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Wind-Tunnel Tests on Seaplane Hulls in the R.A.E. 5-ft Diameter Open Jet Tunnel and the N.P.L. Compressed Air Tunnel

By

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COMMUNICATED BY THE DIRECTOR-GENERAL OF SCIENTIFIC RESEARCH (AIR), MINISTRY OF SUPPLY

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Summary.—Results of research work done in this country and the subject matter of Refs. 1 to 4 on the measurement and analysis of the air drag of seaplane hulls are collected together in this report. The data consist of the results of systematic tests made in the 5-ft Diameter Open Jet Tunnel of the Royal Aircraft Establishment and in the Compressed Air Tunnel of the National Physical Laboratory. These tests were conducted to find out the origin and order of the component drags of a hull and to determine in what way the hull drag differed from that of an equivalent body of revolution. Tests were made over Reynolds numbers ranging from the order of 2 to 60 $\times$ 10^6 in order to examine scale effect as far as possible, and a few tests were made to determine the possible effect of controlling boundary-layer transition. Otherwise all tests were made transition free. Subsequent to the systematic tests, tests were made on a specific hull form to investigate the form of step fairing designed for the *Princess* flying-boat, which form may be regarded as the best so far applied to hulls of contemporary fineness ratio and beam loading.

The results show that the air drag of the hull form need not exceed 1·05 to 1·10 times that of the body of revolution which corresponds to it in length and surface area, if the drag of the body of revolution is estimated to consist only of skin friction with fully turbulent boundary layer and the pressure drag corresponding to its fineness ratio. This hull drag should be obtainable at all Reynolds numbers likely to be achieved full scale.

Further work should be done in the Compressed Air Tunnel to measure the effect of using higher fineness-ratio hulls and new forms of main-step and afterbody shape.

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1. *Introduction.*—This report contains subject matter and data from reports on work done in the Royal Aircraft Establishment's 5-ft Diameter Open Jet Tunnel and the National Physical Laboratory's Compressed Air Tunnel on the air drag of seaplane hulls (Refs. 1 to 4) and also contains some unreported results of tests on the *Princess* hull.

These tests were made in a systematic manner to analyse the drag of a hull form into its constituent parts, particular attention being paid to the drag of steps, chines and the turned up tail characteristic of flying boat hulls, and to determine how far the drag of a hull departed from that of the equivalent streamlined shape. Measurements were made over a wide range of Reynolds numbers and incidences and were extended to show some ways by which the drag of steps, chines and afterbodies could be reduced.

*M.A.E.E. Report F/Res/266, received 14th October, 1955.

An analysis of certain of the important results has been given in Ref. 5 (in which the requirements of aerodynamic design are linked with those for hydrodynamic design), together with analyses of data published in America on the effect of length/beam ratio. It is demonstrated in that report that the aerodynamic efficiency of different hull forms can be compared by determining a cleanness ratio defined as the ratio

$$\frac{\text{drag coefficient per unit surface of hull area}}{\text{drag coefficient per unit surface of an equivalent body of revolution}}$$

and wherever possible the data collected together in this report have been analysed accordingly.

The first systematic series of tunnel tests was made in 1937 in the R.A.E. tunnel (Ref. 1) and is summarised in section 3 of this report. The tests were made at a Reynolds number of $3 \cdot 8 \times 10^6$ with transition free and therefore, by later standards, give results which are very valuable qualitatively but which must be regarded as unsuitable for quantitative comparison with other data. Very thorough tests were made and these showed how the drag of a composite hull form is built up from that of a streamlined body by the successive addition of camber (in effect, the raising of the after portion of the streamlined body), planing bottom or deadrise angle, steps and chines. The work also demonstrated for the first time the very large reductions of step drag which could be obtained by suitable fairings. It should also be noted that this report gave the first evidence of the possible gains in drag which might result from the use of higher fineness ratios, although the application of this possibility was not pursued at the time.

The work done in the Compressed Air Tunnel at the N.P.L. was essentially a follow-up of the work done in the tunnel at the R.A.E. and was made to extend the results over a wide range of Reynolds numbers, *i.e.*, up to 60×10^6. An analysis of some of the data, given in Ref. 5, shows that comparison of various forms with free transition is of doubtful value until the Reynolds number of tests is at least 20×10^6 and preferably 40×10^6, when the boundary-layer transition to smooth turbulent conditions is reasonably well stabilised. New techniques are now being developed for the Compressed Air Tunnel to enable tests to be made with transition fixed artificially where required and with an improved form of balance.

The data of Refs. 1 to 4 are reproduced in sections 2 and 3 in their original form, but the subject matter has been edited to eliminate what is irrelevant here and what has of necessity been repeated from one report to another. Some hitherto unreported data obtained on a model of the *Princess* flying-boat with various step fairings has also been added, together with some results of early attempts to control the position of boundary-layer transition in the Compressed Air Tunnel.

2. *Tests in the R.A.E. 5-ft Diameter Open Jet Tunnel*.*—2.1. *Wind-Tunnel and Tank Tests on the Drag of Seaplane Hulls*

By

K. W. Clark and D. Cameron

Summary.—Tests were undertaken to investigate the effect on air drag of various systematic modifications to a seaplane hull.

A hull form was developed from an airship form by bending the tail upwards until the deck line of the afterbody was straight and adding the vee bottom and steps in stages. Drag measurements were then made on hulls of various beams, with faired steps, pointed steps, tail turned up or down, chines overhung or rounded off and altered angle of deadrise.

The models were all 5 ft in length and were tested at Reynolds numbers of $3 \cdot 8$ and $6 \cdot 3 \times 10^6$.

*Date and subject matter taken and edited from Ref. 1.

Large variations in drag result from changes in hull form. Overhanging the chines and turning up the tail may increase the air drag of a normal hull at 0 deg incidence by about 60 per cent. Rounding off the chines, fairing the steps and turning down the tail may reduce the hull drag by 30 per cent. The vee bottom represents about 10 per cent of the drag of the hull at 0 deg incidence, and half this may be saved by a small radius on the chines. The steps cause 16 per cent of the drag, and the whole step drag may be saved by fairings extending behind the steps to six times the step depth. A pointed rear step is of advantage but not a pointed main step, unless of extreme form. An acute vee bottom has a lower drag than an obtuse vee bottom.

Because of the low Reynolds numbers, further tests will be made over a range of Reynolds numbers in the N.P.L. Compressed Air Tunnel.

2.1.1. *Introductory.*—The design of a flying-boat hull is a compromise between the usually conflicting requirements of good performance on the water and in flight. From aerodynamic considerations, the hull should be without discontinuities, while for low water resistance when planing, discontinuities are necessary in the form of steps and chines, the former to localise the wetted area to that portion providing lift, and the latter to keep the spray as low as possible.

To provide information on the origin of the drag of a hull, a hull of good aerodynamic shape has been developed from an airship form by curving upwards the centre-line of the rear half until the deck line of the tail portion was straight. This form is referred to as the basic streamline form and is illustrated in Fig. 1 (No. 1). The hull was modified systematically to cover most of the likely variations in form, the tests being made for convenience on the hulls alone.

The programme of the tests was as follows :

Modification	Drawings of hull	Results
From basic streamline form to complete hull in stages	Figs. 1 and 2	Table 3 and Fig. 4
Beam increased and decreased	Fig. 3	Table 4 and Figs. 5 and 6
Fairings added to steps	Tables 5 to 7	Tables 5 to 7 and Fig. 7
Elliptical and pointed steps	Table 8 and Figs. 8 and 10	Tables 8 and 9 ; Figs. 9 and 12
Tail turned up and down	Fig. 11	Table 10 and Fig. 12
Overchanging chines	Fig. 13	Table 10 and Fig. 14
Chines rounded	—	Table 11 and Fig. 15
Angle of deadrise increased and decreased	Fig. 16	Table 12

The results are given over a range of incidence referred to the keel line ahead of the main step, and were taken at wind speeds of 120 and 200 ft/sec, corresponding to Reynolds numbers $3{\cdot}8 \times 10^6$ and $6{\cdot}3 \times 10^6$ respectively. The measurements were made in the 5-ft Open Jet Wind Tunnel at the R.A.E. between August and December, 1936.

The results are given in the tables as pounds drag on the model at 100 ft/sec, and also in the form of three coefficients based on maximum cross-sectional area, volume to the two-thirds power, and surface area.

The coefficient based on surface area has been plotted in the figures. Some of the modifications altered the dimensions of the hulls only slightly, so that the comparisons are not materially affected by the choice of coefficient. Three of the modifications, however (beam varied, chines overhung, and angle of deadrise altered), altered the hull dimensions considerably, and the effect of the modifications depends on the coefficient used.

2.2. *Results of Tests.*—2.2.1. *Development of complete hull from basic circular form.*—To ensure a low air drag the design was based on a streamline form of circular cross-section. This form required a fairly bluff nose for seaworthiness and a long tail to carry the control surfaces. A suitable form was obtained by combining airship bodies A and B of Ref. 8, using the bluff form B from the bow to the maximum cross-section and form A (similar to R.101) for the remainder. The diameters were decreased to bring the ratio of overall length to maximum diameter from 5 to 7, and, to suit the position of the rear step, the rear portion was then upswept until the deck line was horizontal. This has been called the basic streamline form, and is shown in Fig. 1 (No. 1).

The vee bottom without steps was next added with as little disturbance as possible to the distribution of cross-sectional area along the length. The upper portion of the hull remained semi-circular and from it depended vertical sides to meet the chines. The keel of the afterbody was next straightened between the proposed step positions. These two forms are shown as numbers 2 and 3 in Fig. 1. The steps were then added to form the complete hull (Figs. 2 and 3b) for which a table of offsets is given in Table 2. A further modification was introduced by hollowing the sections from keel to chine as shown in Fig. 3e of this report.

The drag with the successive modifications described above is shown in Fig. 4 and Table 3. At 0 deg incidence, which would be in the region of top speed for an average seaplane, the addition of the vee bottom to the basic streamline form represents about 10 per cent of the actual drag of the complete hull, and the steps 16 per cent. These are the maximum amounts that can be saved on this hull form by rounding the chines and fairing the steps. The discontinuities introduced by straightening the keel of the afterbody increase the drag at low incidences, but actually decrease it above 4 deg. The hull with hollowed vee sections has a higher drag throughout by about 6 per cent.

2.2.2. *The effect of length/beam ratio.*—In deriving the hulls of wider and narrower beam from the complete hull with straight vee sections, the profile in the plane of symmetry was unaltered and the angles of deadrise of the planing bottom also remained fixed. The horizontal dimensions of the cross-sections at and above the chine were increased or reduced proportionately, so that the top of the hulls became elliptic in cross-section. By this method the height of the chine above the keel varied for hulls of different beams, but the more important parameters, the lateral and longitudinal angles of the planing bottom, remained constant. Fig. 3, which shows the cross-sections, makes the method clear.

The results are given in Table 4 and Figs. 5 and 6. The minimum values in Fig. 6 show that the variation of drag coefficient with length to beam ratio depends on the form of coefficient used, the most useful form for assessment of aerodynamic cleanness being that based on surface areas. The hulls are not representative of full-scale alternatives for the same load capacity, but the cleanness comparisons are valid (*see* Ref. 5).

2.2.3. *Step fairings in side elevation.*—The main step was faired in side elevation by straight fairings from either the full or half depth of the step, or by concave fairings from the full depth. The results and sketches are given in Tables 5, 6 and 7, and in Fig. 7 the effectiveness of various lengths of the straight fairing is shown and compared with the drag caused by the steps. The step drag is taken as being the difference in drag between the complete hull and the basic streamline form with vee bottom added, *i.e.*, hulls 4 and 2 in Fig. 4, and represents about 16 per cent of the drag of the complete hull tested. The fairing from the full depth of the step was very effective and needed to be only equivalent to six times the depth of the step to be fully effective.

Table 6 shows that about 6 per cent of the hull drag may be saved with a good fairing on the rear transverse step.

2.2.4. *Step fairings in planform.*—The elliptical and 30-deg pointed main steps (Table 8 and Fig. 9) show a higher drag coefficient than the straight step. A 60-deg pointed main step designed for low air drag is shown in Fig. 8 and did give a lower air drag. The step at the chines was reduced to $\frac{1}{4}$ depth and rounded off into the sides of the hull. The normal step depth was retained at the keel and the keel behind the step was given a slightly steeper rise.

The pointed rear step (Table 9 and Figs. 10 and 12) shows a decided improvement, particularly at the low incidence association with top speed. In the case of a rear step the taper can be made sufficiently elongated to give a good streamline form, as may be seen in Fig. 10.

2.2.5. *Tail turned up and turned down.*—Fig. 12 shows the large variation in drag according to whether the tail is turned up or down.

Turning down the tail is also advantageous because the minimum drag occurs at an incidence more in accordance with top speed than for the hulls with level deck or tail turned up.

2.2.6. *Chines extended outwards.*—This modification was applied only to the hull with turned up tail as drawn in Fig. 13. The results are given in Table 10 and Fig. 14. The change in drag may be considered as being approximately applicable to the straight-decked hull, and the estimated values for this case are shown in Fig. 14.

The tests show that if a broad beam across the chines is required for take-off, a lower air drag results from widening the hull from top to bottom than by only widening at the chines.

2.2.7. *Fairing the chines.*—The chines were rounded off in stages, beginning at the bow. The results (Table 2 and Fig. 15) show that half the drag due to adding the vee bottom to the basic form may be saved by rounding off the chines from bow to main step, but that there is little advantage to be gained by rounding off the afterbody chines. The radius was kept fairly small (0·125 in. on the model).

2.2.8. *Vee bottom made more obtuse and more acute.*—The results are given in Table 12 and drawings of the hulls in Fig. 16. The acute vee bottom has the smaller total drag by about 11 per cent.

2.3. *Scale Effect.*—The scale effect has been investigated briefly in some cases by testing at two wind speeds giving Reynolds numbers of $3 \cdot 8 \times 10^6$ and $6 \cdot 3 \times 10^6$. The minimum drag coefficients are reduced by increase of Reynolds number by 3 to 4 per cent and, within the limits of experimental accuracy, this appeared to be constant for all hulls. It is considered unlikely that the differences in drag coefficient due to the various step modifications would differ much between model and full scale. The actual values of the drag may, however, alter considerably due to a movement of the position of transition between laminar and turbulent flow. This change would be greater on the basic circular form that on the hulls with chines, so that the difference in drag between the basic form and the complete hull would be affected. The effect of rounding the chines may also vary.

3. *Tests in the N.P.L. Compressed Air Tunnel.*—

3.1. *Effect of Adding Camber, Steps and Chines to a Streamlined Form* Resistance Measurements on Seaplane Hulls in the Compressed Air Tunnel*

By

R. JONES, A. H. BELL, E. SMYTH

Summary.—Tests were conducted in the Compressed Air Tunnel to amplify the results for Reynolds numbers of the investigation made at the R.A.E. at Reynolds numbers of $3 \cdot 8 \times 10^6$ (section 2 of this report).

*Data and subject matter taken from Ref. 2.

Three different models were tested over a range of Reynolds numbers from $1 \cdot 3$ to 60×10^6 at one angle of incidence. The models were :

(*a*) the basic streamline form, a body of revolution of fineness ratio 7, Model 1

(*b*) the same form with the deck line aft of the maximum diameter straight, Model 2

(*c*) the complete hull form with two transverse steps, Model 3

(*d*) the complete hull form with the chines rounded off for a distance of about $1 \cdot 5$ beam from the bow, Model 4.

Deforming the body of revolution to the form of Model 2 increases the drag by about 10 per cent at a Reynolds number of 60×10^6.

The addition of the vee bottom and steps to Model 2 increases the drag by nearly 40 per cent of the drag of number 2 at a Reynolds number of 60×10^6. The increment agrees approximately with that found at the R.A.E. at Reynolds numbers of 4 and 6×10^6.

The effect of rounding off the forward chines of Model 3 was found to be negligible.

3.1.1. *Introductory.*—The experiments described below were conducted in the Compressed Air Tunnel to provide data at high values of Reynolds number on the drag of certain of the derived hull forms of section 2 which had already been tested at the R.A.E. at low values of Reynolds number of $3 \cdot 8$ and $6 \cdot 3 \times 10^6$ and at several angles of incidence. The tests were restricted to four models at zero incidence.

Four models, similar to those tested at the R.A.E. and described in section 2, were made of hard wood and polished. They were five feet long and are described as follows :

Model 1 :

This was a body of revolution of fineness ratio 7, and was the basic streamline form, with plan-form the same as that shown in Fig. 1

Model 2 :

This was the basic streamline form with the deckline aft of the maximum diameter kept straight (Fig. 1) and perpendicular to the maximum section. Forward of the maximum diameter the body was a surface of revolution similar to Model 1

Model 3 :

This was the complete hull form of length/beam ratio 7 (Figs. 2 and 3b) derived from Model 2

Model 4 :

This was a modified form of Model 3. The alteration consisted of rounding off the chines to a radius of $\frac{1}{8}$ in. from the bow aft for a distance of $12 \cdot 5$ in., the rounding fading away at a distance of $13 \cdot 5$ in. from the bow.

A description of the technique employed in the Compressed Air Tunnel for drag tests of this nature is given in Ref. 9.

The models were tested at one incidence only. The centre-line of Model 1 was parallel to the wind direction ; the deck line of the other models was parallel to the wind direction. Measurements were taken at various pressures and wind speeds covering a range of Reynolds numbers from $1 \cdot 3$ to 60×10^6 approximately.

3.1.2. *Results.*—The results are presented graphically in Fig. 17.

The drag of Model 1 is reasonably consistent in trend with that of a series of three models based on the form of the hull of R.101 at the higher values of Reynolds number and also with the results of some experiments carried out in the Variable Density Tunnel in America* (Ref. 9).

*See also ' Discussion ' of this report.

A comparison of the results obtained at the R.A.E. and in the Compressed Air Tunnel for Models 2 and 3 is given in the following table. The drag coefficients are given on a basis of the total wetted area.

	Reynolds number	Model 1	Model 2	Model 3
R.A.E.	$3 \cdot 8 \times 10^6$		0·00359	0·00478
	$6 \cdot 3 \times 10^6$		0·00350	0·00460
C.A.T.	$3 \cdot 8 \times 10^6$		0·00390	0·00505
	$6 \cdot 3 \times 10^6$		0·00372	0·00514
C.A.T.	20×10^6	0·00331	0·00360	0·00486
	63×10^6	0·00297	0·00314	0·00442
R.A.E.	Surface area of model	8·23	8·23	8·40 sq ft
C.A.T.		8·46	8·46	8·50 sq ft

The Compressed Air Tunnel results give a higher drag than was obtained at the R.A.E. but it would appear that the values of Reynolds number at which the R.A.E. tests were conducted are within the transition region of the Compressed Air Tunnel experiments and in this region the Compressed Air Tunnel points are very uncertain for reasons specified in Ref. 9. It will be found, however, that the difference in drag between Models 2 and 3 as obtained at the R.A.E. and in the Compressed Air Tunnel are in fairly good agreement. Thus, from the R.A.E. results, adding a Vee bottom and steps has resulted in an increment of 0·00119 and 0·00110 to the drag at Reynolds numbers of 3·8 and $6 \cdot 3 \times 10^6$ respectively; the Compressed Air Tunnel results give corresponding values of 0·00115 and 0·00142, whereas at Reynolds numbers of 20 and 63×10^6 the increments are 0·00122 and 0·00128 respectively.

Turning up the tail of the streamlined form, Models 1 and 2, has resulted in an increased drag which appears to decrease as Reynolds number increases.

Rounding the chines on the hull form 3 shows no decrease of drag within the limits of experimental error at high values of Reynolds number.

3.2. *Effect of Fairing the Transverse Steps of a Basic Hull Form**

Tests on a Flying-Boat Hull with Faired Steps in the Compressed Air Tunnel

By

R. Jones, A. F. Brown

Summary.—A model of a flying-boat hull (Model 3 of A.R.C. 3409) was tested in the Compressed Air Tunnel with two forms of fairing to both steps for a Reynolds number range of 2 to 60×10^6.

A decrease was observed of about 22 per cent of the drag of the original model at a Reynolds number of 60 millions.

The drag coefficient of the faired model is only 0·00045 greater than that of the smooth basic surface of revolution as compared with 0·0014 in the case of the unfaired model. These increases

*Data and subject matter taken from Ref. 3.

correspond to increases of 15 and 47 per cent of the drag of the basic form at a Reynolds number of 60 millions.

3.2.1. *Introductory.*—Additional tests were made on the hull form of Model 3 of Ref. 2, with both steps faired in order to examine the effect of step fairing at high Reynolds numbers. The R.A.E. tests (Ref. 1) had been limited to a Reynolds number of $3 \cdot 2 \times 10^6$. Two different fairings were arranged, one a straight fairing 2 in. long and the other a curved fairing 3·6 in. long on the model 5 ft long. Fig. 2 and Fig. 3b show the original model and Figs. 18 and 19 show the fairings on the main and rear steps respectively.

The modifications to the model were made by removing parts of the original model near the steps and providing blocks of the appropriate shapes to fit the gaps and to reproduce the original model shape. Great care was taken to ensure a smooth surface at the joints by rubbing down the model so that the surface of the composite model was as good at the joints as that of the original. This is confirmed by the manner in which the results on the composite model with unfaired step agree at high values of Reynolds number with those of the original model of Ref. 2.

3.2.2. *Results.*—The results of the tests are shown in Fig. 20 in which also are reproduced the faired curves presented in Fig. 17 and produced by taking the differences between two smooth curves drawn through the two series of readings which Compressed Air Tunnel technique involved when measuring the drag of unsymmetrical bodies (Ref. 9).

The following table summarises the results at a Reynolds number of 60 millions in terms of the drag of the streamline surface of revolution Model 1 :

Model number	C_F at a Reynolds number of 60 millions	C_F/C_F Model 1
1	0·0030	1·00
2 (1 with camber)	$0{\cdot}0031_3$	1·04
3 (complete hull form)	0·0044	1·47
3 (complete hull form with faired steps)	$0{\cdot}0034_6$	1·15

Fairing the steps has therefore reduced the drag coefficient by over 30 per cent of that of Model 1. No difference was found between the drags with the curved and the straight fairing, within the limits of experimental error.

3.3. *Drag of a Specific Hull Design with Various Fairings**

Drag Measurements on a Model of a Flying-Boat Hull in the Compressed Air Tunnel

By

R. JONES, A. H. BELL, A. F. BROWN

Summary.—Resistance measurements were made on a model of a flying-boat hull and a typical corresponding landplane fuselage at several angles of incidence and over a wide range of Reynolds

*Data and subject matter taken from Ref. 4.

number. Provision was made to fair the step in the hull with six different types of fairing. The effect of fairing the chine at the forward end of the hull was examined, as also was the effect of a cabin on the fuselage.

The results show that a hull form can be evolved having a drag only 6 per cent higher than that of a fuselage.

The results of earlier experiments on the drag of hulls were confirmed.

There is little change in drag coefficient with incidence at positive angles.

3.3.1. *Introductory.*—The object of the investigation was to examine the drag of a typical hull with various designs of step and chine fairing and to compare the results with the drag of a normal low resistance fuselage of a land machine of similar capacity.

Hull tests described in Refs. 2 and 3 had shown great reduction of drag for step fairing, but had been carried out at zero incidence only and on the main Compressed Air Tunnel balance (a balance which is not very suitable for drag measurements on an unsymmetrical body). The difficulties of such measurements are fully discussed in a report dealing with Compressed Air Tunnel technique[9]. It was felt therefore that further confirmation was desirable and that various types of fairing should be examined. For the basic form, a typical fuselage with fin attached should be substituted, therefore the hull model should also be fitted with a similar fin, using a new balance available in the Compressed Air Tunnel. This was specially designed for plain drag measurements with provision for changing the incidence of the model within a limited range without exhausting the tunnel.

The programme included tests on the hull with a normal step and with six different types of step fairings, and the effect of fairing a length of chine near the bow. The fuselage with which the hull was to be compared was also tested with and without a cabin, but fuselage and hull were fitted with a fin to represent a design case.

3.3.2. *Models tested.*—The steps and fairings were made separately to fit a recess in the main model, in order to avoid manufacturing a large number of models or to avoid delays while one model was being modified to represent, in turn, each type of step. This was also the method adopted with the models used in the experiments described in Ref. 3. Under ordinary wind-tunnel conditions, this method is satisfactory, but, unfortunately, under the conditions prevailing in the Compressed Air Tunnel it leaves much to be desired. Compressed air and humid conditions tend to affect the surfaces of the different sections differently and there is a danger of the joints between the step sections and the main model becoming rough and possibly giving rise to effects comparable with those under investigation. On the other hand, if a separate complete model be made to incorporate each type of fairing there is always a possibility that, however careful the workmanship, the models, would not, apart from required modifications, be exact replicas of one another. Moreover, with the timber available for model making under present conditions, it is probable that the surfaces of no two models would react in the same way to Compressed Air Tunnel conditions. The method of using one main model with separate 'step sections' was therefore adopted and great care exercised in preparing the surface. After every experiment, the surface of the model was rubbed down and the joint between step section and main model examined and any swelling or shrinkage of wood carefully smoothed out. As a check, one or two hull–step combinations tested in the early stages of the experiments were tested again later and the results agreed within the limits of experimental accuracy.

A sketch of the hull model with normal step is given in Fig. 21. The length of the model was 5 ft and the depth of the step varied from 0·55 to 0·65 in. A recess ADHE was made in the model to accommodate the step sections. One section extended from A to D and was later modified, so that two 'AD sections' were tested. They are referred to below as the streamline step fairings. The other forms of step extended from B to C only and two sections ADFE and CDHG were made to fill the recesses left in the model when the 'BC sections' were attached to it.

Thus, except for the two streamline fairings, the only alteration to the steps was confined to the length 6·67 in. of the model between B and C.

The shorter sections considered were five in number. Sketches of them are included with the appropriate curves showing the results. The step fairings tested consisted therefore of :

(*a*) Normal step	Figs. 21, 23 and 24
(*b*) Straight step fairing	Fig. 25
(*c*) convex step fairing	Fig. 25
(*d*) concave step fairing 1 in 4	Fig. 26*
(*e*) concave step fairing 1 in 6	Fig. 26*
(*f*) and (*g*) streamline and modified streamline fairings.	Fig. 27.

The difference between the two streamline fairings can best be seen by referring to Fig. 27. The original streamline fairing had a shallow step, and the modified fairing a deeper step (1·05 in.).

The modification to the chine consisted merely of rounding off the corner for a distance of 7·1 in. (parallel to datum) from the forward end of the model. The original chine on the model is shown dotted in Fig. 21.

A sketch of the fuselage is shown in Fig. 22.

The drag of all the hull models at 0·3 deg incidence was tested over a range of values of Reynolds number from 1·4 to 35 millions approximately and in the case of the model with normal step and normal (unfaired) chine at angles of pitch of − 3·9 deg, − 2·2 deg, + 2·3 deg and + 5·2 deg.

The faired-chine model with normal step was tested at the same five angles but the values of Reynolds number were limited to two ranges from 3·0 to 5·5 millions and from 15 to 34 millions.

The remainder of the models were tested over approximately the same two ranges of Reynolds number at incidences of − 3·9 deg and + 5·2 deg in addition to the longer Reynolds number range at 0·3 deg incidence.

The model fuselage was examined both with and without cabin at angles of incidence of − 4·6 deg, 0·1 deg and + 5 deg. The range of Reynolds number for 0·1 deg pitch was from 1·4 to 40 millions approximately and for the other angles from 3·0 to 5·5 millions and from 15 to 35 millions.

3.3.3. *Results*.—The results have been plotted against Reynolds number and are shown in the Figs. 23 to 29. All the observations are shown and different kinds of points are in general used for different pressures. Repeat sets of observations are indicated with a different point for all pressures.

The drag coefficient, C_F is drag/qA where A is the wetted area of the model, 8·5 sq ft in the case of the hull model and 8·12 sq ft in the case of the fuselage. In calculating R, $l = 5$ ft, the length of the models.

In Fig. 29 the smooth curves (with no points shown) at zero pitch from the above figures have been reproduced on the same drawing for ease of comparing one model with another.

*The difference between these two fairings is extremely small. Also, the 1 in 6 fairing, which was the last to be tested, fitted badly owing to the repeated rubbing down of the main model and required considerable attention to ensure smooth joints.

The following table gives the values of C_F at Reynolds number of 40 millions for each of the models at the incidence specified :

Model hull with fin and cabin		Incidence (deg)				
Chine	Step	−3·9	−2·2	0·3	2·3	5·2
Normal	Normal	$0{\cdot}0049_5$	$0{\cdot}0046_5$	0·0046	0·0046	0·0047
	Straight fairing	0·0042		$0{\cdot}0034_5$		$0{\cdot}0035_5$
Faired	Normal	$0{\cdot}0048_5$	0·0046	$0{\cdot}0045_5$	$0{\cdot}0044_5$	$0{\cdot}0045_5$
	Straight fairing	$0{\cdot}0041_5$		0·0034		0·0033
	Convex fairing	0·0041		$0{\cdot}0034_5$		0·0034
	Streamline fairing	$0{\cdot}0038_5$		0·0036		0·0037
	Modified streamline	0·0042		0·0039		0·0041
	Concave 1 in 6 fairing	0·0046		0·0040		0·0039
	Concave 1 in 4 fairing	0·0047		$0{\cdot}0040_5$		$0{\cdot}0039_5$
Ref. 3. Hull with steps, no fin				$0{\cdot}0045_5$ (0 deg)		
Hull with faired steps, no fin				$0{\cdot}0036_5$ (0 deg)		

Fuselage with fin	Incidence (deg)		
	−4·6	0·1	+5
With cabin	0·0035	0·0032	0·0032
Without cabin	0·0035	0·0032	$0{\cdot}0031_5$
Basic model *with no fin* (Ref. 2)		0·0033 (0 deg)	

The change of drag with incidence is small at positive pitch angles, and the minimum drag occurs at positive pitch.

Fairing the chine has little effect.

The effect of step fairing is shown below by the ratios of the drag of the various models with faired step to that of the model with normal step at a Reynolds number of 40 millions (faired chine in all cases and pitch 0·3 deg) :

Straight fairing	$0{\cdot}74_5$
Convex fairing	0·75
Streamline fairing	0·79
Modified streamline fairing	$0{\cdot}85_5$

Concave 1 in 6 fairing	$0 \cdot 87_5$
Concave 1 in 4 fairing	$0 \cdot 88$
Corresponding ratio (Ref. 2)	
Straight or convex fairing, 2 steps	$0 \cdot 80$

The ratio of the drag of the fuselage with cabin and fin to that of the hull with straight step fairing is $0 \cdot 94$, which compares with $0 \cdot 91$ if comparison be made with the cambered streamline form.

These values show that of those tested, the most effective fairing is the straight fairing and that, using such a fairing, it is possible to design a hull having only 6 per cent more drag than a fuselage of similar surface area. The actual reduction in drag obtained by adopting the straight fairing is about 25 per cent in the present instance. The area of the step is about 9 per cent of the cross-section of the hull. In Ref. 3, a reduction of 20 per cent was obtained by fairing two steps, but the main step was shallower than the step of the present model and the after step was deeper and situated at a narrower part of the hull. The step area was about 8 per cent of the cross-section of the model.

The somewhat more drastic modification to the hull lines involved in the streamline fairing (Fig. 27) is less effective than the straight fairing. Deepening the step in this streamline fairing gives a higher C_F although the angle at the trailing edge is fine. The step is however deeper than the normal step.

Finally, the presence of the cabin does not affect the drag of the fuselage at high values of Reynolds number, though at low values there is an appreciable increase.

3.4. *Princess Hull with Various Streamline Step Fairings.*—3.4.1. *Introductory.*—Tunnel tests were made in the Compressed Air Tunnel in 1947 and 1948 to check the aerodynamic cleanness of the *Princess* hull and step fairings, as illustrated in Fig. 30. The original form of step fairing, entitled Modification ' N ' in Fig. 30, was a development of the streamlined step of section 3.3 with a step plan-form of elliptic shape. The step was however only faired in elevation to a distance back of twice the step depth at the keel because emphasis was placed in the first design on high hydrodynamic, rather than high aerodynamic, efficiency in the absence of full-scale evidence on the hydrodynamic efficiency of the more extreme step fairings. This step form was however found to contribute to a hull drag which was no better than that obtained with an unfaired transverse step in the earlier systematic tests of section 3.3. Tests on a succession of modifications to the step fairing in elevation were therefore made in the Saro Wind Tunnel and afterwards tests made on the finally selected form, modification ' AK ' of Fig. 30, in the Compressed Air Tunnel. This final form had a drag equivalent to that of the streamlined step of section 3.3. It was again not the lowest air drag form but the best considered admissible at the time for hydrodynamic reasons. The tests were made over a range of Reynolds numbers to explore scale effect, but represented an extension in technique over those of section 3 as they included the effects of testing two models, one half the length of the other, two positions in the tunnel relative to the jet throat, and a range of fixed transition positions of boundary-layer flow.

3.4.2. *Results of step fairing tests.*—Results of the Compressed Air Tunnel tests on the *Princess* hull, with step form Modification ' N ', are shown in Fig. 31 for a range of incidences and Reynolds numbers. Results at zero incidence are shown in Fig. 32, in comparison with the results obtained in the systematic series of section 3.3. The test conditions were the same as for this series, except that the hull had a better surface finish. The drag is no better than that of a hull with unfaired plan-form step, but decreases more rapidly with increase of Reynolds number, probably because of the improved surface conditions. This rather high drag for the step form was found to be due to insufficient step fairing at both the step and chines, and a series of fairings was tested at a

Reynolds number of $4 \cdot 1 \times 10^6$ in the Saro Wind Tunnel to reduce drag. The types of fairing tested and the results obtained are given in the following table :

Saro Wind Tunnel	
Princess hull	
Step fairing	C_F
Step 2 : 1 at keel, reduced towards chines (Mod. ' N ')	0·00477
8 : 1 at keel, reduced towards chines	0·00406
6 : 1 at keel, reduced towards chines	0·00426
Straight fairing, 8 : 1 at keel, extended towards chines	0·00380
Straight fairing, 8 : 1 at keel, extended towards chines, with cove ..	0·00386
Straight fairing, 10 : 1 at keel, extended towards chines	0·00365

Photographic recordings of the flow conditions, as illustrated by wool tufts, are shown in Fig. 33 for three stages of step fairing. These results showed conclusively that to obtain low drag it was essential not only to attain the order of a 6 : 1 fairing in side elevation in the keel region but to fair in well towards the chines so that minimum discontinuity, both of water lines, *i.e.*, planform, as well as of buttock lines, *i.e.*, elevation, was obtained. This principle is illustrated in Fig. 30 which shows the changes between Modification ' N ' and Modification ' AK ', the finer one used. The confirmatory test results in the Compressed Air Tunnel on Modification ' AK ' are given in Fig. 32 and show a drag reduction to that of the original streamline form at zero incidence.

3.4.3. *Results of scale-effect tests.*—Tests were made on the hull with modified step (Modification ' AK ') up to a Reynolds number of 40×10^6 with :

(*a*) a large model the same size (6·1 ft) as that of section 3, with free transition

(*b*) a model of half the length, with both free and fixed transition.

The two models were also tested at 3·3 in. and 14·4 in. back from the jet throat to check the effect of static-pressure correction on drag. A few measurements were also made on the basic streamline form of section 3.3, transition free, but with a better surface finish.

The transition position was controlled by the positioning of bands of roughness at successively 11 in., $6\frac{3}{4}$ in. and 3 in. from the front of the model. These bands consisted of a layer of carborundum powder, attached to the model with Frigilene and were about $\frac{3}{16}$ in. wide and $\frac{1}{40}$ in. thick. These could be easily applied and removed without damaging the surface of the model, which remained good throughout the test.

The points actually measured are shown in Fig. 34 for all conditions tested so as to indicate the order of consistency obtained with different tunnel pressures and speeds. An analysis of the results showing the effect of incidence, transition band, size and Reynolds number is given in Fig. 35. These results indicate that the transition from laminar to turbulent conditions may normally be at least 11 in. behind the nose for Reynolds numbers up to 7×10^6. The possible increase of air drag due to the drag of the transition band itself is not known, but there is a consistent increase of drag as this band is moved forward on the model, and even when at its furthest back the drag is still greater than that with transition free. Results were not extended to higher Reynolds numbers but the previous results of section 3, although with free transition, showed no obviously large movement of transition position for Reynolds numbers up to the order of 60×10^6. The slope of the curve of drag against Reynolds numbers is, however, steeper for the better finished *Princess* models, and is also about the same with and without fixed transition. This increased slope is also nearer that of the Prandtl-Schlichting turbulent skin-friction curve. The lesser slope of the earlier tests of section 3 is therefore probably due to the effect of greater roughness and the gradual forward movement of transition position with increase of Reynolds number.

The data show that these remarks are generally applicable over the range of incidences and model positions in the tunnel tested, although there is an unknown effect of change of static-pressure gradient correction on the drag. The body of revolution results on the better finished model, made with transition free, also gave a higher slope of drag curve and a smaller value of drag.

4. *Discussion.*—The British systematic data on hulls given in sections 2 and 3 may conveniently be summarised in the following table :

Reference	Hulls	Fairing, etc.	Remarks
A.R.C. 3143	Transverse main and aft steps. Beam increased and decreased. Elliptical and pointed plan-form steps. Tail turned up and down. Overhanging chines. Angle of deadrise increased and decreased.	Both steps faired to various degrees of elevation. Chines rounded.	Range of incidence. Basic streamlined form with and without turned up tail.
A.R.C. 3409	Transverse main and aft steps. $l_f/b = 2\cdot9$	Steps unfaired.	Zero incidence only. Basic body of revolution and also one with uncambered after-body.
A.R.C. 3794	Transverse main and aft steps. $l_f/b = 3\cdot2$	Both steps faired to various degrees in elevation.	
A.R.C. 7784	Pointed plan-form main and aft steps. With fin and with and without cabin. $l_f/b = 3\cdot2$	Range of fairings in plan and elevation.	Range of incidence. Streamlined body included fin and cabin.
Princess	Streamline main step.	Elevation fairings.	Range of incidence. Different transition conditions.

All tests were made with free transition, with the exception of a few on the *Princess* hull, but those made in Ref. 1 were made at a Reynolds number of $3\cdot8 \times 10^6$, whereas tests made in Refs. 2, 3, and 4 were made at a Reynolds number of 2×10^6 to 60×10^6.

The hull shapes of Refs. 1, 2 and 3 are basically the same, and were orthodox at the time of tests (1938), having a straight transverse main step and narrow transverse aft step, a short aft camber, a length/beam ratio of $5\cdot67$*, and height equal to the beam. They were designed for low beam loadings, hence the low height.

The hull of Ref. 4 was evolved on the basis of the results of the earlier tests for a specific design and was tested over a range of incidence, using a new balance technique developed for the purpose. The hull had a main step with some fairing in plan-form, as well as various fairings in elevation, and a rear step known as a ' pointed ' one, but which was essentially a highly faired

*Based on the length from bows to rear step.

plan-form step. The height of the hull was again rather low for propeller propulsion by contemporary standards (1954), because of the low design beam loading. Being a specific design case, the equivalent design shape (on the basis of which aerodynamic cleanness was assessed) was that of a fuselage with a cabin, fin and partially turned-up tail.

The results given in section 3.4 are for a hull form which represents probably the lowest drag shape built to date with orthodox fineness ratio and beam loading. The actual step fairing used was not the best aerodynamically which could have been accepted hydrodynamically, but at the time of design little information was available on the hydrodynamic characteristics, full scale, of highly faired steps.

Comparison of results of various shapes is made by means of the aerodynamic cleanness coefficient given in the introduction, and this clearly depends on the values assumed for the basic streamlined shape and, in particular, on whether boundary-layer conditions are similar for the various cases. A collection of surface drag coefficients for streamlined bodies of revolution, measured in the Compressed Air Tunnel, is shown in Fig. 36, plotted against Reynolds number. The figure also includes theoretical flat-plate and streamlined body shapes and measured camber-body drags.

On most of the bodies, the stabilisation of the transition position appears to be fairly complete at and above a Reynolds number of 20×10^6. Only above this value, therefore, would drag comparisons be expected to be reliable, provided the models were very smooth, and in fact the curves shown are very closely parallel to the theoretical ones. The first data available indicate that transition occurs well aft of the front up to Reynolds numbers of 8×10^6, but these results need checking.

The drag of the streamlined body of Ref. 4 does not, however, show a similar trend and therefore forms an unsound basis of comparison with the hulls of its series and also with the hulls of the other series of this report. In the analysis made in Ref. 5, the theoretical standard is adopted, together with a roughness correction, and all results are as far as possible compared for estimate purposes at a Reynolds number of 40×10^6. Because of these scale-effect difficulties, the effect of such changes as fairing of the chines, cambering of the hull and the presence of the cabin forward are very subject to changes of Reynolds number because of the effect of changes of pressure distribution on transition and also, therefore, on possible flow break-away. The low Reynolds number tests, for example, show considerable gain due to fairing the chines and very considerable increase of drag due to cambering the body of revolution, which changes are much reduced at Reynolds numbers exceeding 25×10^6. The effect of camber on hull drag is, in fact, still rather doubtful because of probable pronounced scale effects.

All the evidence available, however, indicates that gains due to step fairing and so on can be obtained up to the largest full scale Reynolds numbers to be expected and that the drag coefficient will continue to fall off with increase of Reynolds number at a rate predicted by the Prandtl-Schlichting turbulent friction curve. A more useful practical curve to use is probably at present that of Schoenherr[5], which is used in ship design up to Reynolds numbers of the order of 200×10^6.

5. *Conclusions*.—The tests on hull forms show conclusively that the major sources of drag increase of a hull, over that of an equivalent body of revolution, are in order of importance:

(*a*) step discontinuities

(*b*) turn up of the tail, *i.e.*, hull camber

(*c*) chine and planing-bottom discontinuities.

The combined effect of these hydrodynamic requirements, if little attempt is made to reduce air drag, is to make the drag of the flying-boat hull about 1·6 times that of the equivalent body of revolution of the same length and surface area. This result, given by the data in this report, is not applicable to hulls of higher fineness ratios which are being developed for specific future requirements (Ref. 5), since in such hulls the hydrodynamic modifications are of less significance.

The drag due to steps is the primary contribution, and it is now clear that this can be almost eliminated by the addition of step fairings. The hull drag should not then exceed the order of $1 \cdot 15$ times that of the equivalent body of revolution. If the amount of hull camber can be further reduced and its manner modified the drag of a hull should not then exceed $1 \cdot 10$ that of the equivalent body of revolution, and might well be less. This order of gain is to be expected at all values of Reynolds number likely to be met with full scale.

The drag due to the chines is small if the chine line be designed to lie along the chine flow direction and is not made to stand out proud from the sides or be provided with excessive chine flare or turn down on the planing bottom. A summary of the effect of various degrees of fairing on the cleanness ratio of the hulls tested in the Compressed Air Tunnel is given in Table 13, which is taken from Ref. 5.

With the aid of this data, it may therefore be said that the drag of a hull form need not exceed by very much the drag of a basic body of revolution. There still remains, however, the problem in some specific design cases of reducing the actual size of the hull, and this can be done very effectively by increase of length/beam ratio (Ref. 5).

Further, there is also the problem of retaining good hydrodynamic qualities in the presence of the great reduction of discontinuities by fairing for aerodynamic cleanness. Considerable improvement in the hydrodynamic characteristics is being obtained by developing new forms of step and afterbody on the basis of the method given in Ref. 7, when a fully faired afterbody is obtained by shaping it to fit the wake shape formed behind the forebody. Further wind-tunnel tests should be made to measure the effect of such changes in hull shape, and also the effect of the various forms of hull fairing described in this report, on hulls of much higher length/beam ratio.

REFERENCES

No.	*Author*	*Title, etc.*
1	K. W. Clark and D. Cameron	Wind-tunnel and tank tests on the drag of seaplane hulls. R.A.E. Report B.A. 1406. A.R.C. 3143. May, 1937.
2	R. Jones, A. H. Bell and E. Smyth ..	Resistance measurements on seaplane hulls in the Compressed Air Tunnel. A.R.C. 3409. February, 1938.
3	R. Jones and A. F. Brown	Tests on a flying-boat hull with faired steps in the Compressed Air Tunnel. A.R.C. 3794. November, 1938.
4	R. Jones, A. H. Bell and A. F. Brown ..	Drag measurements on a model of a flying-boat hull in the Compressed Air Tunnel. A.R.C. 7784. June, 1944.
5	A. G. Smith and J. E. Allen	Water and air performance of seaplane hulls as affected by fairing and fineness ratio. R. & M. 2896. August, 1950.
6	A. G. Smith, D. F. Wright and T. B. Owen	Towing tank tests on a large flying-boat seaplane (*Princess*, Spec. 10/46). Part II. Porpoising stability, spray and air drag tests, with improved step fairing, afterbody design and aerodynamic modifications. R. & M. No. 2834. November, 1950.
7	K. M. Tomaszewski and A. G. Smith ..	Some aspects of the flow round planing seaplane hulls or floats and improvements in step and afterbody design. Congress of Applied Mathematics. 1948. M.A.E.E. TN/4. A.R.C. 14,376. September, 1954.
8	Hilda M. Lyon	Effect of turbulence on drag of airship models. R. & M. 1511. August, 1932.
9	R. Jones, A. H. Bell and A. F. Brown ..	Experiments on the drag of streamline bodies in the Compressed Air Tunnel with a discussion of technique. A.R.C. 3373. February, 1938.

TABLE 1

(A.R.C. 3143. R.A.E. Tests)

Definition of Coefficients

$$C_D = \frac{D}{\frac{1}{2}\rho S V^2} \quad \text{where } S = \text{maximum cross-sectional area}$$

$$C_D' = \frac{D}{\frac{1}{2}\rho S' V^2} \quad \text{where } S' = (\text{volume of hull})^{2/3}$$

$$C_F = \frac{D}{\frac{1}{2}\rho S'' V^2} \quad \text{where } S'' = \text{surface area of hull.}$$

Hull areas used for coefficients

The hulls are all **5** ft in. length

Length / beam	Hull	S (sq ft)	Volume (cu. ft)	S' (sq ft)	S'' (sq ft)
7	(1) Basic circular form	0·400	1·235	1·150	8·23
	(2) As (1) with vee bottom added	0·408	1·225	1·145	8·45
	(3) As (2) with afterbody keel straightened	0·408	1·185	1·120	8·28
	(4) As (3) with steps added to form a complete hull..	0·408	1·200	1·128	8·40
	(5) As (4) with hollowed sections	0·402	1·180	1·116	8·49
	As (4) with 60 deg pointed main step	0·408	1·200	1·128	8·43
5·5		0·503	1·45	1·282	9·52
8·5	Unmodified hull	0·343	1·010	1·007	7·71
	Separate modifications :				
	Pointed rear step	0·343	1·030	1·019	7·90
	Tail turned down	0·343	1·025	1·018	7·78
	Tail turned up	0·343	0·995	0·996	7·65
	As last, widened across chines to $L/b = 5{\cdot}5$	0·379	1·090	1·059	8·53
	Deadrise angles reduced by 10 deg	0·360	1·070	1·045	7·96
	Deadrise angles increased by 10 deg	0·325	0·940	0·959	7·48
10		0·297	0·874	0·914	7·29

B

TABLE 2

(A.R.C. 3143. R.A.E. Tests)

Ordinates of Hull of Length to Beam Ratio 7

Distance from F.P. (in.)	Distance above base line (in.)			Half beam (in.)	Angle of deadrise (deg)
	Keel	Chine	Deck		
F.P.	4·285	4·285	4·285	0·0	—
0·6	2·83	4·225	5·57	1·285	47·3
1·8	1·89	3·89	6·43	2·145	43·0
3·0	1·30	3·45	6·95	2·665	38·9
6·0	0·47	2·55	7·715	3·43	31·2
12·0	0·01	1·665	8·345	4·06	22·2
18·0	0·0	1·545	8·535	4·25	20·0
24·0	0·0	1·56	8·57	4·285	20·0
25·2 F.	0·0	1·555	8·57	4·28	20·0
25·2 A.	0·335	1·89	8·57	4·28	20·0
30·0	0·95	2·81	8·57	4·14	24·2
36·0	1·72	3·82	8·57	3·75	29·3
42·0	2·49	4·63	8·57	3·125	34·4
48·6 F.	3·335	5·195	8·57	2·19	40·0
				Radius of circular tail	
48·6 A.	—	—	8·57	2·19	—
54·0	—	—	8·57	1·25	—
58·2 A.P.	—	—	8·57	0·395	—
60·0	—	—	8·57	0·0	—

The hulls of length to beam ratio 5·5, and 8·5 and 10 are derived from this hull, keeping the angles of deadrise the same and altering the beam measurements at the chine and above in the ratios of 7/5·5, 7/8·5 and 7/10.

TABLE 3

(A.R.C. 3143. R.A.E. Tests)

Basic Form to Complete Hull *Hull of Length to Beam Ratio* 7

For Drawings of Hulls see Figs. 1, 2 *and* 3

Hull	Reynolds number	Datum incidence (deg)	Drag (lb) at 100 ft/sec	C_D	C_D'	C_F
(1) Basic circular form, with level deck to after position	$3 \cdot 8 \times 10^6$	-5	0·445	0·0937	0·0326	0·00455
	$6 \cdot 3 \times 10^6$	-5	0·435	0·0916	0·0319	0·00444
	$3 \cdot 8 \times 10^6$	+0	0·351	0·0740	0·0257	0·00359
	$6 \cdot 3 \times 10^6$	0	0·342	0·0720	0·0250	0·00350
	$3 \cdot 8 \times 10^6$	5	0·315	0·0663	0·0231	0·00322
	$6 \cdot 3 \times 10^6$	5	0·314	0·0661	0·0231	0·00321
	$3 \cdot 8 \times 10^6$	7·5	0·325	0·0684	0·0238	0·00332
	$6 \cdot 3 \times 10^6$	+7·5	0·318	0·0669	0·0233	0·00325
	Minimum drag					
	$3 \cdot 8 \times 10^6$	+4·5	0·314	0·0660	0·0229	0·00321
	$6 \cdot 3 \times 10^6$	+3·0	0·307	0·0644	0·0225	0·00314
(2) Vee bottom added without steps, profile unaltered	$3 \cdot 8 \times 10^6$	-5	0·546	0·1126	0·0401	0·00544
	$6 \cdot 3 \times 10^6$	-5	0·521	0·1073	0·0383	0·00518
	$3 \cdot 8 \times 10^6$	+0	0·399	0·0824	0·0293	0·00397
	$6 \cdot 3 \times 10^6$	0	0·380	0·0784	0·0279	0·00378
	$3 \cdot 8 \times 10^6$	5	0·371	0·0765	0·0273	0·00369
	$6 \cdot 3 \times 10^6$	5	0·353	0·0728	0·0259	0·00351
	$3 \cdot 8 \times 10^6$	7·5	0·394	0·0814	0·0289	0·00392
	$6 \cdot 3 \times 10^6$	+7·5	—	—	—	—
	Minimum drag					
	$3 \cdot 8 \times 10^6$	+4·5	0·370	0·0765	0·0272	0·00368
	$6 \cdot 3 \times 10^6$	4·5	0·353	0·0728	0·0259	0·00352
(3) Keel of afterbody straightened	$3 \cdot 8 \times 10^6$	-5	0·608	0·1254	0·0456	0·00618
	$6 \cdot 3 \times 10^6$	-5	0·586	0·1208	0·0440	0·00596
	$3 \cdot 8 \times 10^6$	+0	0·412	0·0849	0·0309	0·00418
	$6 \cdot 3 \times 10^6$	0	0·388	0·0800	0·0291	0·00394
	$3 \cdot 8 \times 10^6$	5	0·356	0·0734	0·0267	0·00362
	$6 \cdot 3 \times 10^6$	5	0·341	0·0703	0·0256	0·00346
	$3 \cdot 8 \times 10^6$	7·5	0·372	0·0767	0·0279	0·00378
	$6 \cdot 3 \times 10^6$	+7·5	0·362	0·0746	0·0272	0·00368
	Minimum drag					
	$3 \cdot 8 \times 10^6$	+4·6	0·355	0·0732	0·0266	0·00361
	$6 \cdot 3 \times 10^6$	+4·2	0·340	0·0701	0·0255	0·00345

TABLE 3—*continued*

Hull	Reynolds number	Datum incidence (deg)	Drag (lb) at 100 ft/sec	C_D	C_D'	C_F
(4) Steps added for a complete hull	$3 \cdot 8 \times 10^6$	-5	0·643	0·1326	0·0479	0·00644
	$6 \cdot 3 \times 10^6$	-5	0·630	0·1300	0·0470	0·00631
	$3 \cdot 8 \times 10^6$	$+0$	0·477	0·0983	0·0355	0·00478
	$6 \cdot 3 \times 10^6$	0	0·459	0·0946	0·0342	0·00460
	$3 \cdot 8 \times 10^6$	5	0·450	0·0929	0·0336	0·00451
	$6 \cdot 3 \times 10^6$	5	0·437	0·0903	0·0327	0·00438
	$3 \cdot 8 \times 10^6$	7·5	0·487	0·1003	0·0363	0·00488
	$6 \cdot 3 \times 10^6$	$+7 \cdot 5$	0·470	0·0969	0·0350	0·00471
			Minimum drag			
	$3 \cdot 8 \times 10^6$	$+3 \cdot 5$	0·444	0·0915	0·0331	0·00444
	$6 \cdot 3 \times 10^6$	$+3 \cdot 0$	0·430	0·0887	0·0321	0·00431
(5) Sections hollowed between keel and chines	$3 \cdot 8 \times 10^6$	-5	0·683	0·1429	0·0514	0·00676
	$6 \cdot 3 \times 10^6$	-5	0·663	0·1388	0·0499	0·00657
	$3 \cdot 8 \times 10^6$	$+0$	0·501	0·1049	0·0377	0·00496
	$6 \cdot 3 \times 10^6$	0	0·481	0·1006	0·0362	0·00476
	$3 \cdot 8 \times 10^6$	5	0·466	0·0975	0·0351	0·00462
	$6 \cdot 3 \times 10^6$	5	0·451	0·0943	0·0340	0·00447
	$3 \cdot 8 \times 10^6$	7·5	0·506	0·1059	0·0381	0·00501
	$6 \cdot 3 \times 10^6$	$+7 \cdot 5$	0·489	0·1024	0·0368	0·00484
			Minimum drag			
	$3 \cdot 8 \times 10^6$	$+4 \cdot 0$	0·461	0·0965	0·0347	0·00457
	$6 \cdot 3 \times 10^6$	$+3 \cdot 5$	0·445	0·0931	0·0335	0·00441

TABLE 4

(A.R.C. 3143. R.A.E. Tests)

Effect of Length to Beam Ratio on Drag
See Fig. 3 for Cross-Sections of Hulls

Length to beam ratio	Reynolds number	Datum incidence (deg)	Drag (lb) at 100 ft/sec	C_D	C_D'	C_F
5·5	$3 \cdot 8 \times 10^6$	-5	0·803	0·1342	0·0527	0·00710
	$3 \cdot 8 \times 10^6$	0	0·565	0·0945	0·0371	0·00500
	$3 \cdot 8 \times 10^6$	$+5$	0·520	0·0869	0·0342	0·00460
	$3 \cdot 8 \times 10^6$	$+7 \cdot 5$	0·562	0·0939	0·0368	0·00497
	Minimum drag					
	$3 \cdot 8 \times 10^6$	$+4 \cdot 0$	0·514	0·0860	0·0337	0·00454
For L/B ratio 7 *see* Table 3, section (4)						
8·5	$3 \cdot 8 \times 10^6$	-5	0·545	0·1335	0·0455	0·00595
	$3 \cdot 8 \times 10^6$	0	0·421	0·1031	0·0352	0·00460
	$3 \cdot 8 \times 10^6$	$+5$	0·399	0·0977	0·0333	0·00435
	$3 \cdot 8 \times 10^6$	$+7 \cdot 5$	0·432	0·1059	0·0361	0·00471
	Minimum drag					
	$3 \cdot 8 \times 10^6$	$+3 \cdot 5$	0·394	0·097	0·0332	0·00433
10	$3 \cdot 8 \times 10^6$	-5	0·470	0·1331	0·0432	0·00542
	$6 \cdot 3 \times 10^6$	-5	0·464	0·1315	0·0428	0·00535
	$3 \cdot 8 \times 10^6$	$+0$	0·376	0·1065	0·0346	0·00433
	$6 \cdot 3 \times 10^6$	0	0·362	0·1027	0·0333	0·00412
	$3 \cdot 8 \times 10^6$	5	0·367	0·1040	0·0338	0·00424
	$6 \cdot 3 \times 10^6$	5	0·353	0·0999	0·0325	0·004075
	$3 \cdot 8 \times 10^6$	6·5	0·734	0·1059	0·0344	0·00432
	$6 \cdot 3 \times 10^6$	$+6 \cdot 5$	0·366	0·1037	0·0337	0·00422
	Minimum drag					
	$3 \cdot 8 \times 10^6$	$+3 \cdot 0$	0·365	0·1032	0·0336	0·00422
	$6 \cdot 3 \times 10^6$	$+3 \cdot 0$	0·349	0·0988	0·0321	0·00405

TABLE 5

(A.R.C. 3143. R.A.E. Tests)

Fairings to Steps

Hull of length to beam ratio 7.
For results for unfaired steps *see* Table 3, section 4.
For these results *see* Fig. 7.

Main Step Fairing

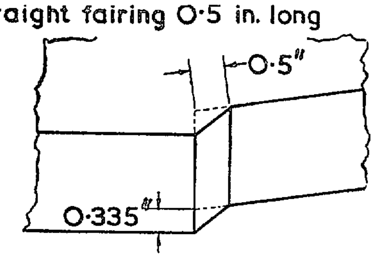
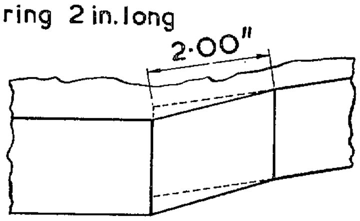
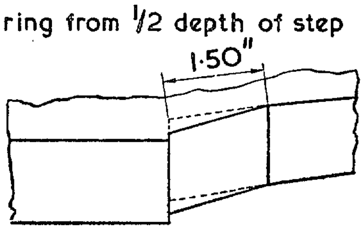
Fairing	Reynolds number	Datum incidence (deg)	Drag lb) at 100 ft/sec	C_D	C_D'	C_F
Straight fairing 0·5 in. long 	$3 \cdot 8 \times 10^6$	−5	0·633	0·1305	0·0472	0·00635
	$6 \cdot 3 \times 10^6$	−5	0·623	0·1285	0·0465	0·00624
	$3 \cdot 8 \times 10^6$	+0	0·471	0·0971	0·0351	0·00472
	$3 \cdot 8 \times 10^6$	5	0·448	0·0923	0·0334	0·00449
	$6 \cdot 3 \times 10^6$	5	0·441	0·0909	0·0329	0·00442
Similar to above with fairing 1 in. long	$3 \cdot 8 \times 10^6$	0	0·466	0·0960	0·0347	0·00467
	$3 \cdot 8 \times 10^6$	5	0·447	0·0921	0·0333	0·00448
	$6 \cdot 3 \times 10^6$	+5	0·436	0·0898	0·0325	0·00437
Fairing 1½ in. long	$3 \cdot 8 \times 10^6$	−5	0·576	0·1189	0·0429	0·00577
	$3 \cdot 8 \times 10^6$	+5	0·393	0·0810	0·0293	0·00394
Fairing 2 in. long 	$3 \cdot 8 \times 10^6$	−5	0·559	0·1153	0·0417	0·00560
	$3 \cdot 8 \times 10^6$	+0	0·403	0·0831	0·0301	0·00404
	$3 \cdot 8 \times 10^6$	5	0·372	0·0767	0·0277	0·00373
	$3 \cdot 8 \times 10^6$	7·5	0·412	0·0849	0·0307	0·00413
Fairing from ½ depth of step 	$3 \cdot 8 \times 10^6$	+5	0·437	0·0901	0·0326	0·00438
Similar to above with fairing 3 in. long	$3 \cdot 8 \times 10^6$	−5	0·604	0·1246	0·0450	0·00605
	$3 \cdot 8 \times 10^6$	+5	0·419	0·0864	0·0312	0·00420
Fairing 6 in. long	$3 \cdot 8 \times 10^6$	−5	0·589	0·1215	0·0439	0·00590

TABLE 6

(A.R.C. 3143. R.A.E. Tests)

Fairings to Steps

Hull of length to beam ratio 7. For results for unfaired steps *see* Table 3, section 4.

Main Step Fairing—continued

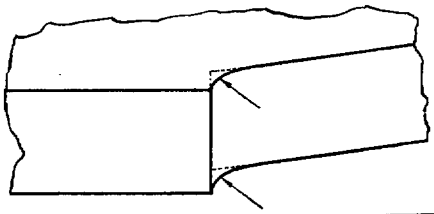
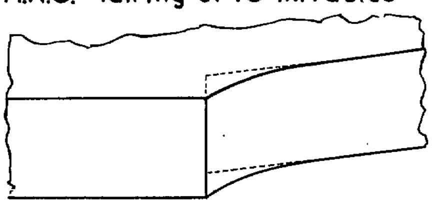
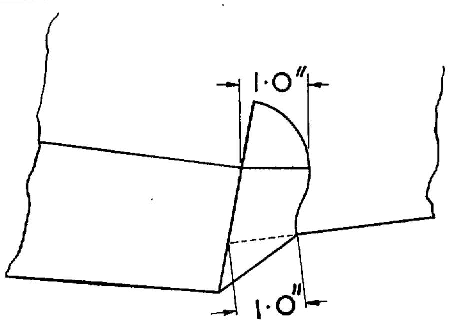
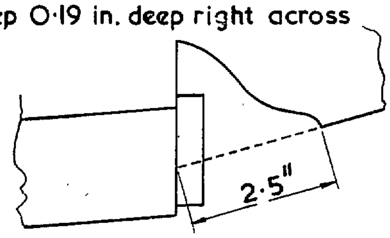
	Reynolds number	Datum incidence (deg)	Drag (lb) at 100 ft/sec	C_D	C_D'	C_F
A.R.C. fairing of 0·6 in. radius 	$3\cdot8 \times 10^6$	0	0·464	0·0956	0·0346	0·00465
	$3\cdot8 \times 10^6$	+5	0·446	0·0919	0·0332	0·00447
A.R.C. fairing of 10 in. radius 	$3\cdot8 \times 10^6$	+5	0·440	0·0907	0·0328	0·00441
			Rear step fairing— Main step not faired			
	$3\cdot8 \times 10^6$	−5	0·613	0·1265	0·0457	0·00614
	$3\cdot8 \times 10^6$	+5	0·436	0·0898	0·0327	0·00437
Similar to above but extended to 2·5 in. back at keel	$3\cdot8 \times 10^6$	−5	0·602	0·1242	0·0449	0·00603
	$3\cdot8 \times 10^6$	+5	0·418	0·0862	0·0312	0·00419
As above sliced away to leave step 0·19 in. deep right across 	$3\cdot8 \times 10^6$	−5	0·620	0·1279	0·0462	0·00621
	$3\cdot8 \times 10^6$	+5	0·436	0·0898	0·0325	0·00437
As above extended from 2·5 in. to 3·0 in. at keel	$3\cdot8 \times 10^6$	+5	0·427	0·0880	0·0318	0·00428

TABLE 7

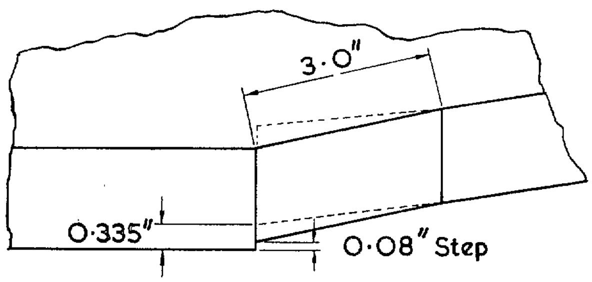
(A.R.C. 3143. R.A.E. Tests).

Fairings to Both Steps

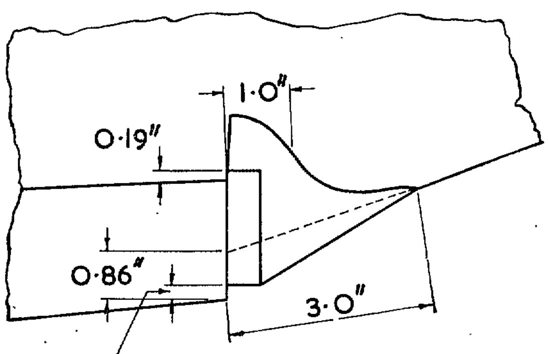
Hulls of four ratios of length to beam. For results on unfaired hulls *see* Table 4 and Figs. 5 and 6.

Fairings

Main step fairing



Rear step fairing



Reynolds number	Datum incidence (deg)	Drag (lb) at 100 ft/sec	C_D	C_D'	C_F
Length to beam ratio 5·5					
3·8 × 10⁶	−5	0·758	0·1269	0·0498	0·00671
3·8 × 10⁶	0	0·523	0·0877	0·0344	0·00463
3·8 × 10⁶	+5	0·478	0·0800	0·0314	0·00423
3·8 × 10⁶	+7·5	0·515	0·0862	0·0338	0·00456
Minimum drag					
3·8 × 10⁶	+4	0·474	0·0793	0·0311	0·00419
Length to beam ratio 7					
3·8 × 10⁶	−5	0·592	0·1221	0·0441	0·00593
3·8 × 10⁶	0	0·433	0·0894	0·0322	0·00434
3·8 × 10⁶	+5	0·399	0·0824	0·0298	0·00400
3·8 × 10⁶	+7·5	0·429	0·0883	0·0320	0·00430
Minimum drag					
	+4·5	0·392	0·0807	0·292	0·00392

Reynolds number	Datum incidence (deg)	Drag (lb) at 100 ft/sec	C_D	C_D'	C_F
Length to beam ratio 8·5					
3·8 × 10⁶	−5	0·504	0·1236	0·0421	0·00554
	0	0·381	0·0934	0·0318	0·00419
	+5	0·353	0·0866	0·0295	0·00388
	+7·5	0·378	0·0929	0·0317	0·00416
Minimum drag					
3·8 × 10⁶	+4	0·350	0·0859	0·0292	0·00382
Length to beam ratio 10					
3·8 × 10⁶	−5	0·444	0·1257	0·0408	0·00512
3·8 × 10⁶	0	0·347	0·0983	0·0319	0·00400
3·8 × 10⁶	+5	0·329	0·0932	0·0303	0·00380
3·8 × 10⁶	+7·5	0·355	0·1006	0·0327	0·00410
Minimum drag					
3·8 × 10⁶	+3·6	0·326	0·0 924	0·030	0·00376

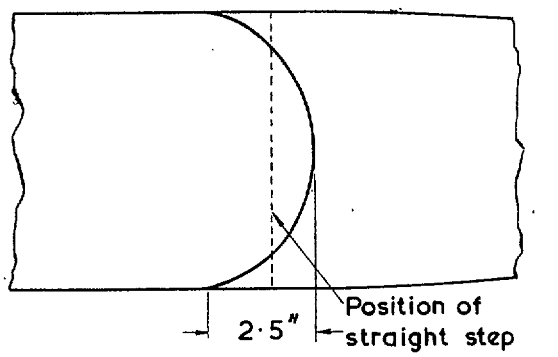
TABLE 8

(A.R.C. 3143. R.A.E. Tests)

Elliptical and Pointed Main Steps

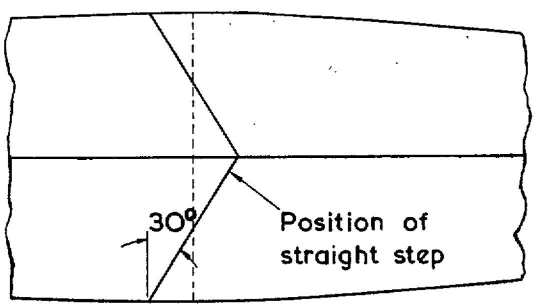
Hull of length to beam ratio 7.
For results with straight step *see* Table 3 and Fig. 4
For these results *see* Fig. 9.

Elliptical step



Depth of step. Normal at keel (0·335 in.) and 1/2 depth at chines

30 deg Pointed step



Depth of step — 0·335 in. throughout

Step	Reynolds number	Datum incidence (deg)	Drag (lb) at 100 ft/sec	C_D	C_D'	C_F
Elliptical step	$3{\cdot}8 \times 10^6$	−5	0·673	0·1389	0·0501	0·00674
		0	0·556	0·1146	0·0415	0·00557
		+5	0·537	0·1108	0·0401	0·00538
	Minimum drag					
	$3{\cdot}8 \times 10^6$	+3·6	0·530	0·1088	0·0395	0·00531
30 deg Pointed step	$3{\cdot}8 \times 10^6$	−5	0·634	0·1309	0·0472	0·00635
		0	0·496	0·1024	0·0370	0·00497
		+5	0·468	0·0967	0·0349	0·00469
		+7·5	0·491	0·1016	0·0367	0·00492
	Minimum drag					
	$3{\cdot}8 \times 10^6$	+3·6	0·463	0·0950	0·0345	0·00464
60 deg Pointed step. *See* Fig. 8. Normal depth at keel (0·335 in.) and ½ depth at chines	$3{\cdot}8 \times 10^6$	−5	0·591	0·1219	0·0440	0·00590
	$6{\cdot}3 \times 10^6$	−5	0·577	0·1189	0·0430	0·00576
	$3{\cdot}8 \times 10^6$	0	0·443	0·0914	0·0330	0·00443
	$3{\cdot}8 \times 10^6$	+5	0·423	0·0873	0·0315	0·00423
	$6{\cdot}3 \times 10^6$	+5	0·411	0·0848	0·0306	0·004411
	$3{\cdot}8 \times 10^6$	+7·5	0·466	0·0962	0·0348	0·00466
	Minimum drag					
	$3{\cdot}8 \times 10^6$	+3·2	0·415	0·0864	0·0309	0·00416

TABLE 9

(A.R.C. 3143. R.A.E. Tests)

Pointed Rear Step on Hull of Length to Beam Ratio 8·5.
For Hull drawing see Fig. 10.

Reynolds number	Datum incidence (deg)	Drag (lb) at 100 ft/sec	C_D	C_D'	C_F	Unmodified hull	Results
$3 \cdot 8 \times 10^6$	−5	0·473	0·1160	0·0390	0·00504	Table 4	Fig. 12
$6 \cdot 3 \times 10^6$	−5	0·457	0·1120	0·0377	0·00486		
$3 \cdot 8 \times 10^6$	+0	0·384	0·0942	0·0317	0·00409		
$6 \cdot 3 \times 10^6$	0	0·363	0·0890	0·0299	0·00386		
$3 \cdot 8 \times 10^6$	5	0·381	0·0934	0·0314	0·00406		
$6 \cdot 3 \times 10^6$	5	0·361	0·0885	0·0298	0·00384		
$3 \cdot 8 \times 10^6$	+7·5	0·416	0·1020	0·0343	0·00443		
$6 \cdot 3 \times 10^6$	+7·5	0·395	0·0968	0·0326	0·00421		
		Minimum drag					
$3 \cdot 8 \times 10^6$	+2·6	0·375	0·0920	0·0309	0·00400		
$6 \cdot 3 \times 10^6$	+2·6	0·355	0·0871	0·0293	0·00378		

TABLE 10

(A.R.C. 3143. R.A.E. Tests)

Effect of Turning the Afterbody Down and Up and Overhanging the Chines

Hull of Length to Beam Ratio 8·5.
See Table 4 for Results for Normal Hull.

Hull	Reynolds number	Datum incidence (deg)	Drag (lb) at 100 ft/sec	C_D	C_D'	C_F	Unmodified hull	Results
Tail turned down, angle between steps reduced by 3 deg	$3 \cdot 8 \times 10^6$	-5	0·437	0·1072	0·0361	0·00473	Table 4	Fig. 12
	$6 \cdot 3 \times 10^6$	-5	0·426	0·1045	0·0352	0·00461		
	$3 \cdot 8 \times 10^6$	$+8$	0·367	0·0900	0·0303	0·00397		
	$6 \cdot 3 \times 10^6$	0	0·350	0·0858	0·0289	0·00378		
	$3 \cdot 8 \times 10^6$	5	0·388	0·0952	0·0321	0·00419		
	$6 \cdot 3 \times 10^6$	5	0·368	0·0903	0·0304	0·00398		
	$3 \cdot 8 \times 10^6$	7·5	0·435	0·1066	0·0359	0·00470		
	$6 \cdot 3 \times 10^6$	$+7 \cdot 5$	0·414	0·1015	0·0342	0·00448		
	Minimum drag							
	$3 \cdot 8 \times 10^6$	$+1 \cdot 2$	0·365	0·0895	0·0301	0·00395		
	$6 \cdot 3 \times 10^6$	$+1 \cdot 5$	0·347	0·0851	0·0287	0·00375		
Tail turned up, angle between steps increased by 3 deg	$3 \cdot 8 \times 10^6$	-5	0·660	0·1619	0·0558	0·00726		
	$6 \cdot 3 \times 10^6$	-5	0·642	0·1575	0·0542	0·00706		
	$3 \cdot 8 \times 10^6$	0	0·484	0·1187	0·0409	0·00532		
	$6 \cdot 3 \times 10^6$	0	0·464	0·1139	0·0392	0·00510		
	$3 \cdot 8 \times 10^6$	$+5$	0·428	0·1050	0·0631	0·00471		
	$6 \cdot 3 \times 10^6$	$+5$	0·411	0·1008	0·0347	0·00452		
	$3 \cdot 8 \times 10^6$	$+7 \cdot 5$	0·442	0·1084	0·0373	0·00486		
	$6 \cdot 3 \times 10^6$	$+7 \cdot 5$	0·424	0·1040	0·0358	0·00466		
	Minimum drag							
	$3 \cdot 8 \times 10^6$	$+5$	0·428	0·1050	0·0361	0·00471		
	$6 \cdot 3 \times 10^6$	$+5$	0·411	0·1008	0·0347	0·00452		

TABLE 10—*continued*

(A.R.C. 3143. R.A.E. Tests)

Effect of Turning the Afterbody Down and Up and Overhanging the Chines

Hull of Length to Beam Ratio 8·5 *with Tail Turned Up Widened to* 5·5 *Across the Chines.*

For Hull Drawing see Fig. 13.

Hull	Reynolds number	Datum incidence (deg)	Drag (lb) at 100 ft/sec	C_D	C_D'	C_F	Unmodified hull	Results
Overhanging chines	$3 \cdot 8 \times 10^6$	−5	0·960	0·2131	0·0762	0·00946	Fig. 14	
	$6 \cdot 3 \times 10^6$	−5	0·944	0·2097	0·0749	0·00931		
	$3 \cdot 8 \times 10^6$	+0	0·661	0·1466	0·0525	0·00652		
	$6 \cdot 3 \times 10^6$	0	0·647	0·1436	0·0514	0·00638		
	$3 \cdot 8 \times 10^6$	5	0·706	0·1566	0·0560	0·00696		
	$6 \cdot 3 \times 10^6$	5	0·694	0·1540	0·0551	0·00684		
	$3 \cdot 8 \times 10^6$	7·5	0·842	0·1869	0·0668	0·00830		
	$6 \cdot 3 \times 10^6$	+7·5	0·831	0·1845	0·0660	0·00819		
				Minimum drag				
	$3 \cdot 8 \times 10^6$	+1·6	0·653	0·1449	0·0518	0·00644		
	$6 \cdot 3 \times 10^6$	+1·5	0·640	0·1418	0·0508	0·00631		

TABLE 11

(A.R.C. 3143. R.A.E. Tests)

Chines Rounded off in Stages with Radius of 0·125 in. on Complete Hull of Length to Beam Ratio 7.

	Reynolds number	Datum incidence (deg)	Drag (lb) at 100 ft/sec	C_D	C_D'	C_F	Unmodified hull	Results
From bow half-way to main step	3·8 × 10^6	−5 +5	0·620 0·429	0·1279 0·0884	0·0462 0·0320	0·00621 0·00430	Table 3	Fig. 15
From bow to main step	3·8 × 10^6	−5 +5	0·598 0·427	0·1234 0·088	0·0446 0·0318	0·00600 0·00428	Table 3	Fig. 15
From bow to half-way between steps	3·8 × 10^6	−5 +5	0·594 0·423	0·1225 0·0872	0·0443 0·0315	0·00595 0·00424	Table 3	Fig. 15
From bow to rear step	3·8 × 10^6	−5 0 +5 +7·5	0·596 0·452 0·422 0·443	0·1230 0·0930 0·0870 0·0910	0·0444 0·0337 0·0315 0·0330	0·00597 0·00453 0·00423 0·00442	Table 3	Fig. 15 and figure not reproduced (Fg. 17 of A.R.C. 3143)
Minimum drag								
	3·8 × 10^6	+4	0·421	0·0869	0·0314	0·00422	Table 3	Figure not reproduced (Fig. 17 of A.R.C. 3143)

TABLE 12

(A.R.C. 3143. R.A.E. Tests)

Alterations to Angle of Vee Bottom on Hull of Length to Beam Ratio 8·5

For unmodified hull see Table 3, *section* 4.

Hull	Reynolds number	Datum incidence (deg)	Drag (lb) at 100 ft/sec	C_D	C_D'	C_F
Obtuse Vee bottom. Angles of deadrise reduced by 10 deg	$3 \cdot 8 \times 10^6$	−5	0·555	0·1296	0·0447	0·00586
	$6 \cdot 3 \times 10^6$	−5	0·538	0·1260	0·0433	0·00568
	$3 \cdot 8 \times 10^6$	+0	0·441	0·1030	0·0355	0·00466
	$6 \cdot 3 \times 10^6$	0	0·424	0·0990	0·0341	0·00448
	$3 \cdot 8 \times 10^6$	5	0·426	0·0995	0·0343	0·00450
	$6 \cdot 3 \times 10^6$	5	0·412	0·0962	0·0332	0·00435
	$3 \cdot 8 \times 10^6$	7·5	0·459	0·1072	0·0369	0·00485
	$6 \cdot 3 \times 10^6$	+7·5	0·443	0·1035	0·0356	0·00468
			Minimum drag			
	$3 \cdot 8 \times 10^6$	+3·2	0·420	0·0981	0·0338	0·00446
	$6 \cdot 3 \times 10^6$	+3·2	0·405	0·0946	0·0326	0·00428
Acute Vee bottom. Angles of deadrise increased by 10 deg	$3 \cdot 8 \times 10^6$	−5	0·512	0·1325	0·0449	0·00576
	$6 \cdot 3 \times 10^6$	−5	0·494	0·1278	0·0433	0·00555
	$3 \cdot 8 \times 10^6$	+0	0·396	0·1025	0·0347	0·00445
	$6 \cdot 3 \times 10^6$	0	0·378	0·0978	0·0332	0·00425
	$3 \cdot 8 \times 10^6$	5	0·377	0·0976	0·0331	0·00424
	$6 \cdot 3 \times 10^6$	5	0·363	0·0939	0·0318	0·00408
	$3 \cdot 8 \times 10^6$	7·5	0·403	0·1043	0·353	0·00453
	$6 \cdot 3 \times 10^6$	+7·5	0·388	0·1004	0·0340	0·00326
			Minimum drag			
	$3 \cdot 8 \times 10^6$	+3·5	0·373	0·0965	0·0327	0·00419
	$6 \cdot 3 \times 10^6$	+3·2	0·358	0·0927	0·0314	0·00403

TABLE 13

The Effect of Degree of Fairing on Cleanness Ratio :
Surface Drag Coefficients Measured in the Compressed Air Tunnel

All values refer to $0 \cdot 3$ deg incidence, unfaired chines and a Reynolds number $R_N = 40 \times 10^6$.

Condition	C_F	K
Hull with normal step	$0 \cdot 00460$	$1 \cdot 51$
Hull with $6 \cdot 1$ concave step fairing	$0 \cdot 00403$	$1 \cdot 32$
Step faired in plan-form only	$0 \cdot 00390$	$1 \cdot 28$
Step faired in plan and elevation	$0 \cdot 00358$	$1 \cdot 17$
Step with straight 9 : 1 fairing	$0 \cdot 00343$	$1 \cdot 13$
*Basic fuselage with turned up tail ($3 \cdot 2$ per cent camber, cabin and fin)	$0 \cdot 00320$	—
N.P.L. A.R.C. 3409, $7 \cdot 1$ per cent cambered body	$0 \cdot 00330$	$1 \cdot 08$
†Cambered body derived from N.P.L. R.101	$0 \cdot 00314$	$1 \cdot 03$
N.P.L. A.R.C. 3409 symmetrical body	$0 \cdot 00312$	$1 \cdot 02$
N.P.L. R.101 symmetrical body (basic)	$0 \cdot 00305$	$1 \cdot 00$
Theoretical value for streamline body	$0 \cdot 00270$	$(0 \cdot 89)$
Prandtl-Schlichting flat-plate turbulent value	$0 \cdot 00244$	$(0 \cdot 80)$

* Suspect model.

† Assuming camber increment from A.R.C. 3409.

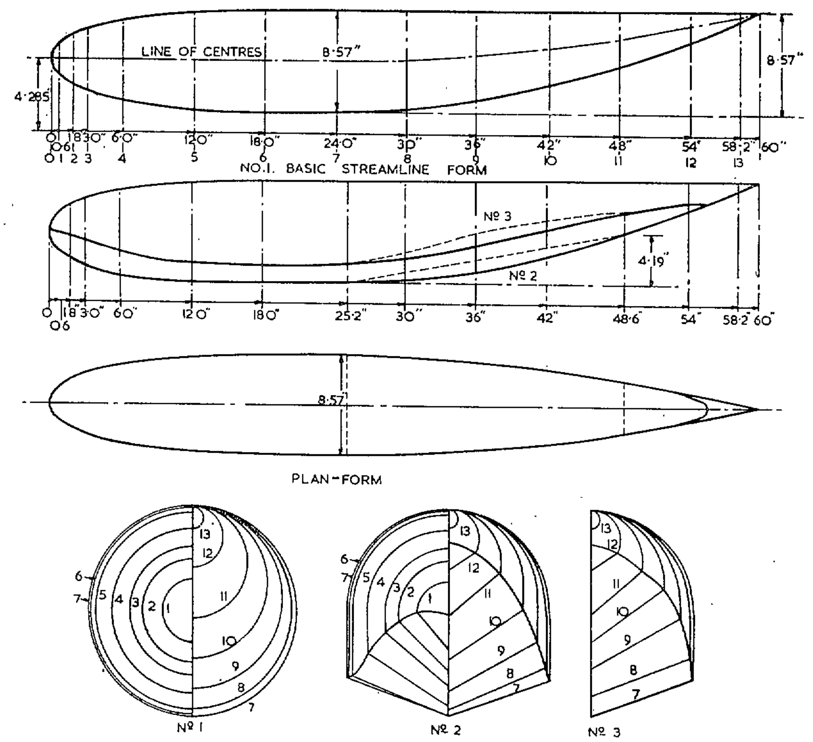


FIG. 1. Basic streamline form and the addition of Vee bottom (A.R.C. 3143).

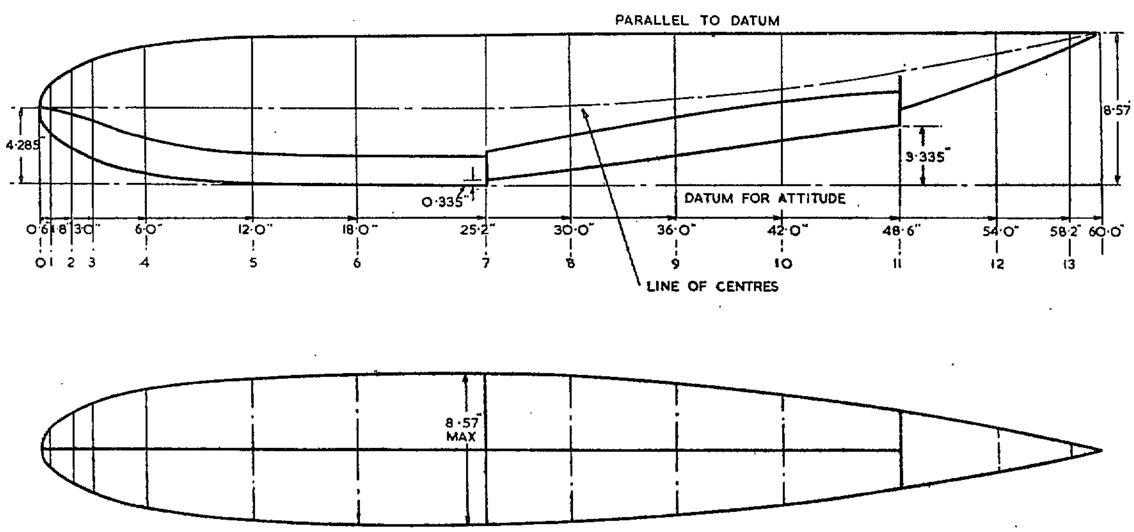


FIG. 2. Hull of length to beam ratio 7 (A.R.C. 3143).

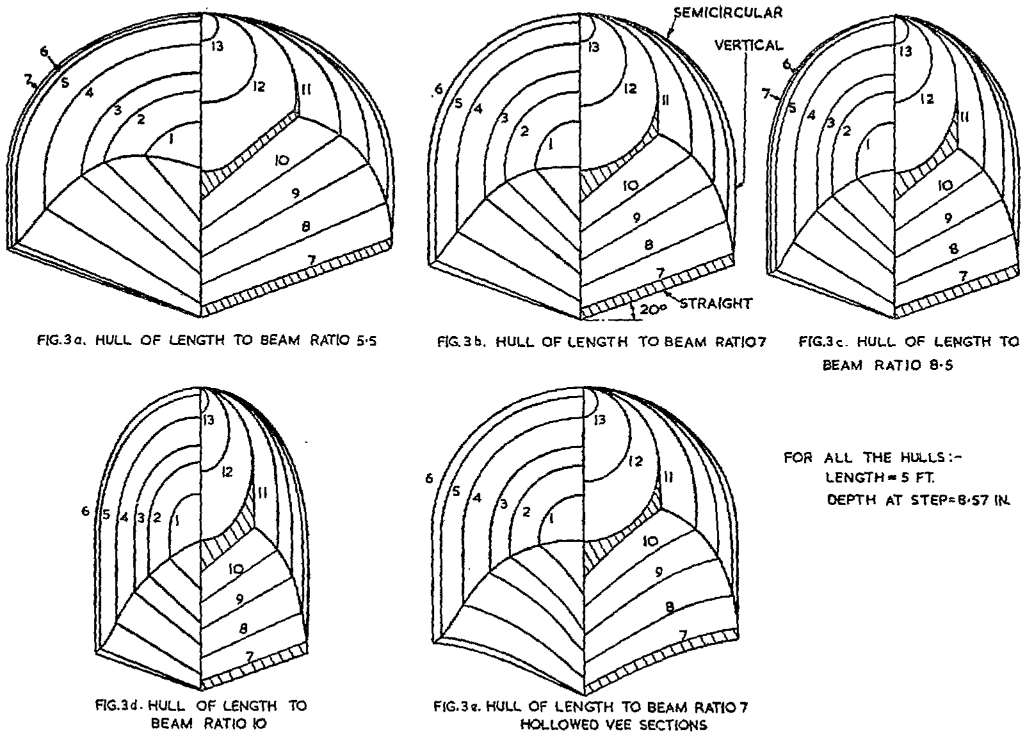


FIG. 3. Cross-sections of hulls (A.R.C. 3143).

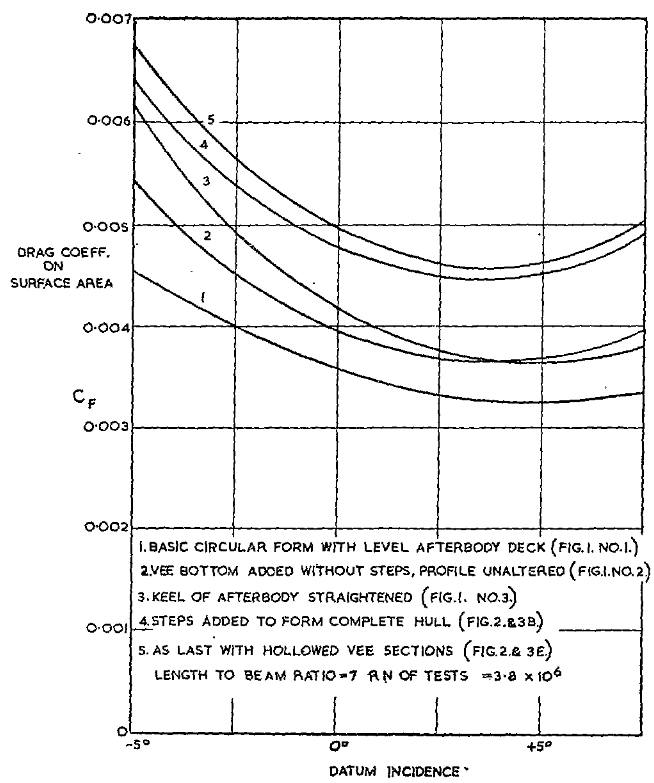


FIG. 4. From basic form to complete hull in stages (A.R.C. 3143).

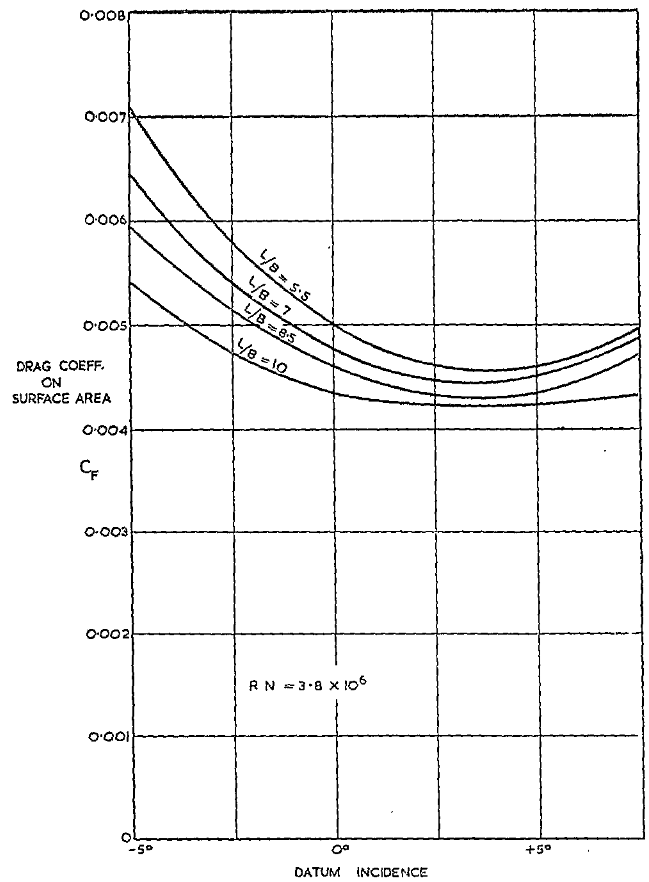


FIG. 5. Effect of beam. All hulls 5 ft in length by 8·57 in. in depth. *See* Figs. 3a, 3b, 3c and 3d. (A.R.C. 3143).

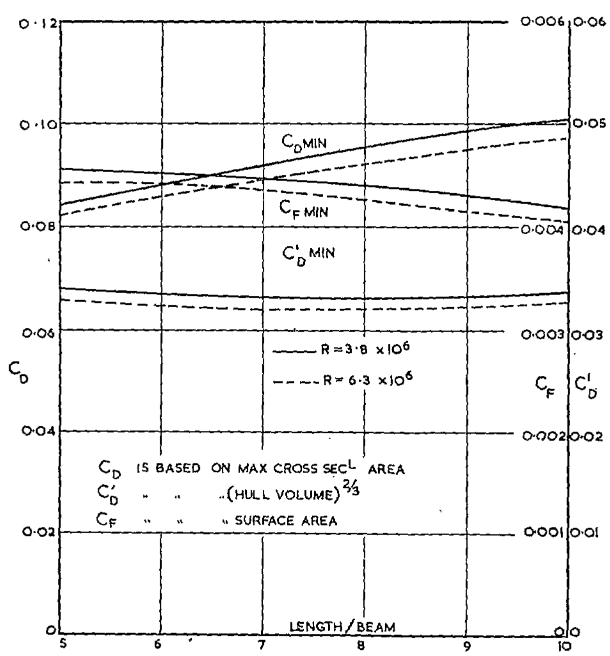


FIG. 6. Variation of air drag with beam (A.R.C. 3143).

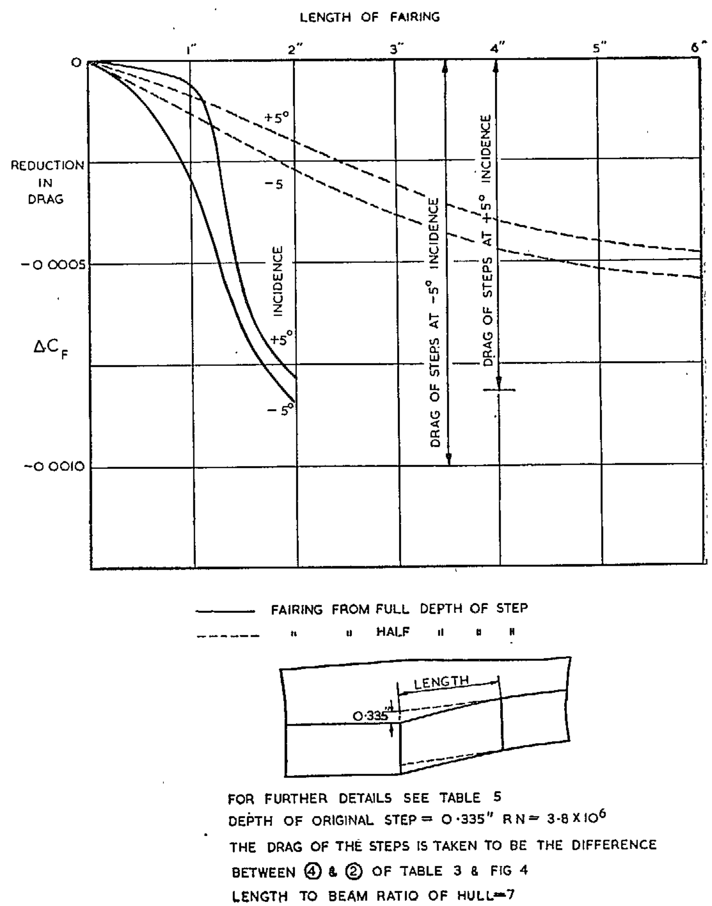


FIG. 7. The drag saved by fairing the main step (A.R.C. 3143).

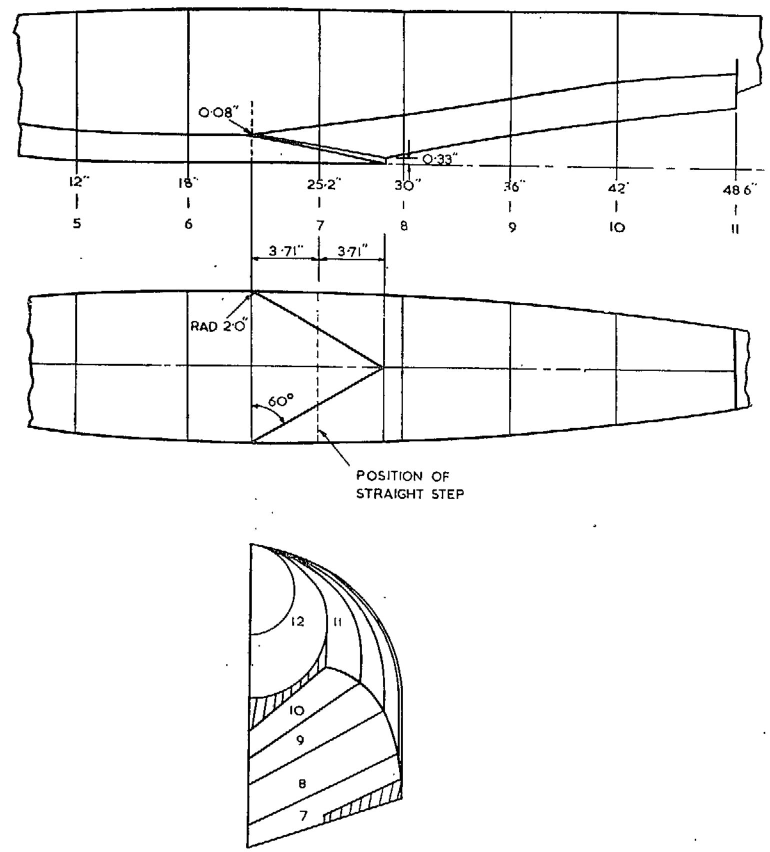


FIG. 8. 60-deg pointed step. Hull of length/beam = 7 (A.R.C. 3143).

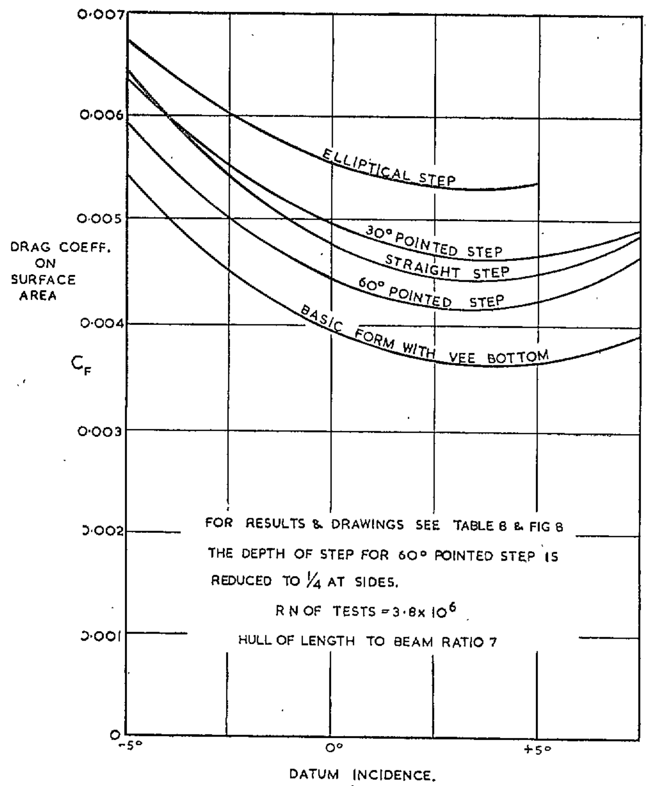


FIG. 9. Comparative drag of elliptical, pointed and straight steps (A.R.C. 3143).

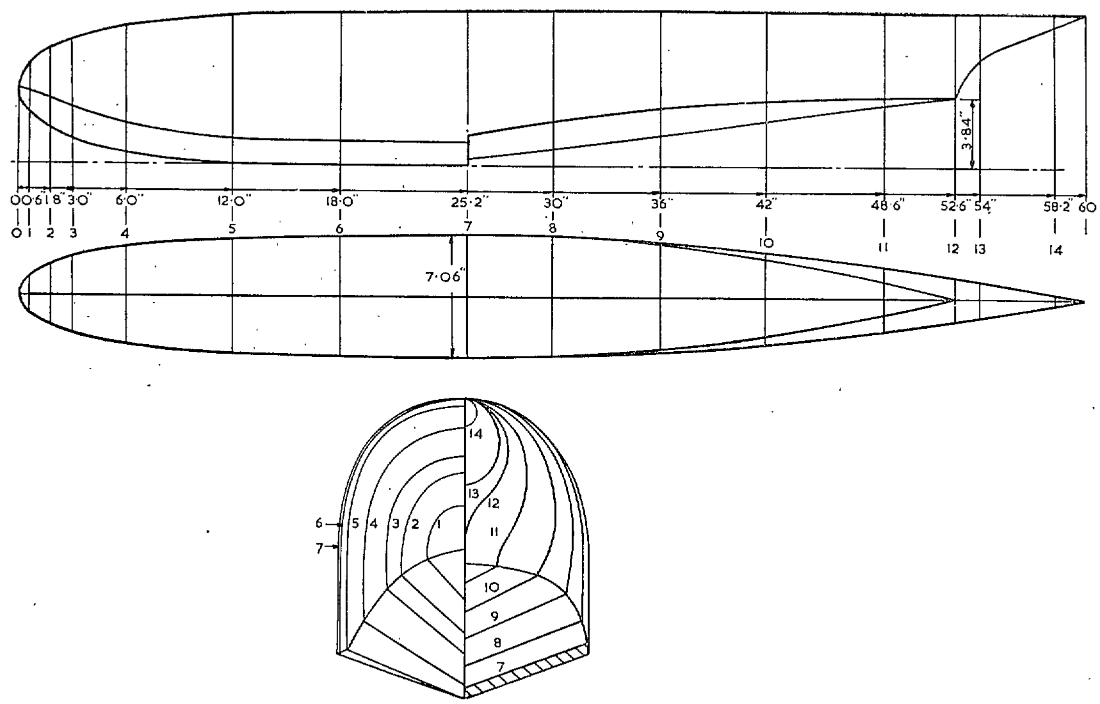


FIG. 10. Pointed rear step on hull of length to beam ratio 8·5 (A.R.C. 3143).

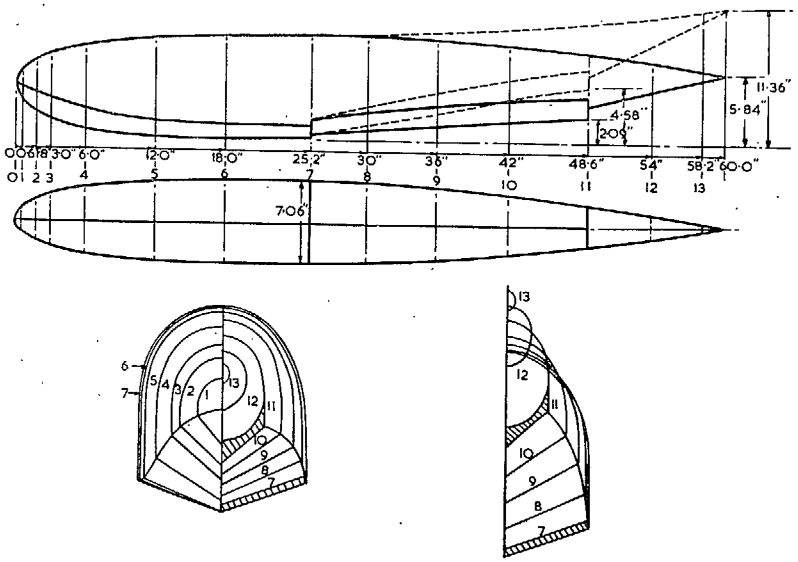


FIG. 11. Afterbody swept up and down on hull of length to beam ratio 8·5 (A.R.C. 3143).

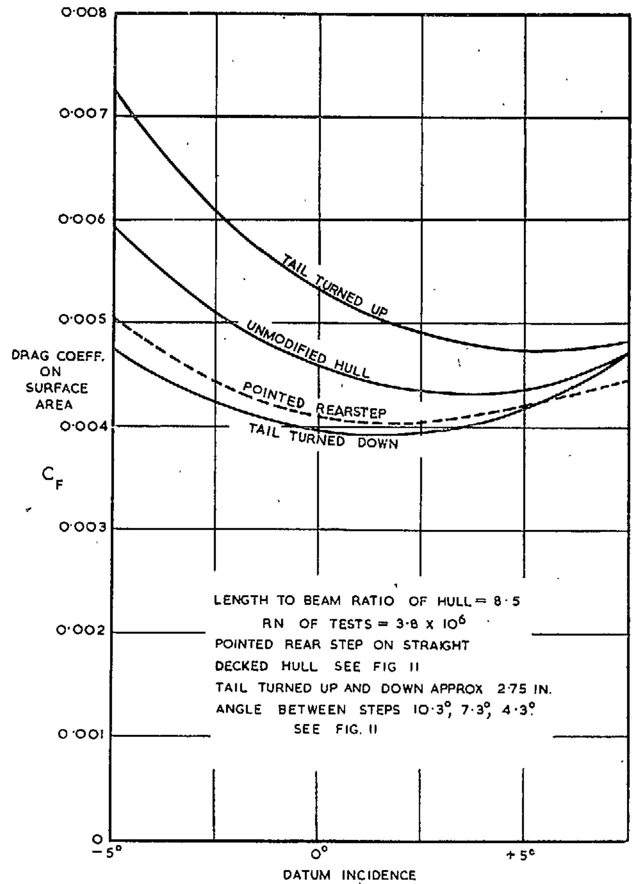


FIG. 12. Drag with pointed rear step and tail turned up and turned down (A.R.C. 3143).

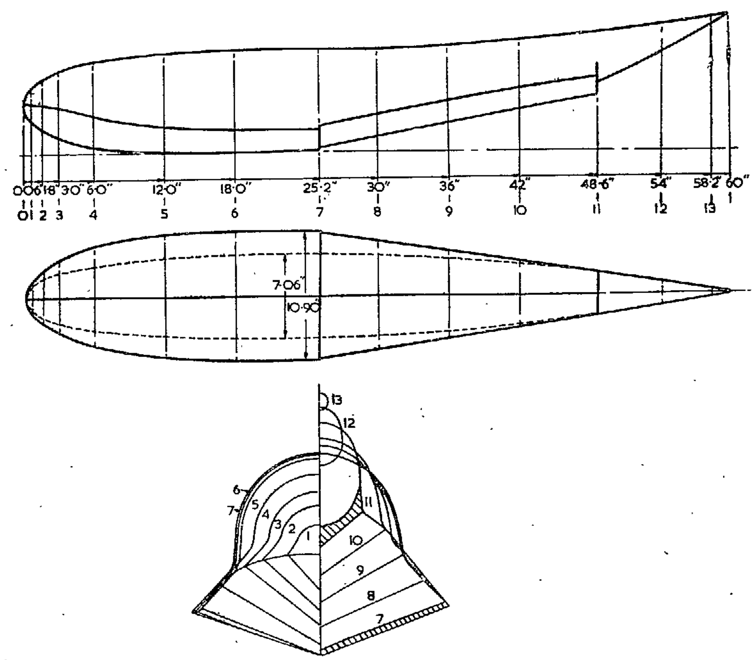


FIG. 13. Hull of length to beam ratio 8·5 widened to 5·5 across chines (A.R.C. 3143).

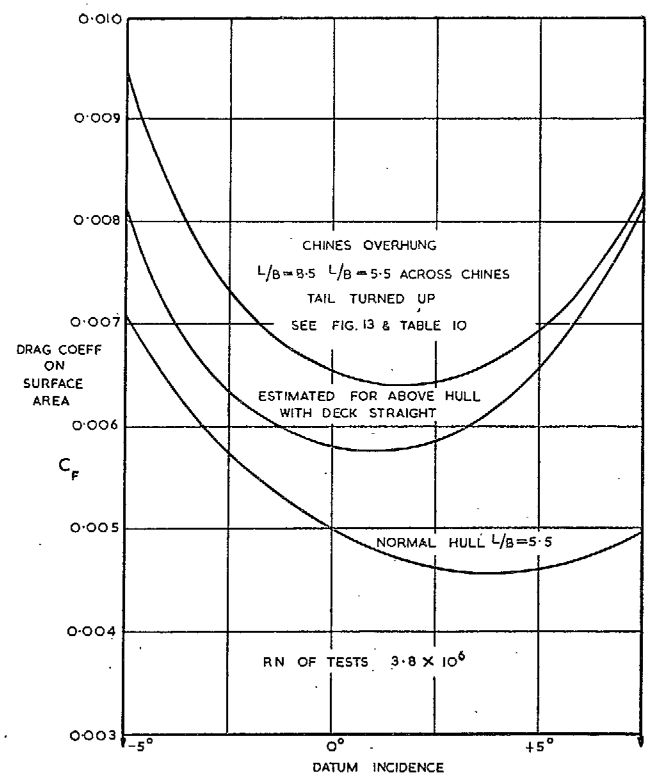


FIG. 14. Effect of overhanging chines (A.R.C. 3143).

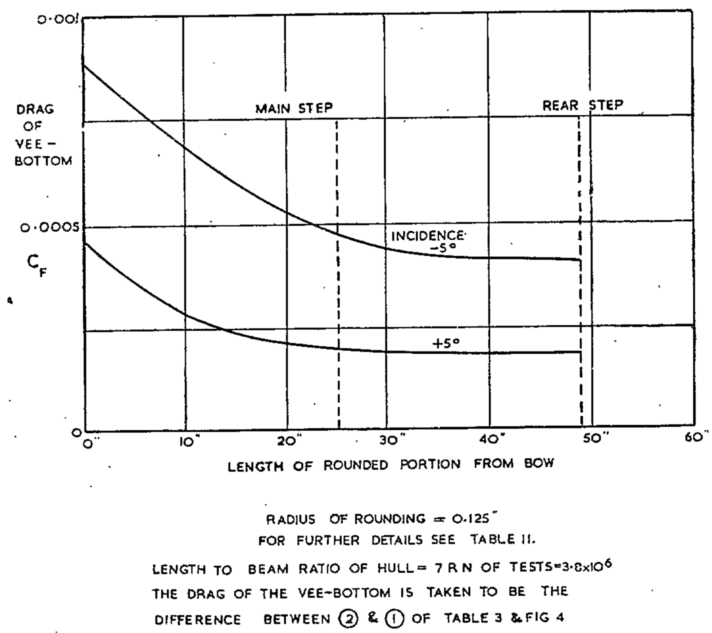


FIG. 15. Saving in drag due to rounding off the chines in stages (A.R.C. 3143).

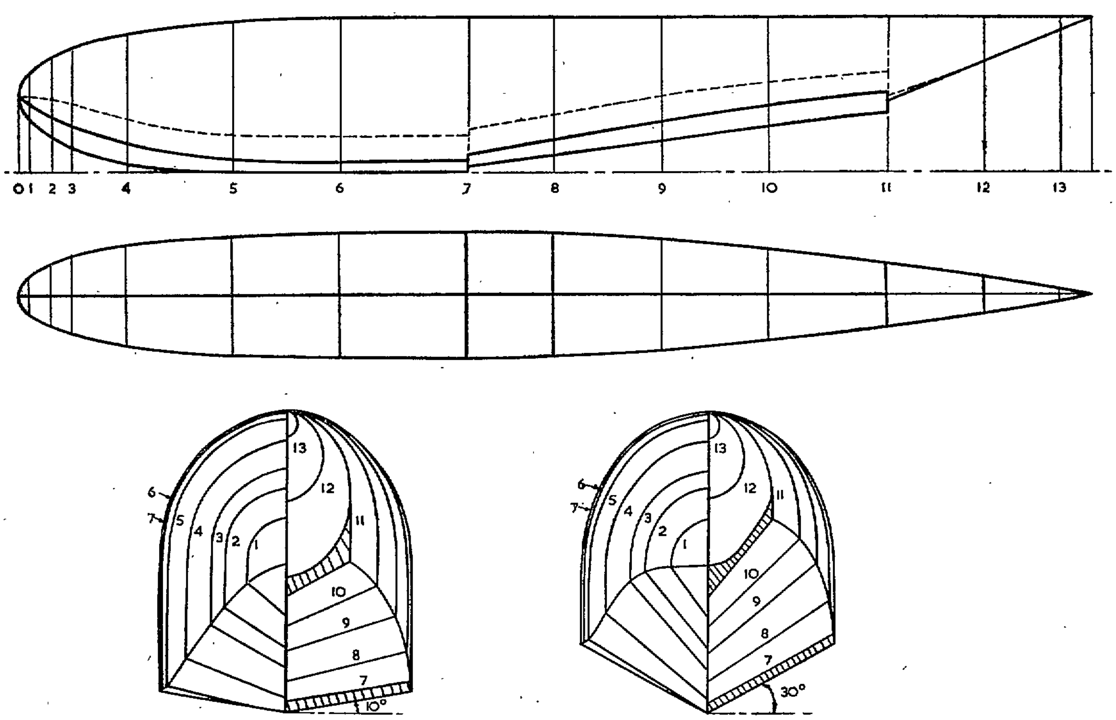


FIG. 16. Angle of deadrise decreased and increased by 10 deg. Length to beam ratio 8·5 (A.R.C. 3143).

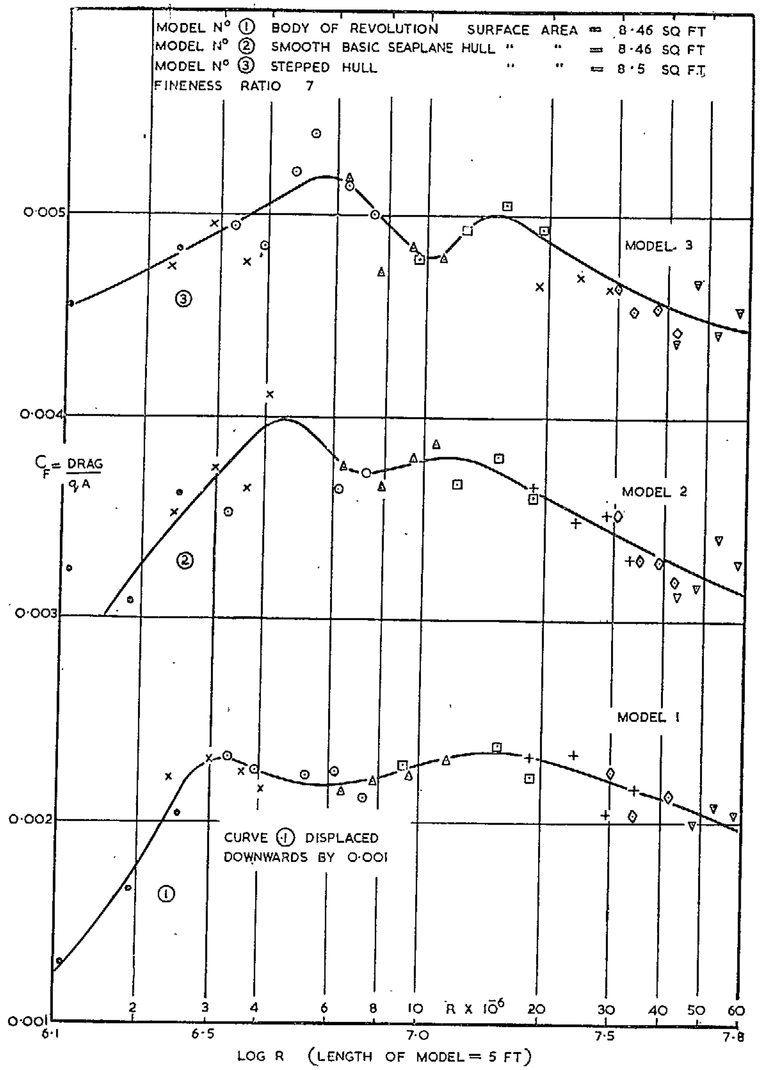


FIG. 17. Drag of basic form to complete hull with unfaired steps. Reynolds numbers 1 to 60 $\times 10^6$ (A.R.C. 3409).

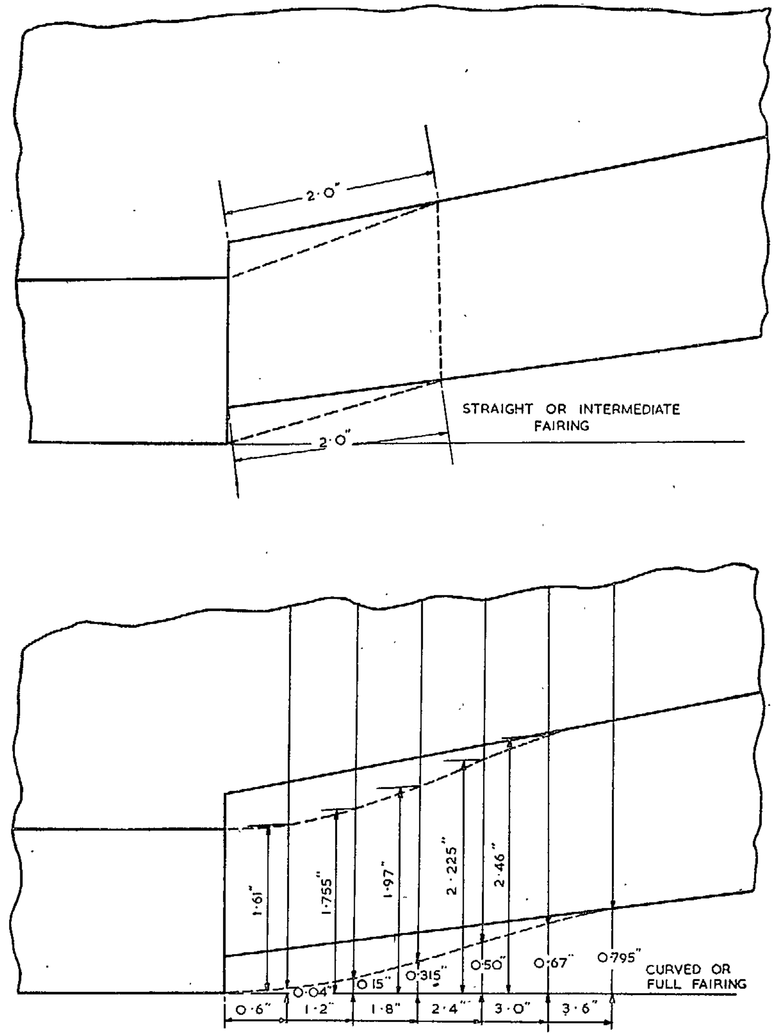


FIG. 18. Details of main-step fairing (A.R.C. 3794).

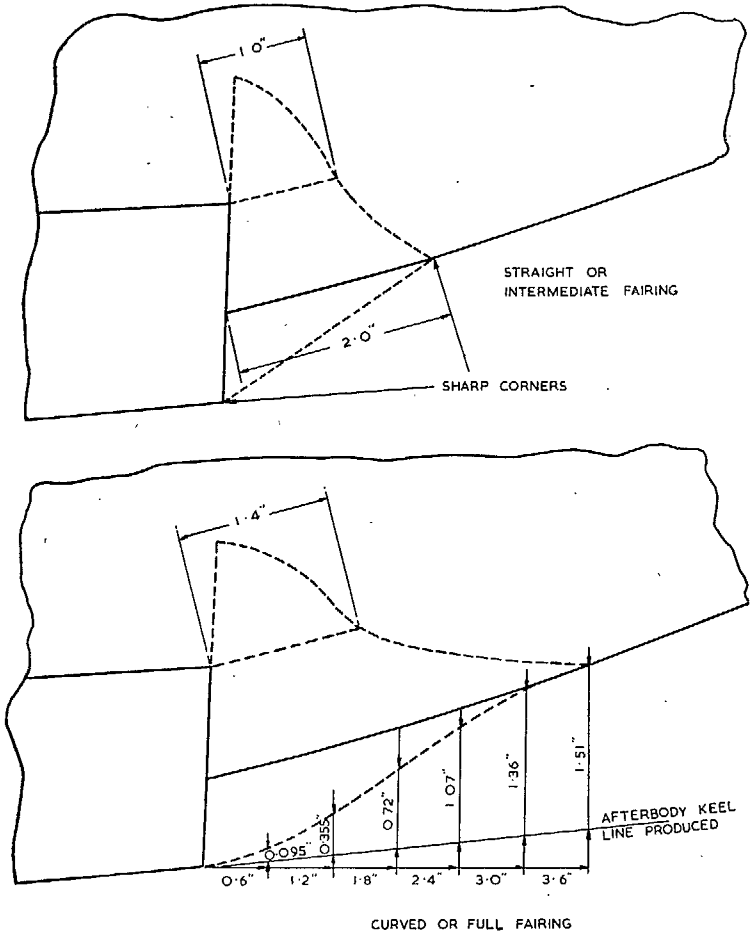


FIG. 19. Details of rear-step fairing (A.R.C. 3794).

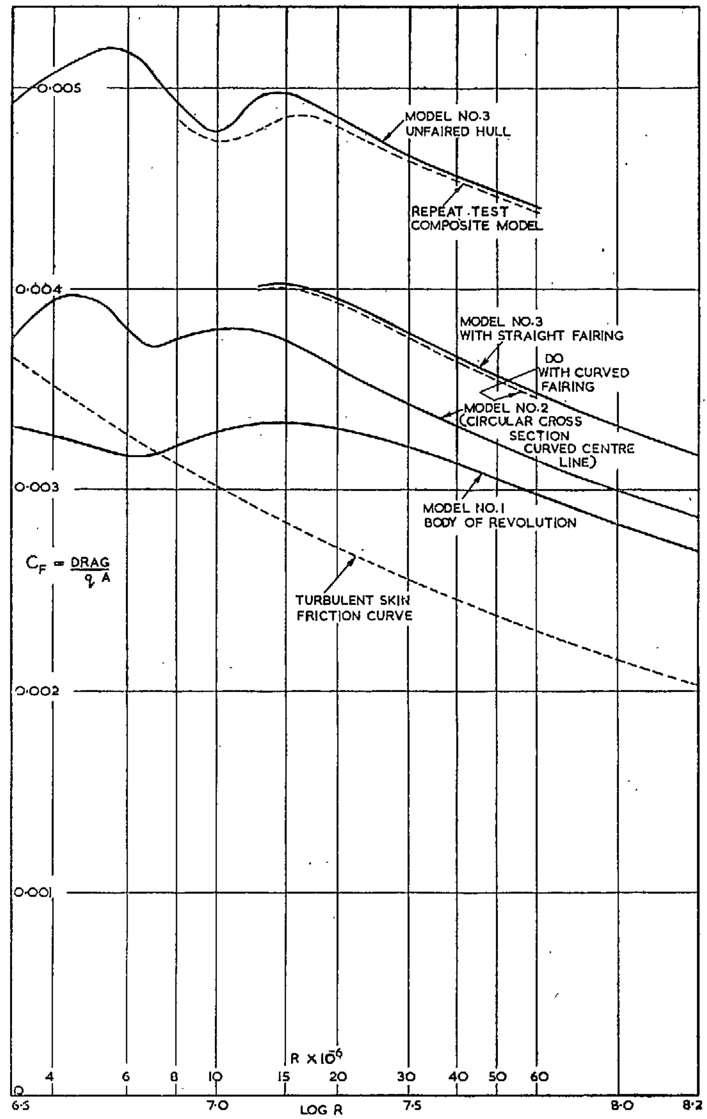


FIG. 20. Drag of flying-boat hull. Effect of step fairing (A.R.C. 3794).

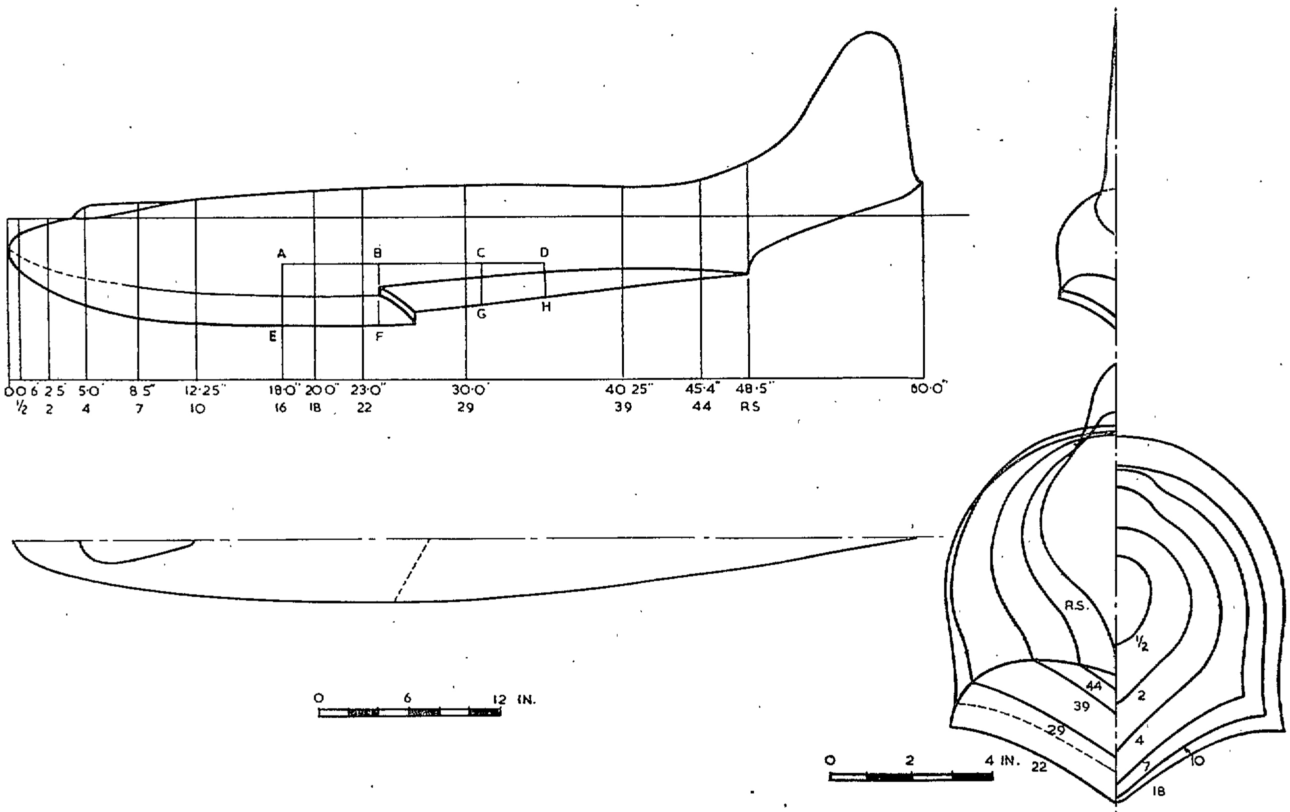


FIG. 21. Specific hull form with unfaired steps and chines (A.R.C. 7784).

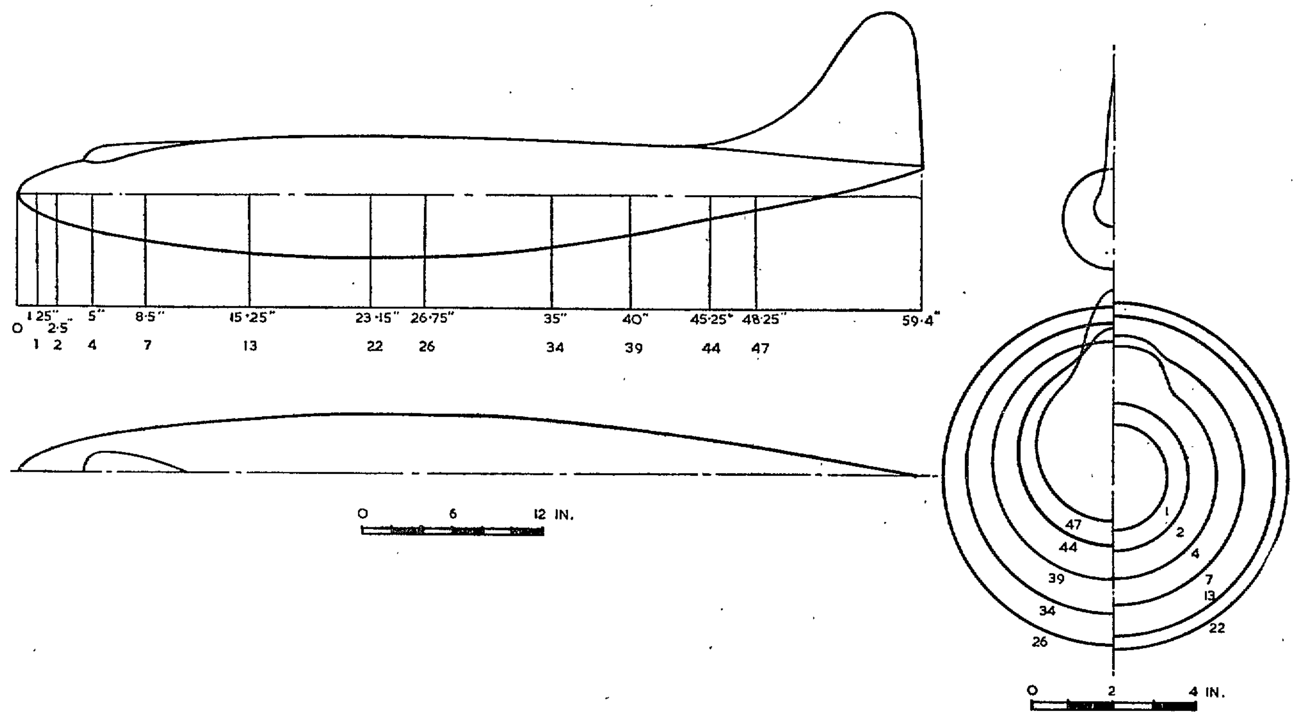


FIG. 22. Comparable fuselage, length to beam ratio 7 (A.R.C. 7784).

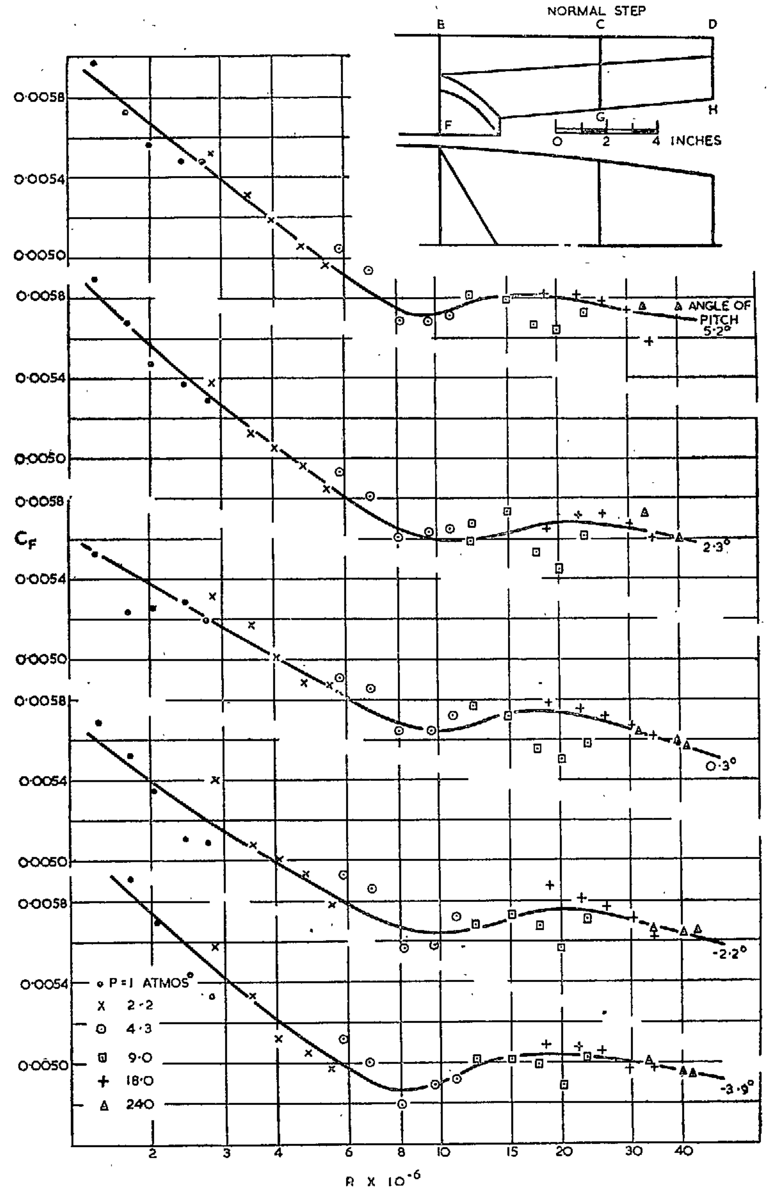


Fig. 23. Drag of hull with normal steps and chines (A.R.C. 7784).

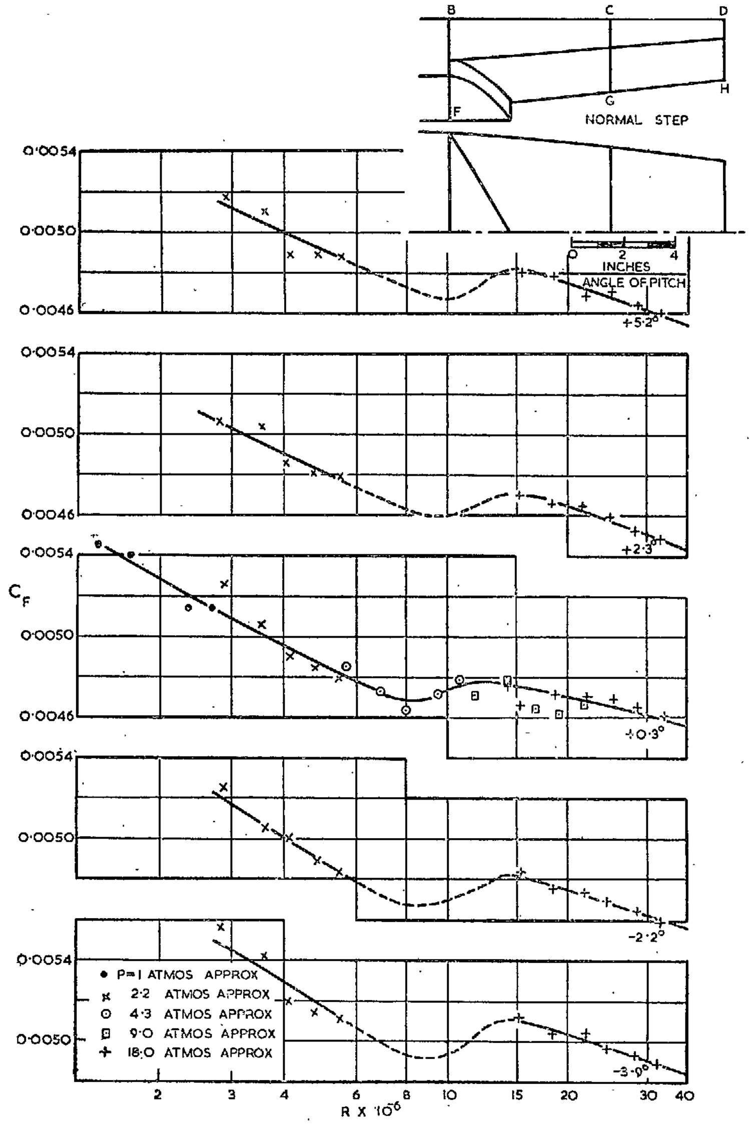


Fig. 24. Drag of hull with normal steps and faired chines forward (A.R.C. 7784).

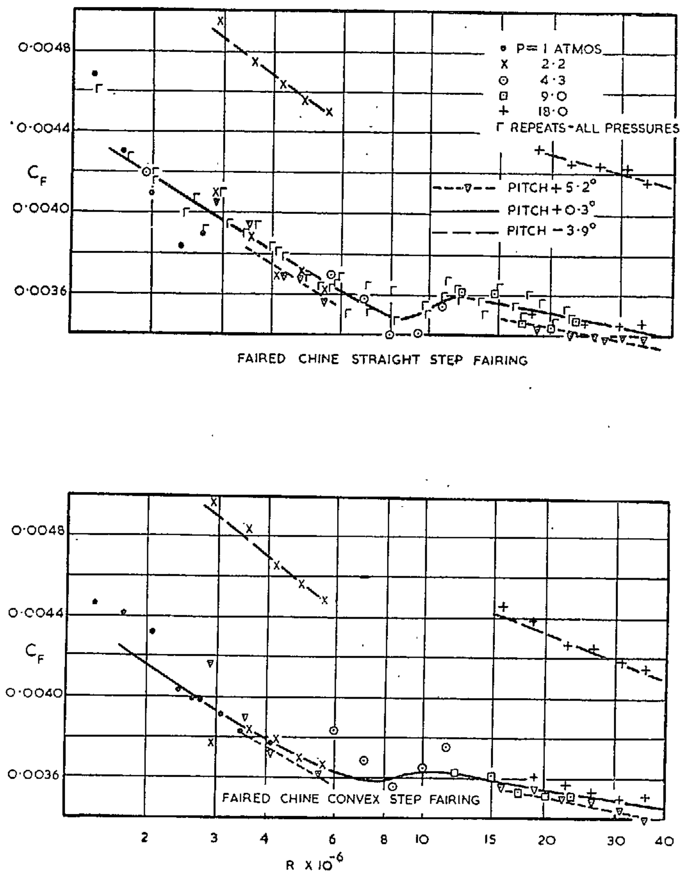


FIG. 25a. Effect of straight and curved step fairings in elevation and of chine fairings (1)—(A.R.C. 7784).

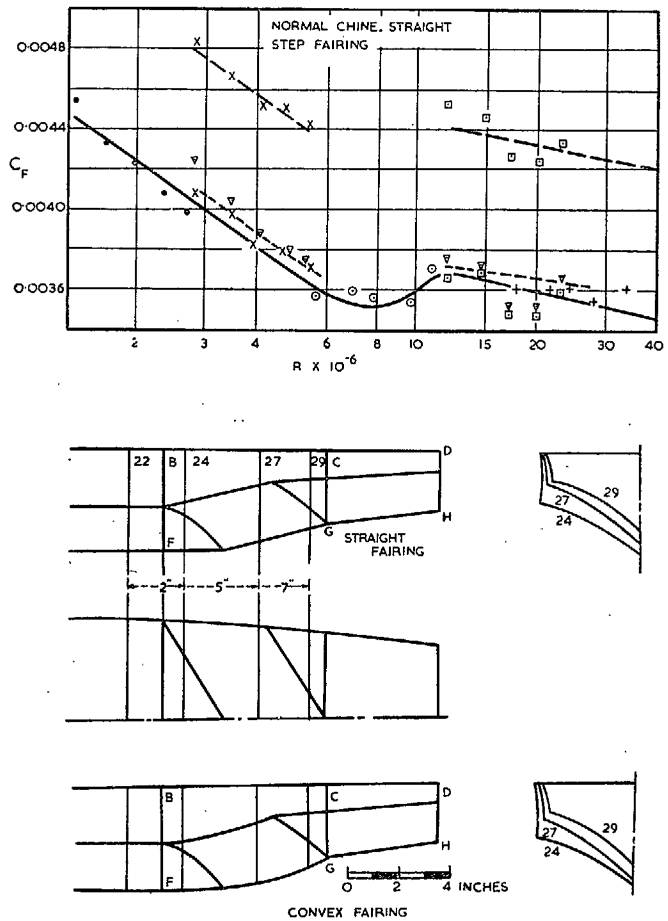


FIG. 25b. Effect of straight and curved step fairings in elevation and of chine fairings (2)—(A.R.C. 7784).

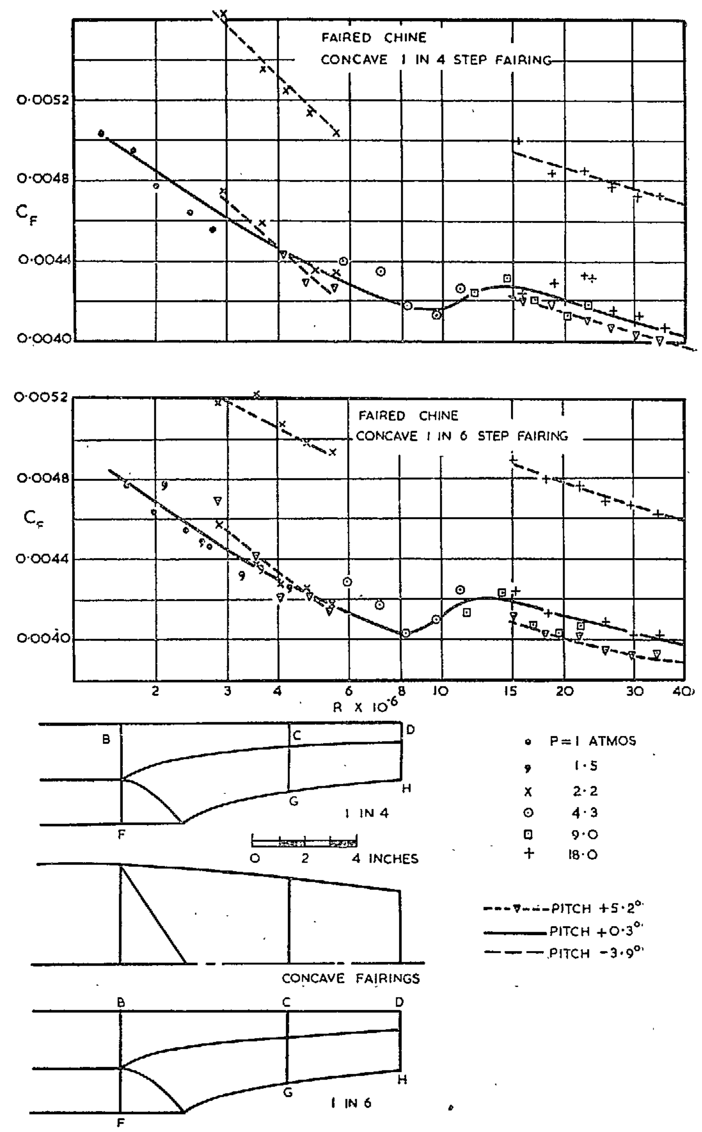


FIG. 26. Effect of concave fairing in side elevation and chine fairing (A.R.C. 7784).

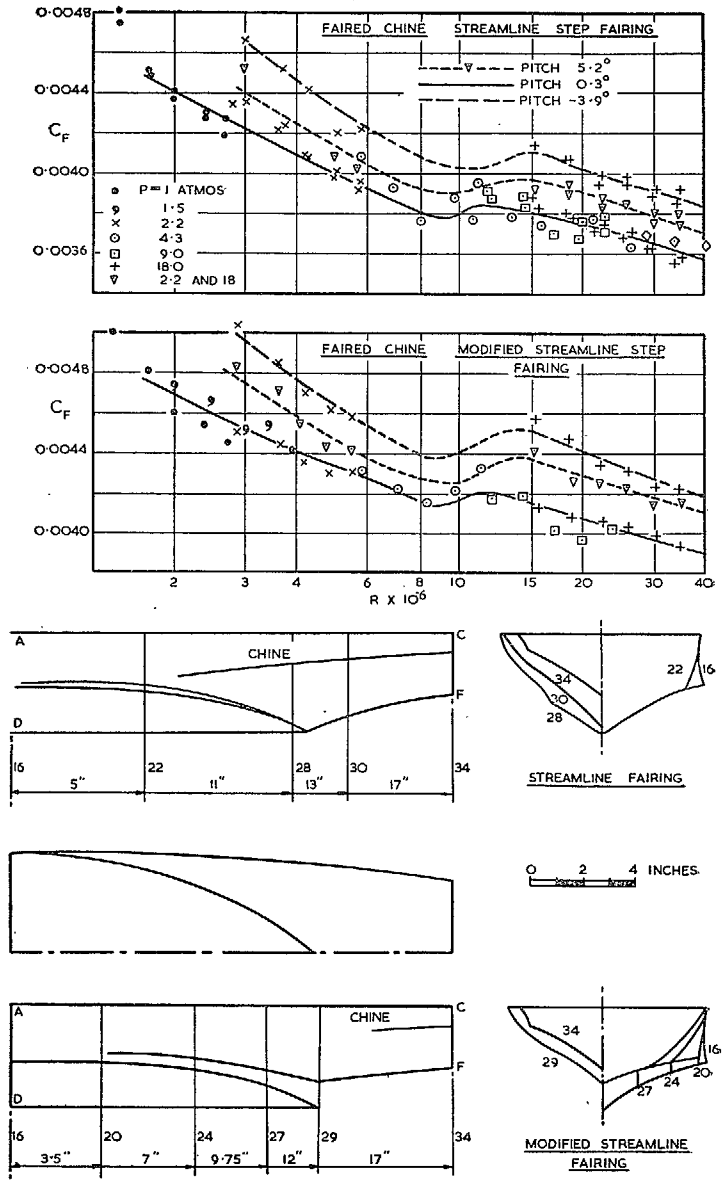


FIG. 27. Effect of fairing step in side elevation and plan-form and chine fairing (A.R.C. 7784).

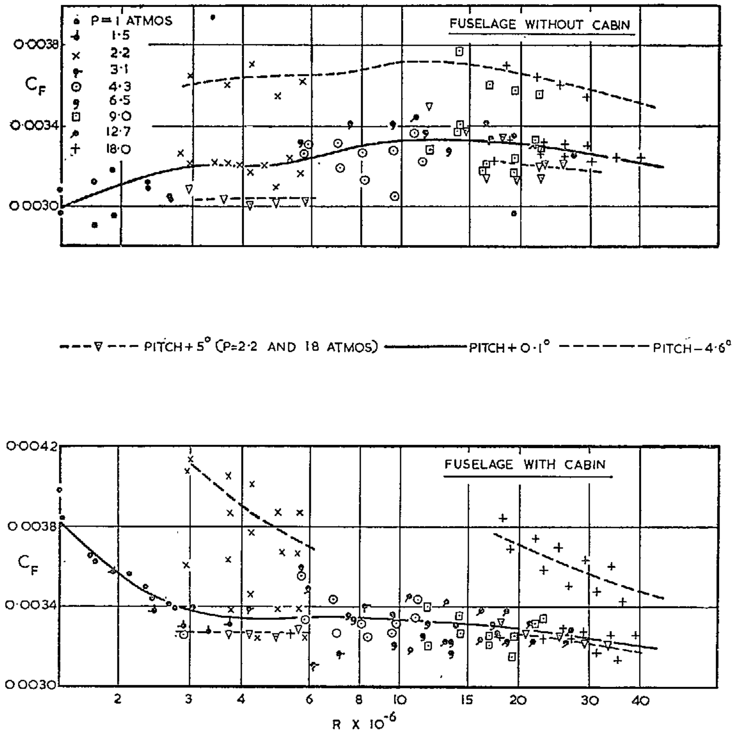


FIG. 28. Drag of basic fuselage with fin, with and without cabin (A.R.C. 7784).

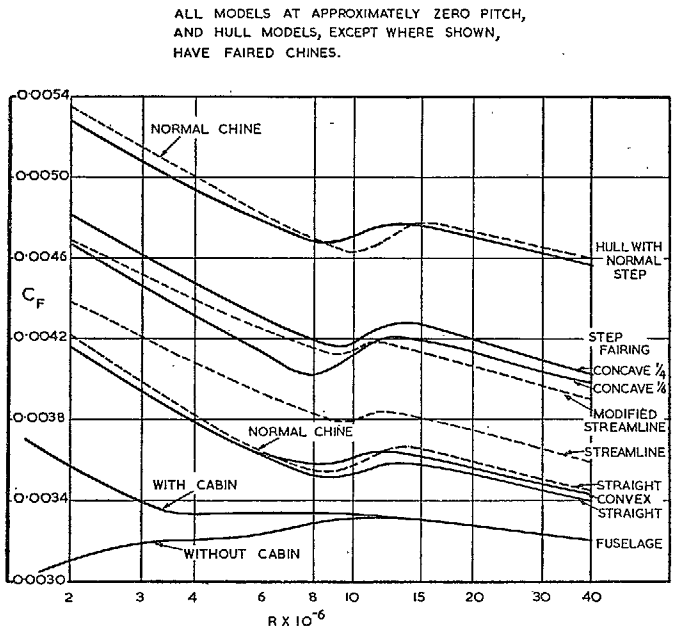


FIG. 29. Summary of effect of various fairings on hull drag (A.R.C. 7784)

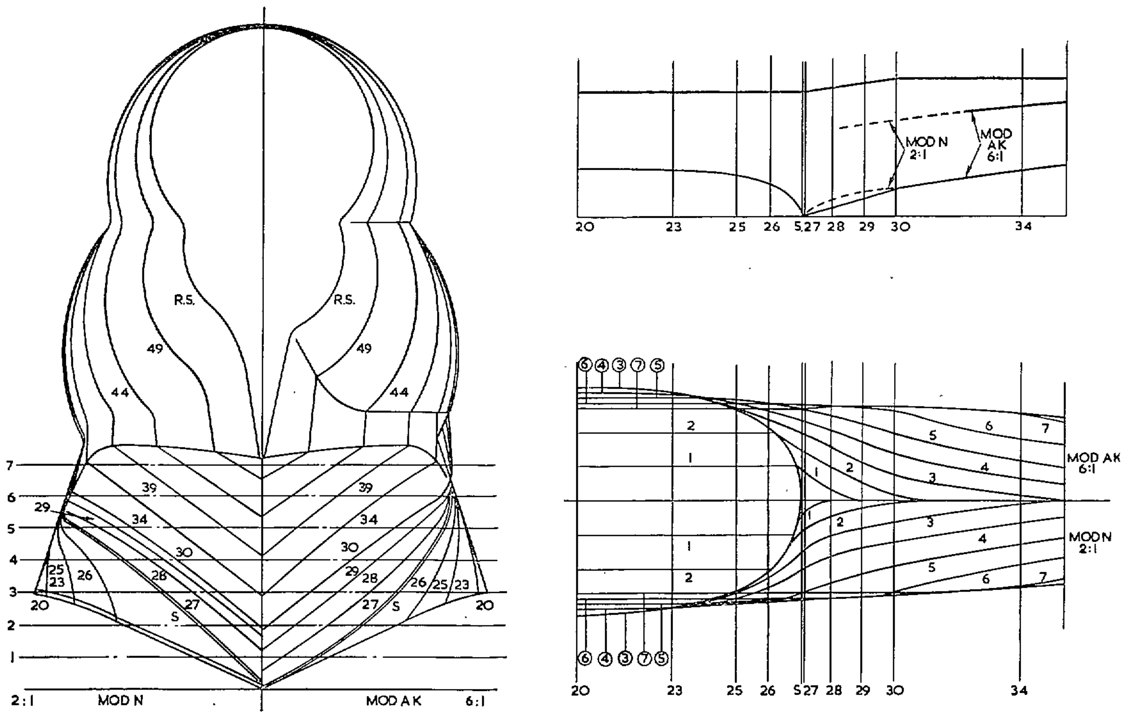


FIG. 30. Sketch of *Princess* streamline step with 2 : 1 and 6 : 1 fairings (A.R.C. 13964).

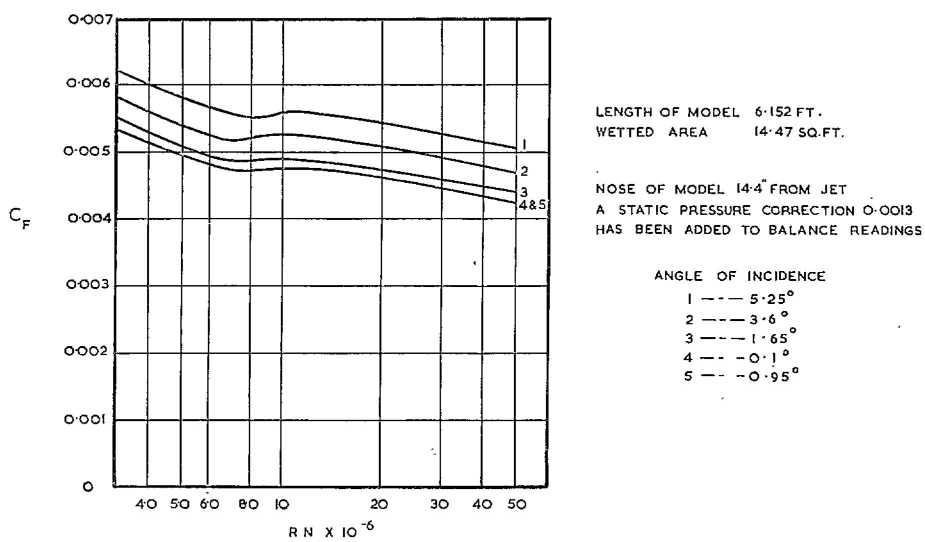


FIG. 31. Drag of *Princess* hull with streamline step and 2 : 1 fairing (Mod. N) (C.A.T.).

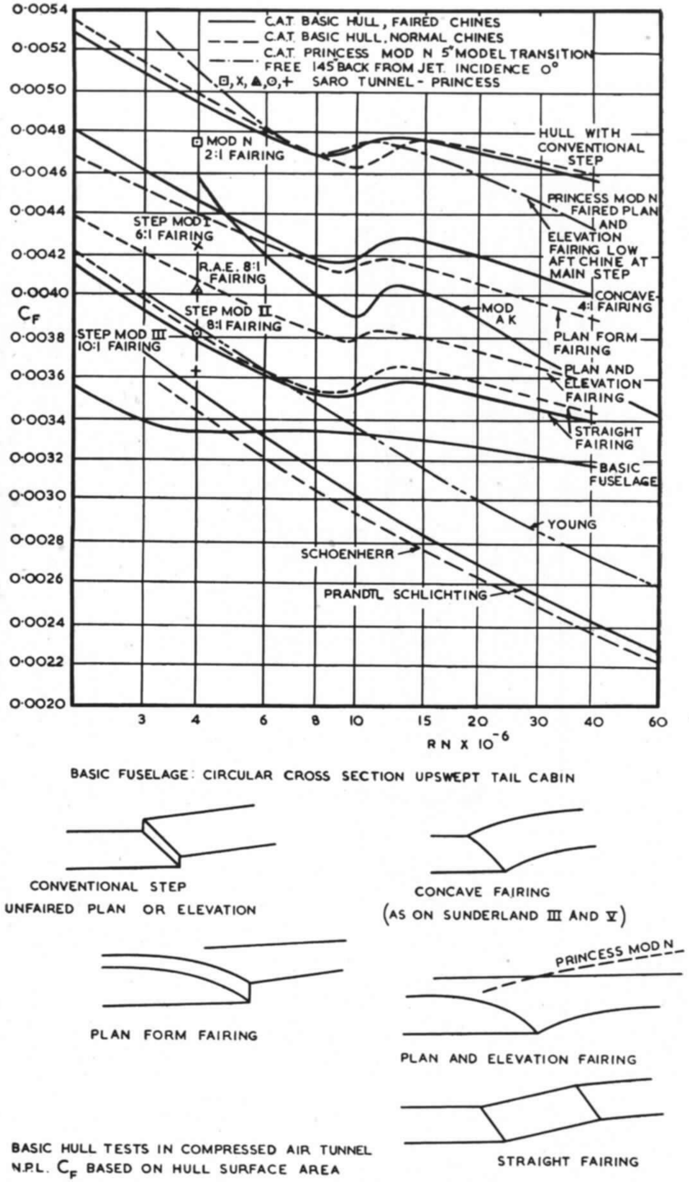
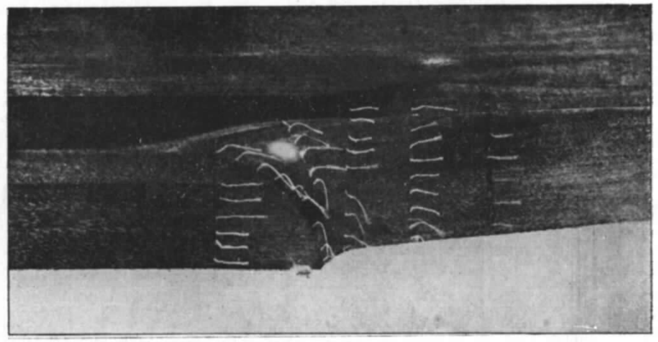
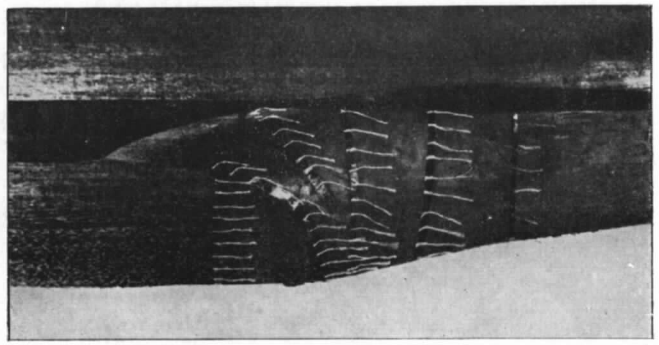


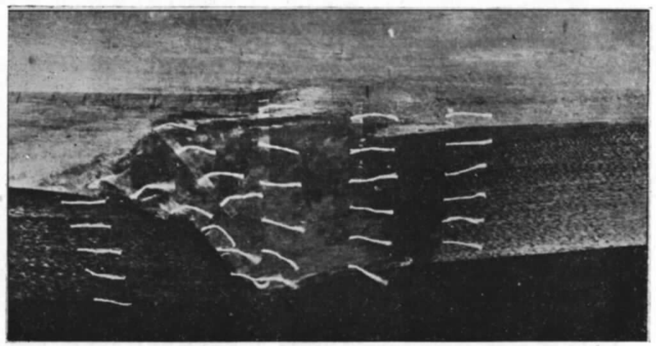
FIG. 32. Comparison of *Princess* drag with that of basic C.A.T. hulls.



2 : 1 step fairing (Mod. N)



8 : 1 step fairing



10 : 1 step fairing

FIG. 33. Air-flow photographs of three *Princess* main-step fairings at Reynolds number = 4×10^6 (A.R.C. 13964).

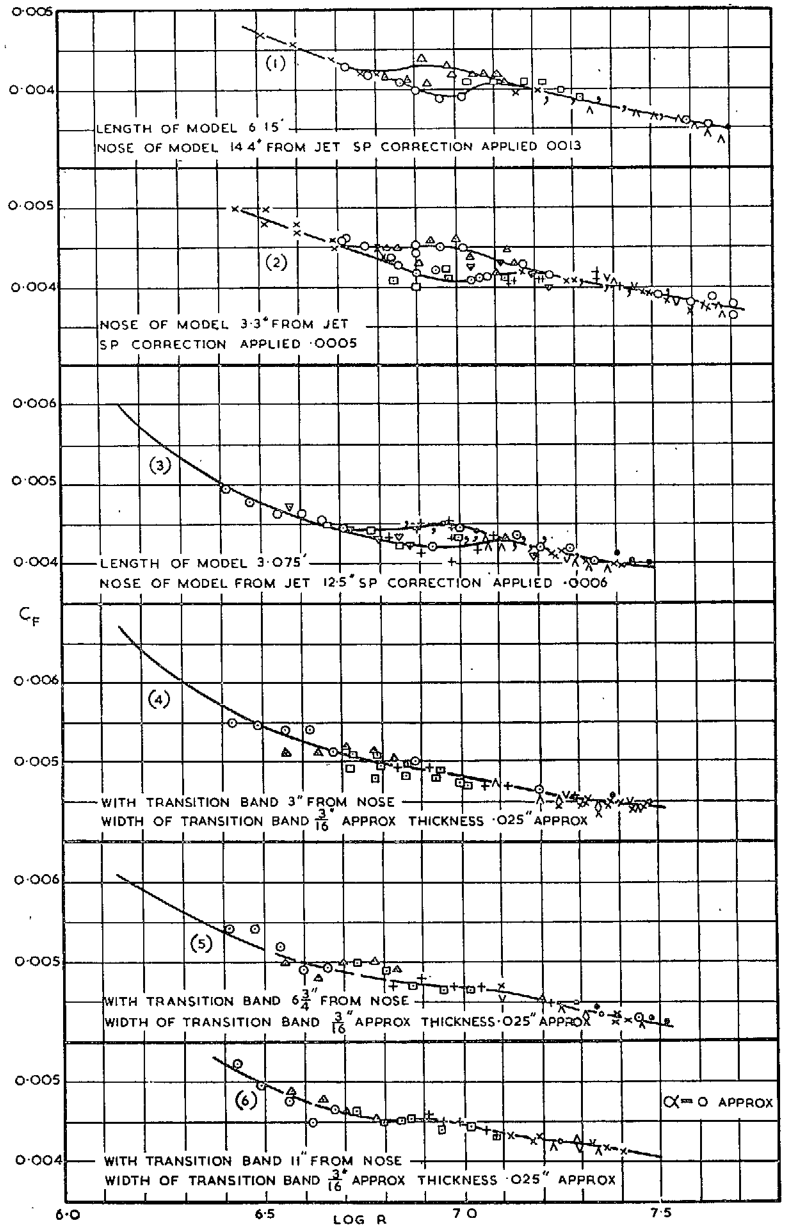
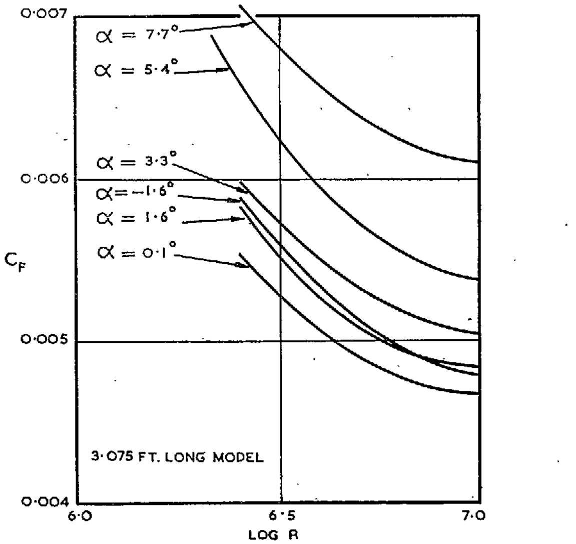


FIG. 34. Drag of *Princess* hull with streamline step and final 6 : 1 fairing (Mod. AK) (C.A.T.).



EFFECT OF RN TRANSITION BAND 3″ FROM FORWARD END.

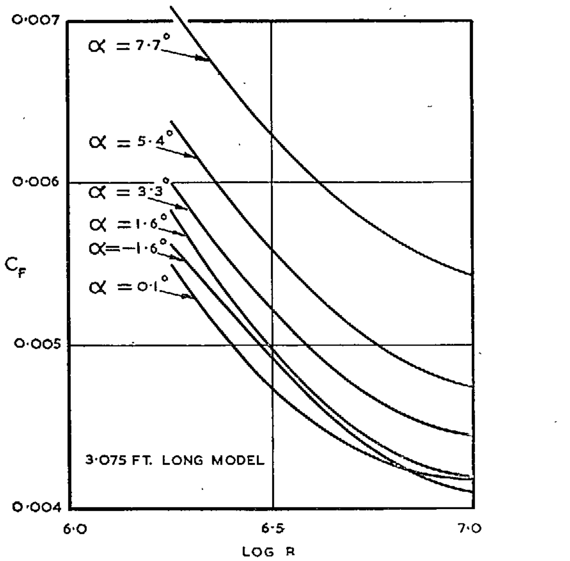
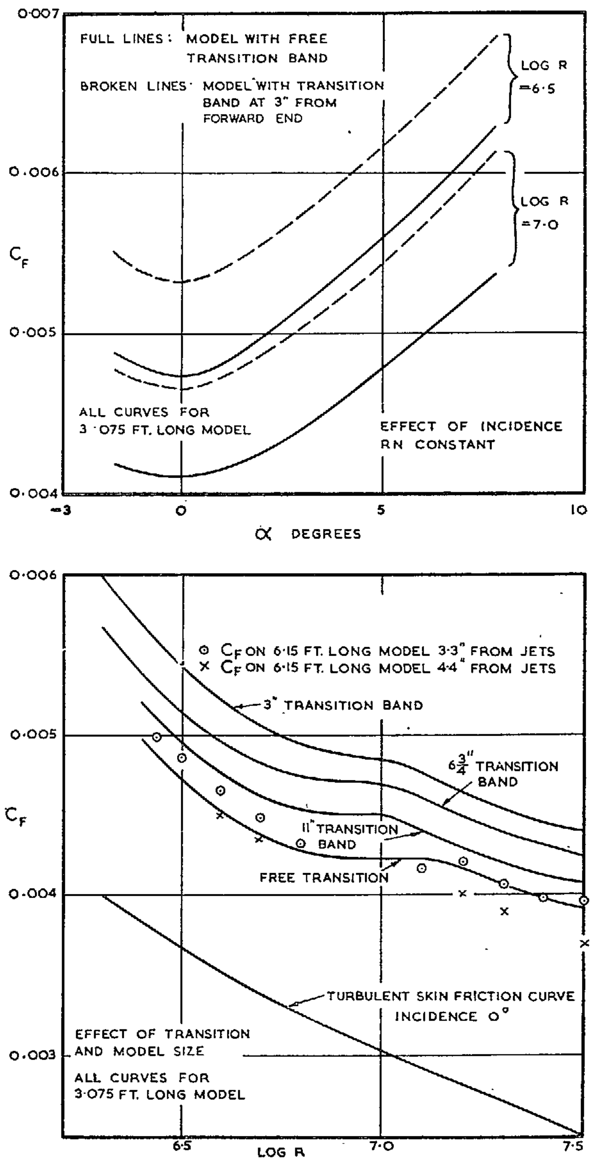


FIG. 35a. Effect of Reynolds number free transition (C.A.T.).

J4375 Wt.20/9036 K7 11/56 D&Co. 34/263



FIGS. 35b and 35c. Effects of incidence, transition position, model size and position in tunnel on *Princess* hull drag (Mod. AK) (C.A.T.).

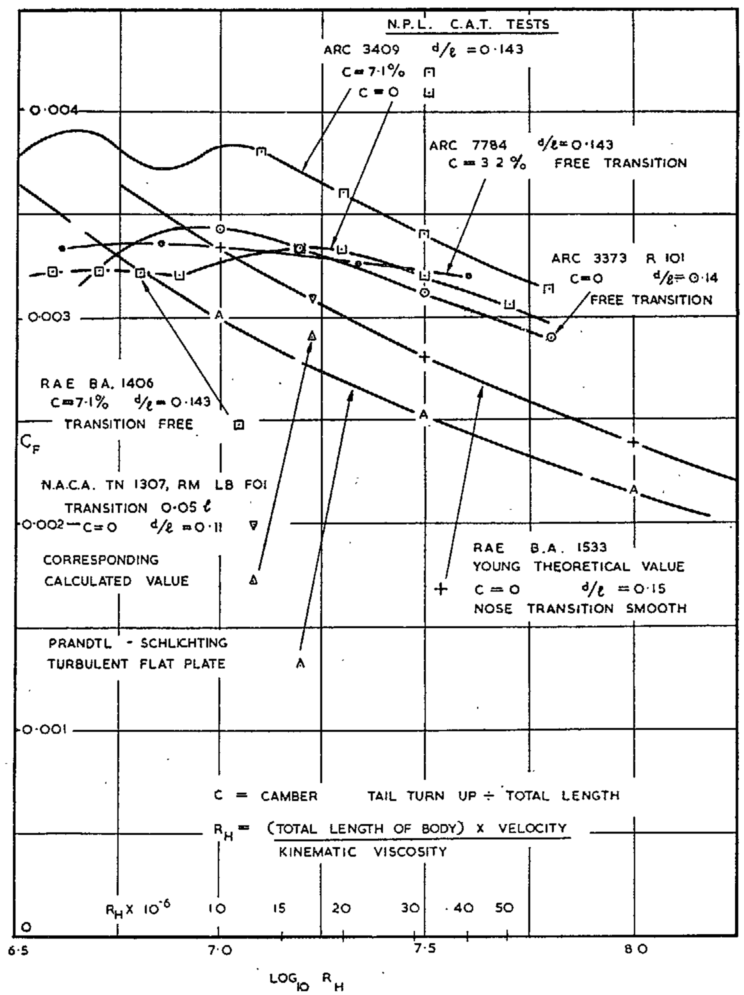


FIG. 36. Surface drag coefficients of streamline bodies of revolution (A.R.C. 13644).

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