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Tank Tests on a Jet-Propelled Boat-Seaplane Fighter (Saunders-Roe E6/44)

By

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Summary.—Investigations into porpoising stability, water resistance, and seaworthiness have been made on the hull design of the E6/44. The original lines were unsatisfactory for seaworthiness and porpoising stability at overload and modifications to improve these qualities have been made. Results on the final lines indicate that porpoising stability should be adequate at all loads up to the design overload, and take-off time should be well within the specified limit. Seaworthiness tests show that the limiting condition for satisfactory operation at normal load is a 2-ft sea. The hump spray is severe and due to likelihood of damage, full advantage of flaps may not be gained unless a preselector control be used.

1. *Introduction.*—Tank tests were required to provide data for the design and development of the Saunders-Roe jet-propelled boat-seaplane fighter. The prototype hulls were to be conventional, developed from the firm's S.37 lines and the Shetland lines, with a straight Vee-step of included angle 120 deg, faired in elevation. Eventually a step faired in plan-form was to be considered.

This report describes the development of the hull lines with the straight Vee-step, and includes the results of porpoising stability, resistance, and seaworthiness tests.

2. *Description of Aircraft.*—The E6/44 is a single-seat high-wing boat-seaplane fighter designed to operate from sheltered waters. The hull lines are conventional. The wing-tip floats retract sideways and upwards, rotating as they retract, to form a streamlined shape on the underside of the wing. Propulsion is by two Metropolitan-Vickers F2/4 jet-turbine units housed in the hull. There is a single entry duct at the nose, and a jet exit projects from either side of the hull in the form of an underslung trunk at each wing root. The cabin is pressurised for operation to 40,000 ft. Provision is made for droptanks or bombs to be stowed externally under the wing. Fig. 1 shows a general arrangement of the aircraft and Tables 1 and 2 give the leading particulars.

3. *Porpoising Stability.*—The E6/44 loading during take-off at overload has been scaled up on a basis of the same beam to compare with the Shetland at its overload (Fig. 4). Beyond the hump speed, the waterborne load of the E6/44 is comparatively higher, and its take-off speed is appreciably higher. Associated with more severe loadings on most existing flying boats is a deterioration in porpoising stability. It is, therefore, to be expected that to attain the same degree of stability as existing boats, more exacting design will be required.

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It has been suggested[1] that porpoising which would be dangerous on a large boat may be controllable on a small one, and hence a smaller stability range may be accepted for a boat such as the E6/44, but full-scale tests[2] made at a later date indicate that this may not be the case. Evidence[3] on certain models shows that stability can be greatly influenced by the airflow round the afterbody, and in view of the unusual superstructure lines near the step, the possible adverse effects of the jet exhaust stream at the wing roots, and the high take-off and landing speeds, it was decided to develop lines which gave a large stable range. The hull, therefore, was required to be satisfactory for porpoising stability under the severe disturbance conditions outlined in Ref. 4.

3.1. *Choice of Scales and Description of Models.*—The take-off speed of the flying boat is of the order of 90 to 100 kt, and to cover the whole take-off range, the largest model that could be used was $\frac{1}{15}$-th scale, giving a beam of 5·46 in. and a scale normal loading weight of 4·5 lb. This was considered objectionably small for satisfactory development work, and a $\frac{1}{9}$-th scale model was also made on which the major part of the work was done. This model could be tested to a maximum speed corresponding to 72 kt.

The $\frac{1}{9}$-th scale model was made in balsa wood following the usual method of construction, except that the planing bottom was made detachable so that different types could be tested on the same superstructure. The internal duct passages were represented, and the compressed air supply normally used for driving the turbines for propellers was fed in and exhausted through the jet exit ducts. This also induced a certain flow of air through the intake duct. Only about 35 per cent of the scale thrust was obtained, but the resulting air flow was considered sufficient to provide a good indication of the effect of the jet exhaust stream on spray and porpoising stability.

The required weight of the $\frac{1}{15}$-th scale model ballasted to the correct c.g. was 3·3 lb to represent the landing case, so the construction was made as light as possible. The air was exhausted at the jet exits as on the $\frac{1}{9}$-th scale model but the intake duct was not represented. True scale thrust was obtained and speeds corresponding to take-off at normal load could be represented.

3.2. *Experimental Method.*—The wing-tip method of towing was adopted, and measurements of the air-lift were first made with the models held just clear of the water. The stalling angles were considerably lower than those anticipated full scale, and as preliminary experiments indicated that provision of the correct lift and stalling angle had an important bearing on stability, wing leading-edge slats were fitted to each model to bring its stalling characteristics nearer to the estimated full-scale values. Fig. 5 shows the lift curves obtained for the two models.

The c.g. positions for light landing load, normal load, and over-load are 19·76 ft, 19·34 ft, and 19·47 ft from the forward perpendicular respectively. The model c.g. position was fixed at a position corresponding to 19·50 ft from the forward perpendicular, the travel being considered small enough to be neglected.

The applied disturbances were in general of the order of 6 deg to 8 deg nose down. At fine angles of trim this was not always possible, but the disturbances were such that the keel attitude was lowered to 0 deg instantaneously.

The effect of the jet exhaust stream was found to be reasonably small on the original form, and in general tended to make the boat more stable. For convenience, a hull stable in the absence of the exhaust was developed, and the effects studied in detail on the final lines.

3.3. *Stability, Original Lines.*—Fig. 2 gives the lines and offsets of the original form tested on the dynamic models, and Table 1 gives the leading dimensions. Fig. 6 shows stability pictures obtained on the $\frac{1}{9}$-th scale dynamic model for Δ_0 15,200 lb and Δ_0 17,250 lb with 50 deg flaps, no jet thrust being applied in either case. In both cases the hump attitude is high, as was expected from the geometry of the boat and the high loading, but there is a tendency to stick at a high attitude beyond the hump, and even at 70 kt the trim is high at 8 deg. The weight of spray encountered at the delayed hump is sufficient to render the use of 50 deg flaps impossible, and the danger of damage at smaller flap angles likely.

At the lighter load the lower limit of stability is reasonable, and although the upper limit is low just beyond the hump speed, it may be considered acceptable at that weight provided the stability from 70 kt to take-off is good. At the higher load, however, the stability limits close down completely beyond the hump speed from 40 to 50 kt, and modifications to improve this were made.

3.4. *Modifications.*—Table 3 contains a complete list of the modifications which were made in consultation with the firm until the final lines were achieved. Increasing the afterkeel angle to 9 deg was sufficient to extend the stable range to give adequate stability at overload. When modifications to improve running cleanliness were made mild instability at the hump occurred. Wind-tunnel tests showed that the tailplane area and arm had to be increased for aerodynamic stability, and fitting the revised tail unit cured this mild porpoising. The stability was very sensitive to the type of fairing used, and tests showed that a cove depth 14 to 15 per cent of the unfaired step depth was needed to give the necessary discontinuity to break away the flow, and a 3 : 1 fairing was the largest that could be accepted without introducing patter near take-off. The provision of this step fairing will give little improvement in air drag but will relieve the structural problem of a sudden discontinuity of an unfaired step. This problem would be serious on this flying boat where to get adequate stability an unfaired step depth of 11 per cent of b has been used.

3.5. *Stability, Final Lines.*—Tests were made on both the $\frac{1}{9}$-th and the $\frac{1}{15}$-th scale models with the final lines, as follows :

(1) Take-off at normal load, 15,200 lb : flaps 33 deg and flaps up.

(2) Take-off at overload, 17,250 lb. : flaps 33 deg and flaps up.

(3) Landing at normal load, 15,200 lb : flaps 33 deg and flaps up.

(4) Landing at light load, 11,200 lb : flaps 75 deg and flaps up.

From these tests the effect on stability of model scale, flap setting, all-up-weight, and jet thrust could be studied.

3.5.1. *Take-off at normal load,* 15,200 *lb.*—The normal flap setting for take-off is 33 deg and Fig. 7 shows the stability diagram for this condition. The free-to-trim curve shows that the sticking at the hump has been eliminated and the boat trims down well so that the high attitude is of short duration. There is a difference in hump attitude between the two models which may be due to the fact that total scale thrust was obtained on the $\frac{1}{15}$-th scale model only. The lower limit of stability is good, although rather high at the hump, possibly due to the forward c.g. position relative to the step and the weak afterbody. On the $\frac{1}{9}$-th scale model there is no evidence of the upper limit, and on the $\frac{1}{15}$-th scale model there is an isolated unstable point. In neither case is there any patter at the high-speed high-attitude condition. Above 60 kt both models show a sharp increase of attitude with a small increase of speed at a constant stick-back elevator setting but this can be controlled by a small change of elevator angle.

Fig. 8 shows the corresponding stability diagrams for a take-off flaps up. The lower limit is raised in the planing region due to the higher load on water, and is about one degree higher at 70 kt, but the $\frac{1}{15}$-th scale model confirms that there is adequate stability right up to take-off. The hump attitude is higher, and the $\frac{1}{15}$-scale model shows a region of mild instability from 20 to 40 knots which is not confirmed on the $\frac{1}{9}$-th scale model.

3.5.2.—*Take-off at overload,* 17,250 *lb.*—Fig. 9 shows the stability diagrams for take-off at the normal flap setting of 33 deg. The $\frac{1}{9}$-th scale model results show that the hump trim is almost 1 deg higher than at normal load, and there is a tendency to stick at a high attitude at 35 kt. Above 40 kt, however, the boat trims forward well. The lower limit at the hump is no worse than at normal load, but is about 1 deg higher in the mid-planing range. The $\frac{1}{15}$-th scale model test confirms that there is adequate stability from 70 kt until take-off but shows a closing down of the stability limits between 30 and 40 kt. The same tendency to increase trim sharply above 60 kt is present as at the normal load.

For the flaps up take-off (Fig. 10) there is an increase in hump trim and deterioration in lower limit stability at the hump, otherwise the stability is much the same as that with flaps.

3.5.3. *Landing case at* 15,200 *lb.*—Fig. 11 shows the stability for landing with a flap setting of 33 deg. and no jet thrust applied. The hump trim for both models is the same and there is good agreement between the free-to-trim curves throughout the speed range. The lower limit is good, although it approaches close to the free-to-trim just after touchdown. There is evidence of the upper limit just above the hump speed on the $\frac{1}{15}$-th scale model, but it vanishes at high speed. The trimming up at high attitudes is present in this case above a speed of 60 kt, indicating that the cause is not the jet exhaust stream, although this appears to intensify it.

A landing case with flaps up is shown in Fig. 12. The $\frac{1}{15}$-th scale model shows a deterioration in stability at the hump, and an isolated point on the upper limit where pattering occurred, otherwise the diagrams are much the same as those with flaps.

3.5.4. *Landing case at light load,* 11,200 lb.—Fig. 13 shows the stability diagram obtained on the $\frac{1}{9}$-th scale model with flaps at the landing setting of 75 deg. There is a wide stable range at all speeds. Fig. 14 shows the corresponding condition with flaps up and shows the stability to be good.

4. *Resistance and Pitching Moments.*—Measurements of water drag for take-off were required to see whether the E6/44 would meet the specification which calls for a take-off time at normal load not exceeding 25 sec.

4.1. *Description of Model.*—This model was made in hardwood to $\frac{1}{12}$-th scale. The scale was chosen to give as high a testing speed as possible while still maintaining a large enough beam to minimise scale effect at the hump. The planing surface was not finished with clear varnish, but treated with 'Phenoglaze', this being a suitable surface for application of a chemical indicator to determine the boundary-layer conditions of the model. Generalised check tests on the hull of the $\frac{1}{9}$-th scale dynamic model indicated that the effect of this change of surface finish on the measured forces was small.

4.2. *Experimental Method.*—Tests were made with the model screened from air flow. The estimated air lift curves for determining load-on-water are shown in Fig. 15. The following conditions were chosen to show the effect of flap setting and all-up-weight on take-off:

(1) Take-off at normal load, 15,200 lb. Flaps at take-off setting 33 deg.

(2) Take-off at normal load, 15,200 lb. Flaps up.

(3) Take-off at overload, 17,250 lb. Flaps at take-off setting 33 deg.

4.3. *Results.*—Full results are given in Table 4, and drag and pitching moments are plotted against attitude for different speeds in Figs. 17 to 19. The thrust curve and estimates of air drag for computing take-off times and distances are given in Fig. 16. The trim curves used for take-off calculations were those obtained in corresponding tests on the $\frac{1}{15}$-th scale dynamic model, with elevators neutral for the first part of the run, and the hull attitude held to 6 deg and 8 deg for the latter part of the run where elevator control was available. Figs. 20 to 22 show these curves with water drags cross-plotted from Figs. 17 to 19 and air drags from Fig. 16 to give the total drag against speed for a take-off run. Table 5 gives details of the calculated times and distances.

5. *Seaworthiness.*—In studying the seaworthiness of a flying boat it is convenient to consider it during three different conditions on the water; at rest or low speed, the displacement region; during transition from displacement to planing flow, the hump region; and planing on the fore-body, the planing region.

5.1. *Displacement Region*.—In this region the characteristic bow wave is determined by the forebody design[5]. In the past, the criterion has been adequate spray clearance for the propellers and unobscured vision from spray thrown near the windscreen under rough water conditions. On this boat, no undue amount of spray must enter the intake duct.

Preliminary tests on a resistance model showed that the original forebody did not give adequate spray clearance and the firm decided to redesign the bows before a dynamic model was tested. The most promising modification to make was to increase the forebody length, and at the same time increase the sharpness of the bow to give finer entry conditions. This was done by adopting a cruiser-type bow which gave increased forebody buoyancy and higher static trim.

5.1.1. *Bow spray tests*.—Tests were made on the $\frac{1}{9}$-th scale dynamic model at the normal loading of 15,200 lb with jet flow represented. With the present wave-making apparatus it is only possible to represent a regular swell, the smallest length/height ratio being of the order of 15 : 1.

Tests were made in swells corresponding to wave heights of 18 in., 24 in. and 30 in. at wave length/height ratios of 16 : 1 and 20 : 1 which should adequately cover the most severe conditions. encountered in sheltered water operation. Tests were also made with a deflector fitted to the intake duct projecting forwards 12 in. full scale. Full results are given in Table 6.

5.2. *Hump Region*.—In this region the types of spray to be considered are the main spray, consisting of blister and lateral spray, and the roach[6]. Heavy blister spray is likely to damage flaps and the wing trailing edge, also the leading edge of the tailplane, while the other two types do not normally cause damage.

5.2.1. *Hump spray on original lines*.—The original lines were tested with a flap angle of 50 deg for take-off. At the free-to-trim attitude shown in Fig. 6 the blister hits the flaps very hard over a speed range of 20 to 30 kt and damage would certainly occur full scale. The lateral spray hits the trailing edge near the wing-tip fairly hard.

5.2.2. *Modifications to improve hump spray*.—The leading parameters determining main spray characteristics are load-on-water, forebody deadrise angle, beam at the main step, and trim attitude, while the forebody flare may affect the lateral spray to a certain extent. Load-on-water at any speed depends on the static loading and wing characteristics. At the hump speed the wing lift is small and trim variation over an extreme range only alters the load-on-water on this boat by about 3 per cent, hence load-on-water may be considered a non-variable for modification purposes. The forebody deadrise angle is fixed by a compromise, a low deadrise for resistance and lower limit porpoising stability, and a high deadrise for impact and spray characteristics. The two major factors for modification purposes are therefore trim attitude, and beam at the main step.

It was desirable to test whether any advantage gained in decreasing trim would be lost due to the blister leaving the chine nearer the bows, so that although the overall blister height was less, the local height at the flaps and wing trailing edge remained the same. At the hump speed the elevators are not powerful enough to affect the attitude, hence the hull lines had to be altered to test this effect. Modifications made to reduce the hump interference and subsequent running attitudes were (A) to raise the afterkeel angle to improve afterbody ventilation (B) to increase the afterbody length, and (C) to lower the afterkeel angle to 6 deg. All had little or no effect and (B) and (C) had an adverse effect on stability.

Increase in beam is effective so long as there is full chine immersion. It was increased until the hump beam loading coefficient was comparable with that of the Shetland. The spray was slightly less severe, but the delayed hump condition was still present and the spray severity still considered unacceptable.

Finally, the main step was moved aft, and although the hump trim was high, the boat trimmed forward very well with no signs of a delayed hump. The main blister still caught the flaps at the hump, but at a lower speed than previously and over a very small range, with reduction in likelihood of damage.

Spray clearances covering normal and overload cases with flaps at the take-off setting, and flaps up on the final lines are given in Figs. 23 and 24. Flap clearances for different settings on landing at normal and light load are compared in Fig. 25.

5.3. *Planing Region.*—In this region the main blister has travelled far enough aft to be clear of the wing and flaps. Before the mid-planing region is reached the blister may be high enough to hit the tailplane leading edge, and impact of heavy spray has been known to cause damage on existing boats[7]. As the speed further increases the blister height becomes less. When there is no longer full chine immersion the blister and lateral spray leave the main step under the afterbody, and dependent on the air flow conditions and clearances may be thrown clear, or may cling to the afterbody causing wetting and increased drag. This in itself does not affect seaworthiness but it was important to find the effect of the jet exhaust stream on the interference and whether the spray was thrown up over the tailplane.

5.3.1. *Spray in the planing region, final lines.*—The tailplane is clear of the main spray blister in the mid-planing range at all loads except at conditions representing stick well back. Then the blister breaks over the tailplane tips.

With no jet exhaust stream represented, and elevators neutral there is no afterbody wetting, but above 60 kt with the stick held back there is evidence of interference (Figs. 11, 12, 13, 14 and 26). With the jet thrust applied the region of the interference is much the same as in the landing cases, but when it occurs it is more severe and with the stick right back, loose spray is thrown over the tail-plane. The spray should not, however, be severe enough to cause damage.

6. *Discussion.*—The porpoising stability at all loads tested on the $\frac{1}{5}$-th scale model is good based on seaplane tank standards. The lower limit of stability at the hump is high, and may be due to the aft position of the step necessary for seaworthiness or to the weak afterbody, but in all cases it is below the free-to-trim attitude. At high speed the lower limit is very good. The upper limit of stability could not be reached in any of the tests. The $\frac{1}{15}$-th scale model was made primarily for verification of stability beyond 70 kt, and shows this to be adequate at all loads. Full stability diagrams were obtained at each test condition on this model for investigation of scale effect on trim and stability. The two scale models are only directly comparable in the landing cases because of the different jet thrust values used in take-off cases. Comparison shows there is good agreement of both trim and stability in the planning range, and of trim at the hump speed, but at this speed the stability of the $\frac{1}{15}$-th scale model is less. This difference is probably due to a scale effect on the air damping forces. It seems reasonable to assume that the hump instability shown in the take off cases is due to the same effect, and not to the difference in jet thrust of the two models.

The E6/44 hull has good lift and drag characteristics compared with contemporary flying boats. Some interference between the air and water flow occurs under the afterbody at high attitudes above 60 kt on dynamic model tests. This is encountered during take-off or landing if the stick is held much aft of central. Drag and pitching moments have been measured on a screened resistance model, the present technique. This assumes[8] that, for a stable hull, closer agreement with full scale is obtained than with an unscreened model because interference effects should be small full scale. If, however, interference effects are intensified full scale on this boat due to the jet exhaust stream, take-off times and distances estimated with the boat trimmed up for the take-off will tend to be optimistic. Resistance model tests also show that at high speed there is small or zero rate of change of hydrodynamic pitching moment at constant speed over a considerable attitude range (Figs. 17, 18 and 19). This condition will be met full scale provided interference effects are small, and response to stick movement, therefore, will be of the same order as in flight.

If interference is present full scale, then the dynamic model tests may give a closer indication of elevator efficiency. Above 60 kt interference on this model occurs with the stick aft of central (Fig. 26), when there is a sharp increase of attitude at constant elevator setting with small increase of speed (Figs. 7 to 14). Progressive elevator movement should be sufficient to hold the desired attitude until take-off, or there would be sufficient control available to trim to a lower attitude below the interference region. It will be necessary to avoid abrupt or excessive stick back movements to avoid a pull-off, but on the other hand, sensitive control is available for rough water take-off and landing at high speeds.

There is as yet no definition or requirement set out for sheltered water operation, but tests show that at normal load the E6/44 should be capable of operation in a 2-ft sea, and this should cover the most severe condition. The limitation at low speeds is due more to the pitching to the swell than the intake clearance from spray. Above 12 kt the intake is clear in heavier seas. The hump spray is heavy and in take-off at overload with flaps at take-off setting 33 deg damage may occur. Landing tests indicate that 33 deg flaps is the maximum safe setting for a load of 15,200 lb and 75 deg will probably be satisfactory at 11,200 lb. It is recommended that pre-selector and quick action flap control be used and the flaps be retracted in the hump region.

7. *Conclusions*.—(1) Porpoising stability should be adequate at all loads up to the design overload. The lower limit at the hump is rather high, but is below the free-to-trim attitude.

(2) The boat should take-off well within the specified time of 25 sec at normal load.

(3) The limiting sea condition for satisfactory operation, when water enters the intake duct in the bow, occurs at low taxi-ing speeds. At normal load this is a 2-ft sea. Above 12 kt the duct is clear in heavier seas. The main spray is severe and may limit the flap setting in take-off at overload, and in landing above 11,200 lb unless pre-selector and quick action flap control be used. The tailplane is unlikely to be damaged by spray.

Symbols and Definitions

b	Maximum beam of planing bottom (ft)
Δ_0	Static load on water (lb)
Δ	Load on water (lb)
V	Velocity (ft/sec)
V_s	Stalling speed (kt)
w	Density of sea-water (64 lb/cu ft)
C_Δ	Beam loading coefficient (Δ/wb^3)
η	Elevator angle (deg)
Afterkeel angle	The angle between the forebody keel at the main step and the afterbody keel.
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 of the planing bottom to the horizontal at the keel, on a section normal to the keel datum.
Overall deadrise angle	The angle between the horizontal and the line joining the keel and chine, on a section normal to the keel datum.

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TABLE 1

Leading Particulars of Flying Boat

	Original form	Final form
Hull		
Maximum beam (b)	6·50 ft	6·83 ft
Forebody length	21·83 ft = 3·36b	22·75 ft = 3·33b
Afterbody length	19·75 ft = 3·04b	18·83 ft = 2·76b
Counter length	6·36 ft = 0·98b	8·42 ft = 1·23b
Afterkeel angle	7° 45′	8° 28′
Heel-to-heel angle	9° 30′	10° 40′
Forebody deadrise angle at step	25° 0′	25° 0′
Forebody overall deadrise angle	21° 30′	21° 30′
Afterbody deadrise angle	30° 0′	30° 0′
Step depth unfaired	7·29 in. = 9·35 per cent b	9·00 in. = 10·98 per cent b
Cove depth		1·30 in. = 1·59 per cent b
Fairing		3 : 1
Wing		
Span	46·0 ft	
Gross area	415·0 sq ft	
Root chord	140·0 in.	
Tip chord	66·0 in.	
Taper ratio	0·47	
Aspect ratio	5·1	
S.M.C.	108·36 in.	
Sweepback	3·0 deg	
Section	Goldstein Modified	
T/C ratio	14 to 11 per cent	
Dihedral (at 0·35c) top surface	0 deg	
Setting (to hull datum)	4·5 deg	
Flap setting. Take-off	33 deg	
Landing at minimum weight	75 deg	
Flap area	27·0 sq ft	
Flap span per cent of wing span	30·5	
Tailplane		
Horizontal tail area	81·60 sq ft	
Gross elevator area	30·00 sq ft	
Span	16·0 ft	
Root chord	86·0 in.	
Tip chord	43·5 in.	
Aspect ratio	3·2	
Setting (to hull datum)	2·5 deg	
C.G. Position		
Above hull base line	6·5 ft	
Range aft of F.P.	19·34 to 19·76 ft	
Range per cent S.M.C.	26·8 to 31·4 per cent	
Power Unit		
2 Metropolitan-Vickers	F2/4 units	
Static thrust for take-off	2 × 3,500 lb	

TABLE 2

Loading Data used for Model Tests

Loading Condition	All-up-weight lb	$C_{\Delta 0}$	Wing loading lb/sq ft
Empty (landing)	11,200	0·550	27·0
Normal operating	15,200	0·745	36·6
Overload (max.)	17,250	0·845	41·6

TABLE 3

List of Modifications

Modification	Nature of Modification	Effects of Modification
A	Afterkeel angle raised from 7° 45′ to 9° 0′.	Hump stability good even at overload. Trim slightly better at high speed. Hump trim 1 deg higher, delayed hump still present.
B	Afterbody lengthened 3 ft and chine faired to new length.	No improvement in hump trim. Upper limit deteriorated badly at 65 kt. Pattering.
C	Afterbody reduced to original length and afterkeel angle reduced to 6 deg.	This mod. was to observe effect of lower hump attitude on hump spray rather than an attempt at a stable form. Little effect on spray observed.
D	Afterkeel angle raised to 8° 15′.	This mod, was not tested, but used as stepping off point for modifications to reduce hump spray. Stability should be adequate with this afterkeel angle.
E	Maximum beam raised to 7 ft full scale.	Peak of hump earlier. Improvement in running angle and spray beyond hump but interference still present.
F	Chine flare reduced by filling in with Plasticine between straight portion and chine line to make weaker chine radius.	No improvement. Hump trim worse. Delayed hump worse than Mod. A.
G	Step moved back 1 ft 6 in. in Plasticine.	Radical change in trim curve. Hump trim 16 deg but all signs of delayed hump removed.
H	Step moved forward 9 in. on Mod. G.	Hump trim 14 deg. Interference showing beyond peak of hump.
I	Step moved back $4\frac{1}{2}$ in. on Mod. H, *i.e.*, 1 ft $1\frac{1}{4}$ in. backward from original form.	Hump trim 14 deg, little or no interference. Trim at high speed good, 6 deg at 70 kt. No upper limit found. Lower limit good.
J	5 : 1 fairing with cove depth constant at $\frac{1}{2}$ in. full scale added.	Pattered badly at 70 kt upper limit down to 7 deg.
K	Fairing straightened to give increase in cove depth at chine flare.	Patter still present but better than Mod. J.
L	4 : 1 fairing, constant cove depth $\frac{1}{2}$ in. full scale.	Pattered badly at 70 kt.

TABLE 3—*continued*

Modification	Nature of Modification	Effects of Modification
M	3 : 1 fairing not following forebody chine flare. 1·35 in. cove at keel local increase in cove depth at chine.	No pattering at 70 kt. No sign of upper limit.
N	Deadrise at rear step 20 deg for 1 beam forward increased to 30 deg in $\frac{3}{4}$ beam.	This was an effort to lower the hump trim, but instability showed itself at 35 kt.
O	Deadrise at rear step as original form, cove depth reduced on Mod. M.	Evidence of patter though not always easy to produce.
P	Beam reduced to offsets provided by firm. Max. beam 6 ft 10 in.	Trim slightly higher at hump, only just stable at 35 kt.
Q	All Plasticine mods. replaced to give permanent and accurate lines to those of Mod. I.	Lower limit rose to 13$\frac{1}{2}$ deg between 35 to 40 kt. Very mild porpoising.
R	Detachable fairing in wood to that of Mod. M added.	Unstable band 30 to 40 kt pattering badly to 7 deg at 70 kt.
S	Heel-to-heel angle made equal to that of Mod. I. Afterkeel angle becomes 8° 28′. No fairing.	Unstable band persisted.
T	Step moved forward 2$\frac{1}{2}$ in. full scale. No fairing.	No effect.
U	Tailplane size and arm increased to conform with latest position. No fairing.	Stability completely restored.
V	Fairing 3 : 1 at keel and 5 : 1 at chine, cove depth 1·35 in. added to Mod. U.	Pattered at 70 kt.
W	As Mod. V but with ellipses instead of radii.	Pattered at 70 kt.
X	3 : 1 keel and chine 1·35 in. cove depth.	Stability good.
Y	Fairing adjusted to firm's offsets.	Stability good.

TABLE 4

Resistance Test Results

Speed (kt)	Attitude to hull datum (deg)	Load on water (lb)			Drag (water) (lb)			Pitching moment (lb/ft)			Draft (in.)		
		15,200 lb 0° flaps	15,200 lb 33° flaps	17,250 lb 33° flaps	15,200 lb 0° flaps	15,200 lb 33° flaps	17,250 lb 33° flaps	15,200 lb 0° flaps	15,200 lb 33° flaps	17,250 lb 33° flaps	15,200 lb 0° flaps	15,200 lb 33° flaps	17,250 lb 33° flaps
8·2	0		15,040	17,160		1,060	1,150		49,900	56,700		33·8	37·2
	2		14,680	16,980		1,110	1,150		27,600	32,100		35·2	37·4
	4		14,680	16,810		1,150	1,100		4,700	8,300		36·7	38·3
	6		14,510	16,630		1,290	1,060		−18,000	−20,600		37·2	39·0
	8		14,330	16,450		1,330	1,010		−48,600	−52,000		37·4	39·0
16·4	2	14,860	14,680	16,810	4,510	4,640	5,660	77,900	65,800	76,200	37·1	35·9	38·3
	4	14,680	14,510	16,630	4,510	4,490	5,480	50,500	50,300	53,500	37·1	36·4	38·8
	6	14,330	14,150	16,270	3,060	2,990	3,430	43,300	41,400	46,300	37·0	34·7	38·0
	8	14,150	13,800	15,920	2,720	2,740	3,010	12,700	11,900	15,300	34·4	33·8	35·6
	10	13,980	13,620	15,740	2,570	2,480	2,830	−16,800	−16,600	−14,000	33·0	32·3	34·1
	12	13,880	13,440	15,570	2,570	2,530	2,800	−38,600	−37,200	−36,100	31·0	29·0	32·2
20·5	4		14,330			3,930			83,200			34·7	
	6	13,980	13,980		3,730	3,500		80,300	66,900		34·2	33·6	
	8	13,800	13,620	15,740	3,310	3,200	3,660	63,900	51,200	53,500	33·4	32·0	34·7
	10	13,440	13,280	15,390	2,970	2,990	3,340	39,900	33,500	34,000	31·1	31·2	33·0
	12	13,270	13,090	15,210	3,060	2,920	3,310	16,600	8,500	9,800	27·8	26·5	30·1
	14	13,090	13,910	15,040	3,270	3,080	3,470	−11,000	−18,900	−13,000	25·2	23·7	27·1
	16	12,910	12,740	14,860	3,470	3,340	3,660	−40,000	−45,700	−38,600	22·2	21·2	24·2
24·6	8	13,440	13,270	15,390	2,810	2,780	3,500	76,200	76,700	98,500	27·2	27·1	29·9
	10	13,090	12,910	15,040	2,740	2,780	3,170	48,200	50,500	61,200	25·6	25·8	28·1
	12	12,910	12,740	14,860	2,990	3,010	3,340	25,500	23,400	35,200	21·8	22·3	25·4
	14	12,740	12,560	14,680	3,310	3,080	3,820	2,300	2,300	9,800	20·5	21·5	21·7
	16	12,740	12,380	14,510	3,820	3,540	4,120	−20,200	−21,700	−17,400	18·6	17·4	21·0
32·8	6	13,440	12,910	15,040	2,320	1,980	2,600	62,600	53,300	76,000	20·0	18·4	22·0
	8	12,910	12,560	14,680	2,140	2,140	2,370	28,200	20,600	35,000	17·5	15·2	17·8
	10	12,380	12,210	14,330	2,480	2,390	2,850	10,600	7,800	13,400	15·8	14·0	16·3
	12	12,210	11,850	13,980	2,810	2,830	3,130	2,100	− 1,300	2,300	14·9	13·3	15·4
	14	12,030	11,680	13,800	3,130	3,170	3,540	− 6,600	− 7,000	− 7,400	13·7	12·8	14·3
	16	12,210		13,800	3,490		3,840	−22,700		−22,900	13·8		14·0

TABLE 4—*continued*

Speed (kt)	Attitude to hull datum (deg)	Load on water (lb)			Drag (water) (lb)			Pitching moment (lb/ft)			Draft (in.)		
		15,200 lb 0° flaps	15,200 lb 33° flaps	17,250 lb 33° flaps	15,200 lb 0° flaps	15,200 lb 35° flaps	17,250 lb 35° flaps	15,200 lb 0° flaps	15,200 lb 33° flaps	17,250 lb 33° flaps	15,200 lb 0° flaps	15,200 lb 33° flaps	17,250 lb 33° flaps
41·0	6	12,740	12,030	14,150	1,840	1,800	1,890	24,600	20,200	28,700	14·3	12·7	14·4
	8	12,030	11,500	13,620	2,090	2,050	2,250	6,400	4,200	9,800	12·8	12·2	13·2
	10	11,500	11,140	13,270	2,320	2,390	2,550	− 2,100	− 3,200	400	11·6	11·4	12·6
	12	11,320	10,790	12,910	2,650	2,650	2,850	− 7,600	− 7,400	− 7,000	11·5	12·7	12·1
	14	11,320	10,610	12,740	3,060	2,900	3,260	−11,900	−11,710	−12,100	11·0	9·8	11·9
49·2	4	12,560	11,850	13,980	1,870	1,980	2,070	40,600	34,600	45,000	13·9	12·8	14·2
	6	11,850	10,970	13,090	1,770	1,730	2,160	11,300	8,900	12,300	12·5	10·8	12·2
	8	11,140	10,440	12,560	1,960	1,890	2,160	− 3,000	− 3,000	− 1,700	10·8	9·7	10·7
	10	10,440	9,910	12,030	2,140	2,050	2,320	− 8,500	− 8,900	− 8,700	10·2	9·0	10·3
	12	10,080	9,550	11,680	2,390	2,480	2,670	−13,600	−13,800	−13,800	9·5	8·4	10·0
	14		9,910	12,030		2,780	3,130		−15,100	−17,200		8·3	10·1
57·4	4	11,850	10,800	12,910	2,570	2,270	2,320	26,100	21,700	29,100	12·5	10·8	12·0
	6	10,970	9,730	11,850	1,880	1,730	1,980	4,200	1,100	4,000	10·6	9·4	10·0
	8	9,730	9,020	11,140	1,800	1,800	2,070	− 6,800	− 9,300	− 7,000	9·2	8·0	9·7
	10	8,670	8,310	10,440	1,730	1,980	2,230	−13,200	−13,200	−12,300	9·0	7·7	8·4
	12	8,310	7,960	10,080	2,230	2,140	2,490	−16,600	−14,900	−16,300	7·3	6·7	8·3
	14	8,670	8,310	10,440	2,650	2,740	2,850	−20,600	−21,000	−21,600	7·8	5·6	7·4
65·6	4	10,970	9,550	11,680	2,480	2,300	2,490	13,600	6,800	16,300	10·9	9·2	10·2
	6	9,730	8,310	10,440	1,800	1,800	1,980	0	− 5,900	− 5,100	8·8	7·8	8·8
	8	8,670	7,250	9,380	1,720	1,540	1,820	−10,600	−10,400	−11,500	8·0	6·8	7·1
	10	7,610	6,190	8,310	1,630	1,650	1,820	−13,200	−12,300	−15,500	6·6	4·2	6·7
	12	7,080	5,840	7,960	2,140	1,890	2,230	−16,300	−17,000	−19,100	6·1	5·6	6·1
	14		6,190			2,990			−30,600			5·8	
73·8	2	11,320	9,550		5,010	4,850		53,100	43,500		12·4	10·6	
	4	9,910	8,140	10,260	2,650	2,210	2,580	5,900	4,700	4,200	10·0	8·2	9·4
	6	8,490	6,550	8,670	1,560	1,650	1,650	− 8,700	− 9,600	− 8,500	8·2	5·5	7·9
	8	7,080	5,310	7,430	1,380	1,450	1,490	−11,500	−10,400	−11,000	5·5	3·6	6·7
	10	5,840	4,250	6,370	1,630	1,540	1,650	−14,000	−11,000	−14,000	5·4	4·1	5·5
	12	5,310	3,710	5,840	2,320	2,300	2,190	−19,700	−18,500	−17,000	4·9	4·4	5·3
	14		4,250	6,370		1,190	3,270		−67,700	−48,000		4·2	4·4
82·0	2	10,610	8,310	10,440		4,920		37,200	20,400	32,100	11·6	8·4	10·6
	4	8,850	6,550	8,670	2,320	1,890	2,320	− 3,400	− 5,300	− 3,200	8·0	6·7	7·7
	6	7,250	4,780	6,900	1,800	1,110	1,650	− 9,700	− 6,200	− 8,500	7·0	4·6	5·8
	8	5,480	3,180	5,310	1,560	1,200	1,490	−10,000	− 7,200	− 9,300	5·6	3·8	5·0
	10	4,070	2,120	5,130	1,730	1,540	1,700	−13,200	− 8,900	−14,200	5·8	2·8	4·4
	12	3,360	1,420	3,540	2,810	3,000	2,510	−22,900	−15,700	−21,900	4·6	1·9	3·7

TABLE 5

Take-off Times and Distances

All-up-weight (lb)	Flap setting (deg)	$C_{L\ max}$	Stalling speed V_s (kt)	Take-off speed/stalling speed		Take-off time sec		Take-off distance (yd)	
				Attitude 6 deg	Attitude 8 deg	Attitude 6 deg	Attitude 8 deg	Attitude 6 deg	Attitude 8 deg
15,200	33	1·31	90·5	1·12	1·04	19	17·5	540	475
15,200	0	1·12	98·0	1·18	1·07	22	19·5	710	580
17,250	33	1·31	96·5	1·12	1·04	25	23	760	660

TABLE 6

Seaworthiness in Waves. Jet Intake Clearance

Wave height in.	Wave length to height ratio	Speed (kt)			
		0	7·1	10·7	14·2
12	16	Well clear at all speeds			
18	16	Well clear at all speeds			
24	16	Waves breaking very near intake.	Clear.	Well clear.	Well clear.
30	16	Quite a lot of water through intake.	Large amount of water through intake.	Borderline case.	Clear.
	20	Quite a lot of water through intake.	Large amount of water through intake.	Small amount of water through intake.	Clear.
	20 1 ft deflector fitted to intake.	Some improvement on above.	Condition worse than above.	As above.	As above.

Note.—The limitation was generally due to the effect of pitching to the waves and taking in green water rather than entry of bow spray into the jet intake duct.

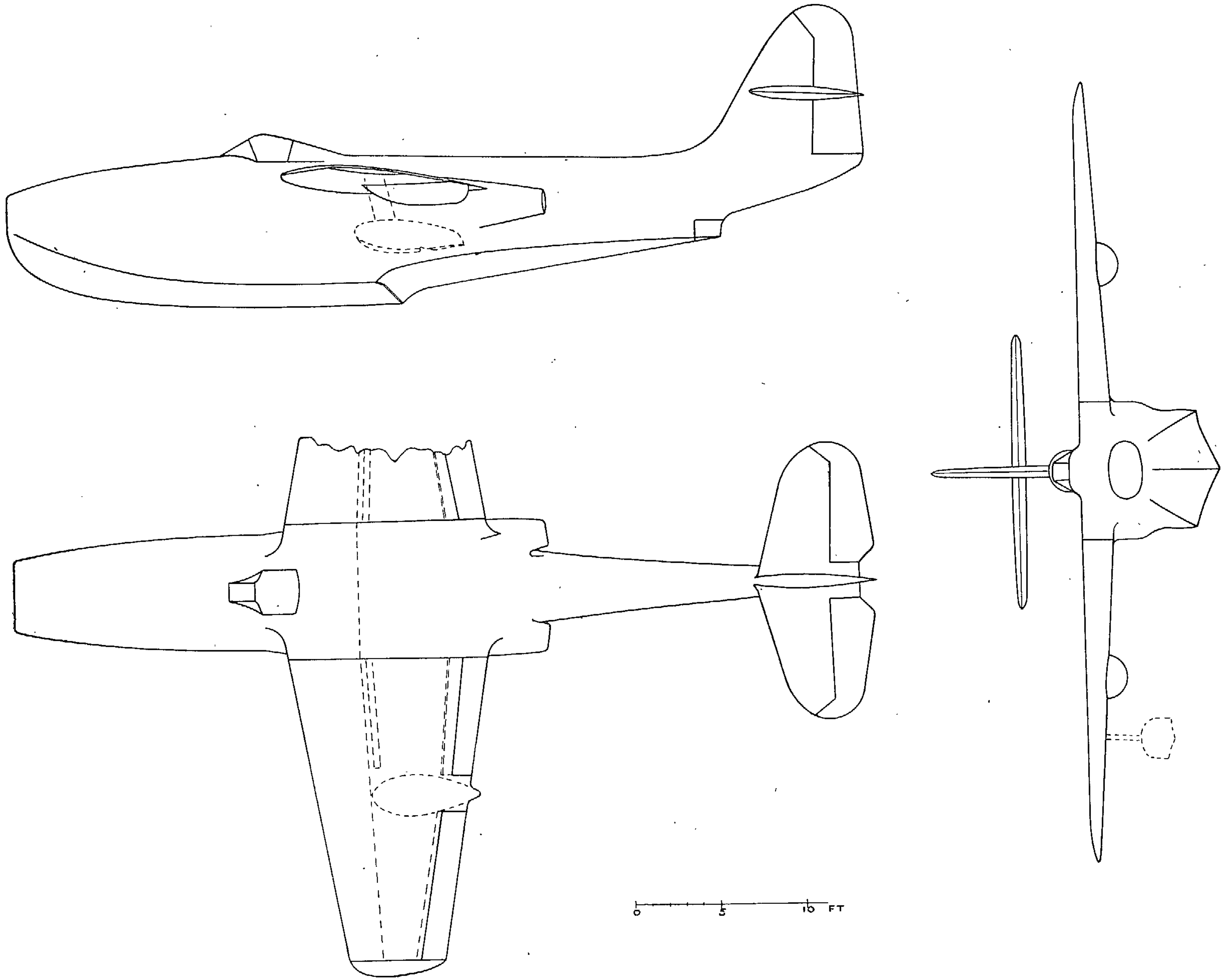
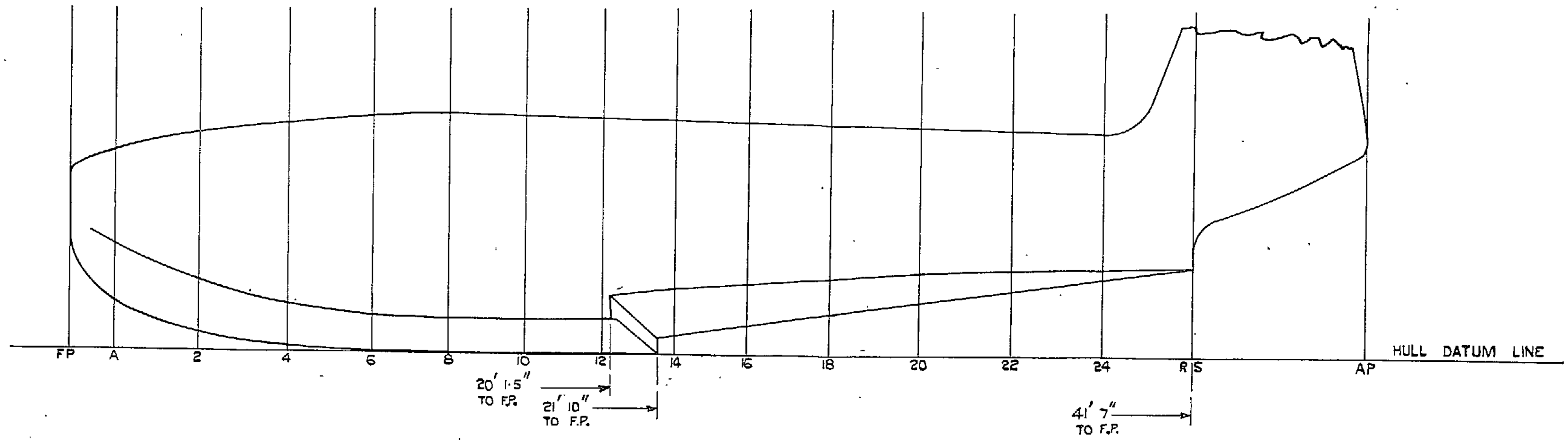
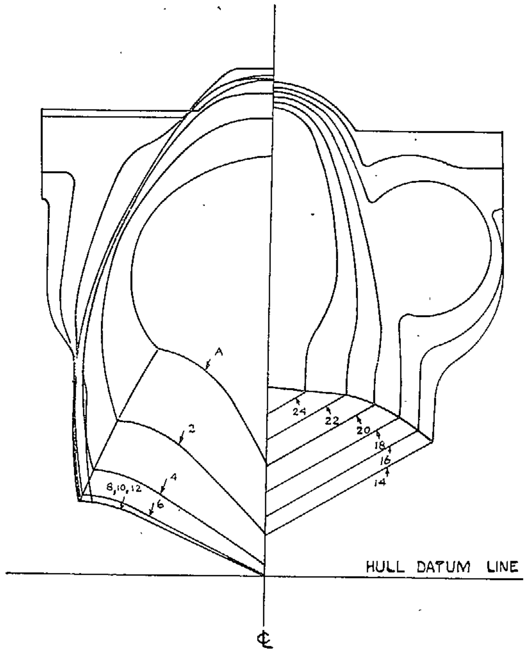


FIG. 1. E.6/44 general arrangement. Wing span 46 ft, overall length 50 ft.



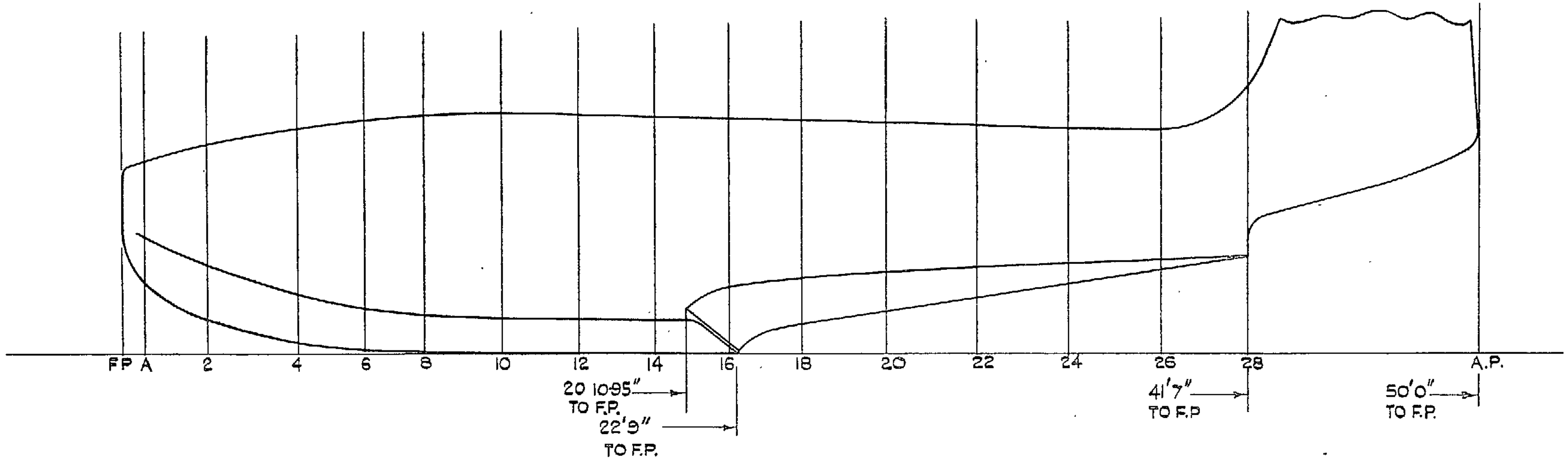


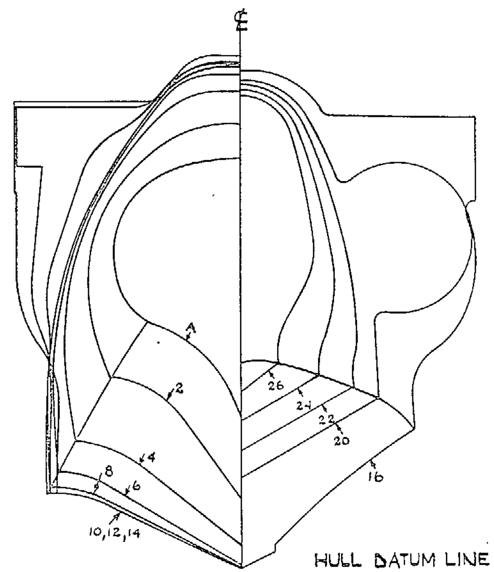
STATION Nº	DIST. FROM F.P.	KEEL HEIGHT	CHINE HEIGHT	BOTTOM PRODUCED TO 4′ 0″ LINE HEIGHT	CHINE HALF BREADTH	CHINE RADIUS	PROFILE HEIGHT	MAXIMUM BEAM HEIGHT	MAXIMUM BEAM HALF BREADTH
F.P.	0	—	—	—	—	—	—	—	—
A	19·5	23·15	46·40	111·50	23·00	23·45	88·21	59·50	22·99
2	57·5	8·70	32·00	58·30	31·40	20·28	95·99	51·35	31·77
4	97·0	2·50	21·80	32·80	36·30	26·38	101·02	42·80	37·27
6	135·0	0·30	16·55	23·55	38·55	28·25	104·60	37·00	38·50
8	169·0	0	15·45	22·38	39·00	28·50	106·23	34·00	40·00
10	203·0	0	15·41	22·38	38·00	28·50	104·65	33·15	39·80
12	237·2	0	15·21	22·38	35·85	28·50	104·25	33·95	37·80
14	269·0	8·50	28·80	—	34·80	—	103·50	35·90	35·10
16	300·52	12·50	31·05	—	31·90	—	102·70	38·90	32·00
18	337·5	17·55	33·75	—	28·00	—	101·65	43·95	28·10
20	377·0	23·05	36·30	—	22·80	—	100·55	50·45	23·65
22	418·0	28·70	38·05	—	16·35	—	99·45	58·38	18·85
24	459·0	34·30	38·55	—	7·50	—	98·30	67·15	14·30
R.S.	499·0	39·65	39·65	—	—	—	—	—	—

ALL DIMENSIONS IN TABLE GIVEN IN INCHES

FIG. 2. E6/44 original hull lines for dynamic model tests.

(98581)





FRAME Nº	DIST FROM F.P.	KEEL HEIGHT	CHINE HEIGHT	BOTTOM PRODUCED TO 4'0" LINE HEIGHT	CHINE HALF BREADTH	CHINE RADIUS	PROFILE HEIGHT	HALF FLAT AT DECK	DECK RADIUS	MAXIMUM BEAM HEIGHT	MAXIMUM BEAM HALF BREADTH
F.P.	0	—	—	—	—	—	—	—	—	66·25	—
A	9·5	31·79	50·93	140·20	19·83	—	85·17	0·38	36·08	64·84	26·89
2	37·5	14·50	39·27	80·51	27·61	21·72	92·40	2·12	25·40	58·79	32·31
4	78·0	4·80	26·27	42·07	35·11	27·23	98·97	4·49	17·19	46·62	37·16
6	108·0	1·49	19·99	28·82	38·55	35·53	102·39	5·52	13·19	38·02	39·48
8	135·0	0·21	16·75	23·59	40·29	38·29	104·60	5·91	10·64	31·71	40·81
10	169·0	0	15·44	22·38	41·00	38·53	106·23	6·00	8·85	25·40	41·33
12	203·0	0	15·43	22·38	40·50	38·53	105·35	4·41	13·77	20·38	40·62
14	237·2	0	15·35	22·38	39·00	38·53	104·41	3·16	16·99	16·57	39·00
16	269·0	0	29·31	36·12	36·20	—	103·53	2·29	17·69	29·31	36·20
18	300·8	—	—	—	—	—	—	—	—	—	—
20	337·5	18·59	35·17	46·30	28·72	—	101·65	0·70	16·26	40·00	28·84
22	377·0	24·45	37·88	52·17	23·25	—	100·56	0·13	14·86	49·40	24·10
24	418·0	30·55	39·99	58·26	16·35	—	99·43	—	13·05	58·90	19·41
26	459·0	36·65	41·05	64·36	7·63	—	98·30	—	11·05	68·15	15·37
28	499·0	42·60	42·60	—	0	—	—	—	—	—	—
A.P.	600·0	—	—	—	—	—	—	—	—	—	—

FIG. 3. Final hull lines developed by dynamic model tests.

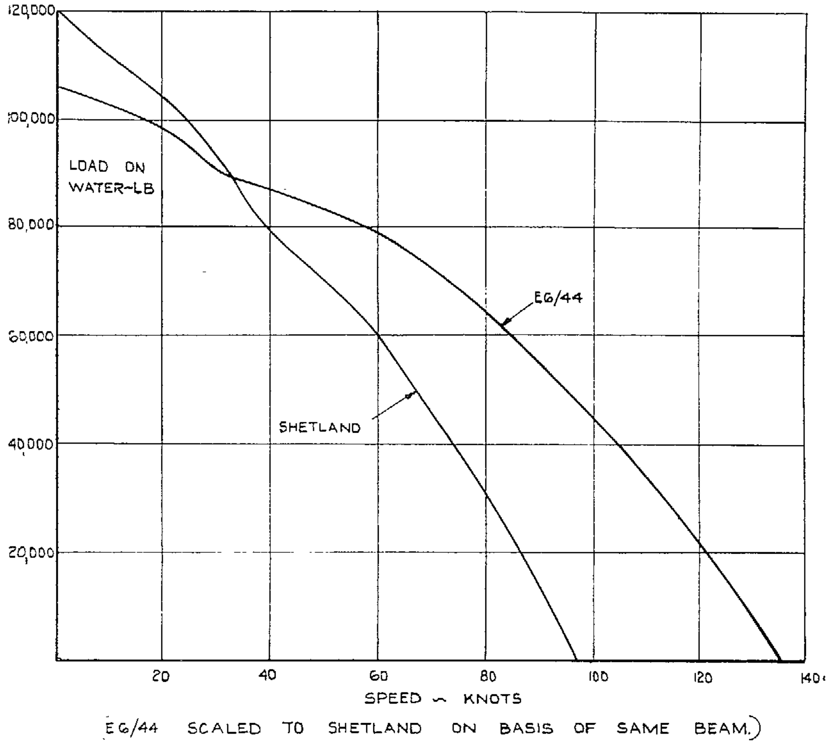


FIG. 4. E6/44 and Shetland.
Comparative loading during take-off at overload.

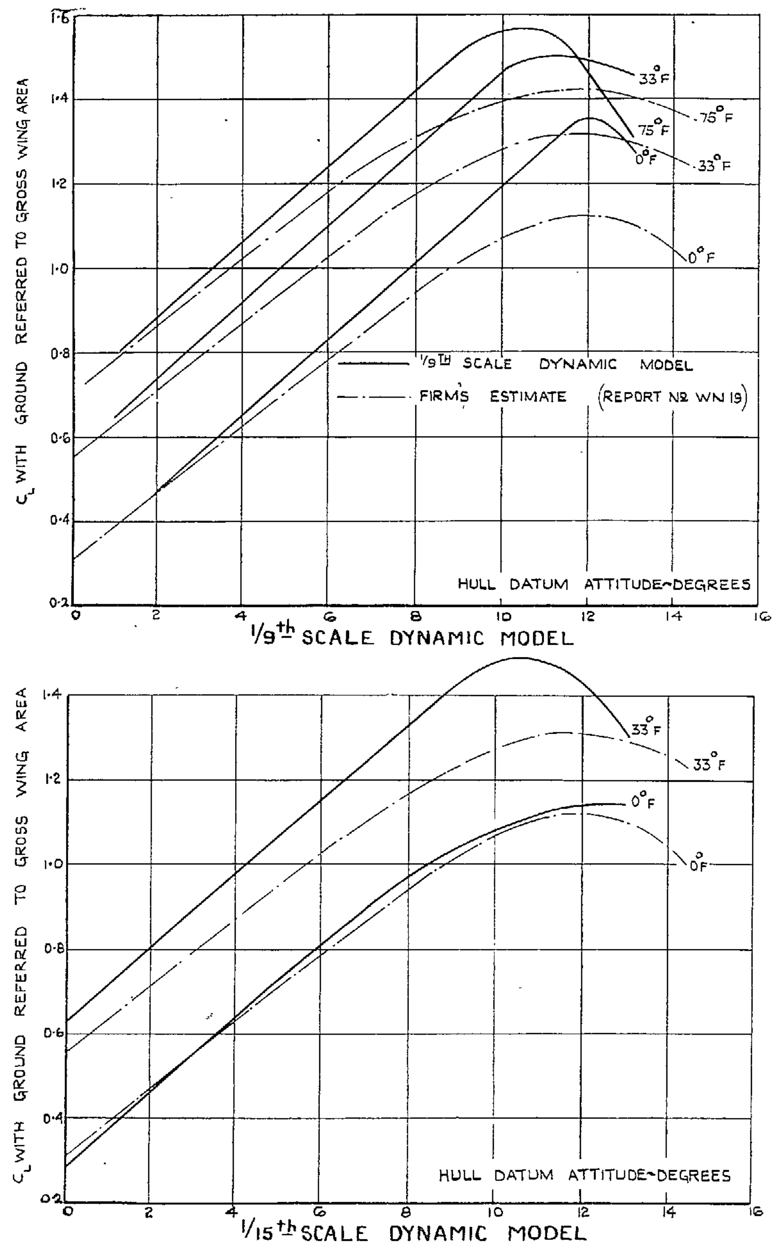


FIG. 5. Model lifts. Wing leading edge slats fitted.

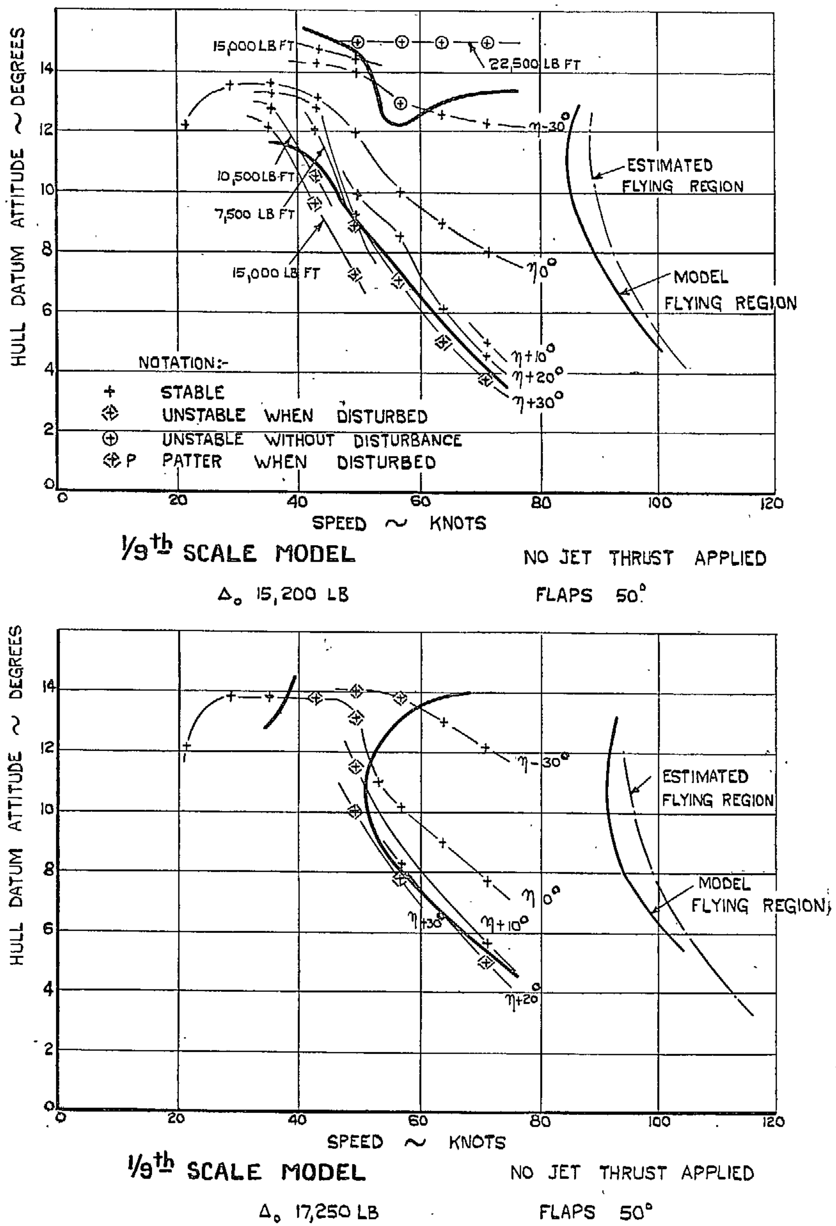


FIG. 6. Stability tests. Original lines.

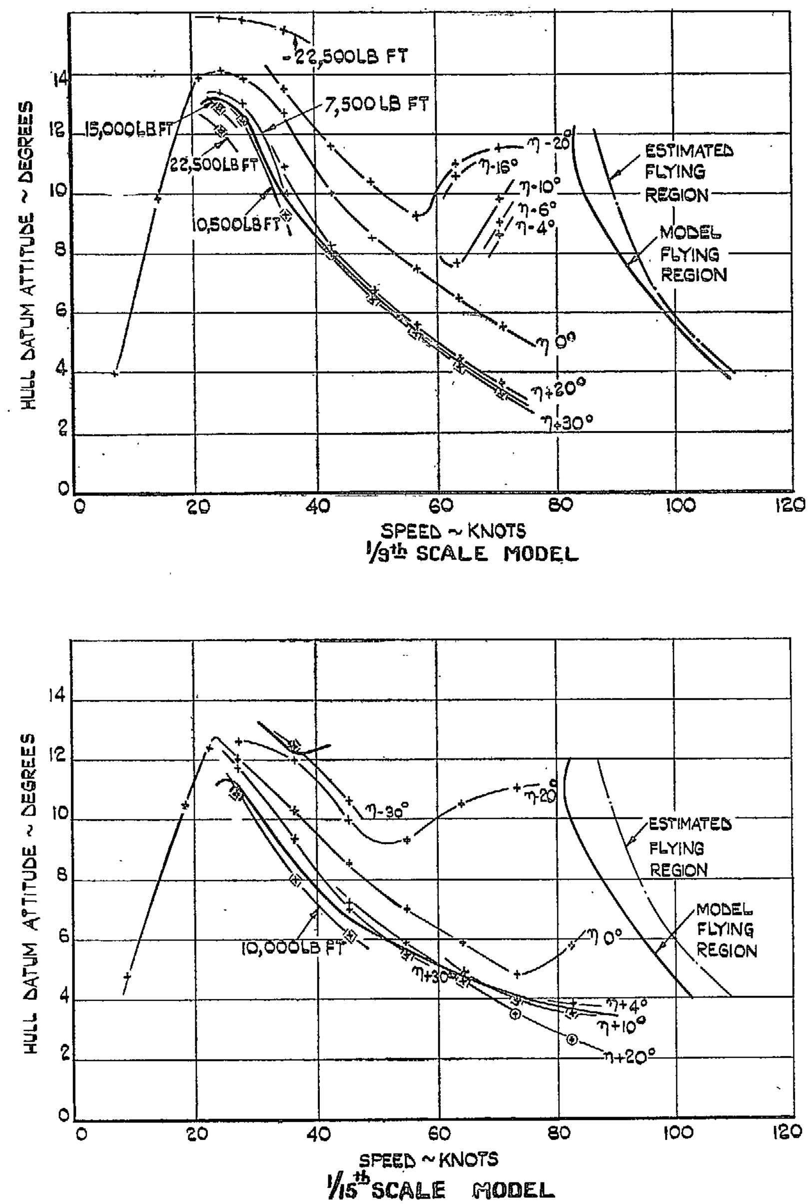


FIG. 7. Take-off at normal load 15,200 lb, flaps 33 deg. Stability tests. Final lines.

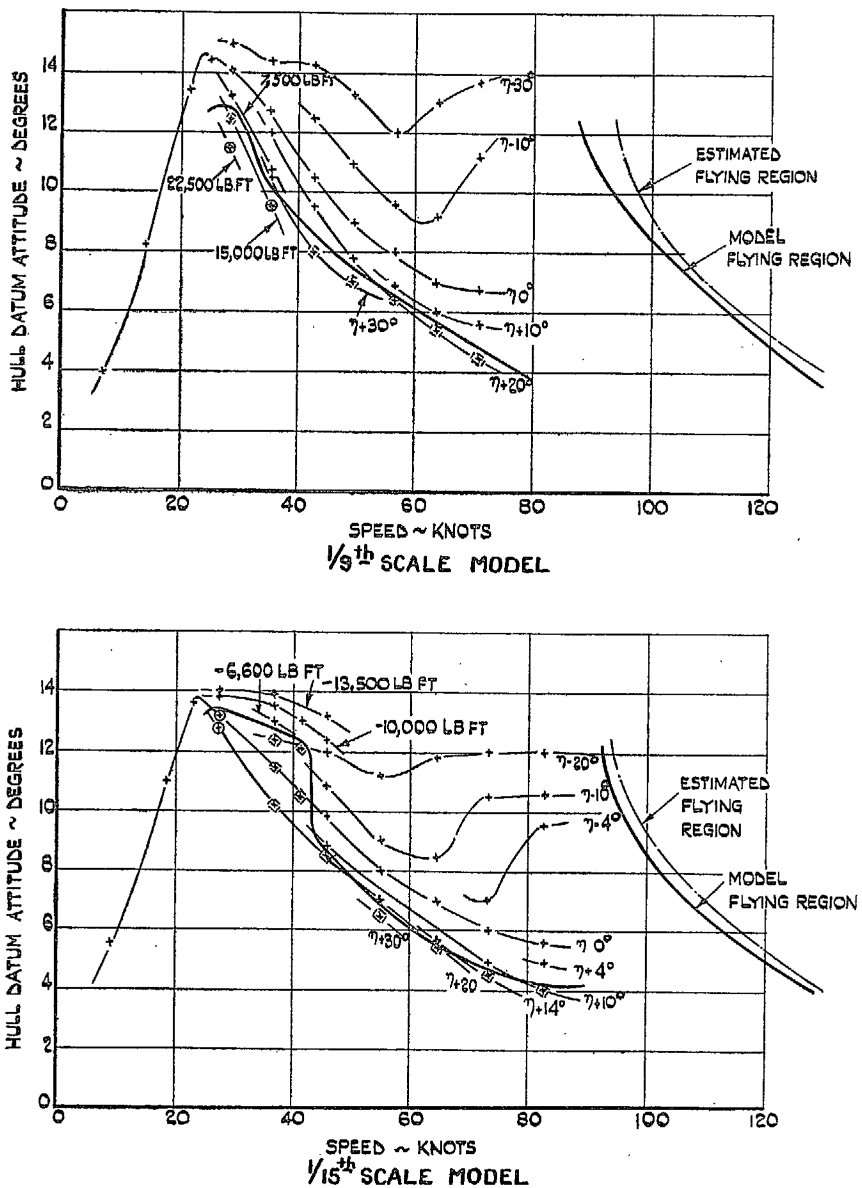


Fig. 8. Take-off at normal load 15,200 lb, flaps up.
Stability tests. Final lines.

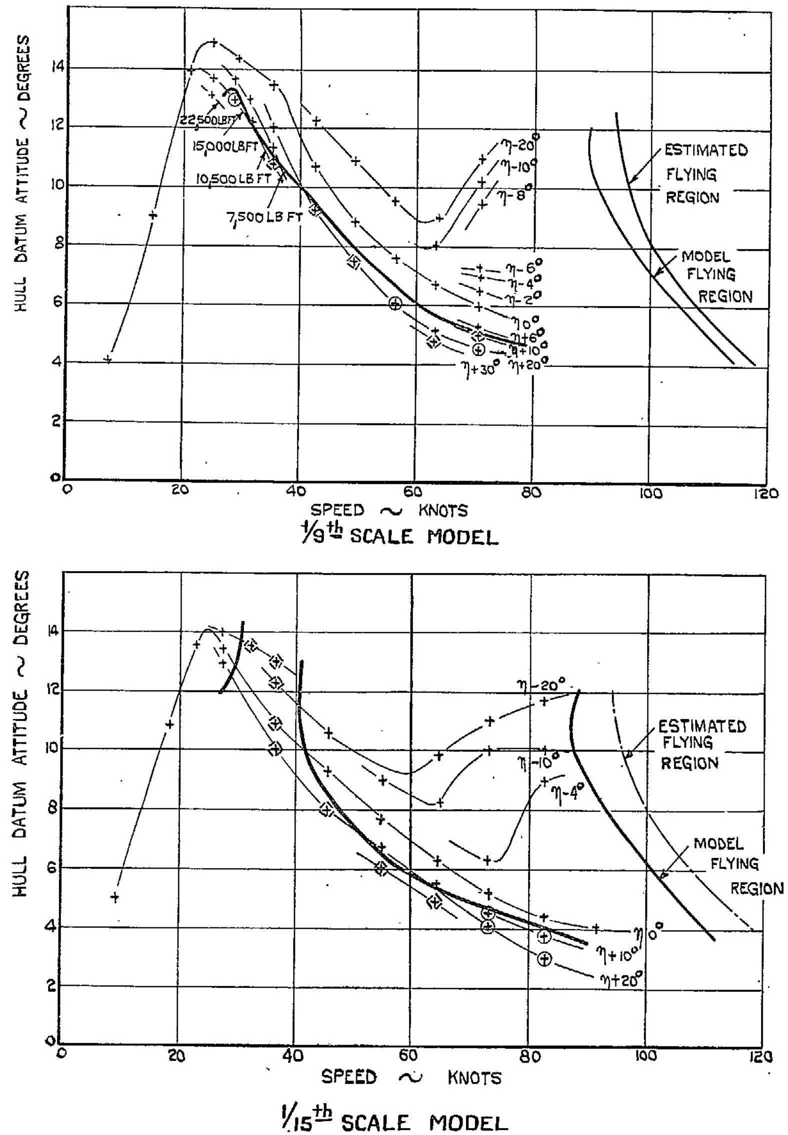


Fig. 9. Take-off at overload 17,250 lb, flaps 33 deg.
Stability tests. Final lines.

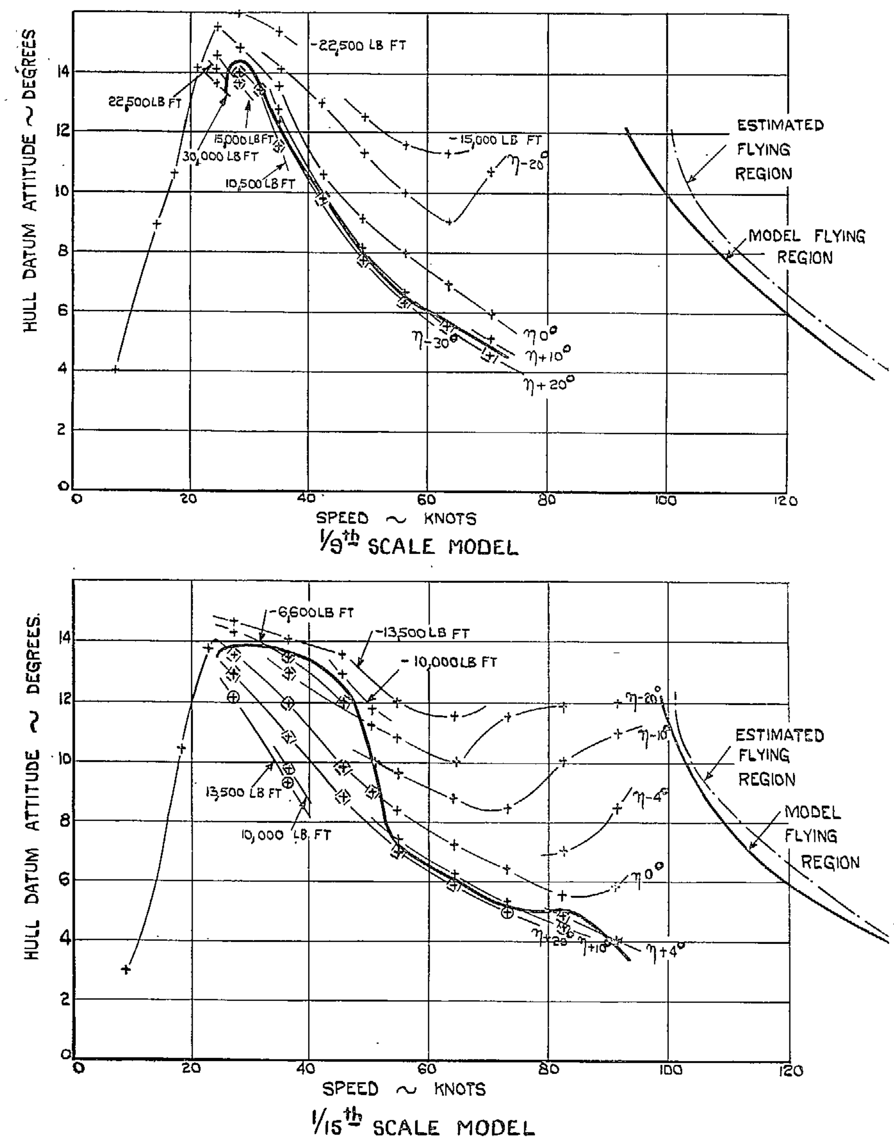


Fig. 10. Take-off at overload 17,250 lb, flaps up.
Stability tests. Final lines.

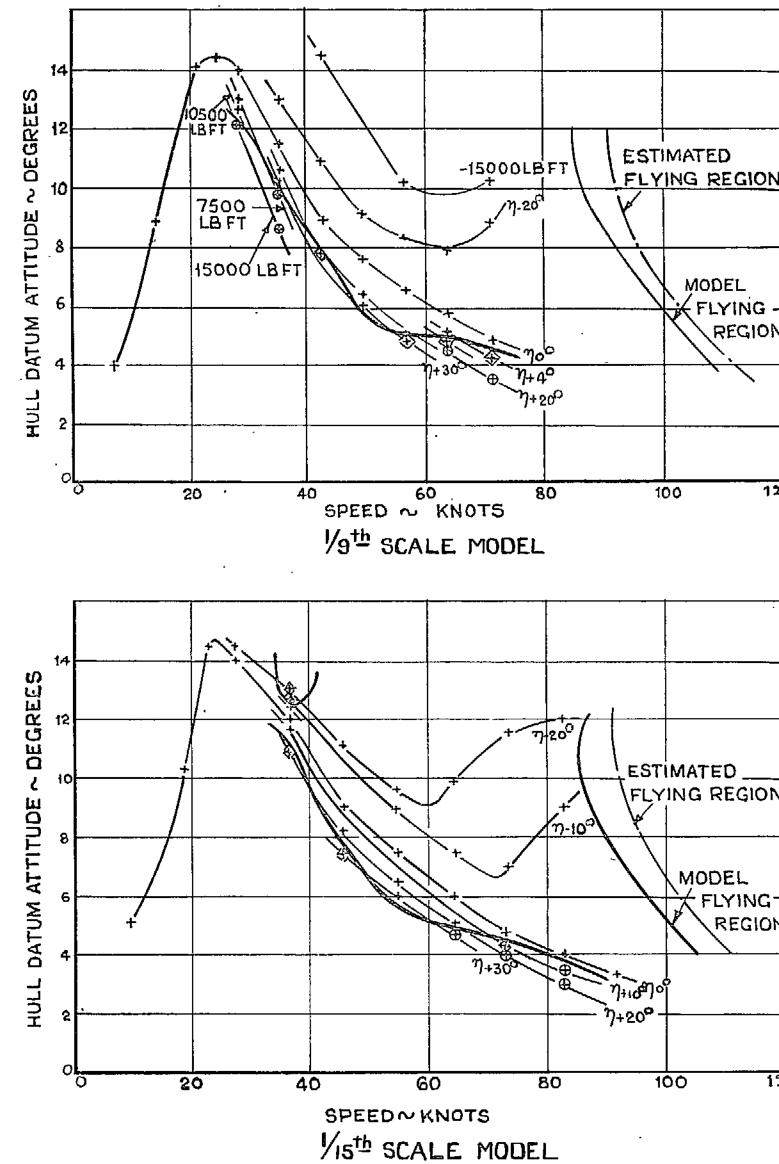


Fig. 11. Landing case at 15,200 lb, flaps 33 deg.
Stability tests. Final lines.

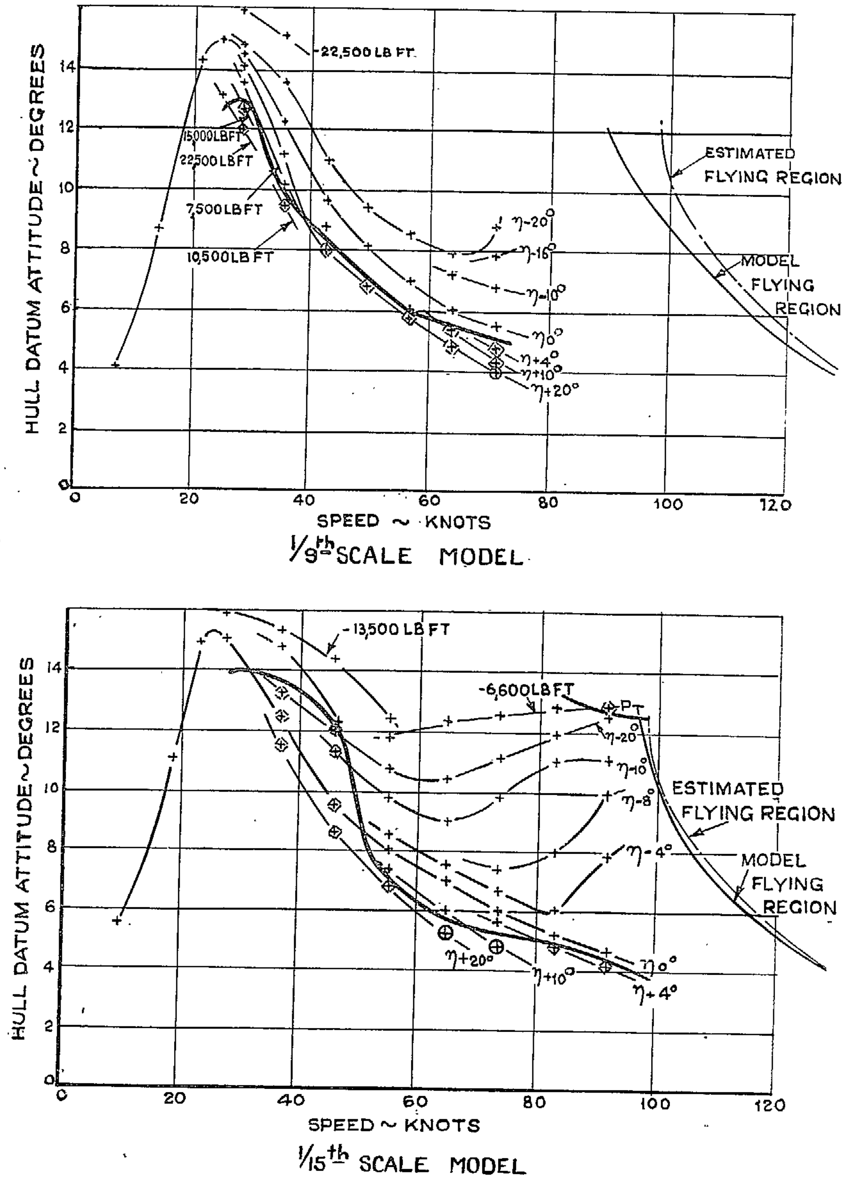


FIG. 12. Landing case at 15,200 lb, flaps up. Stability tests. Final lines.

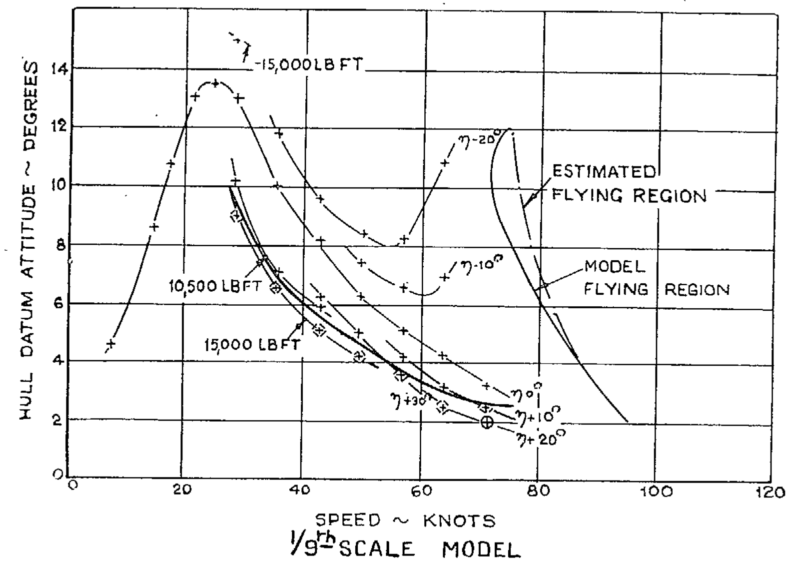


FIG. 13. Landing case at light load 11,200 lb, flaps 75 deg. Stability tests. Final lines.

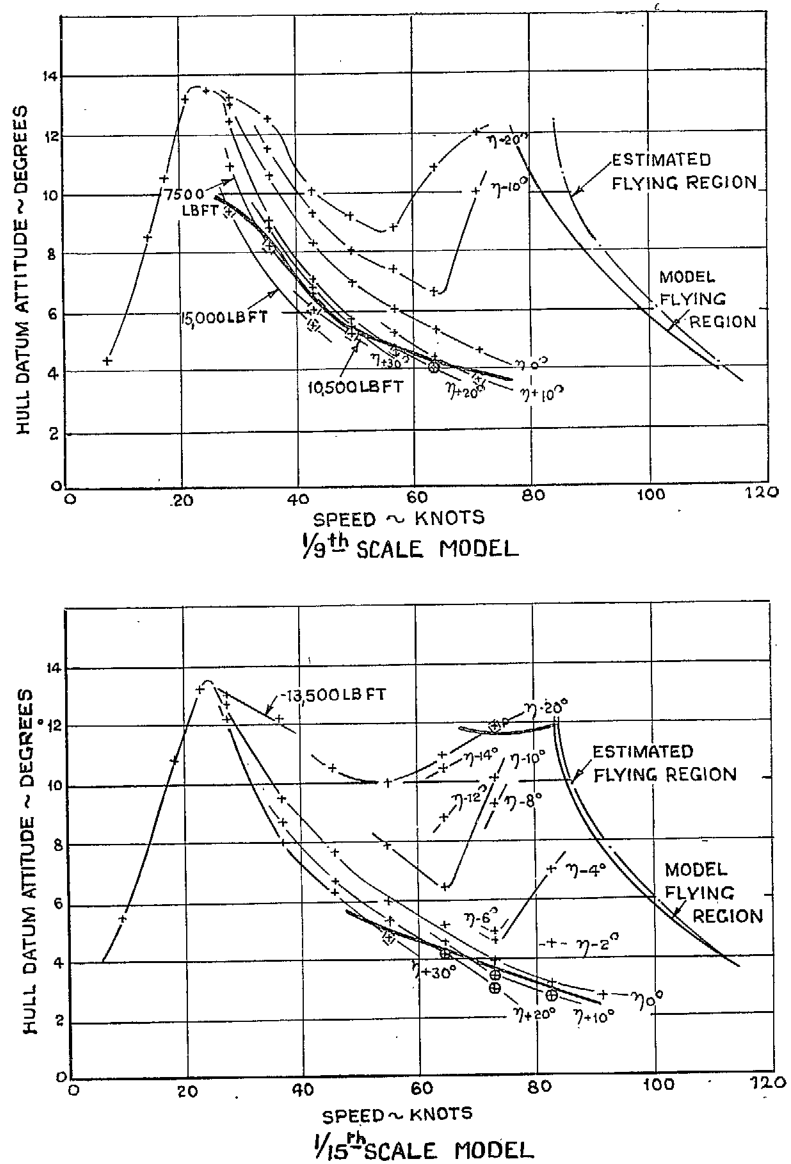


FIG. 14. Landing case at light load 11,200 lb, flaps up. Stability tests. Final lines.

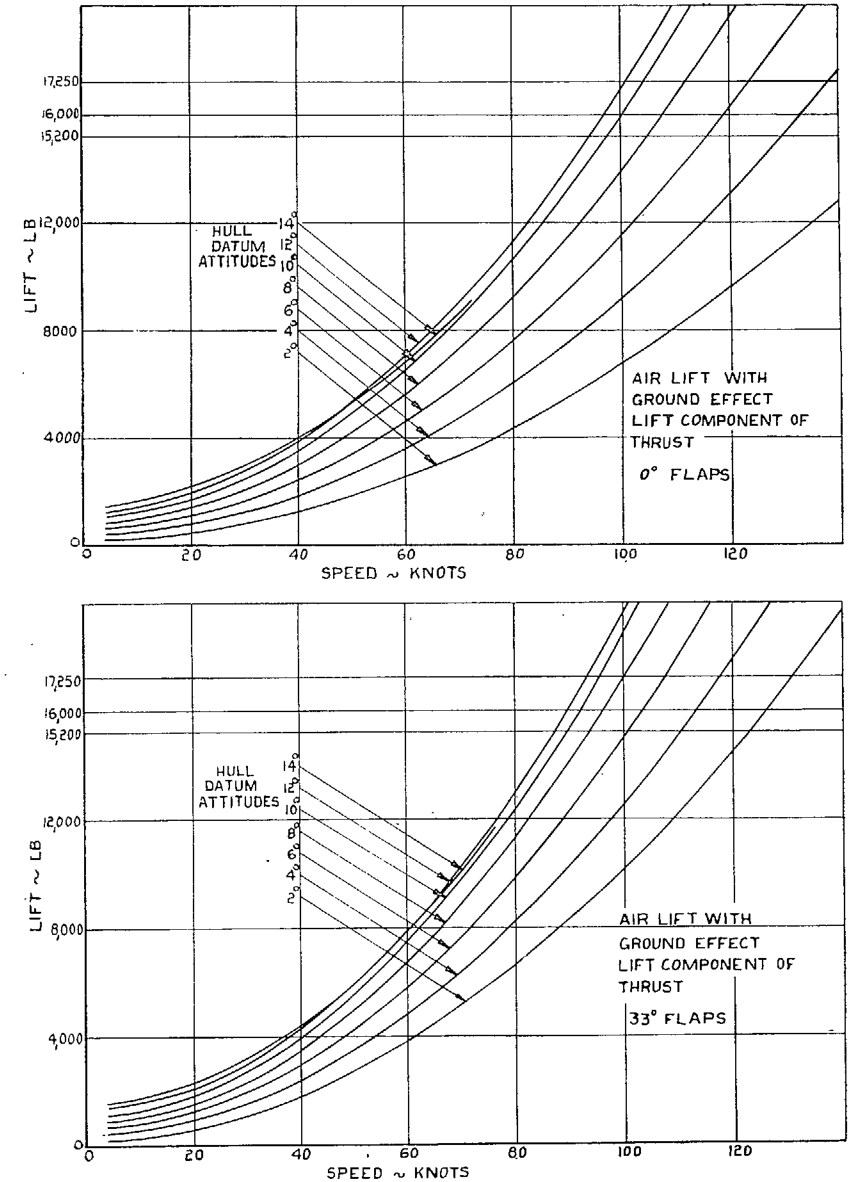


FIG. 15. Estimated air lifts for take-off.

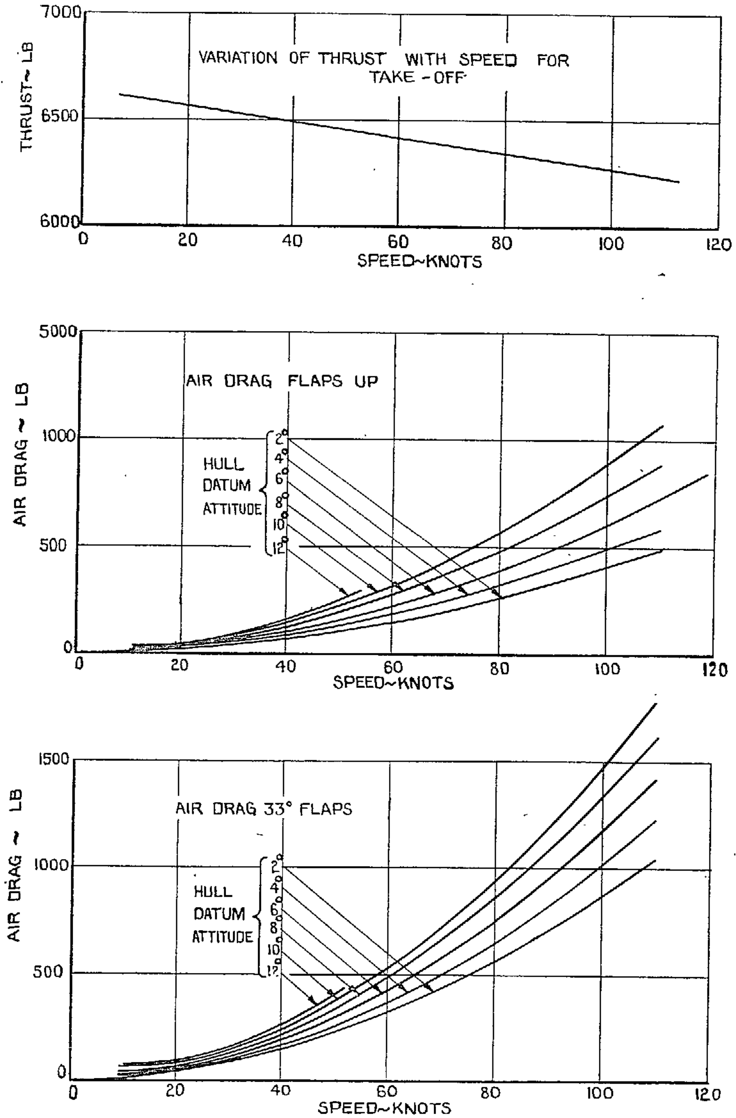


FIG. 16. Thrust and air drag estimates for take-off.

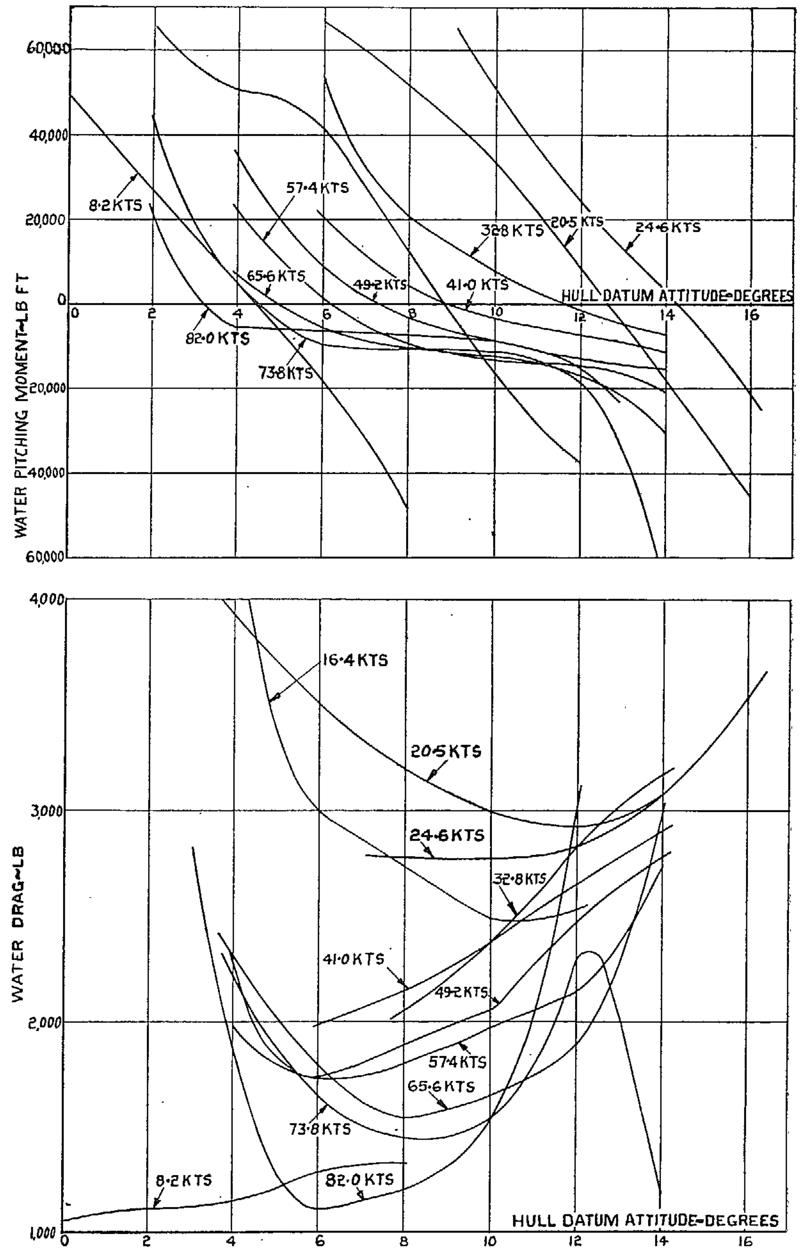


FIG. 17. Take-off at normal load 15,200 lb, flaps 33 deg. Resistance and pitching-moment tests. Final lines.

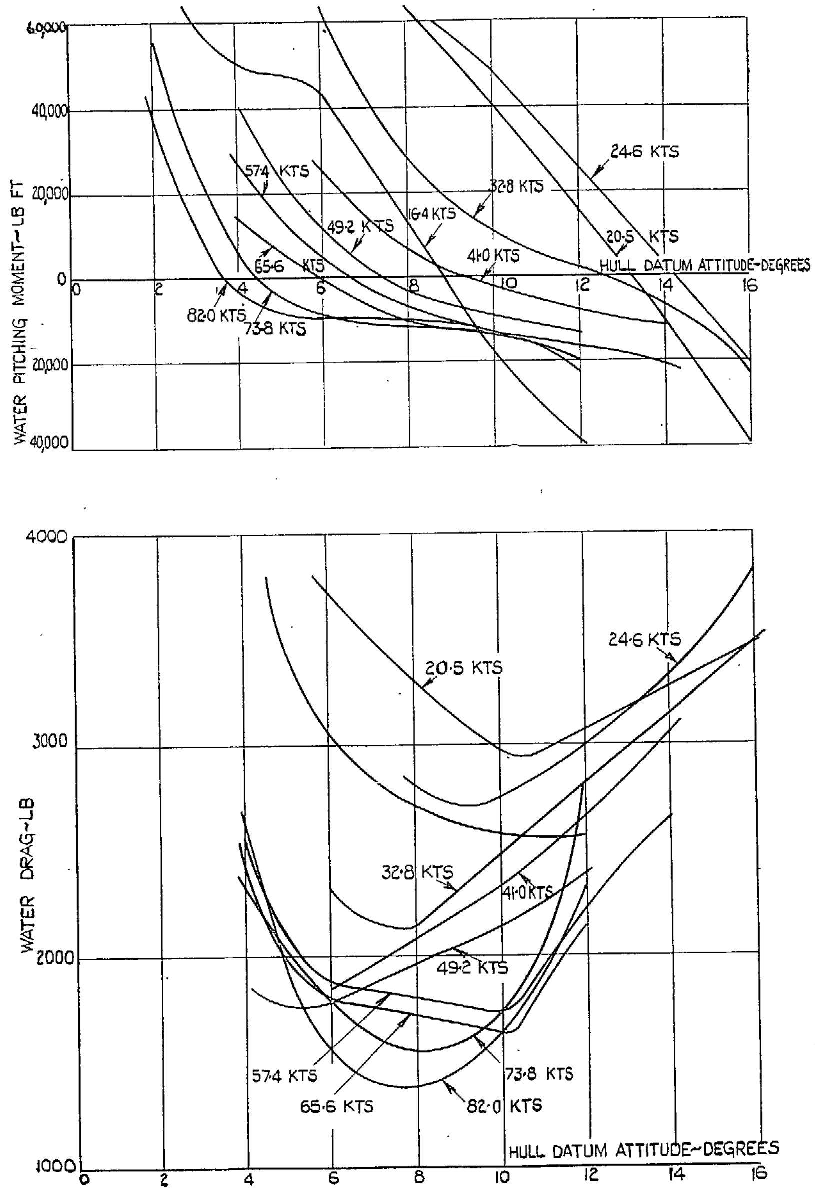


FIG. 18. Take-off at normal load 15,200 lb, flaps up. Resistance and pitching-moment tests. Final lines.

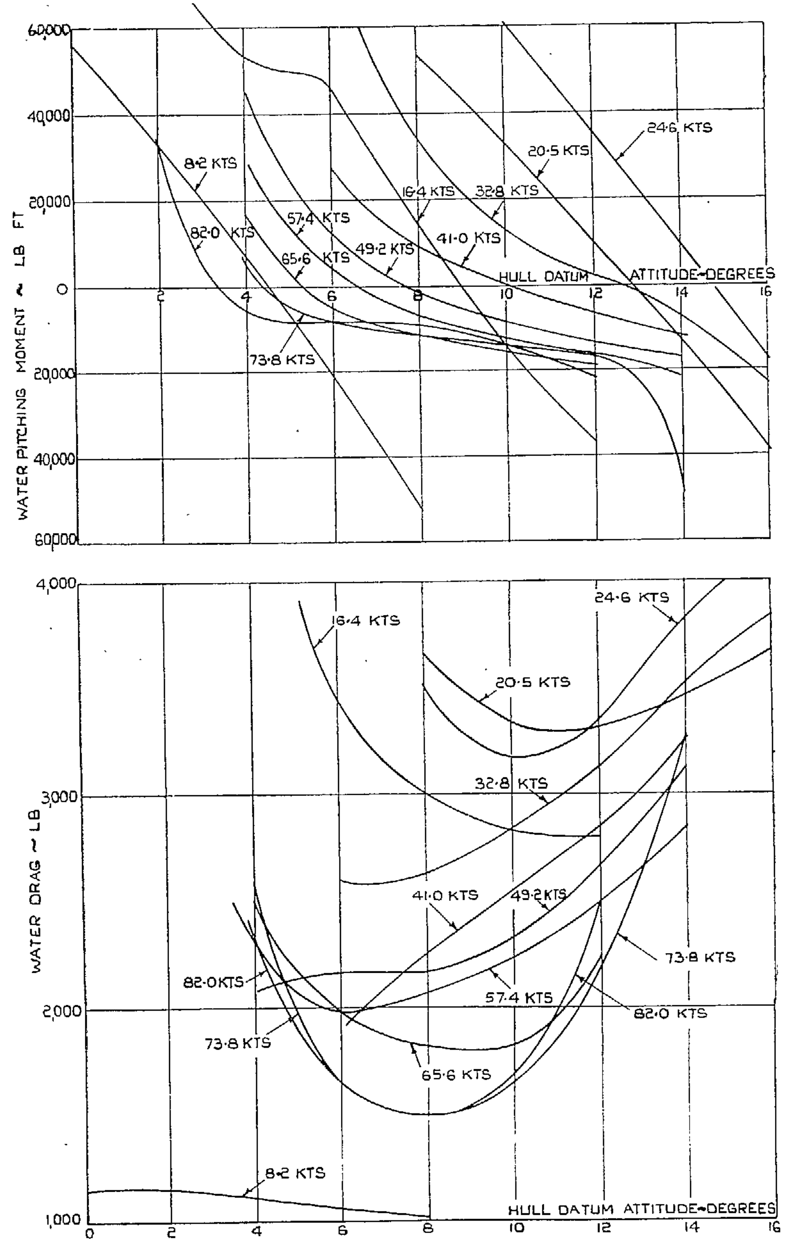


FIG. 19. Take-off at overload 17,250 lb, flaps 33 deg. Resistance and pitching-moment tests. Final lines.

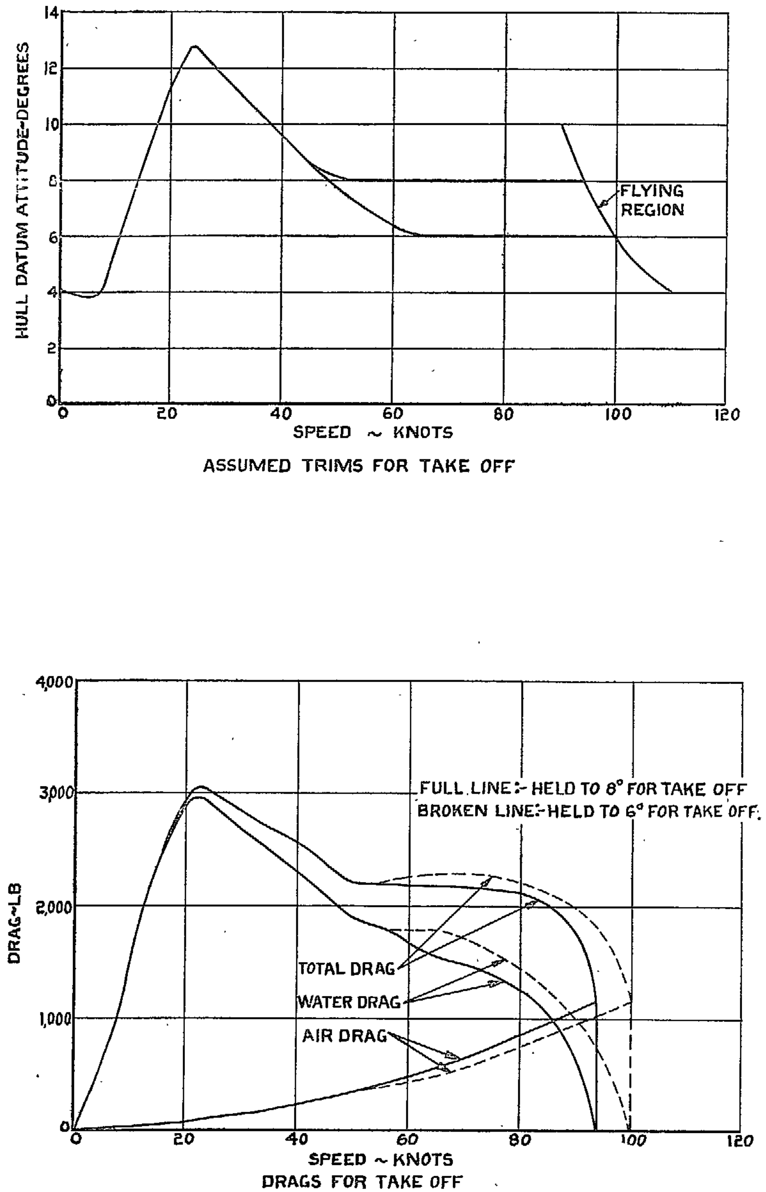


FIG. 20. Take-off at normal load 15,200 lb, flaps 33 deg. Trim and take-off resistance.

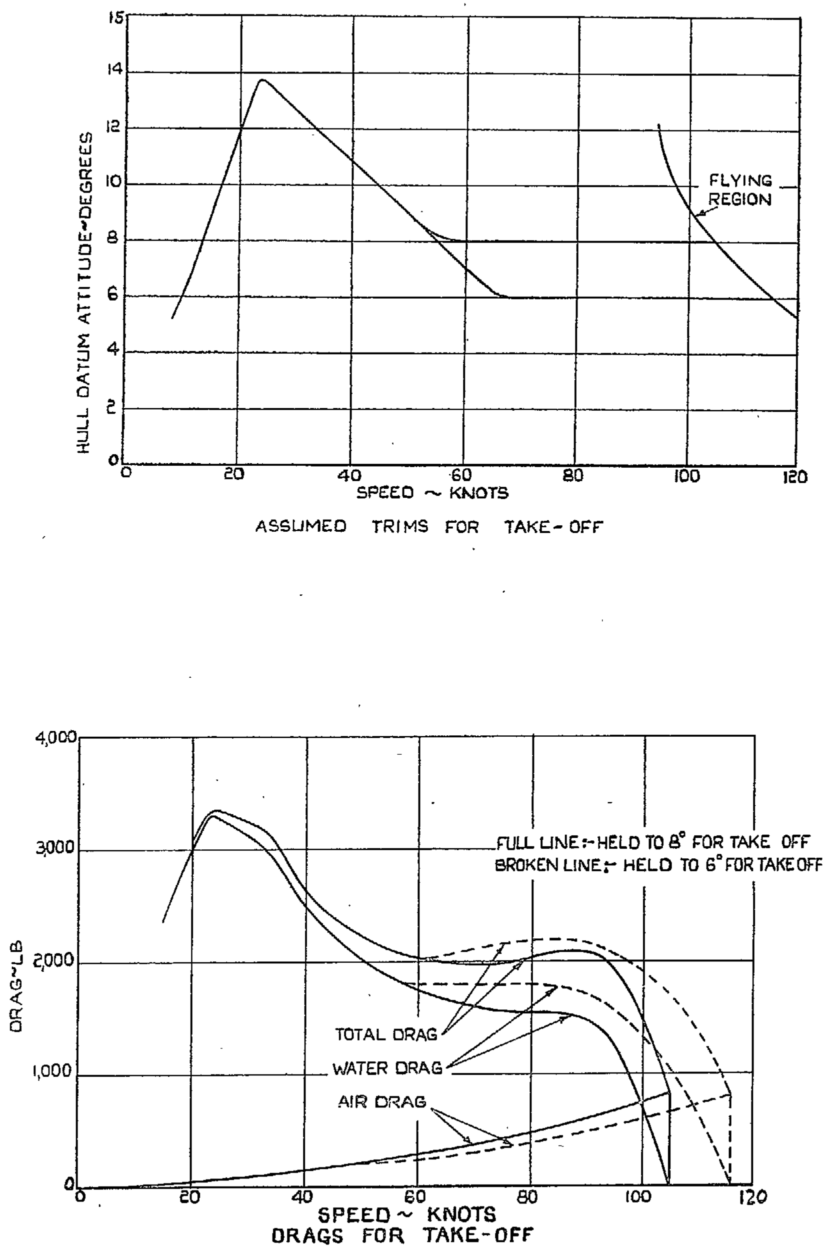
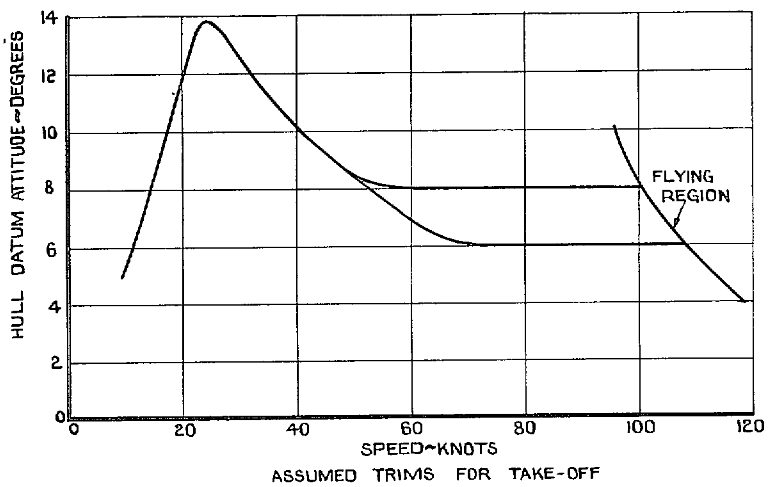


FIG. 21. Take-off at normal load 15,200 lb, flaps up. Trim and take-off resistance.



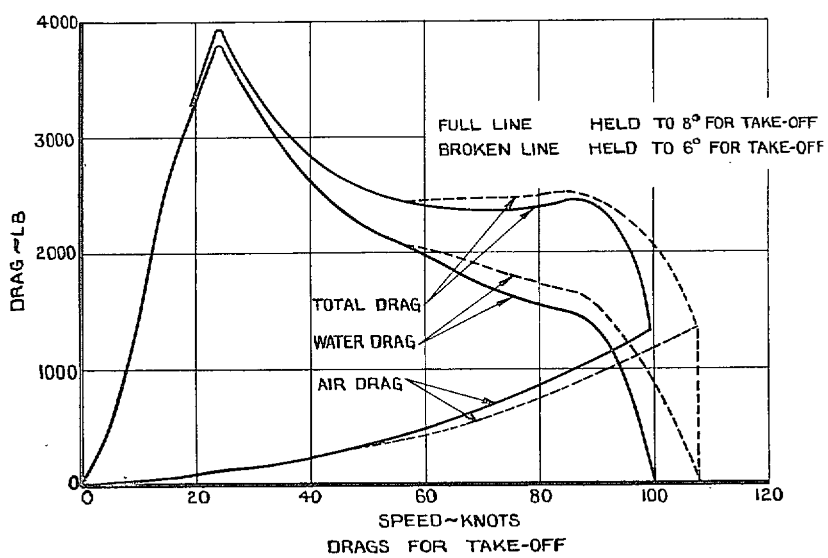


FIG. 22. Take-off at overload 17,250 lb, flaps 33 deg. Trim and take-off resistance.

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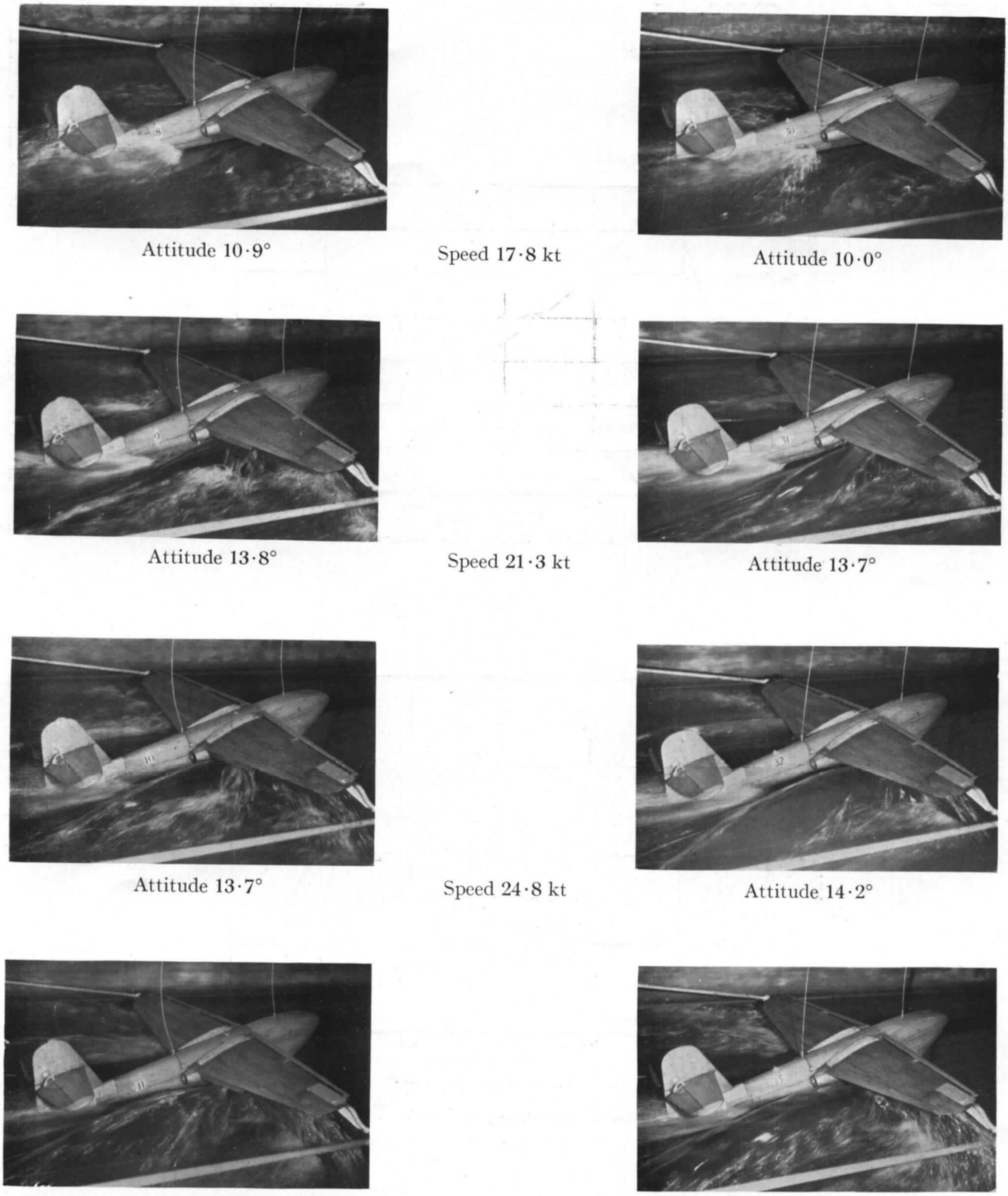
Flaps 33° | Flaps up



Attitude 10·9° | Speed 17·8 kt | Attitude 10·0°

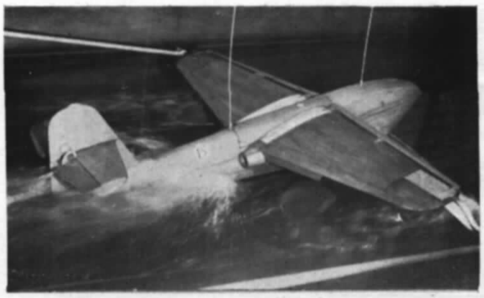
Attitude 13·8° | Speed 21·3 kt | Attitude 13·7°

Attitude 13·7° | Speed 24·8 kt | Attitude 14·2°

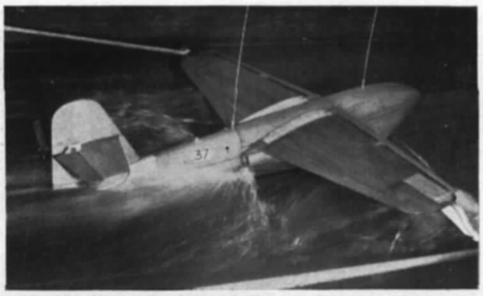
Attitude 13·5° | Speed 28·4 kt | Attitude 14·1°

FIG. 23. Take-off at normal load 15,200 lb. Seaworthiness tests.

Flaps 33° | Flaps up

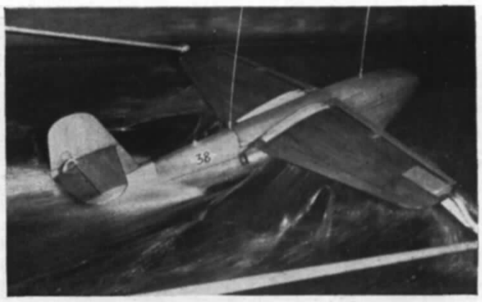

Attitude 10·3°

Speed 17·8 kt


Attitude 10·2°

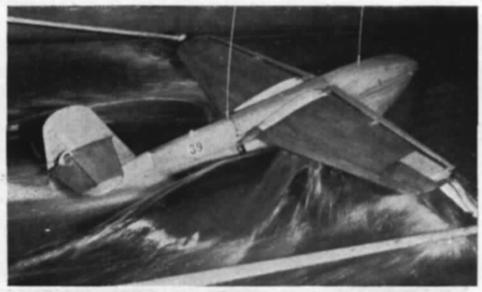

Attitude 13·8°

Speed 21·3 kt


Attitude 13·8°


Attitude 15·1°

Speed 24·8 kt


Attitude 15·5°


Attitude 13·8°

Speed 28·4 kt

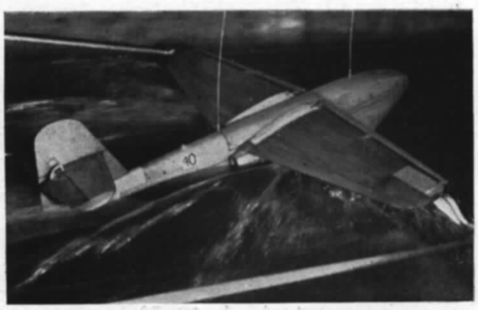

Attitude 14·7°

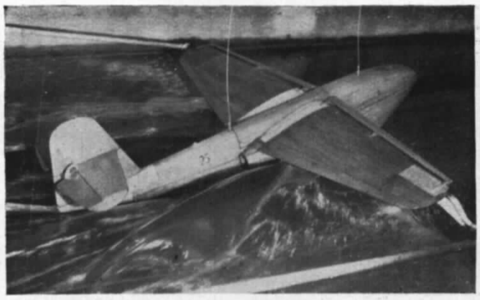
FIG. 24. Take-off at overload 17,250 lb. Seaworthiness tests.

Landing at 11,200 lb

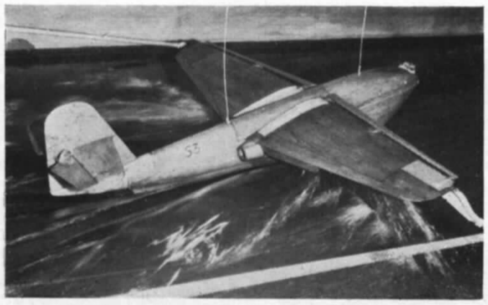
Landing at 15,200 lb

Attitude 13·5°

Flaps up

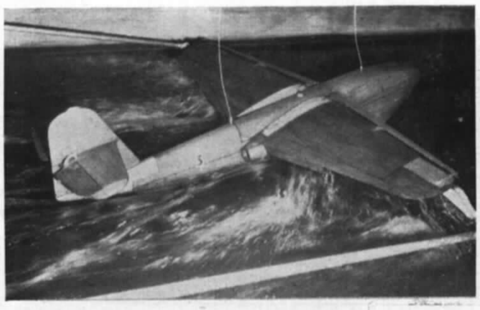


Attitude 15·0°

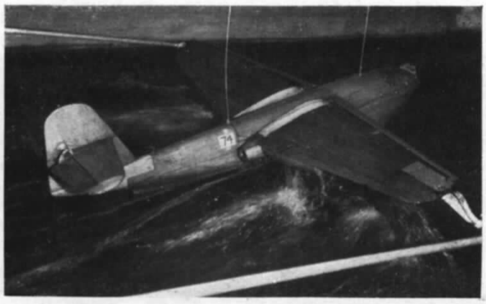


Attitude 13·2°

Flaps 33°

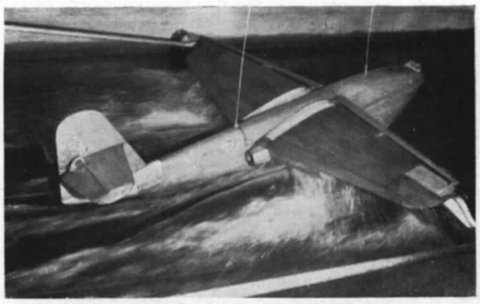


Attitude 14·2°

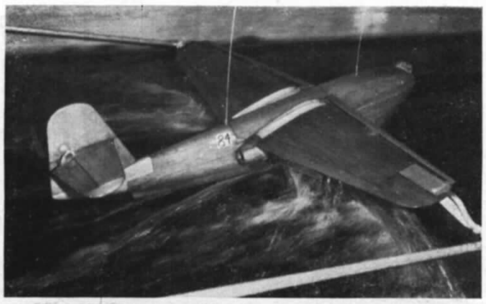


Attitude 13·2°

Flaps 50°



Attitude 13·6°

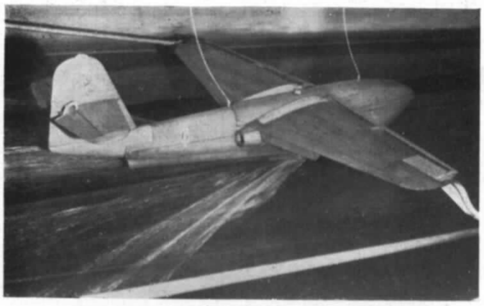


Attitude 13·5°

Flaps 75°

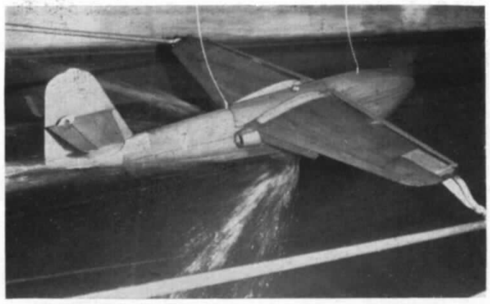
FIG. 25. Flap clearances at 24·8 kt. Seaworthiness tests.

Landing at 15,200 lb, 33° flaps



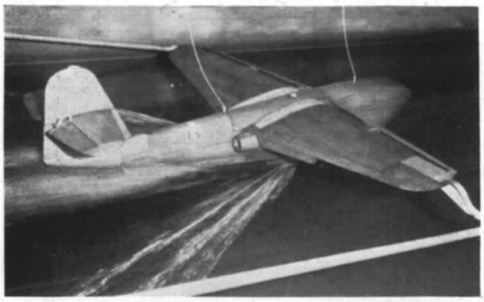
Attitude 4·8° η 0°

Speed 71·0 kt.



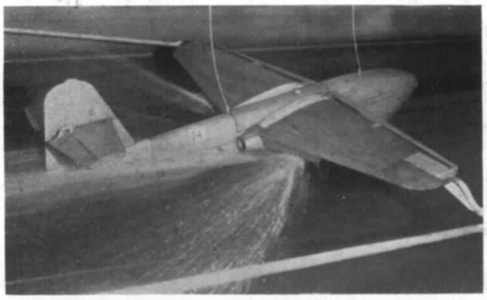
Attitude 8·0° η 20°
Interference beginning

Take off at 15,200 lb, 33° flaps



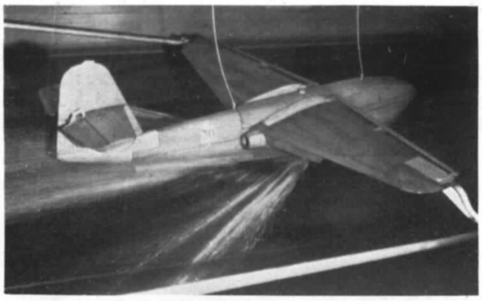
Attitude 5·4° η 0°
Interference but no attitude increase

Speed 71·0 kt



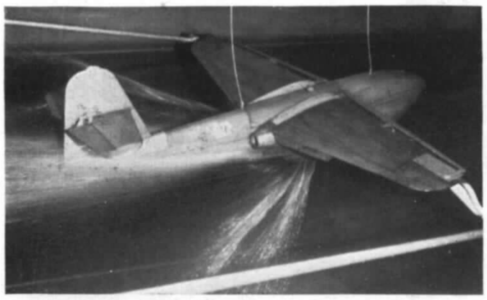
Attitude 9·5′ η 10°
Bad interference attitude increased

Take off at 17,250 lb, 33° flaps

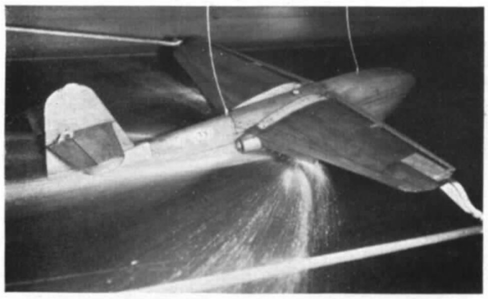


Attitude 5·2° η 0°
Interference but no attitude increase

Speed 71·0 kt



Attitude 7·0° η 10°
Interference immediately before attitude increase



Speed 71·0 kt

Attitude 10·0° η 10°
Bad interference after attitude increase

FIG. 26. Interference effects. Seaworthiness tests.

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