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AERODYNAMICAL LABORATORY

# HYDROMECHANIC EXPERIMENTS WITH FLYING BOAT HULLS

(With Six Plates)

BY
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Chairman of Sub-Committee on Hydromechanic Experiments in Relation to Aeronautics

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During the latter half of 1913 the following work of interest was carried on at the Model Basin at the Washington Navy Yard.

This work comprised an investigation of the forms of hulls of flying boats in order to determine (1) their resistance at "displacements corresponding to speeds," on the water, and (2) their resistances "submerged," as a means of approximating their total head resistances in air and of determining an approximate "coefficient of fineness of form."

As a result a form of hull has been derived which appears to have decided advantages over those already in use in the Navy, so far as resistance on the surface and in the air is concerned. Such a hull slightly modified to overcome structural difficulties is now being tried on a new navy machine.

Plates 1, 2, and 3 contain plots of the results of the experiments, while plates 4, 5 and 6, illustrate the models used.

## PLATE 1

This plate contains plots of model runs for the following models, 1591-3, 1592-1, 1592-5, 1593-1, 1602-1, and 1617-1.

At the foot of the sheet are plots of net resistance, and of derived e. h. p. for the full size computed on the assumption that the total resistance of the full size model at the corresponding speed is proportional to the displacement. As the models were all 1/9 full size the corresponding speeds for the full size are $\sqrt{9}=3$ times those for the models, and the resistances $9^3=729$ times those of the models.

This assumption is interesting as a means of comparison but the e. h. p.'s so determined are inaccurate and exceed the true values, because the frictional resistance which is an important component varies with the speed to some power less than the square, approximately the 1.85 power. It is probable that the maximum error is less than 40% and the minimum as high as 20% in excess of the actual e. h. p., but the discrepancies are not considered to invalidate their value for comparative purposes. At the top of the plate the change of level curves are plotted.

The resistance curves were determined by towing the models at "displacements corresponding to speeds," with the models at a set "trim" but free to rise and fall under the influence of "suction" or "planing," and the change of level curves show how much the planing effect changes the draft at each condition.

All models were towed under conditions representing a full load of 2,200 lbs. and the assumption that the get-away occurs at 45 m. p. h. All were of the ventilated step type. An inspection of the resistance and trim curves will show the following general features:

a. At low speeds, suction is present.

b. This is succeeded by a condition in which the models run hard.

c. Which is succeeded by a condition at which the model begins to plane.

d. And just before the planing is established the slope of the curve lessens rapidly.

e. And when planing is established the resistance falls off sharply with one exception.

f. Just preceding the "get-away" there is a tendency for the resistance to remain at an appreciable value, which

g. Falls to nothing sharply at the last.

Model 1591-3 was designed to obviate the defects of the flat scow bow type, and introduces the V bottom for the purpose of parting rather than pushing the water aside. The ventilated step was located so as to be slightly to the rear of the center of gravity. This model 1591-3 was derived from 1591-1, which was a true V type. 1591-1 ran very well except for a remarkable sheet of spray at a speed corresponding to 12 m. p. h. This sheet of spray is shown in plate 4, fig. 2. Due to this spray it was considered necessary to modify the model and this was done by making the V sections "full," the principal effect of the change was to augment the sheet of spray, so the opposite tack was next taken, that of making the V sections hollow in wake of the position from which the sheet of spray originated, and 1591-3 was thus derived. The result was that the spray was held down, the planing effect increased and the resistance reduced, an all round improvement.

Model 1592-1 was made from the lines of the Navy Flying Boat C-1.

Model 1593-1 was made from the lines of the Navy Flying Boat D-1.

Model number 1602-1 was derived from 1591-3, but the beam was increased from 30″ to 34″, otherwise the bottom was the same, at the same time an attempt was made to improve the form by changing the form of the front hood, and by sloping the upper deck abaft the position of the planes. The results of these changes are apparent in the submerged runs.

Model 1592-5 was derived from 1592-1 by adding a shallow V bottom just forward of the step of 1592-1.

Model 1617-1 was designed on the general lines of the E-1, combination type (Owl, type). The object of this experiment was principally to determine whether the shorter form was disadvantageous from an air resistance point of view.

An inspection of the performance of 1591-3, shows that from a resistance point of view it excels all but 1592-5, and an inspection of the change of level curves will show this to be intimately associated with the valuable "planing" qualities of 1591-3.

1592-1 behaves very similarly but the resistance is higher, while 1592-5 behaves very similarly but the resistance is lower than either of the two preceding and the change of level curves clearly demonstrate that the improvement is due principally to the improved "planing" effect, and it is also due to the better flow induced by parting rather than pushing the water aside, due to the V-shape at the step.

1602-1 behaves much the same, but the broader beam appears to increase the resistance slightly except where the planing effect reaches its maximum:

1593-1 behaves well at low speeds, but the resistance grows to a maximum at a much higher speed than any of the other models and falls off steadily but much less sharply than any of the others. The hump for the resistance curves occurs at about 27 m. p. h. for this model; at about 21 m. p. h. for 1591-3, 1592-1 and 1602-1, and at 19.5 m. p. h. for 1592-5. The sustained hard running of this model is clearly due to its failure to "plane" as is evidenced by the change of level curve.

1617-2 has high resistance at speeds corresponding to 24 m. p. h., but in general behaves similarly to the other central step models.

Comparison of the model results with the actual performance of full sized machines, show a fair analogy exists, confirming satisfactorily the behavior of the models. Certain experiments indicate that up to about 15 or 20 m. p. h. the aeroplane controls have very little influence on the change of trim of the full size machines, and thus practically require the full size machines to follow the trim imposed by the flow of the water about the hulls, and the models were set to closely approximate the " natural trim." Once planing is attained, or the same thing once " suction " is broken, the controls become effective and may be used to modify the trim. In the case of D-1, however, this condition is not reached till about 39 m. p. h. These experiments have also shown that the "planing" effect is very sensible to improvement if the angle of the bottom is increased, and as this can be brought about once planing is attained this shows a further advantage for those models which plane early.

The conclusions drawn from these and previous experiments are as follows:

a. The step should be close to the position of the center of gravity, to eliminate a nosing tendency, to facilitate change of trim while planing, to avoid change of balance when getting away or landing.

b. Hollow V sections keep the spray down, cut the water more easily and cleanly, plane better, and greatly reduce shock on landing or when ploughing through broken water, and practically eliminate the necessity of shock absorbers.

c. A shallow step is sufficient, but ventilation is essential to facilitate the breaking of suction effects.

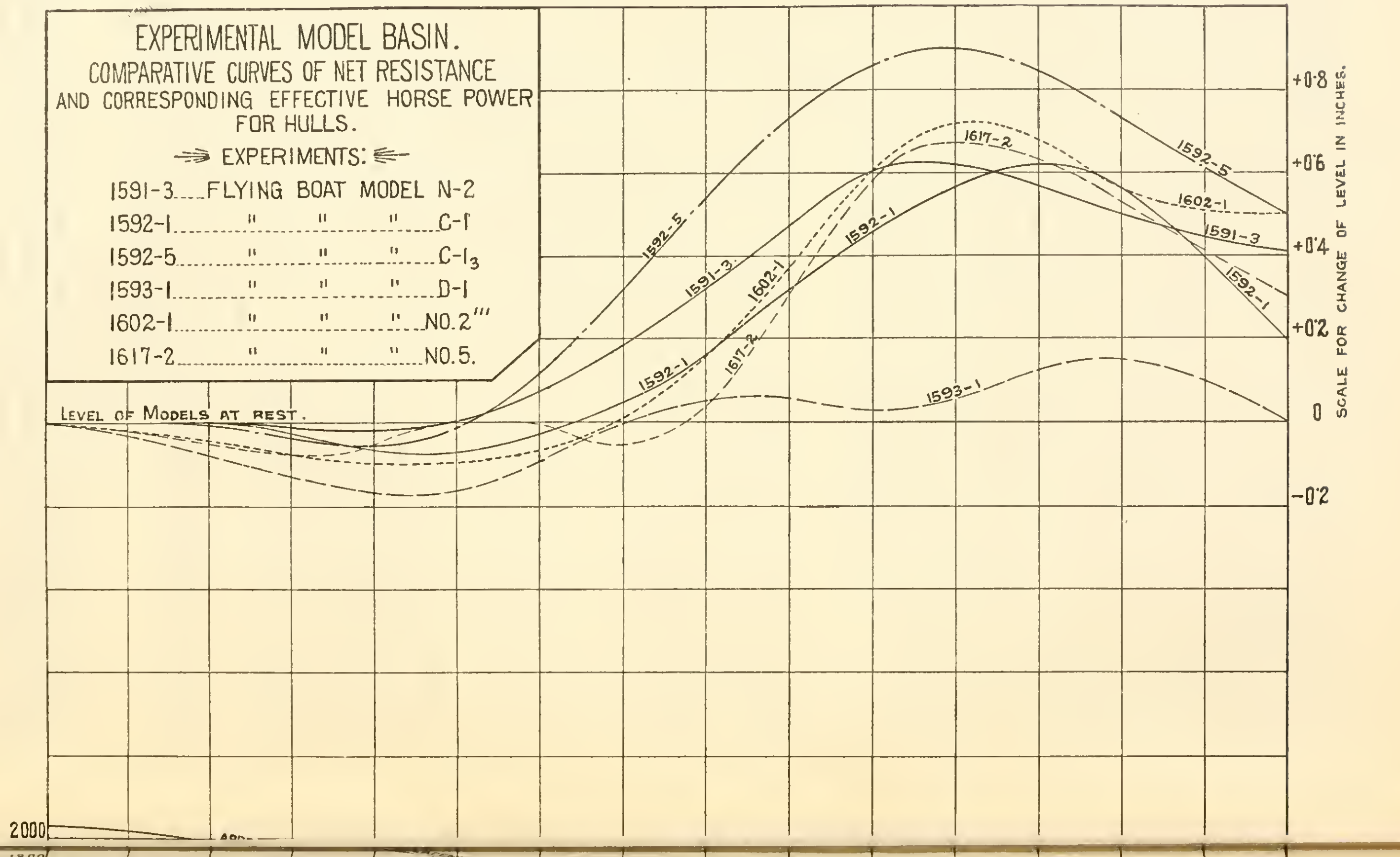
d. The bottom forward of the step should be inclined to the axis of the machine, but

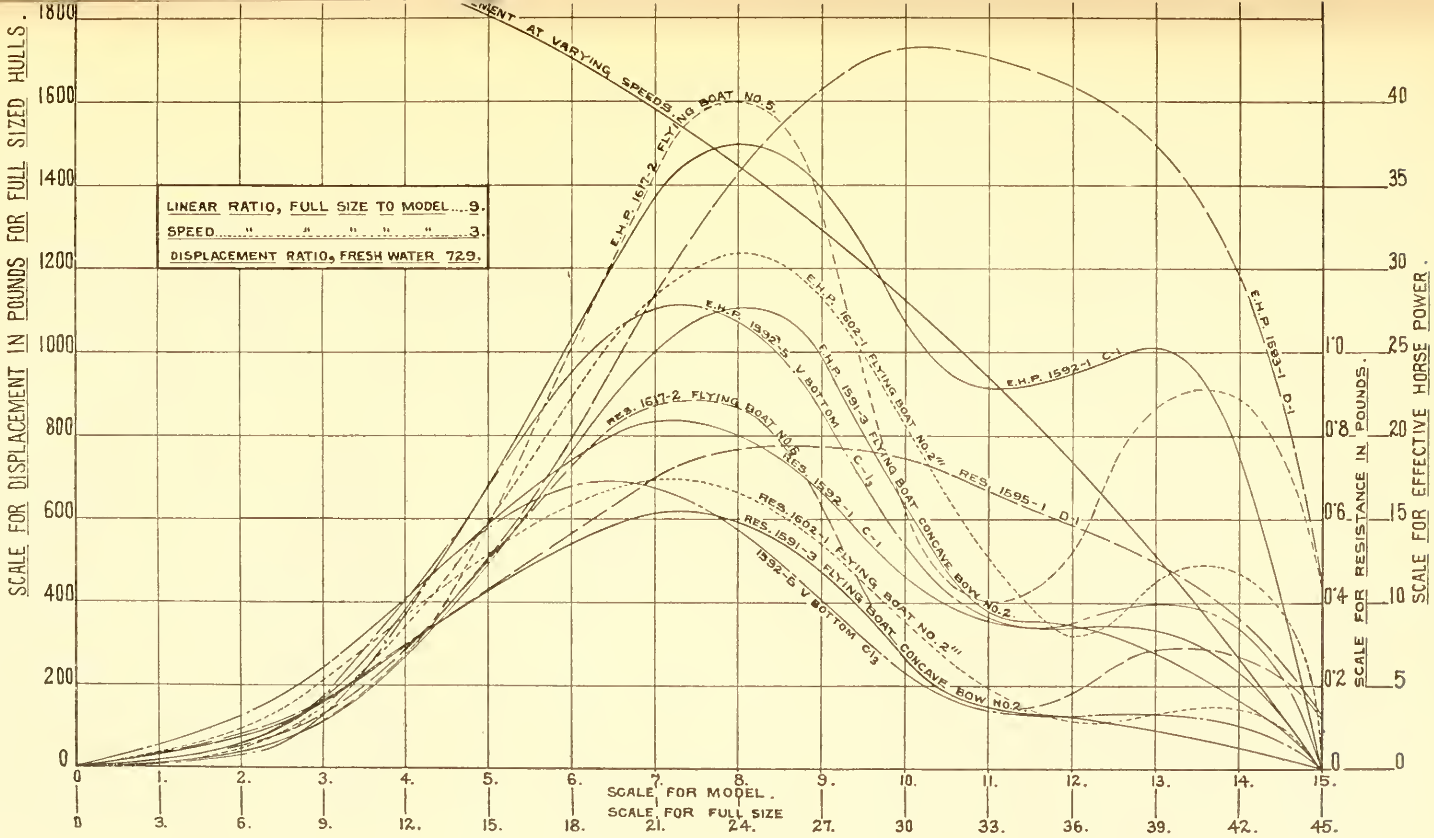
e. The inclination must not be so great as to cause planing before the controls are effective, and this is particularly necessary when running before the wind. If the planing of the hull is too pronounced, the machine rises to the surface with but very little control available to maintain balance, and when running before the wind this is more apt to occur due to the higher water speed necessary before the machine can take the air.

f. The bottom abaft the step should rise strongly as this favors a steepening of the planing bow before suction is eliminated, and gets the tail well clear when planing begins.

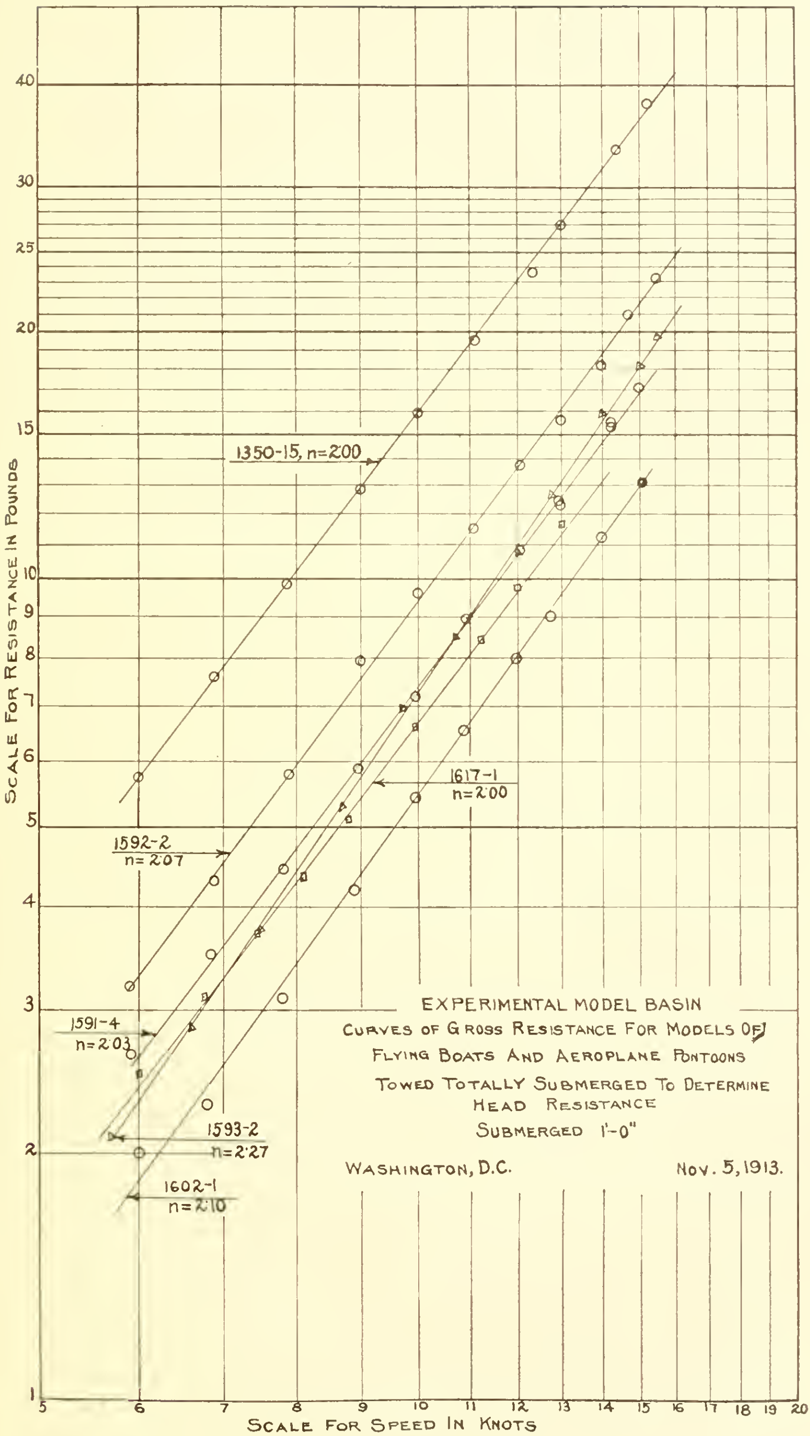
## PLATES 2 AND 3

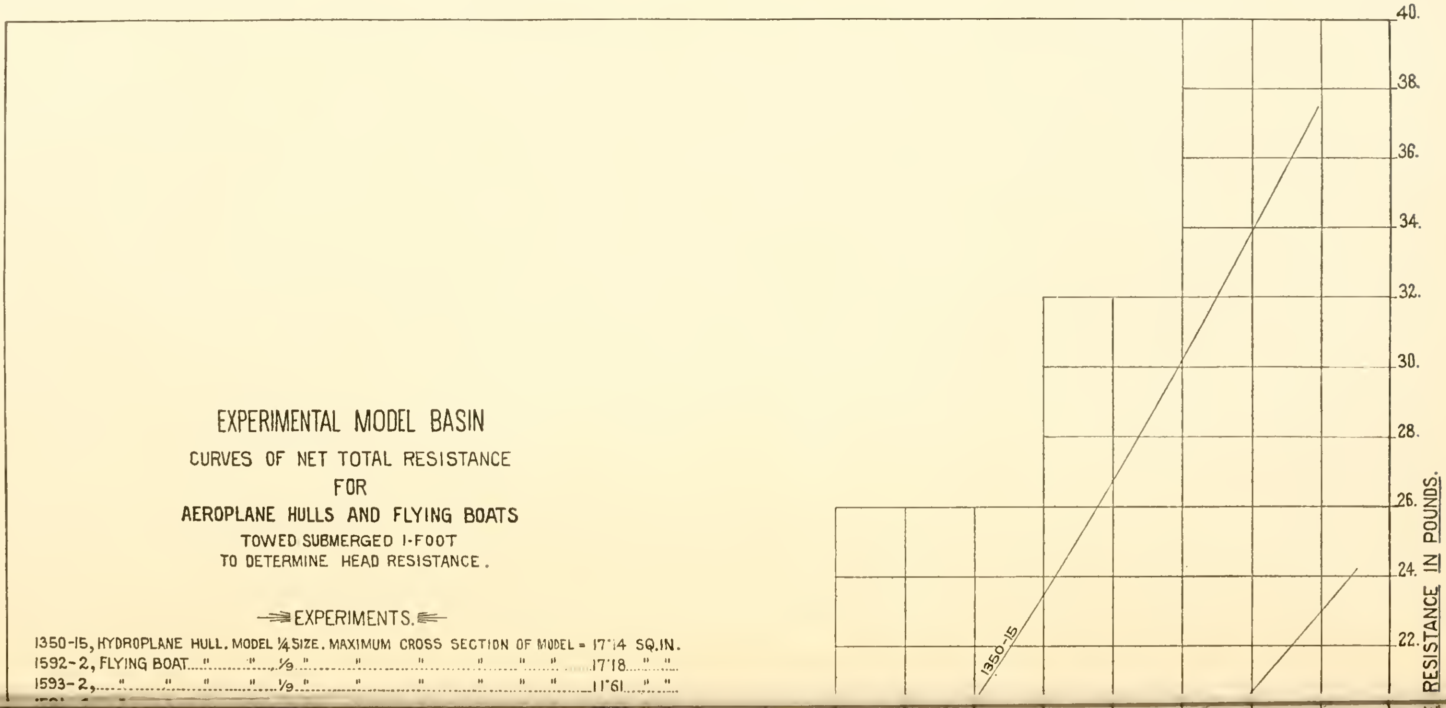
Plate 2 shows the logarithmic plots of the resistance of the preceding models towed submerged at speeds up to 15 knots; and also for model 1350-15, a quarter sized model of the original Curtiss

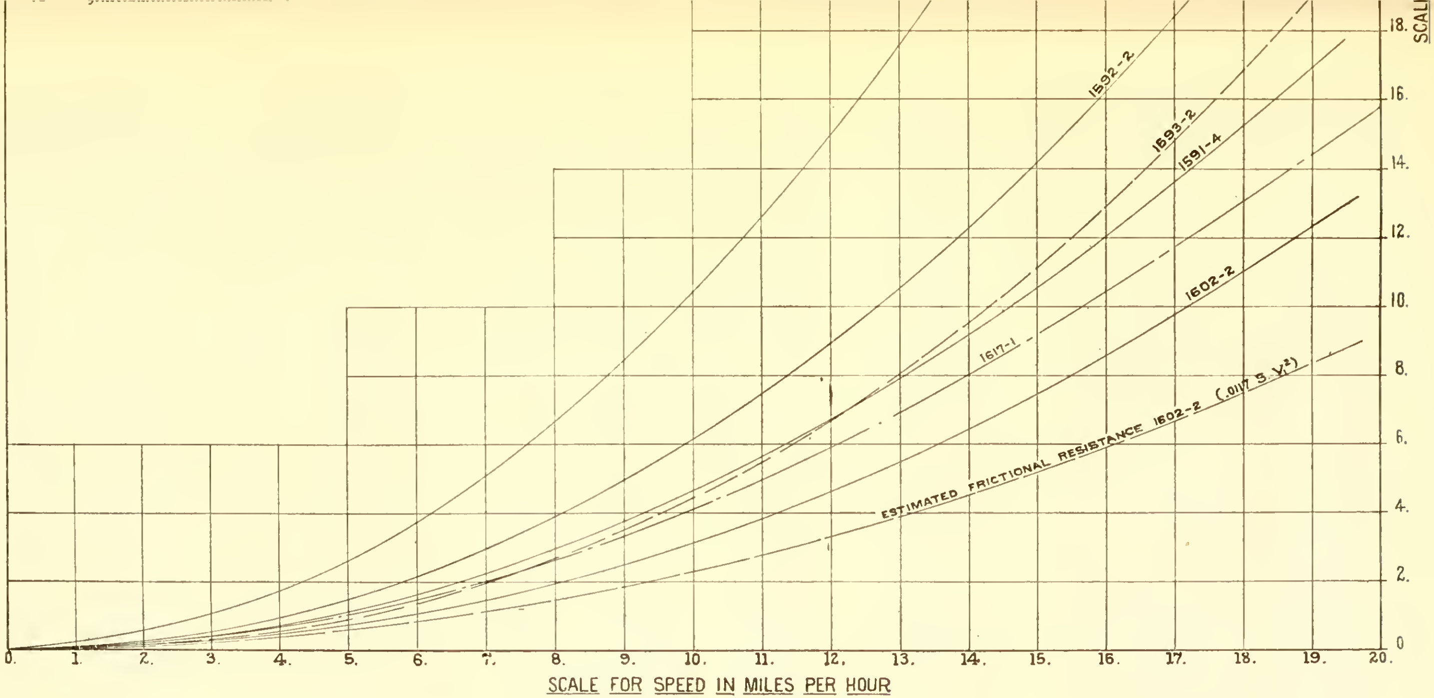

EXPERIMENTAL MODEL BASIN.
COMPARATIVE CURVES OF NET RESISTANCE AND CORRESPONDING EFFECTIVE HORSE POWER FOR HULLS.
EXPERIMENTS:
1591-3....FLYING BOAT MODEL N-2
1592-1........" " " C-1
1592-5........" " " C-I3
1593-1........" " " D-1
1602-1........" " " NO.2'''
1617-2........" " " NO.5.
LEVEL OF MODELS AT REST.
1592-5
1602-1
1591-3
1592-1
1617-2
1593-1
+0·8
+0·6
+0·4
+0·2
0
−0·2
SCALE FOR CHANGE OF LEVEL IN INCHES.
2000




SCALES FOR SPEED IN MILES PER HOUR.


40
30
25
20
15
10
9
8
7
6
5
4
3
2
1
5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Scale For Resistance In Pounds
Scale For Speed In Knots
1350-15, n=2.00
1617-1
n=2.00
1592-2
n=2.07
1591-4
n=2.03
1593-2
n=2.27
1602-1
n=2.10
EXPERIMENTAL MODEL BASIN
Curves of Gross Resistance For Models of
Flying Boats And Aeroplane Pontoons
Towed Totally Submerged To Determine
Head Resistance
Submerged 1'-0"
Washington, D.C.
Nov. 5, 1913.


EXPERIMENTAL MODEL BASIN
CURVES OF NET TOTAL RESISTANCE
FOR
AEROPLANE HULLS AND FLYING BOATS
TOWED SUBMERGED 1-FOOT
TO DETERMINE HEAD RESISTANCE.
EXPERIMENTS.
1350-15, HYDROPLANE HULL. MODEL ¼ SIZE. MAXIMUM CROSS SECTION OF MODEL = 17·14 SQ.IN.
1592-2, FLYING BOAT " " 1/9 " " " " " " 17·18 " "
1593-2, " " " " 1/9 " " " " " " 11·61 " "
1350-15
40.
38.
36.
34.
32.
30.
28.
26.
24.
22.
RESISTANCE IN POUNDS.



1592-2
1693-2
1591-4
1617-1
1602-2
ESTIMATED FRICTIONAL RESISTANCE 1602-2 (.0117 S V²)
0 2. 4. 6. 8. 10. 12. 14. 16. 18.
SCALE
0. 1. 2. 3. 4. 5. 6. 7. 8. 9. 10. 11. 12. 13. 14. 15. 16. 17. 18. 19. 20.
SCALE FOR SPEED IN MILES PER HOUR

pontoon. It will be seen that a straight line on the logarithmic plots very closely represents the locus of the observed points and thus indicate that the resistances of the models closely approximate the law of the square of the speed. As is well known, any equation of the form $Y=a\ x^n$ will plot as a straight line on a logarithmic plot, and the slope of the curve transferred to the origin passes through the margin at the upper end at a point corresponding to the exponent n. The exponents are given in line 12 of Table 1, which shows the value of the exponent n in the equation of the lines plotted on Plate 3 from the equation $R \propto V^n$ the points being taken direct from the straight line plots.

TABLE I

Table 1 shows the computation of the head resistance in water for each of these models, in detail, the final results appearing in lines 19, 20 and 21, giving results by three different methods of computation.

TABLE II

Line 22 gives the head resistance computed by analysis of the total resistance of the model into frictional resistance and residual resistance, and then augmenting these values to the "full size" values in accordance with Froude's method.

Line 23 gives the head resistance in the same manner as line 22, except the residual resistance is determined on the basis of relative areas and relative speeds, being proportioned to the latter in accordance with the exponent determined for the variation of residual resistance of the model, instead of using the law of the square.

Line 24 is an *approximation*, assuming the resistance to be directly proportional to the cube of the linear ratio at "corresponding speeds."

Line 25 is computed on the basis of the Lord Rayleigh method, which has been found reasonably satisfactory for the comparison of dirigible models in England. In England ebonite models 1 inch in diameter were used in water, and in air gold beater's skin models 3 feet in diameter.

The National Physical Laboratory formula, which is based on the Lord Rayleigh method, is

$$H=\kappa\rho v^{.14}L^{1.86}V^{1.86}$$

in which $\kappa$ is a constant of form to be derived by experiment, $\rho$ is the density of the medium in which the experiment is carried on, $v$ is the kinetic viscosity, L is the length in feet, and V is the velocity in feet per second.

This method has been introduced at the suggestion of Naval Con-

TABLE I.

Computation of Head Resistance of Aeroplane Hulls, from Resistances of Models Towed Submerged in Model Basin.

| Model | A-1 | C-1 | D-1 | N-1 | N-2 | N-3 |
|---|---|---|---|---|---|---|
| 1. Number | 1350-15 | 1592-2 | 1593-2 | 1591-4 | 1602-2 | 1617-2 |
| 2. Linear ratio, full size to model ... K | 4 | 9 | 9 | 9 | 9 | 9 |
| 3. Wetted surface of model in sq. ft. ... s | 5.95 | 2.440 | 2.488 | 2.688 | 2.618 | 2.144 |
| 4. Wetted surface, full size, in sq. ft. ... $K^2s=S$ | 95.25 | 197.5 | 201.5 | 218.0 | 212.0 | 173.6 |
| 5. Maximum section of model in sq. ft. ... $=a$ | .118 | .119 | .081 | .103 | .116 | .146 |
| 6. Maximum section, full size, in sq. ft. ... $K^2a=A$ | 1.91 | 9.65 | 6.55 | 8.3 | 9.4 | 11.86 |
| 7. Speed of model, m. p. h. ... $=v$ | 20 | 20 | 20 | 20 | 20 | 20 |
| 8. Speed of model, k. p. h. ... $=v'$ | 17.38 | 17.38 | 17.38 | 17.38 | 17.38 | 17.38 |
| 9. Corresponding speed, full size, m. p. h. ... $\sqrt{K}v=V$ | 40 | 60 | 60 | 60 | 60 | 60 |
| 10. Corresponding speed, full size, k. p. h. ... $\sqrt{K}v'=V'$ | 34.76 | 52.14 | 52.14 | 52.14 | 52.14 | 52.14 |
| 11. Total resistance of model at v m. p. h. ... $=r_t$ | 41.25 | 25.4 | 21.2 | 18.65 | 13.65 | 15.8 |
| 12. Exponent of v with which $r_t$ varies ... n | 2.0 | 2.07 | 2.27 | 2.03 | 2.1 | 1.96 |
| 13. Frictional resistance of model $.0117sv'^2$ ... $=r_f$ | 21.0 | 8.63 | 8.8 | 9.54 | 9.25 | 7.58 |
| 14. Residual resistance of model ... $r_t-r_f=r_r$ | 20.25 | 16.77 | 12.4 | 9.11 | 4.4 | 8.22 |
| 15. Exponent of v with which $r_r$ varies ... $n'$ | 2.0 | 2.06 | 2.48 | 2.00 | 2.28 | 1.91 |
| 16. Residual resistance of full size at V m. p. h. ... $r_r\times K^3=R_r$ | 1,295 | 12,250 | 9,050 | 6,630 | 3,210 | 5,992 |
| 17. Residual resistance of full size at V m. p. h., $r_r\times\left(\frac{A}{a}\right)\times\left(\frac{V^{n'}}{v}\right)=R'_r$ | 1,296 | 13,060 | 15,490 | 6,570 | 5,183 | 5,430 |
| 18. Frictional resistance at V m.p.h., full size ... $.01\times S\times V'^{1.85}=R_f$ | 672 | 2,970 | 3,025 | 3,270 | 3,180 | 1,506 |
| 19. Total resistance at V m. p. h., full size ... $R_r\times R_f=R_t$ | 1,967 | 15,220 | 12,075 | 9,900 | 6,390 | 7,498 |
| 20. Total resistance at V m. p. h., full size ... $R'_r\times R_f=R'_t$ | 1,968 | 16,030 | 18,515 | 9,840 | 8,363 | 6,936 |
| 21 Total resistance at V m. p. h., full size ... $K^3r_t=R''_t$ | 2,640 | 18,500 | 15,450 | 13,600 | 9,950 | 11,518 |

TABLE II.

| Model | A-1 | C-1 | D-1 | N-1 | N-2 | N-3 |
|---|---|---|---|---|---|---|
| 1. Number | 1350–15 | 1592–2 | 1593–2 | 1591–4 | 1602–2 | 1617–2 |
| 19. Total resistance in water, Table I ........ $R_r+R_t=R_t$ | 1,967 | 15,220 | 12,075 | 9,900 | 6,390 | 7,498 |
| 20. Total resistance in water, Table I ........ $R'_r+R_t+R'_t$ | 1,968 | 16,030 | 18,515 | 9,840 | 8,363 | 6,936 |
| 21. Total resistance in water, Table I ........ $K^3r_t=R''_t$ | 2,640 | 18,500 | 15,450 | 13,600 | 9,950 | 11,518 |
| 22. Resistance in air, full size, at V m. p. h. ........ $R_t/813=H_1$# | 2.42 | 18.72 | 14.85 | 12.18 | 7.86 | 9.22 |
| 23. Resistance in air, full size, at V m. p. h. ........ $R'_t/813=H_2$# | 2.42 | 19.72 | 22.77 | 12.15 | 10.29 | 8.53 |
| 24. Resistance in air, full size, at V m. p. h. ........ $R''_t813=H_3$# | 3.24 | 22.75 | 19.00 | 16.73 | 12.24 | 14.17 |
| 25. Resistance in air, full size.... $K\rho v.^{14}V^{1.86}L^{1.86}$(Rayleigh)$=H_4$# | 3.48 | 20.56 | 17.16 | 15 09 | 11.05 | 12.78 |
| 26. Resistance in air of normal plane of equal maximum section, $0033AV^2=H_5$#. | 10.10 | 114.5 | 77.7 | 86.5 | 111.6 | 141.0 |
| 27. Ratio in per cent ........ $H_1/H_5=$ | 107.2 | 90.3 | 90.3 | 90.00 | 90.3 | 90 25 |
| 28. Fineness coefficient, assuming $H_4$ as best value.... $H_4/H_5=F$ | .34 | .179 | .221 | .156 | .0991 | .0906 |
| 29. Excess resistance at 60 m. p. h., over 1602–2 ........ $=E$ | * | 9.5# | 9.5# | 4.04# | ...... | 1.74# |
| 30. ($K\rho v.^{14}$) from model tests, "form factor" ........ $=F'$ | .0000258 | .0000364 | .00002984 | .0000239 | .0000183 | .0000261 |

* Model of radically different form from others.

structor J. C. Hunsaker, in commenting on the proofs of this paper as originally written. He further suggested the comparison with line 24, which is of peculiar interest as shown by the percentage relation of these values. Investigation of the relation of the two methods as per line 27, shows that if we confine the use of the "approximate" method to the "corresponding speed," as per the Law of Comparison, the values as determined by Lord Rayleigh's method should be 90.25% of the values attained by the approximate method, for models one-ninth the full size, and 107% for models one-quarter the full size, so that the approximate method which is much simpler can be used with a fair degree of accuracy if we put it in the form—

$$H_6 = .00176K^{2.79}r_t$$

$$\text{This assumes } \frac{\rho_1}{\rho_2} = .00123 \text{ and } \frac{v_1}{v_2} = 13.$$

Line 26 gives the head resistance of a plane of the maximum section according to Eiffel's coefficient for flat plates normal to the wind.

Line 28 gives a fineness coefficient based on the comparison of lines 25 and 26.

Line 30 gives the value of $\kappa\rho v^{.14}$ for each of the boat models. These "form factors" are of interest when compared with the values of the same coefficients for models of dirigibles in which the form is unrestricted by requirements such as enter into the flying boat problem. Thus, to make the comparison more ready, Table III is compiled:

TABLE III.

| Model | Type | $\kappa\rho v^{.14}$ (Air) |
|---|---|---|
| N. P. L. | Dirigible | .0000152 |
| Beta | do | .0000164 |
| Gamma | do | .0000165 |
| B. F. 36 | do | .0000142 |
| Lebaudy | do | **.0000124** |
| B. F. 32 | do | .0000140 |
| A-1 | Pontoon | .0000258 |
| C-1 | Flying boat | .0000364 |
| D-1 | do | .0000298 |
| N-2 | do | **.0000183** |
| N-3 | Owl | .0000261 |

It thus appears that the N-2 form, while superior in the air to the other flying boat forms, may still be improved, and if the efficiency of the Lebaudy form could be approached its head resistance might be reduced to 68% of the present value.

However, when we come to consider that the total head resistance of the N-2 model is only about 11# in air at 60 m. p. h., and consider


FIG 1.—BOW END OF MODELS

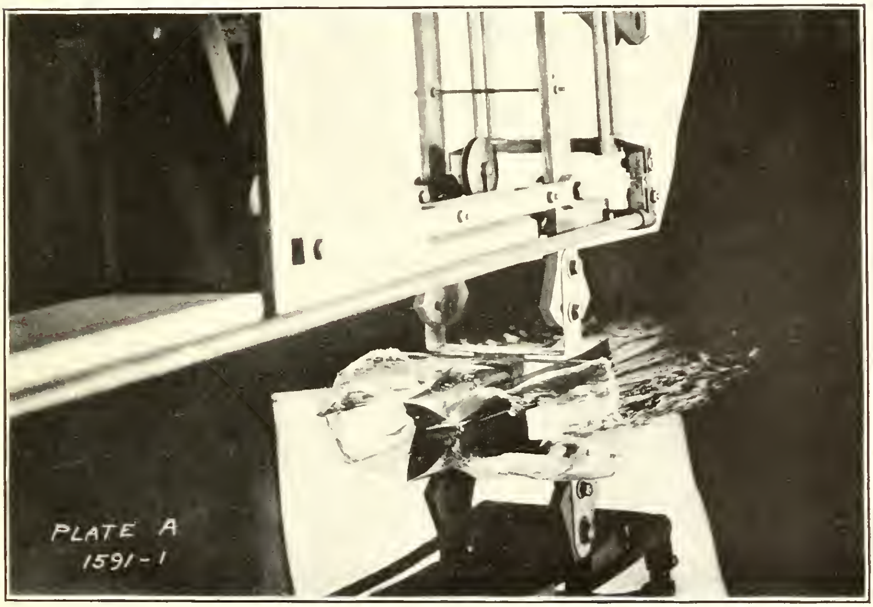
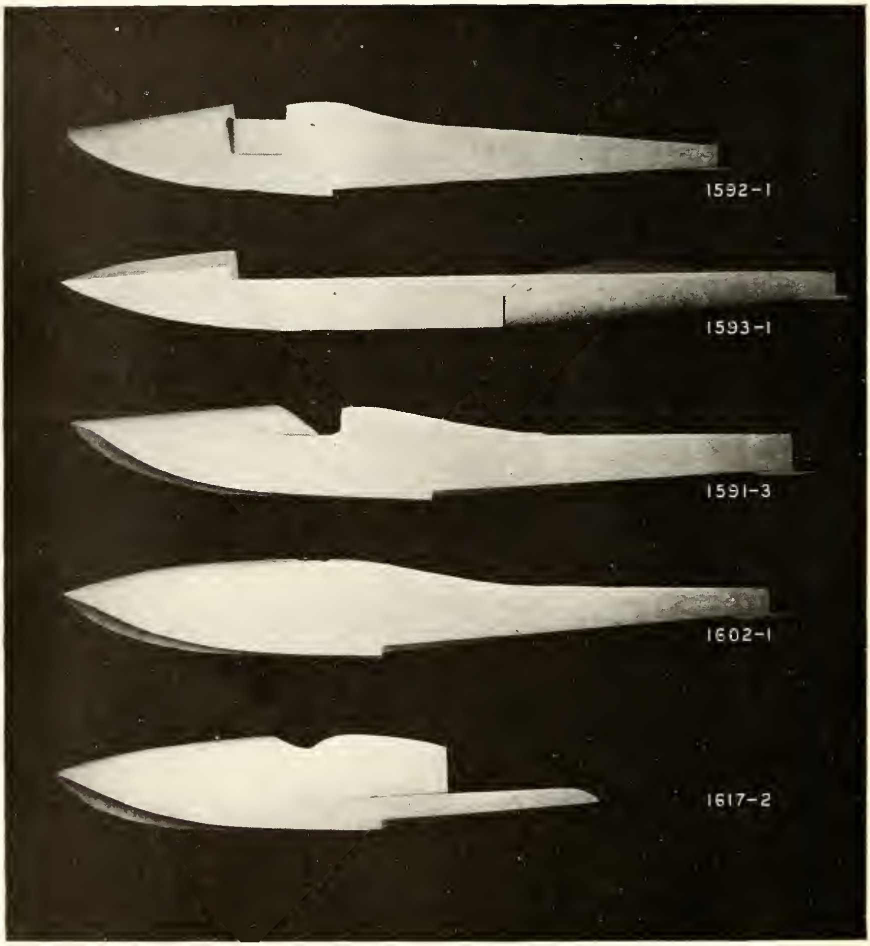
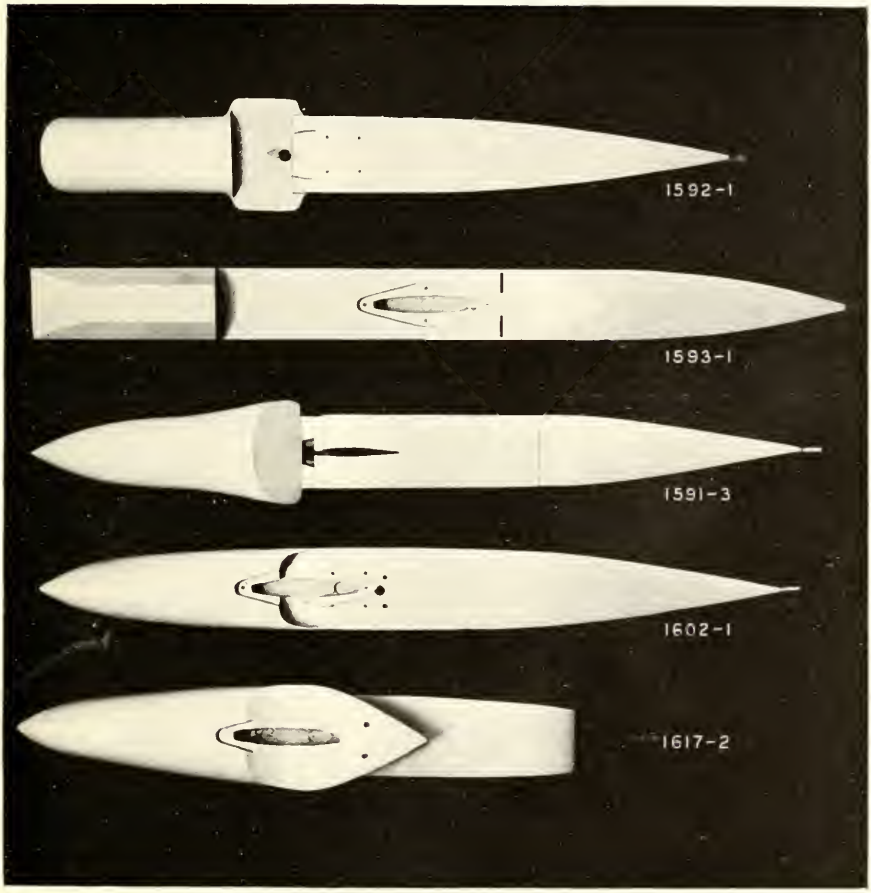



FIG. 2.—SHEET OF SPRAY MADE BY MODEL AT SPEED OF 5.5 M. P. H.




SIDE VIEW OF MODELS




VIEW OF MODELS FROM ABOVE

the difficulty of construction involved, particularly if the surface running qualities are to be retained, we see that the present forms are reasonably satisfactory. While the possible saving of 3.5# head resistance is worth considering, it must only be considered if its attainment does not involve increased weight, cost or difficulty of construction to such a degree as to outweigh the small gain possible. Such savings increase in importance in proportion to the square of the speed desired. It thus appears that increased efficiency must be aimed at in those members of the structure which offend to a greater degree than the hull, namely, the multiplicity of the truss members; and the exposed power plant, especially the water cooled power plant.

The peculiar form of Model 1617-1 is due to an attempt to utilize the advantage of the flying boat arrangement of bottom and step, together with a good shape stream line hood in place of the ordinary pontoon with the hydro-aeroplane type of machine.

It is interesting to note that the coefficient of fineness of this model is less than that for Model 1602-2 which indicates that per unit of area of maximum section the resistance of this form is slightly less than that of the 1602 model. An inspection of line 29 will show that the probable reason for this is due to the very low value of the frictional component of the resistance of this model. However, when the comparison is based on $\kappa \rho v^{\cdot 14}$, the form factor used by Lord Rayleigh, this form is much coarser than the 1602 model.

An independent experiment is worthy of note at this time. An experiment was made to determine the existence and amount of "nosing" torque on model 1350, at various angles of incidence. Unfortunately the apparatus carried away before the experiments were completed, but it was found that there is a "nosing" torque of about 90 ft. lbs. when the deck of the pontoon is parallel with the line of flight. To this torque should be added that due to the head resistance which is approximately 5.42 lbs. $\times$ 5 ft. $=$ 26.10 ft. lbs. or a total torque due to the pontoon tending to make the machine head down of about 116 ft. lbs. This with the c. p. of the diving rudder 15 ft. abaft the c. g. would require the diving rudder to carry a negative load of about 7.75 lbs. if the machine were "balanced" for all other effects, at 60 m. p. h.

Additional experiments on submerged models are contemplated with a view to determining the stream line flow about the models as a means of arriving at improvement of form, and other experiments to determine the effects of the cockpit openings, sponsons, etc., and a more complete series for determining torque at different angles.