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DAVID TAYLOR MODEL BASIN
WASHINGTON, D.C.

DEPARTMENT OF THE NAVY

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THE PLANING CHARACTERISTICS OF A 15-DEGREE DEADRISE SURFACE WITH CIRCULAR-ARC CAMBER

by

Eugene P. Clement

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HYDROMECHANICS LABORATORY

RESEARCH AND DEVELOPMENT REPORT

September 1966

Report 2298

THE PLANING CHARACTERISTICS OF A 15-DEGREE DEADRISE SURFACE WITH CIRCULAR-ARC CAMBER

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NOTATION

Symbol	Definitions
b	Beam of planing surface, feet
C_{L_b}	Lift coefficient based on beam, $\frac{L}{\frac{\rho}{2} v^2 b^2}$
$C_{L,d}$	Two-dimensional lift coefficient at infinite depth (see Reference 3)
D	Horizontal drag, pounds
L	Vertical lift, pounds
ℓ_p	Center-of-pressure location (measured along line of straight portion of keel forward of transom at centerline), $\frac{M}{L \cos\alpha + D \sin\alpha}$, feet
M	Pitching moment about intersection of line of straight portion of keel with transom at centerline, foot-pounds
R	Horizontal resistance (equals drag), pounds
v	Horizontal velocity, feet per second
W	Gross weight of boat (equals lift), pounds
α	Angle of attack of straight part of model ahead of the cambered region, degrees
β	Deadrise angle, degrees
γ	Angle between stagnation line and centerline, in plan view, degrees
ρ	Mass-density, $\frac{\text{pounds seconds}^2}{\text{feet}^4}$

ABSTRACT

A planing surface with 15-deg deadrise, circular-arc camber, and a moderate amount of trailing edge sweep was designed as the main lifting surface for an existing experimental stepped planing boat. A model of the planing surface was then built and tested in the towing basin. The test results indicate that the lift/drag ratio of the main planing surface of the boat will be increased 10 percent by utilization of this design. Also, the performance in head seas should be significantly improved since the cambered surface will develop the necessary lift at approximately one-half the forebody angle of attack at which the boat now operates.

INTRODUCTION

Development of a particular configuration of stepped planing boat has been underway for some time at the David Taylor Model Basin. This design has a small transverse step at midlength, a relatively narrow transom, and utilizes the Plum-type of adjustable planing stabilizer at the stern for stability and control of trim. A number of models have been built and tested in the towing basin. Also, a 30-ft manned model has been built and tested in open water. The test results from both the towing tank models and the manned model have shown significantly lower power requirements than for the conventional stepless planing boat. A representative comparison of the performance of this stepped hull with a number of stepless hulls is presented in Reference 1.*

---

* References are listed on page 10.

As a further contribution to the development of this type of boat, Reference 2 proposed a design method for stepped planing boats that involved sweeping the step back (in plan view) to obtain a relatively high value of aspect ratio for the main lifting surface. (A further important reason for sweeping the step back is explained in the Appendix of the present report.) An additional development has been a Model Basin computer study of the lift and drag of cambered as opposed to straight planing surfaces. The equations presented by Johnson (Reference 3) were utilized for making the calculations. The results (which are necessarily for zero deadrise only) indicate that a substantial improvement in the lift-drag ratio of a stepped planing hull can be attained by incorporation of an appropriate camber curvature.

The foregoing developments indicated the desirability of incorporating a sweptback step and a cambered planing surface in the existing 30-ft manned model. Such a planing surface was therefore designed for this craft. A scale model of the planing surface was then tested in the towing basin to check performance before installation on the 30-ft boat. A discussion of the design of the sweptback cambered planing surface and the results of the tests of the model in the towing basin are given in this report.

DESIGN OF THE CAMBERED PLANING SURFACE

Analytical expressions for the lift, drag, and center of pressure of supercavitating hydrofoils operating at finite depth are given in Reference 3. These equations have been used to calculate the characteristics of zero-deadrise surfaces of a variety of camber shapes and a range of drafts including zero draft (leading edge at the surface of the water). The flow pattern for the zero draft case corresponds closely to the planing case. Therefore the equations of Reference 3 were programmed for solution by electronic digital computer, and the characteristics of cambered planing surfaces were calculated for a variety of camber shapes and a range of aspect ratios and angles of attack. Promisingly high values of lift-drag ratio were calculated for certain camber shapes at low angles of attack. Two models of zero-degree deadrise planing surfaces were also built and tested, and the encouraging result was obtained that the experimental values of lift-drag ratio were somewhat higher than the calculated values. The results of the foregoing work will be available in a forthcoming report. The preliminary results of that work were used to guide the design of the 15-degree deadrise cambered planing surface.

The existing 30-ft stepped boat has a gross weight of approximately 10,000 lb and model tests indicate that about 90 percent of the weight will be carried by the main planing surface. The width of the bottom of the craft at the present transverse step location is 6.2 ft, and the speed for which the planing surface was to be designed was taken to be 50 mph. The foregoing values give a value of C_{L_b} (equals $\frac{L}{\rho/2\ v^2 b^2}$) of 0.044. Calculated values of the performance of cambered planing surfaces indicate that for a circular-arc cambered planing surface with the above value of C_{L_b} and an aspect ratio of 2, optimum performance will be attained with a value of the two-dimensional design lift coefficient $C_{L,d}$ of about 0.075. The configuration of a circular-arc camber curve is defined by the value of the central angle subtending the chord of the arc. Also, from Reference 3, the relationship between $C_{L,d}$ and the central angle in radians is:

$$\text{Central Angle} = C_{L,d} \cdot \frac{32}{9\pi}$$

A value of 0.075 for $C_{L,d}$ then gives a value of 0.085 radians (4.9 deg) for the central angle. The model planing surface, based on a value of 0.085 radians for the central angle, is shown in Figure 1. The width of the planing surface was taken to be 1 ft; thus for practical purposes, it became a 1/6-scale model of a lifting surface for the 30-ft boat.

TESTS AND RESULTS

The model was tested on Carriage 3 at the Model Basin, using the towing gear shown in Figure 2. The water temperature was 70 F for all of the tests. Test runs were made with the model fixed in angle of attack but free to heave. The reference for angle of attack was taken to be the straight part of the planing surface forward of the cambered region. This straight portion is tangent to the leading edge of the cambered portion.

The weight of model and towing gear were initially counterbalanced by means of the counterweight indicated (with the model in the air), and the desired load on the water for each test run was then established by removing an equivalent weight from the counterweight pan.

Most of the runs were made with a load on the water of 50 lb, and the speed was varied to give a range of values of C_{L_b}. Tests were run at angles of attack from 1 1/2 to 4 deg, at 1/2-deg intervals. Resistance and pitching moment were measured, and readings were made of the wetted lengths of keel and chine. For many of the runs, the width which was wetted by solid water was less than the chine width of the model; in these cases, actual width wetted by solid water was read on a scale marked on the transom.

Air drag tares were measured with the model attached to the towing gear. These measurements were made for a range of speeds and angles of attack of the model, with the lowest point of the transom 1 in. above the water surface. There was no significant variation of air drag with model angle of attack. The air drag values were subtracted from the measured total drags to give the net values of hydrodynamic drag which are reported here.

Tabulated values of the test results are given in Table 1. The wetted lengths of keel and chine for the model are plotted in Figure 3. The chine wetted lengths are also presented in Figure 4, together with the wetted widths of the transom.

The model values of resistance were also corrected to correspond to a load of 10,000 lb in sea water at 59 F. The 1947 ATTC friction coefficients were used with zero roughness allowance. This was done to enable comparing the data with corresponding values for an uncambered planing surface having the same deadrise angle. The values of L/D for 10,000-lb load etc. are given in Figure 5. Values of ℓ_p/b for the tests are plotted in Figure 6; ℓ_p is the center of pressure location measured along the line of the straight portion of the keel, forward of the transom at centerline. Photographs of the model underway are shown in Figure 7.

DISCUSSION

The design requirement that C_{L_b} be equal to 0.044 can be best satisfied at an angle of attack of 2 deg (see Figure 5), in which case the L/D ratio will be 8.4. The maximum value of L/D for this planing surface is 8.5 (Figure 5b). Reference 4 indicates a maximum L/D value of 7.7 for an uncambered planing surface of the same deadrise angle (15 deg). Therefore, the utilization of a circular-arc camber increased the L/D ratio of the 15-deg deadrise planing surface by 10 percent.

A comparison of the performance of the cambered planing surface with that of a corresponding stepless hull is also of interest. Reference 4 was therefore utilized to determine the resistance of a 10,000-lb stepless hull having 15-deg deadrise, an appropriate length beam ratio, and a loading condition similar to that of the stepped hull. It was determined that appropriate dimensions for a comparable stepless hull would be a beam over chines of 7.6 ft, and an LCG location forward of the transom of 10.25 ft. The calculation method of Reference 4 then gives a value of R/W of 0.18 for a stepless hull of these dimensions at a speed of 50 mph. The corresponding value for the stepped cambered hull (obtained by inverting L/D equals 8.4) is 0.12. Accordingly, this comparison shows that the stepless hull would have 50 percent more hydrodynamic drag than the stepped hull with cambered lifting surface.

It is also important to note the effect of camber on the running attitude of the 30-ft boat. In its present condition with an uncambered main planing surface, the forebody of the boat runs at an angle of attack of 5 1/2 deg. The model test results for the cambered planing surface indicate, however, that the necessary lift will be provided by this surface at a forebody angle of attack of only 2 to 2 1/2 deg (depending on the speed attained). The reduction in trim angle from 5 1/2 to 2 or 2 1/2 deg will, according to Reference 5, result in a large reduction in impact accelerations in rough water.

The experimental results for the intersection points of the stagnation line with the chine (or the step) are of particular significance in connection with the behavior of stepped hull configurations. This is because of the drag rise which occurs if the outer end of the stagnation line intersects the step instead of the chine (see the Appendix for a detailed discussion of this drag-rise phenomenon). The line of the stagnation pressure on the bottom of a planing hull (i.e., the stagnation line) corresponds closely to the forward boundary of the area which is wetted by solid water. The latter boundary (or, for simplicity, the stagnation line) is ahead of the line of intersection of the undisturbed water surface with the planing hull. The two lines essentially coincide at the forwardmost point, which is at the keel intersection with the water surface. Aft of this point, however, the wetted width to the stagnation line at any fore and aft location is greater than the width to the intersection of the plane of the undisturbed water surface with the hull bottom. The ratio of the actual solid-water wetted width to the width defined by the intersection of the undisturbed water surface is the "wave-rise factor," which has been shown to be approximately equal to $\pi/2$. This ratio can vary appreciably, however, for different planing configurations, and it is important to attempt to establish its value for the configuration considered here. Figure 8 was drawn for that purpose. It shows the lines of intersection of the undisturbed water surface with the cambered planing surface model for several angles of attack. The intersection of the water surface with the keel was taken in each case to coincide with the point at which the camber curvature of the keel begins. This point is 12 in. forward of the intersection of keel and transom. Interpolated values of chine wetted length for 12 in. keel wetted length were determined from the experimental results in Figure 3 and are indicated in Figure 8. Values of the ratio of the solid-water wetted width in the planing condition (12 in. in most cases) to the width at the same fore-and-aft location of the corresponding undisturbed water surface intersection are tabulated below:

Angle of Attack deg	Wave Rise Factor
2	1.60
2.5	1.61
3	1.64
3.5	1.73

Accordingly, the experimental result for this configuration is that the wave-rise factor is somewhat greater than π/2 (equals 1.57), and it tends to increase with increase in angle of attack.

APPENDIX

ADVANTAGES OF A SWEPTBACK STEP CONFIGURATION FOR A STEPPED PLANING HULL

The usual practice in designing the step of a planing boat, seaplane, or hydrofoil hull is to make the step either transverse, or V-shaped with the point of the V aft. An important disadvantage of both the transverse step and the point-aft, V-step can be explained as follows. When a stepped V-bottom hull is planing on the surface of the water, the boundaries of the lifting area and the spray generated are as shown in Figure 9. It can be seen that a "main spray blister"* originates at the intersection of the stagnation line with the chine of the boat. This spray shoots upward and outward from its point of origin and forms approximately the shape of a cone. The stagnation line is near the bow at the lower speeds and moves progressively aft as the speed increases. The reason for this is that the dynamic lift of the lifting surface is proportional to the square of the speed, so that as the speed increases, less and less hull bottom area is required to support the weight of the boat; accordingly, the forward boundary of the wetted area moves aft in such a way as to maintain a balance between lift and hull weight. Eventually, however, when a moderately high speed is reached, the stagnation line will intersect the step of the usual type, and with further increase in speed, the stagnation line will intersect the step a short distance inboard of the chine. When this occurs, an unsatisfactory flow condition arises. The main spray blister will originate, as before, at the outboard end of the stagnation line. However, this point is now under the bottom of the boat, and as a result, the upward-shooting spray blister will wet a large portion of the afterbody and will interfere with the flow of ventilating air to the step. This will cause a large increase in resistance. This critical speed also marks the point at which the width of the hydrodynamic pressure area supporting the boat will begin to decrease, and therefore the point at which the transverse stability will begin to deteriorate.

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* The character and origin of the main spray blister are described in detail in Reference 6.

The above unsatisfactory flow condition can be obviated by giving the step a "sweptback" character. Figure 10 indicates several alternative configurations for such a step.

It can be seen that if the line of the sweptback step is straight and its angle with the centerline is made approximately equal to the angle of the stagnation line with the centerline (Step a), then it is possible for the supporting wetted surface to decrease almost to zero without producing wetting of the afterbody by the main spray blister. Accordingly, it is possible to attain very high speeds in the case of a planing boat (or to attain takeoff speed in the case of a hydrofoil boat) without encountering the unsatisfactorily high resistance produced with the conventional types of steps.

The angle of the stagnation line with the centerline (γ) can be determined from model tests, or it can be approximately determined from the relationship:

$$\tan\gamma = \frac{\pi}{2} \frac{\tan\alpha}{\tan\beta}$$

In addition to preventing wetting of the afterbody, the sweptback step results in a higher aspect ratio of the planing area than is obtained with a conventional step. In the case of a conventional transverse step, or a step with the V-point aft, the aspect ratio will increase with increase in speed, up to the condition where the stagnation line intersects the step. With further increase in speed, however, the aspect ratio remains constant. With the step configuration proposed here, the aspect ratio will increase to a value several times that attainable with the conventional step, and a higher efficiency should thereby be attained.

In the event that the hull is intended to be run at only moderately high speeds, the step configuration can take the alternative forms indicated by lines b or c.

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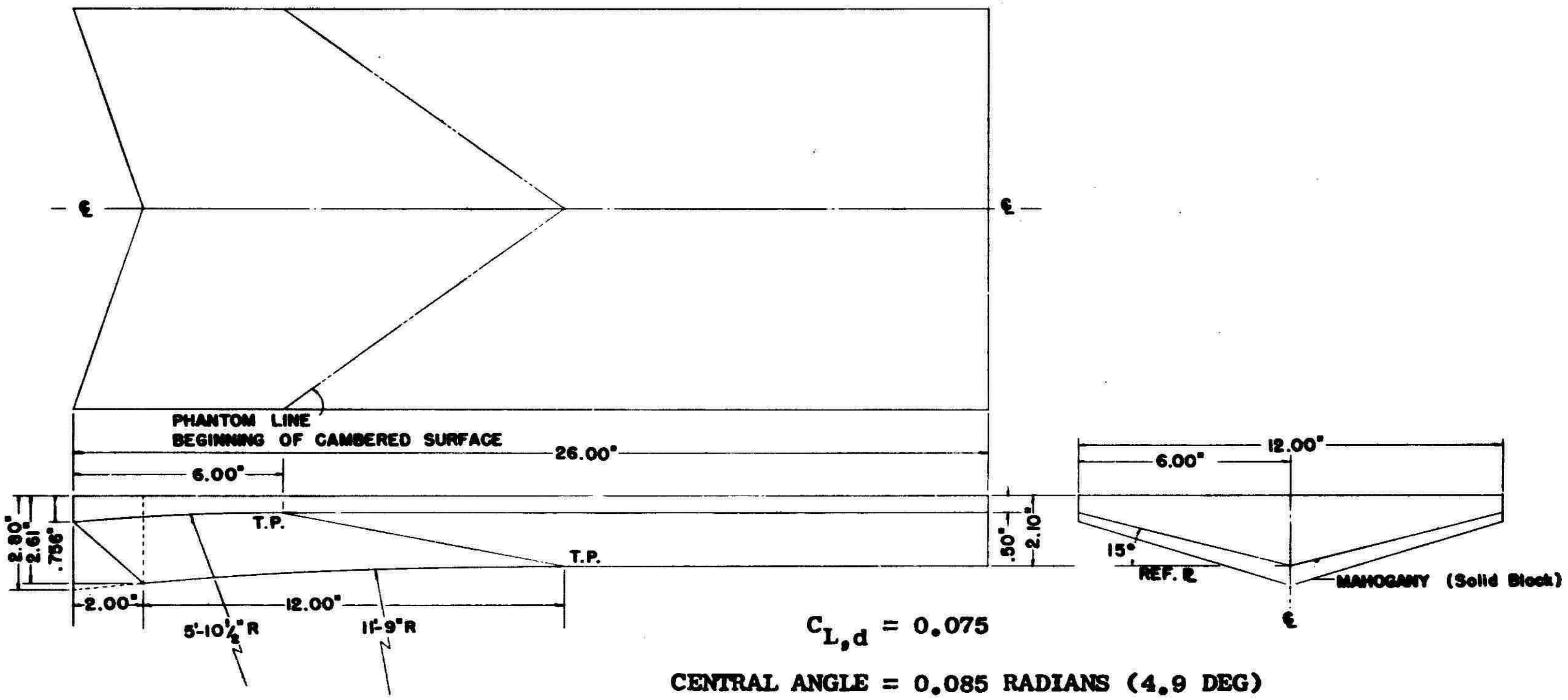


$C_{L,d} = 0.075$

CENTRAL ANGLE = 0.085 RADIANS (4.9 DEG)

Figure 1 - Model 5076

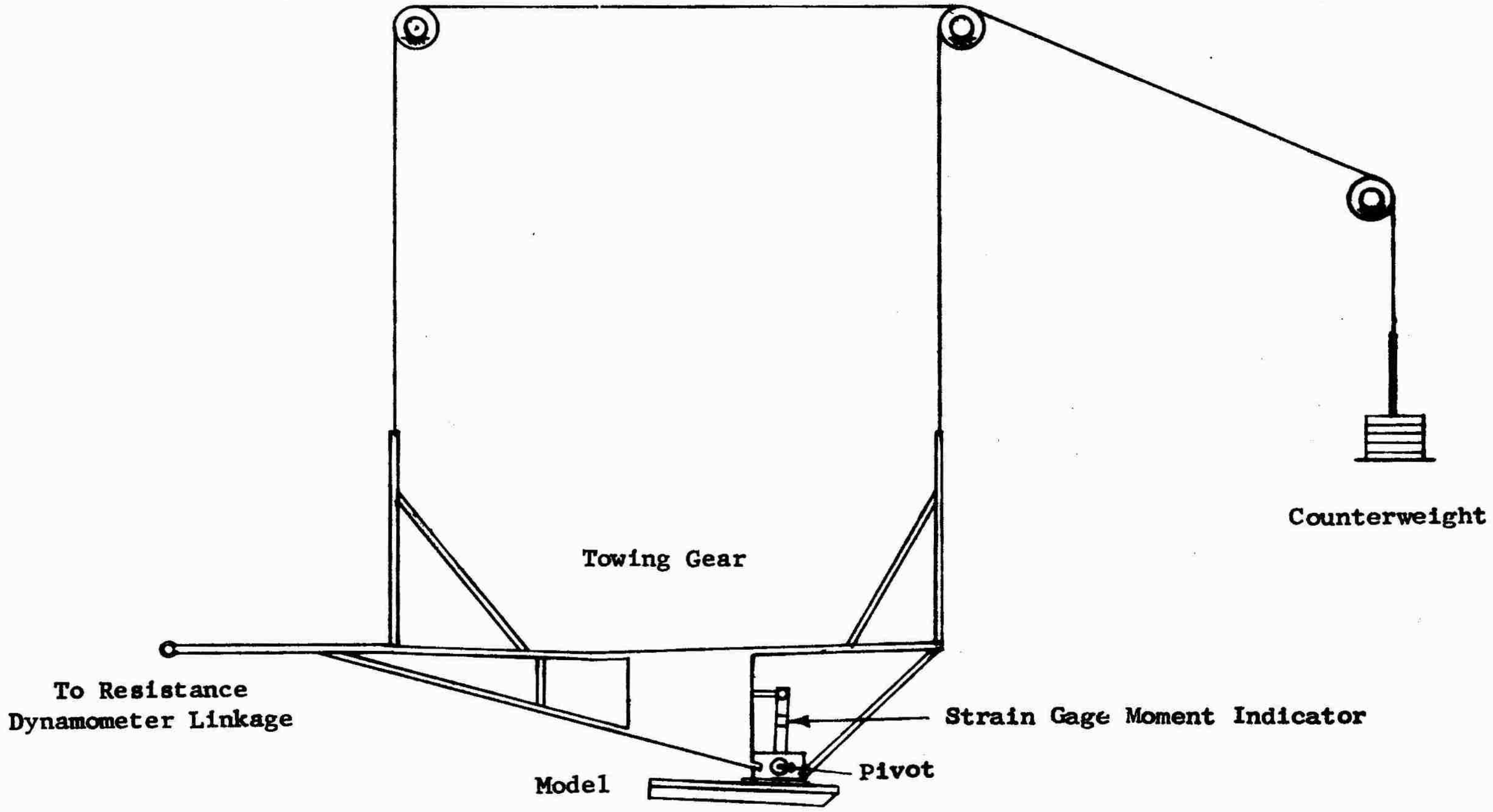


Figure 2 - Setup of Model and Towing Gear

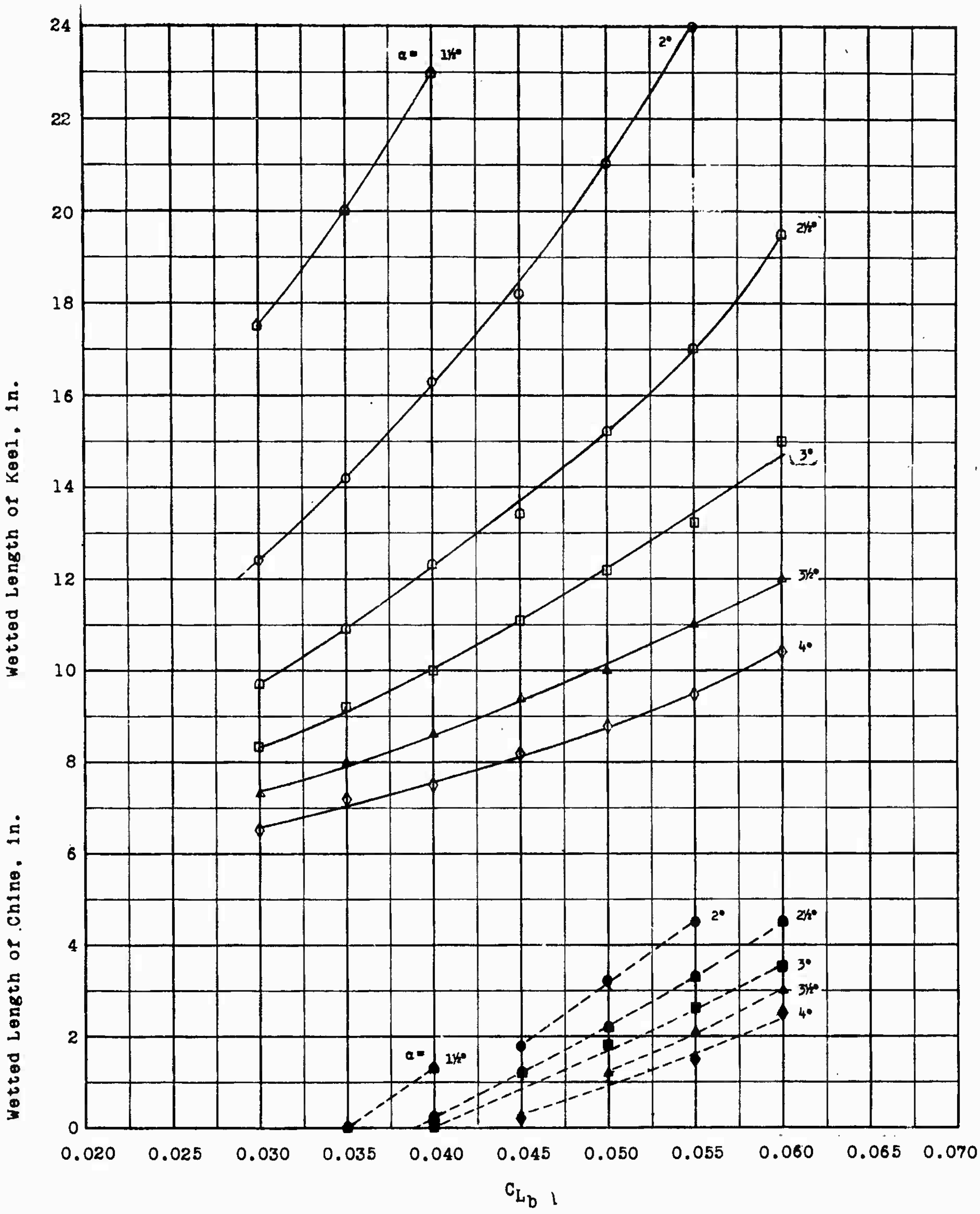


Figure 3 - Solid-Water Wetted Lengths of Keel and Chine

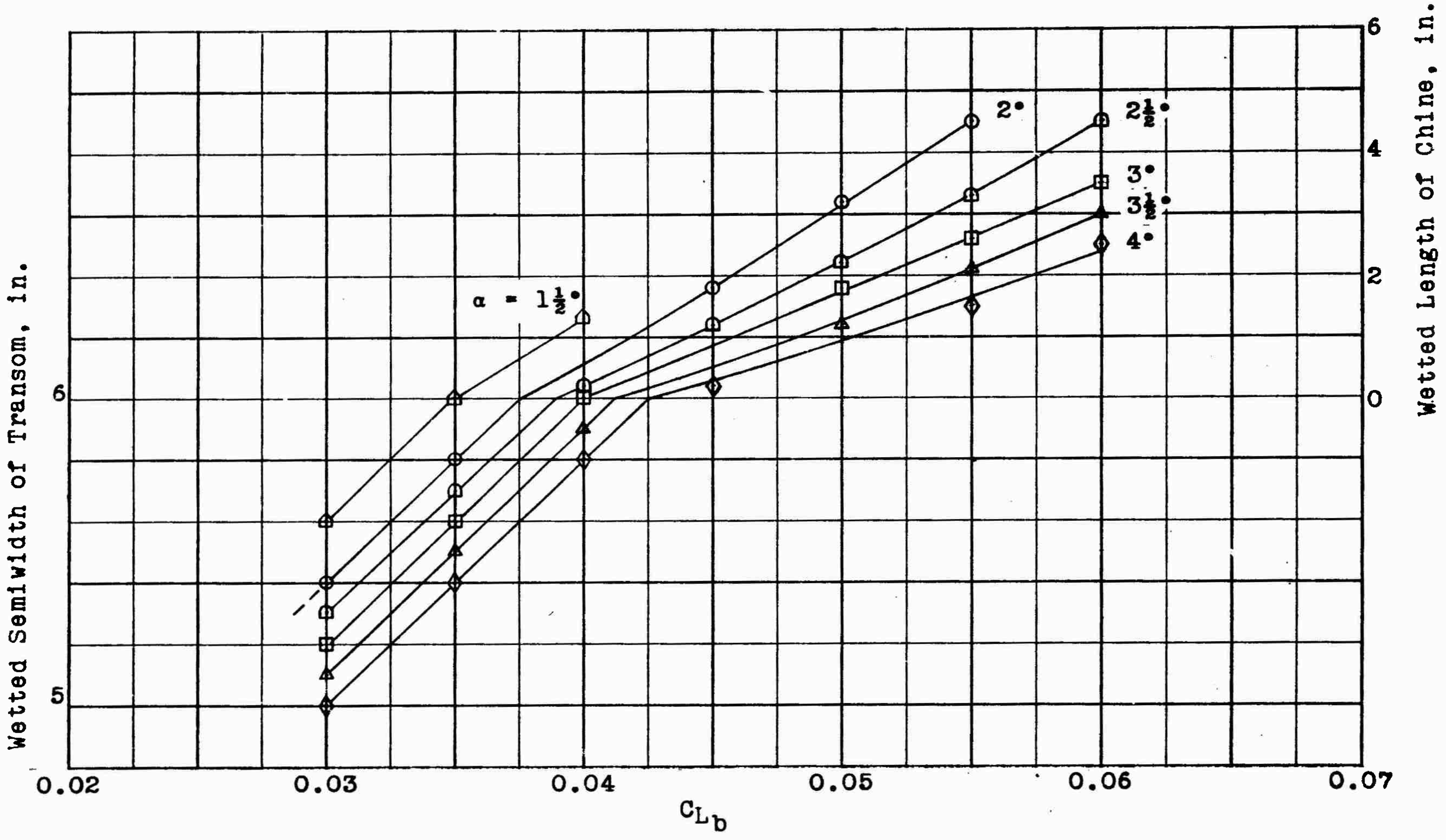


Figure 4 - Solid-Water Wetted Lengths of Chine and Wetted Widths of Transom

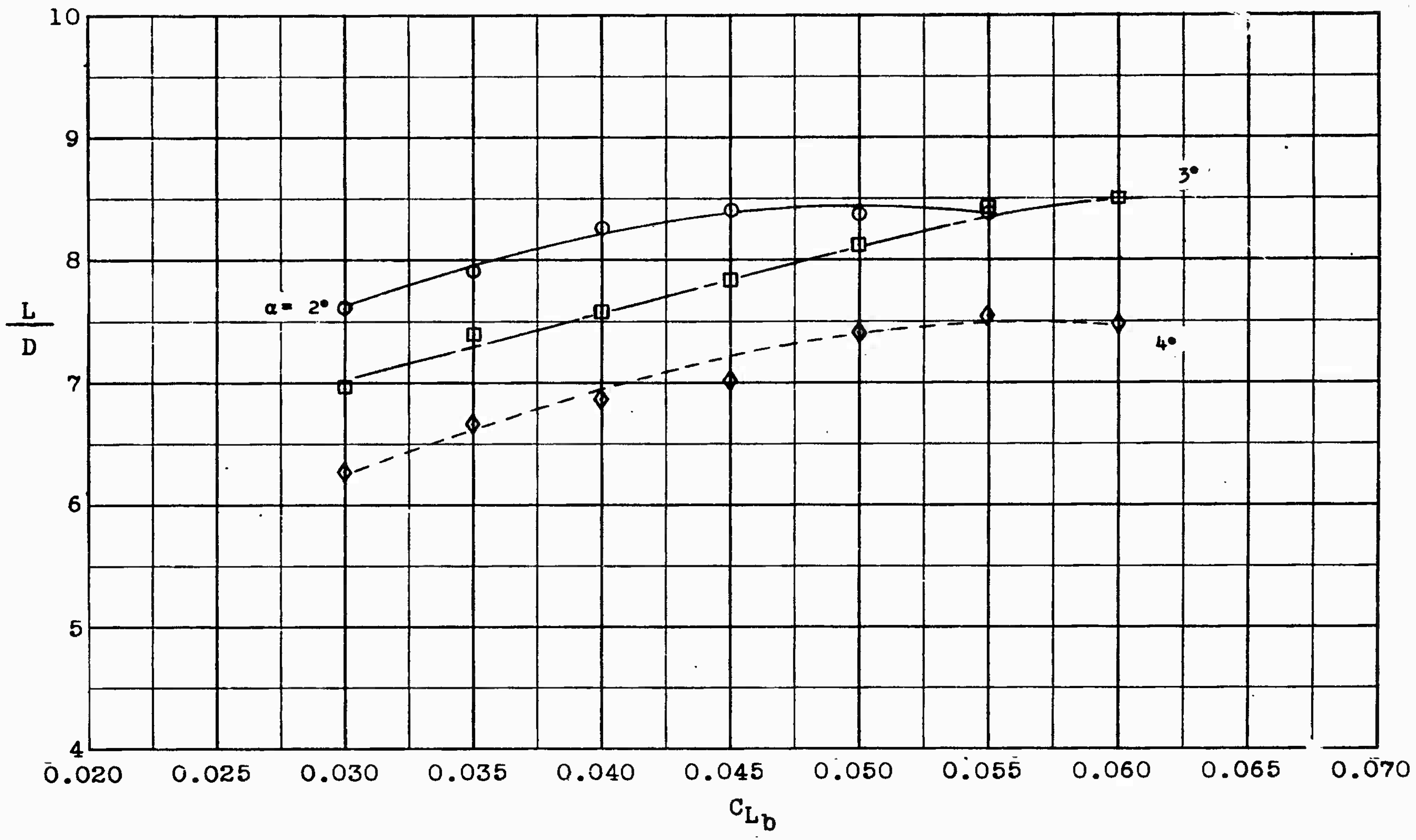


Figure 5a - For 2-, 3-, and 4-Degree Angles of Attack

Figure 5 - Variation of Lift/Drag Ratio with Lift Coefficient

Drag values corrected to correspond to 10,000-lb lift in sea water at 59F, using the 1947 ATTC friction coefficients with zero roughness allowance.

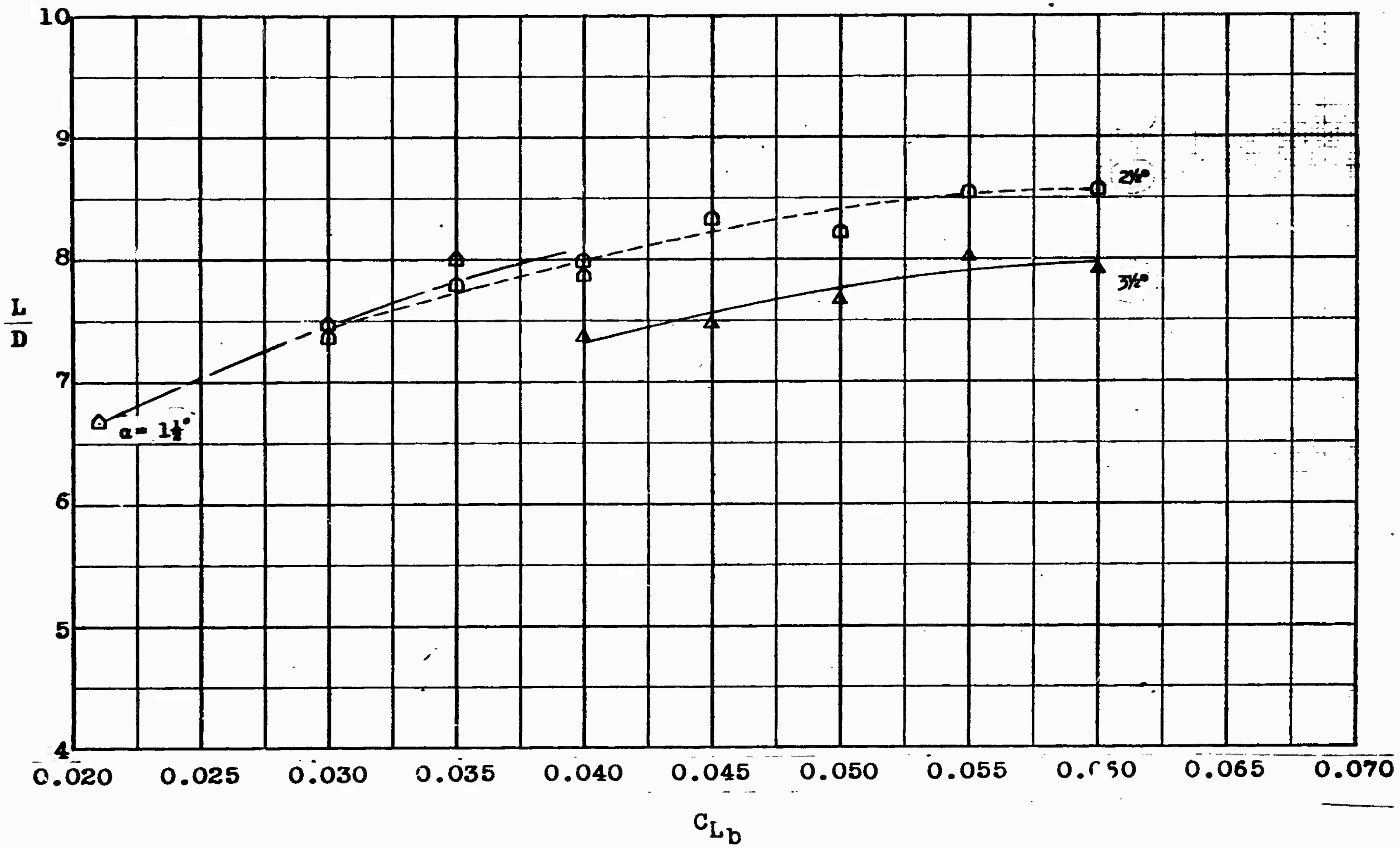


Figure 5b - For $1\frac{1}{2}$-, $2\frac{1}{2}$-, and $3\frac{1}{2}$-Degree Angles of Attack

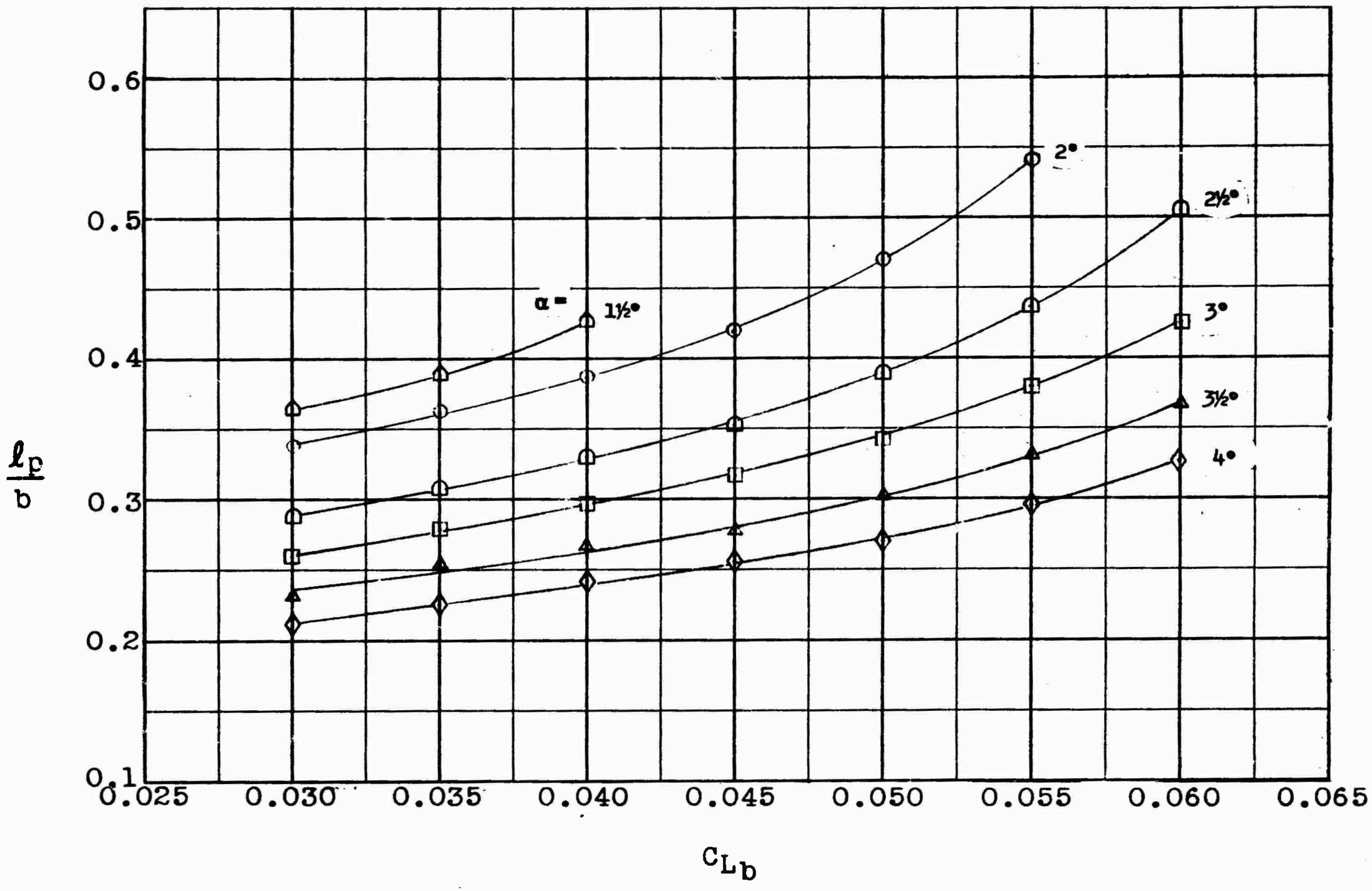


Figure 6 - Variation of Nondimensional Center-of-Pressure Location with Lift Coefficient

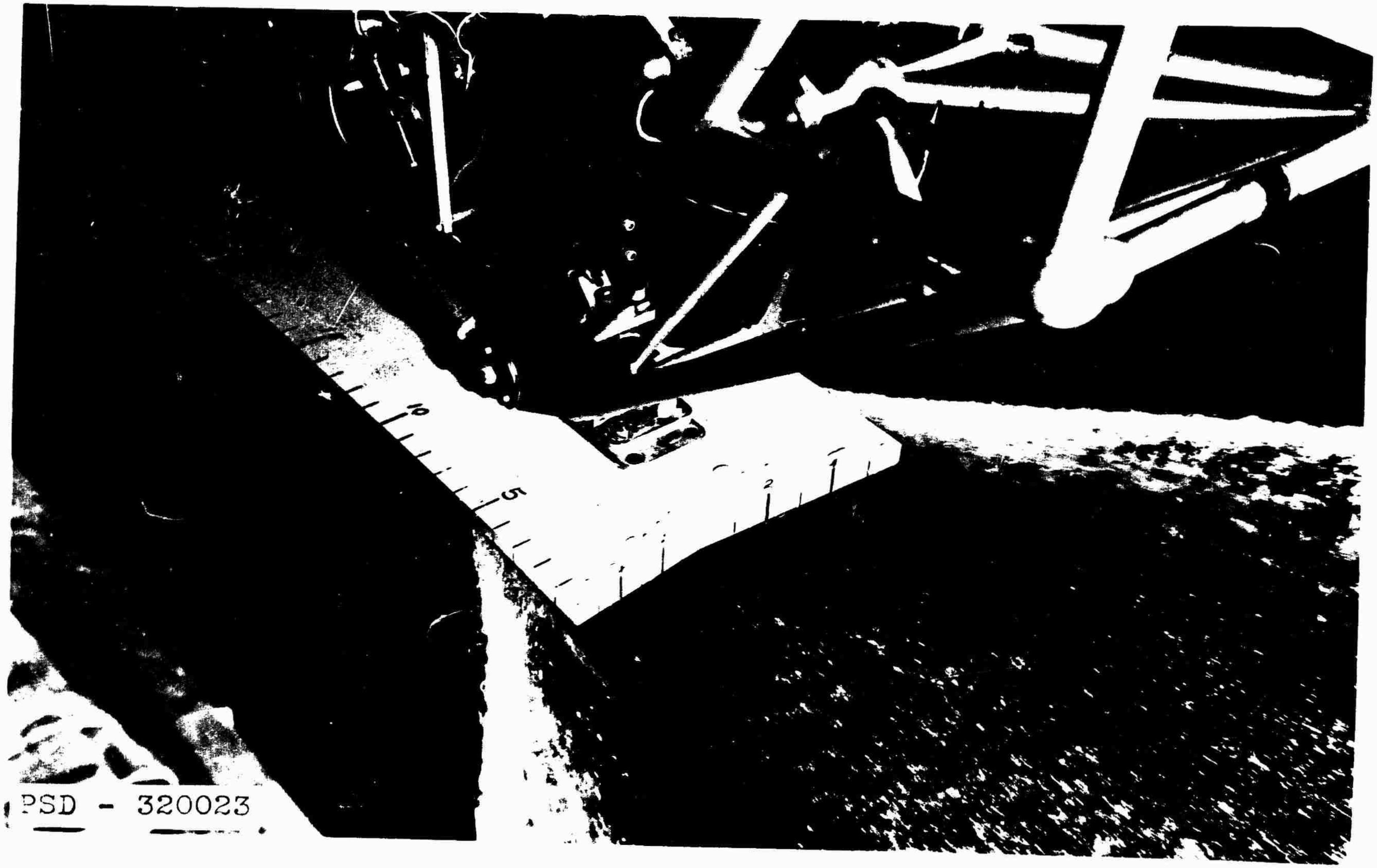
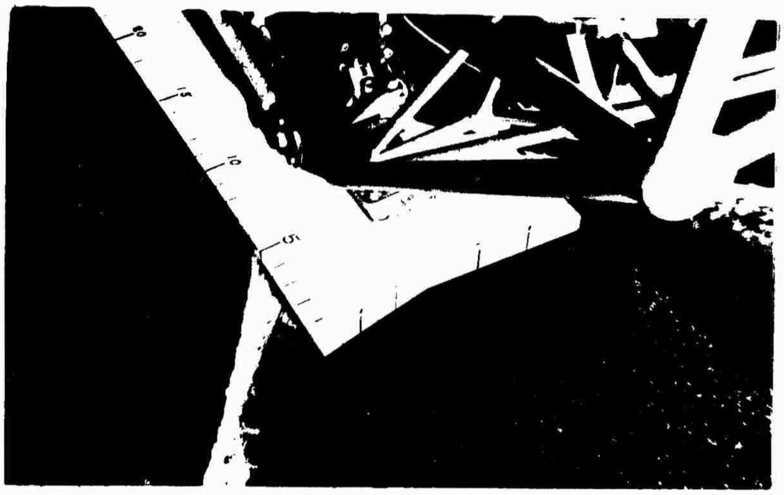


Figure 7a - $C_{L_b} = 0.040$; $\alpha = 1\frac{1}{2}$ deg

Figure 7 - Spray and Wake of Model for Various C_{L_b} Values and Angles of Attack

$\alpha = 2$ deg

(PSD - 320047)



$\alpha = 2\frac{1}{2}$ deg

(PSD - 320026)

$\alpha = 3\frac{1}{2}$ deg

(PSD - 320036)

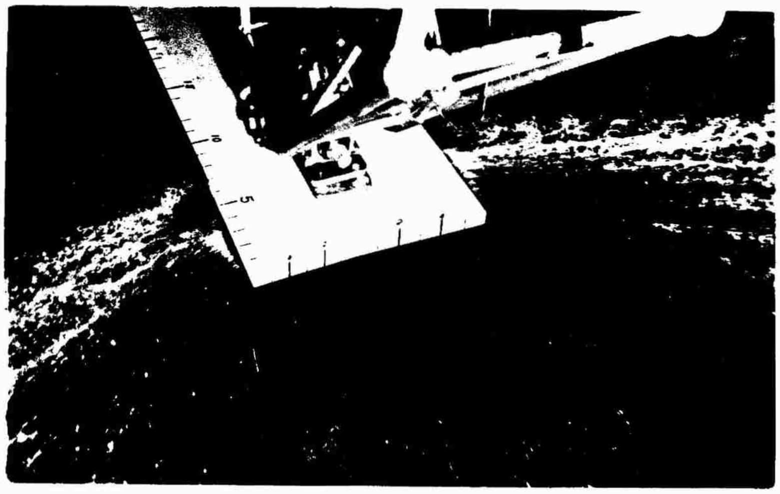
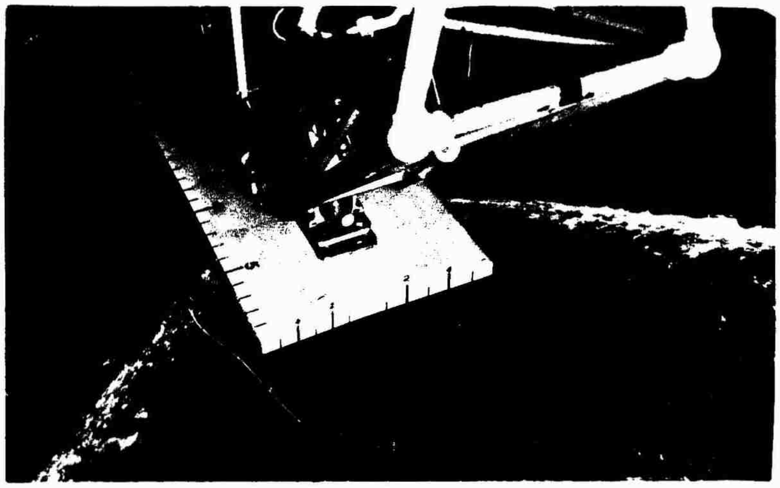


Figure 7b - $C_{L_b} = 0.045$

$\alpha = 2\frac{1}{2}$ deg

(PSD - 320030)



$\alpha = 3\frac{1}{2}$ deg

(PSD - 320038)

$\alpha = 4$ deg

(PSD - 320045)

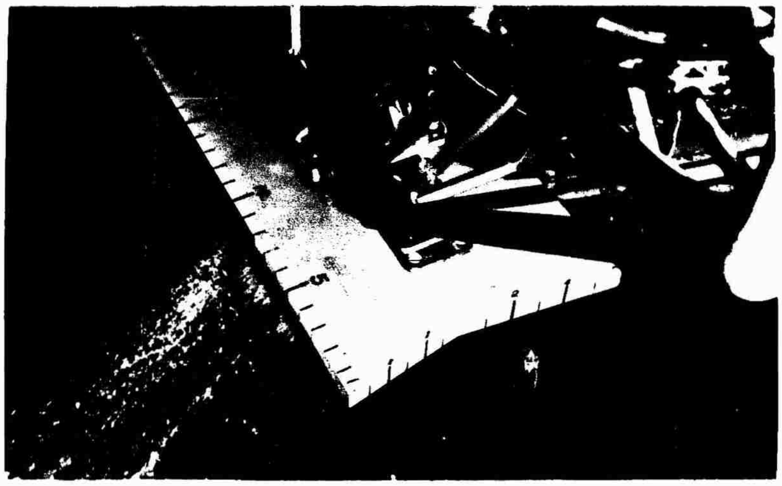


Figure 7c - $C_{L_b} = 0.055$

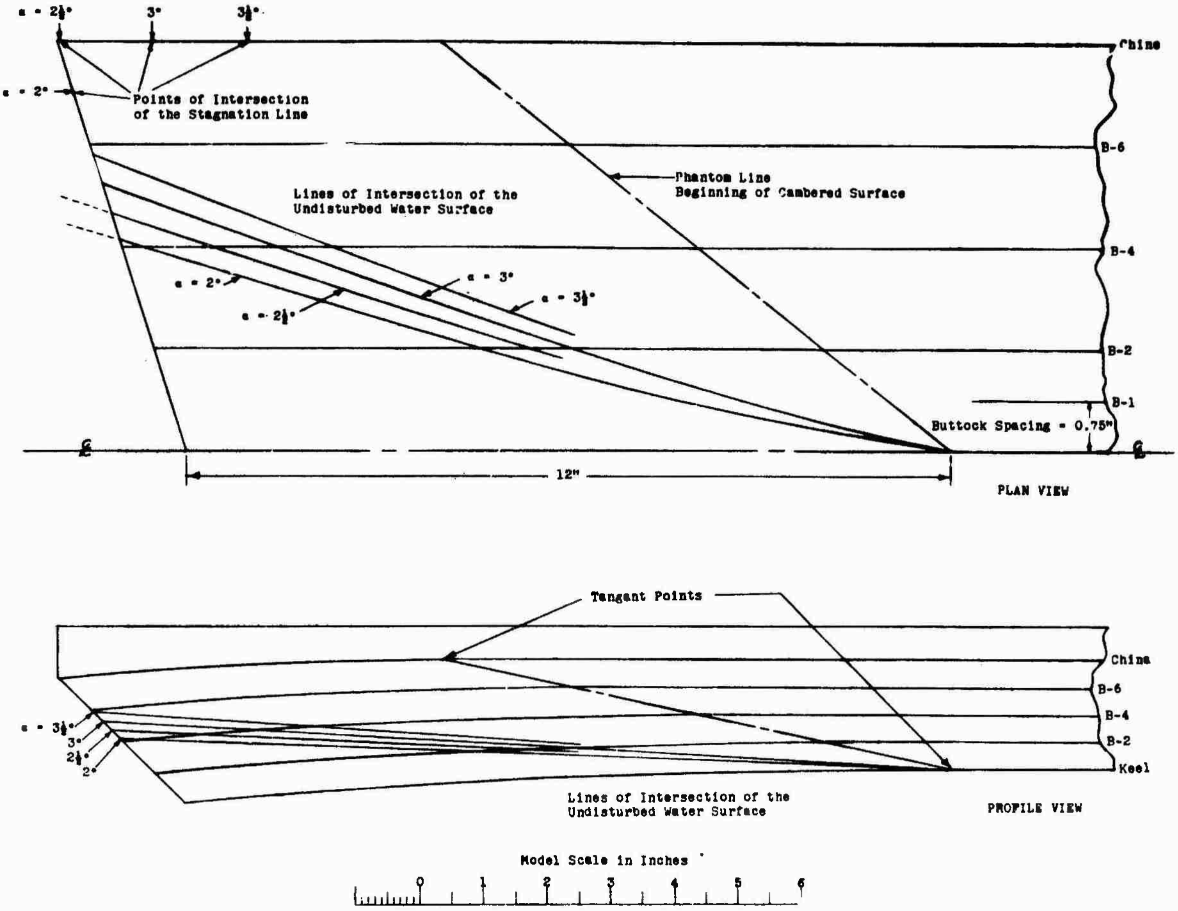


Figure 8 - Lines of Intersection of the Undisturbed Water Surface and Points of Intersection of the Stagnation Line

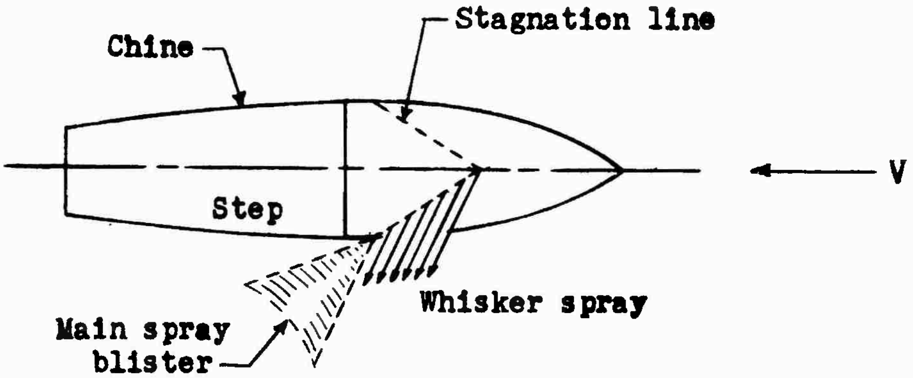


Figure 9 - Planing Boat with a Transverse Step

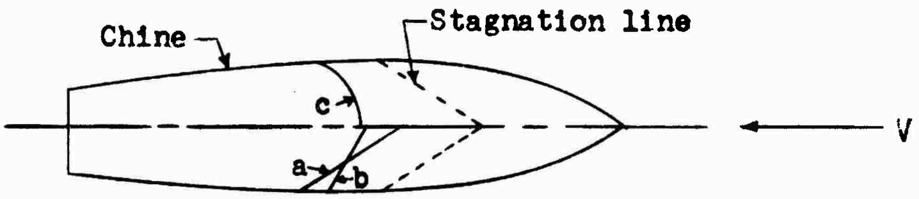


Figure 10 - Several Alternative Configurations for a Sweptback Step
(Magnitude of lifting area maintained the same as in Figure 9)

TABLE 1

Experimental Results for Model 5076

V Knots	C_{Lb}	Net Resistance lb	Wetted Length of Keel in.	Wetted Length of Chines in.	Wetted Length of Spray in.	Wetted Semi-width of Transon in.	Pitching Moments* ft-lb
α = 1 1/2 deg, L = 50 lb							
24.59	0.030	8.09	17.5	--	3.8	5.6	10.04
22.80	0.035	7.71	20.0	0	4.5	6.0	8.75
21.30	0.040	7.86	23.0	1.3	5.3	---	6.82
30.70	0.0146	9.43	11.2	--	2.8	4.5	----
29.70	0.0156	8.61	11.8	--	2.9	4.5	13.35
α = 2 deg, L = 50 lb							
24.55	0.030	7.62	12.4	--	4.5	5.4	12.21
22.80	0.035	7.40	14.2	--	5.0	5.8	10.73
21.30	0.040	7.26	16.3	--	5.5	---	9.34
20.10	0.045	7.13	18.2	1.8	6.2	---	7.52
19.10	0.050	7.21	21.0	3.2	7.7	---	4.90
18.20	0.055	7.25	24.0	4.5	10.0	---	1.34
α = 2 deg, L = 30 lb							
15.6	0.045	4.33	18.2	1.8	6.0	---	4.50
α = 2 deg, L = 70 lb							
23.75	0.045	10.25	18.5	1.9	6.3	---	10.43
α = 2 1/2 deg, L = 50 lb							
24.45	0.030	7.64	9.7	--	5.3	5.3	13.50
22.80	0.035	7.24	10.9	--	5.3	5.7	12.36
21.30	0.040	7.11	12.3	0.2	5.7	---	11.22
20.10	0.045	6.93	13.4	1.2	6.8	---	9.99
19.10	0.050	7.04	15.2	2.2	7.5	---	8.21
18.20	0.055	6.85	17.0	3.3	8.3	---	5.74
17.45	0.060	6.89	19.5	4.5	10.3	---	2.32

---

* See footnote on page 24.

α = 3 deg, L = 50 lb

24.55	0.030	7.92	8.3	---	6.0	5.2	14.88
22.85	0.035	7.52	9.2	---	6.3	5.6	13.79
21.30	0.040	7.36	10.0	0	6.8	6.0	12.85
20.10	0.045	7.18	11.1	---	7.0	---	11.77
19.10	0.050	6.96	12.2	1.8	8.0	---	10.38
18.20	0.055	6.75	13.2	2.6	8.2	---	8.45
17.40	0.060	6.74	15.0	3.5	9.2	---	6.13

α = 3 1/2 deg, L = 50 lb

24.55	0.030	8.47	7.3	---	6.0	5.1	16.32
22.85	0.035	8.80	8.0	---	6.5	5.5	15.33
21.30	0.040	7.44	8.6	---	7.0	5.9	14.29
20.1	0.045	7.43	9.4	---	7.5	---	13.64
19.1	0.050	7.21	10.0	1.2	7.7	---	12.31
18.2	0.055	6.95	11.0	2.1	8.4	---	10.83
17.4	0.060	7.04	12.0	3.0	9.0	---	9.05

α = 4 deg, L = 50 lb

24.5	0.030	8.53	6.5	---	6.4	5.0	17.26
22.8	0.035	8.12	7.2	---	6.8	5.4	16.36
21.3	0.040	7.86	7.5	---	7.5	5.8	15.42
20.1	0.045	7.73	8.2	0.2	7.8	---	14.73
19.1	0.050	7.36	8.8	---	7.0	---	13.84
18.2	0.055	7.25	9.5	1.5	8.5	---	12.56
17.4	0.060	7.34	10.4	2.5	8.8	---	11.02

Pitching moments were measured with respect to the pivot about which the model was rotated in changing angle of attack (see Figure 2). This pivot was 3.9 in. from the line of the straight portion of the forebody keel. A perpendicular from the pivot to this line intersected it 6.25 in. from the intersection of the line with the transom at centerline.

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13. ABSTRACT

A planing surface with 15-deg deadrise, circular-arc camber, and a moderate amount of trailing edge sweep was designed as the main lifting surface for an existing experimental stepped planing boat. A model of the planing surface was then built and tested in the towing basin. The test results indicate that the lift/drag ratio of the main planing surface of the boat will be increased 10 percent by utilization of this design. Also, the performance in head seas should be significantly improved since the cambered surface will develop the necessary lift at approximately one-half the forebody angle of attack at which the boat now operates.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Planing surface						
Deadrise						
Cambered planing surface						
Stepped planing boats						
Sweptback step for planing boat						
High aspect ratio planing surface						

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3. Planing boats (Stepped)
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SUPPLEMENTARY

INFORMATION

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