAPS UP

FIG. 34. Hull efficiencies for take-offs at 100,000 lb and 150,000 lb A.U.W. Original experimental hull

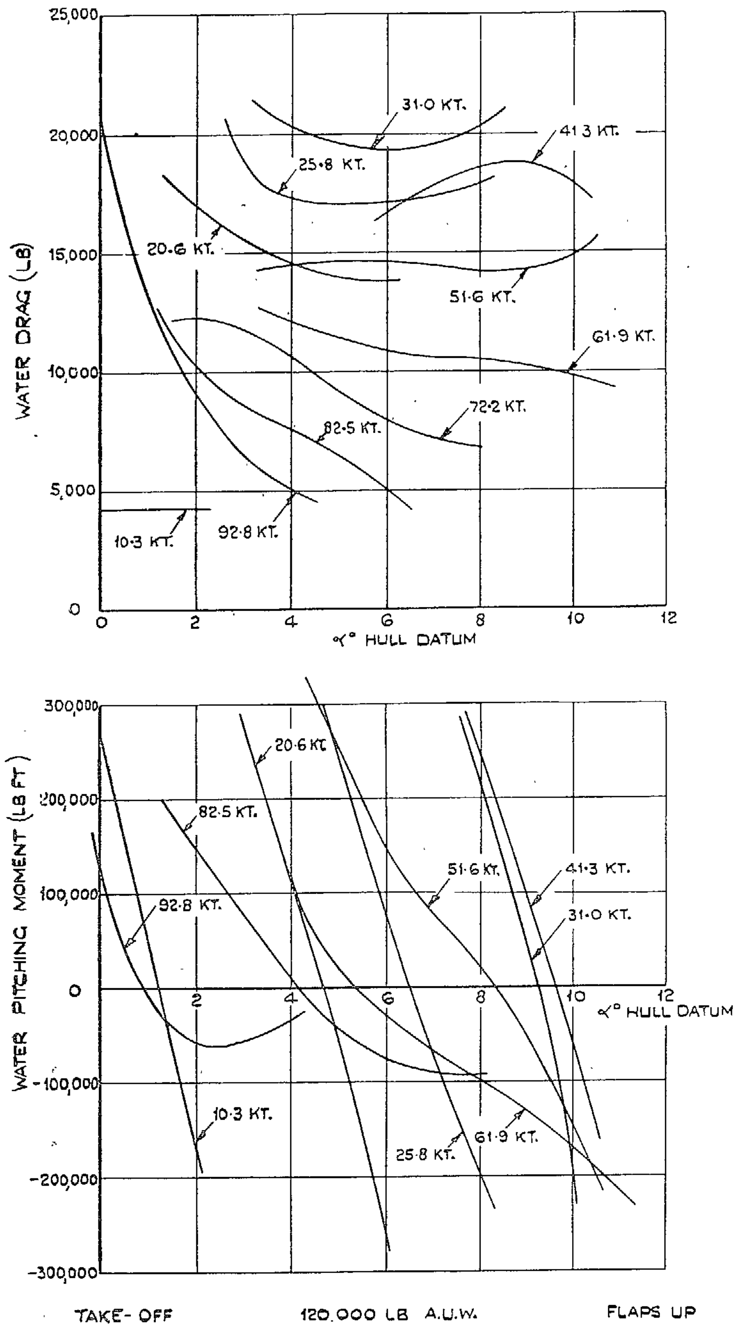


FIG. 35. Water drags and pitching moments. Final experimental hull. Step fully faired

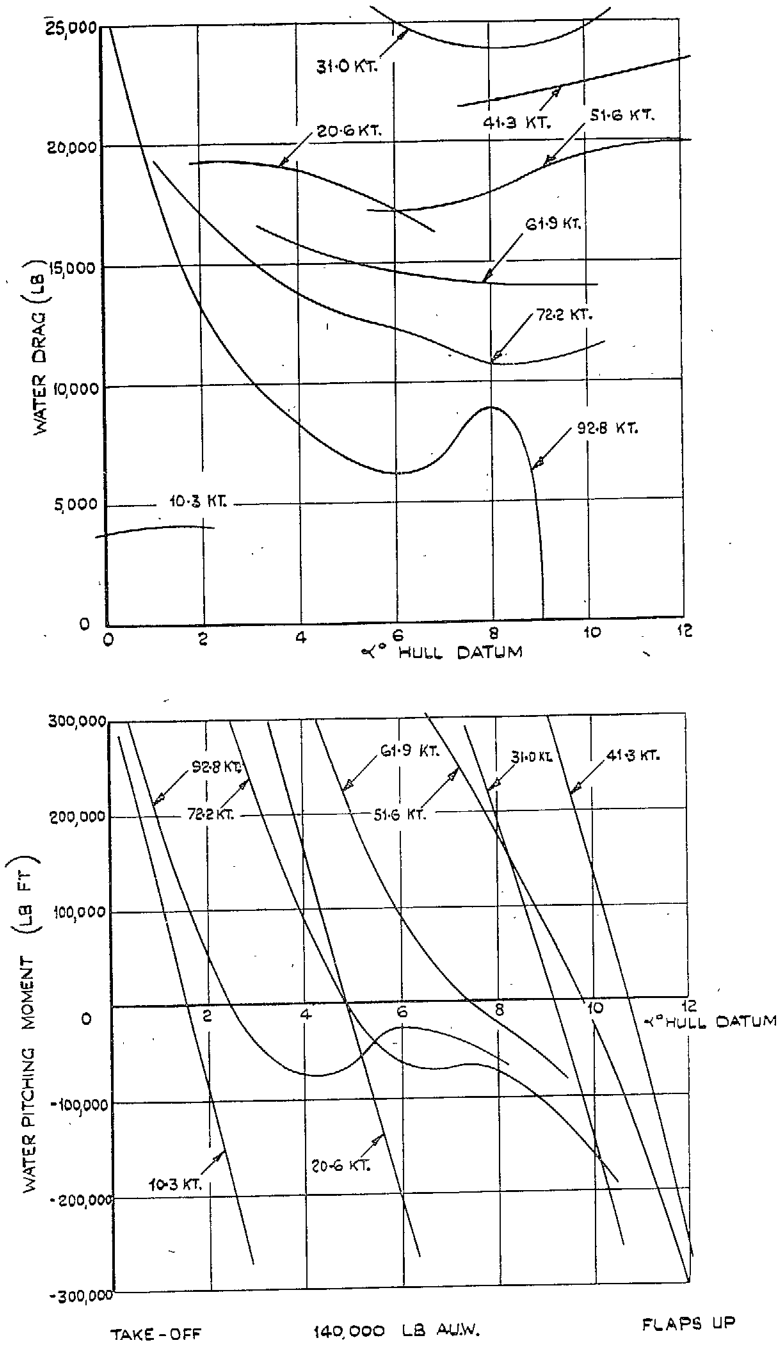


FIG. 36. Water drags and pitching moments. Final experimental hull. Step fully faired

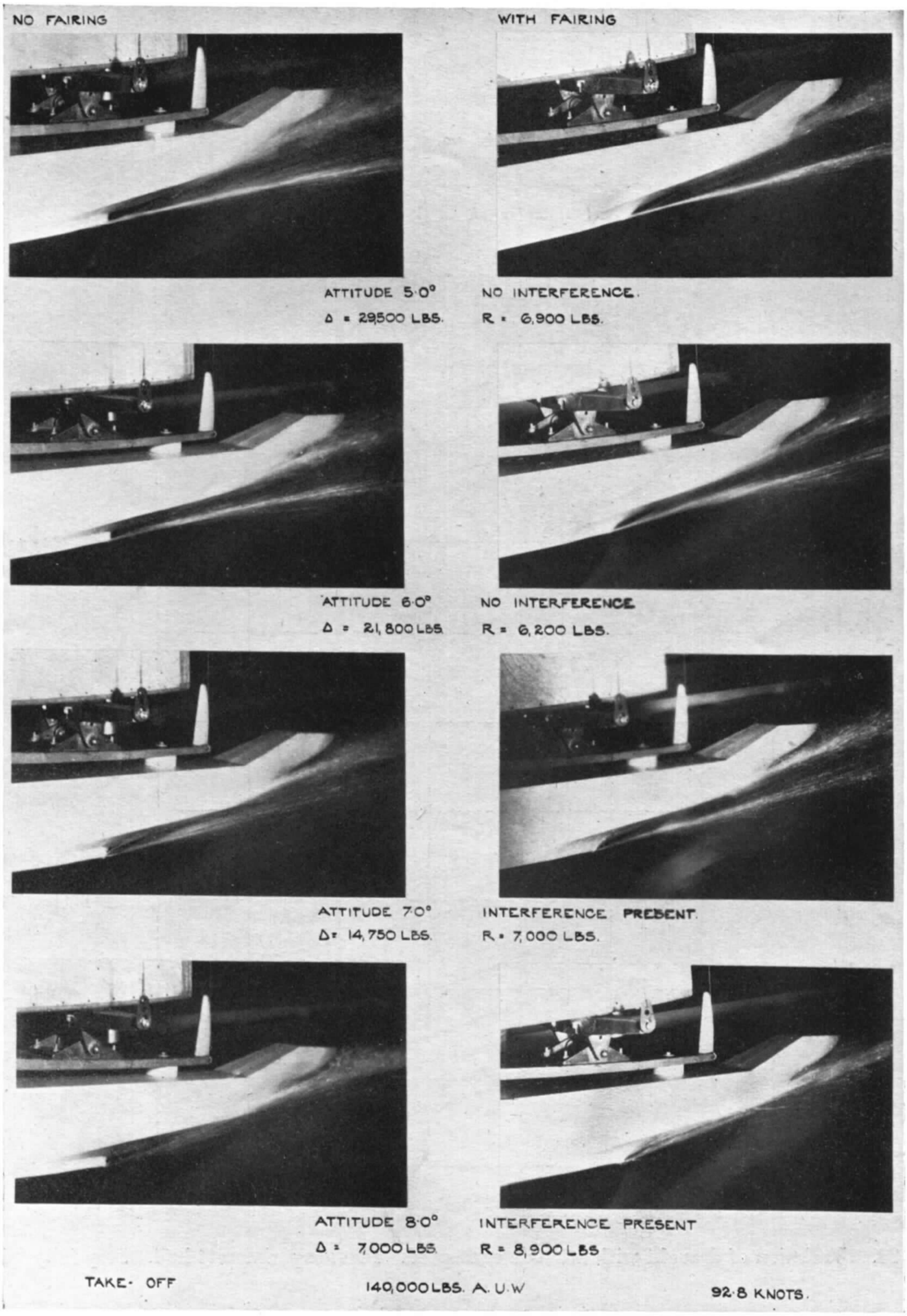


FIG. 37. Effect of step fairing in elevation on afterbody interference

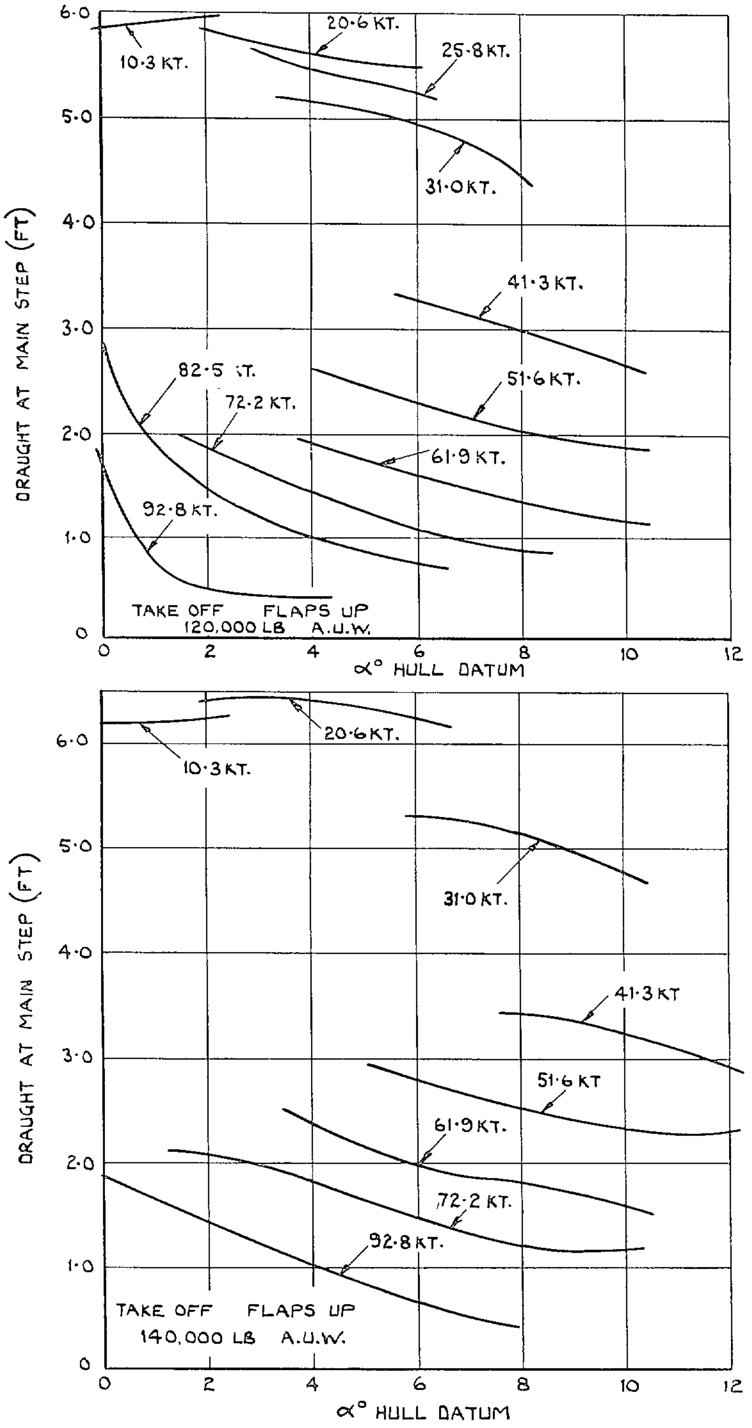


FIG. 38. Variation of draught with attitude and speed. Final experimental hull. Step fully faired

(98580) Wt. 15/680 K.5 1/52 Hw.

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