A LIFTING SURFACE APPROACH TO PLANING BOAT DESIGN

by

Eugene P. Clement

September 1964

Report 1902
S-R009 01 01

ABSTRACT

The utilization of a design approach for a planing boat similar to that followed in the design of a hydrofoil boat or an airplane leads to a new, more efficient type of planing boat configuration. The lift-drag ratio of the new configuration is approximately 50 percent greater than that of the conventional stepless planing boat.

INTRODUCTION

The fact that a planing boat at high speed is supported mainly by dynamic lift suggests that the lifting surface of such a craft should be designed for the efficient attainment of dynamic lift. Also, it is evident that helpful guidance in attaining this end can be expected from the hydrofoil and aircraft design fields, since it is well known that extensive analytical and experimental studies of the performance of the lifting surfaces of these craft have led to effective design procedures for the efficient attainment of dynamic lift. On the other hand, when present-day methods of designing conventional planing boats are examined, it becomes apparent that these methods do not treat such craft from the point of view of producing hulls which will develop dynamic lift in the most efficient manner. Therefore, a new approach which should yield substantial improvements in performance seems to be suggested.

In this report the characteristics and efficiency of the present-day conventional planing boat are compared with those of a craft which has been designed for the efficient attainment of dynamic lift - the hydrofoil boat is the craft with which the comparison is made. Also, a determination is made of the effects on configuration and performance of a planing boat of designing its lifting surface in such a way that the desired lift is attended by a low value of drag.

COMPARISON OF A CONVENTIONAL PLANING BOAT WITH A HYDROFOIL

Figure 1 gives the characteristics of a representative conventional planing boat which was designed for a gross weight of 50,000 lb and a speed of 50 knots. Also shown, to the same scale, is a hydrofoil designed to carry the same gross weight at the same speed. A noteworthy contrast between the two craft is the large disparity in the sizes of their lifting areas. The lifting area of the planing boat (i.e., the area wetted by solid water in plan view) is ten times as large as the lifting area of the hydrofoil. Therefore the planing boat has the disadvantage of much higher frictional resistance than the hydrofoil. The relationship between the lifting areas is also reflected by the respective values of lift coefficient; i.e., the value of lift coefficient for the planing boat is 1/10 the value for the hydrofoil. (C_L here equals $\frac{W}{\rho/2\ Sv^2}$, where W is 50,000 lb, and S is the lifting area in plan view; since $\rho/2$ equals 1.00 for salt water, this simplifies to $C_L = \frac{W}{Sv^2}$). It is clearly important in connection with lifting efficiency, or lift-drag ratio, that the aspect ratio of the hydrofoil is six times as large as the aspect ratio of the planing boat, and that the hydrofoil has a carefully designed camber whereas the planing boat has no camber.

In summary then, the planing hull differs markedly from the hydrofoil in the values of three of the parameters - lift coefficient, aspect ratio, and camber - which are of particular importance in connection with the efficient attainment of dynamic lift. Furthermore, the hydrofoil was designed with particular attention to those factors, while the design procedure for the planing hull ordinarily neglects such considerations. It is, therefore, not surprising that the lift-drag ratio for the hydrofoil (including its associated strut and nacelle) is 50 percent higher than the lift-drag ratio for the planing hull. It is also evident that a promising approach for improving the planing hull would be to design it from the point of view of the efficient attainment of dynamic lift.

LIFT-DRAG RATIO VERSUS LIFT COEFFICIENT FOR A HYDROFOIL

One of the significant relationships which guides the design of an efficient hydrofoil is that between lift-drag ratio and lift coefficient. Such a relationship is shown in Figure 2 for a representative foil-strut-nacelle configuration. This figure indicates that the maximum lift-drag ratio attainable for this configuration is approximately 9.5 and that the corresponding lift coefficient is 0.24. To avoid cavitation at the design speed of 50 knots, however, it is necessary to reduce the design lift coefficient to a value of 0.20. The lift-drag ratio will then be equal to 9.0, which is the value indicated in Figure 1. If the value of the design lift coefficient were reduced to 0.10 (corresponding to a doubling of the foil area), the lift-drag ratio would drop to a value of 5.3. In other words, the lifting efficiency would be reduced by about 40 percent.

EFFECTS OF LIFT COEFFICIENT AND ASPECT RATIO ON THE PERFORMANCE OF PLANING HULLS

The relationship between lift-drag ratio and lift coefficient is of primary importance for planing hulls as well as for hydrofoils. This relationship can be determined for planing hulls by means of equations for planing lift and drag, which have been developed by the NACA and the David Taylor Model Basin, and subsequently programmed for solution by electronic computers. These equations are discussed in Reference 1.* The resistance equation has been revised for the present report to include the effect of the spray area deflectors described in Reference 2. These deflectors give a reduction in drag. Computed values of lift and drag for planing hulls having 12.5-deg deadrise angle are plotted in Figure 3 in the form of lift-drag ratio versus lift coefficient. Curves are shown for several values of aspect ratio. It can be seen that for a particular value of aspect ratio the relationship between lift-drag ratio and lift coefficient for a planing hull is similar to that for a hydrofoil; i.e., the curve is concave downward so that an optimum lift-drag ratio can be obtained by appropriate selection of the lift coefficient.

---

* References are listed on page 7.

The highest values of lift-drag ratio for the various values of aspect ratio (see Figure 3) have been plotted in Figure 4 to give a curve of maximum L/D versus aspect ratio. It can be seen that the maximum L/D improves markedly as the aspect ratio is increased from 0.5 to 2.0 but that there is only a slight further improvement in efficiency with further increase in aspect ratio. Also, an aspect ratio of 2.0, together with the associated optimum value of lift coefficient of 0.0575 (Figure 3), will give a lift-drag ratio of 8.7. This is only slightly less than the value for the hydrofoil, and represents a substantial improvement in performance over that of the conventional planing boat shown in Figure 1. The conventional planing boat, with an aspect ratio of 0.5 and a lift coefficient of 0.02, is operating at point "A" in Figure 3. Accordingly, as pointed our previously, its lift-drag ratio is 6.0.

PROCEDURE FOR DESIGNING AN EFFICIENT LIFTING SURFACE FOR A PLANING BOAT

A method of selecting appropriate values of aspect ratio and lift coefficient for an efficient planing surface is suggested above. The remaining steps in a procedure for designing an efficient lifting surface for a planing hull are as follows:

Knowing the value of the aspect ratio (assumed equal to 2.0 as discussed above) and the corresponding value of optimum lift coefficient (equal to 0.0575), the angle of attack α can be determined from Figure 5 to be 3.65 deg.

Also, since

$$C_L = \frac{W}{Sv^2}$$

then

$$S = \frac{W}{C_L v^2} = \frac{50,000}{0.0575\ (50 \cdot 1.688)^2} = 122\ \text{ft}^2$$

Next, since

$$A = \frac{b^2}{S}$$

where A is the aspect ratio and b is the span of the lifting surface, then

$$b = \sqrt{AS} = \sqrt{2(122)} = 15.6 \text{ ft}$$

Also, since

$$A = b/\ell_m$$

where ℓ_m is the mean length (or mean geometric chord) of the lifting surface, then

$$\ell_m = b/A = 15.6/2 = 7.8 \text{ ft}$$

The ratio ℓ_{cp}/ℓ_m can be read from Figure 6 to be equal to 0.841 (ℓ_{cp} is the distance of the center of pressure, or center of gravity, forward of the trailing edge of the lifting surface). Then

$$\ell_{cp} = 0.841\ (7.8 \text{ ft}) = 6.6 \text{ ft}$$

Knowing the dimensions ℓ_m and ℓ_{cp} makes it possible to lay off the mean geometric chord of the lifting surface, as shown in Figure 9. The location of the mean geometric chord will be at a distance b/4 outboard of the centerline of the boat.

γ (the angle of the stagnation line with the centerline in plan view) is determined from Figure 7 to be equal to 24 deg, and θ (the angle of the spray direction with the centerline in plan view) is determined from Figure 8 to be equal to 47.5 deg. Equations for determining the values of γ and θ were obtained from Reference 3.

The dimensions and angles which have been derived make it possible to lay out most of the details of the lifting surface shown in Figure 9. To define the trailing edge of the lifting surface, however, it is necessary to assume a value for the taper ratio (ratio of tip chord to root chord). Analogy with the design of airplane wings and hydrofoils suggests that a taper ratio of about 0.5 would be suitable (see, for example, Figure 1.45 in Reference 4). This value has accordingly been utilized and thus it is possible to complete the plan view drawing of the lifting surface. A step is then introduced in the hull bottom, coinciding with the line of the trailing edge of the lifting surface.

Figure 9 shows that the width of the optimized lifting surface exceeds the chine width of the conventional boat of Figure 1. A number of modifications (see Figure 10) might be utilized in order to resolve this discrepancy. One possibility would be to add hydrofoil-like appendages to the chines of the boat as shown in Figure 10a. The bottoms of these additions should form continuations of the planing surface of the hull. By curving the top surfaces to give hydrofoil-like section shapes, the added drag at low speed could be minimized. Alternatively, the chine width throughout the length of the boat could be increased so as to provide the desired lifting surface width as in Figure 10b, or the chine width of the forebody only (back to the step) could be increased as in Figure 10c.

The planing boat configuration proposed here would certainly require, like the airplane or hydrofoil boat to which it has some resemblance, an adjustable stabilizer at the stern for stability and trim control. Such a stabilizer could presumably be of either the planing or hydrofoil type and could be expected to carry about 10 percent of the weight of the boat. The area of the main lifting surface can therefore be reduced by this same percentage.

SUGGESTED FURTHER REFINEMENTS FOR IMPROVING THE PERFORMANCE OF STEPPED PLANING HULLS

The performance values and design methods proposed so far have been for uncambered planing surfaces since this is the only type for which the necessary data and analytical expressions are available. References 5 and 6 indicate, however, that significant improvements in performance can be achieved by utilization of camber. Additional analytical and experimental work will be needed to make it possible to determine optimum camber curvature for realistic design cases. Analytical expressions or graphs for lift and center of pressure will also be needed as part of a complete design method for optimized cambered planing surfaces. Work on these items is proceeding at the Taylor Model Basin.

Additional refinements can be incorporated into planing lifting surfaces which will lead to further improvements in performance. Reference 7 indicates that the utilization of either horizontal chine flare or vertical chine strips (i.e., end plates) will increase the lift-drag ratio of a planing surface by more than 15 percent. Reference 8 indicates that such small end plates will also effectively suppress the main spray blister created by a planing surface. A number of the foregoing factors taken together suggest that the type of optimized high-aspect-ratio, cambered lifting surface proposed here, when fitted with the end plates just referred to, would probably give a planing boat the desirable characteristic of making only a small surface disturbance and would, therefore, make it suitable for running at high speed in restricted waters.

REFERENCES

1. Clement, E. P. and Pope, J.D., LTJG, USN, "Stepless and Stepped Planing Hulls - Graphs for Performance Prediction and Design," David Taylor Model Basin Report 1490 (Jan 1961).

2. Clement, E. P., "Effects of Longitudinal Bottom Spray Strips on Planing Boat Resistance," David Taylor Model Basin Report 1818 (Feb 1964).

3. Savitsky, D., "Hydrodynamic Design of Planing Hulls," Davidson Laboratory Report 1000 (Dec 1963).

4. Millikan, C. B., "Aerodynamics of the Airplane," John Wiley and Sons, Inc. (1941).

5. Sottorf, W., "Experiments with Planing Surfaces," NACA TM 739 (Mar 1934).

6. Tulin, M. P., "The Theory of Slender Surfaces Planing at High Speeds," Schiffstechnik, Band 4 (1956/1957), Heft 21, pp. 125-133.

7. Kapryan, W. J. and Boyd, G. M., Jr., "The Effect of Vertical Chine Strips on the Planing Characteristics of V-Shaped Prismatic Surfaces Having Angles of Dead Rise of 20° and 40°," NACA TN 3052 (Nov 1953).

8. Savitsky, D. and Breslin, J. P., "On the Main Spray Generated by Planing Surfaces," SMF Fund Paper No. FF-18, Institute of the Aeronautical Sciences (Jan 1958).

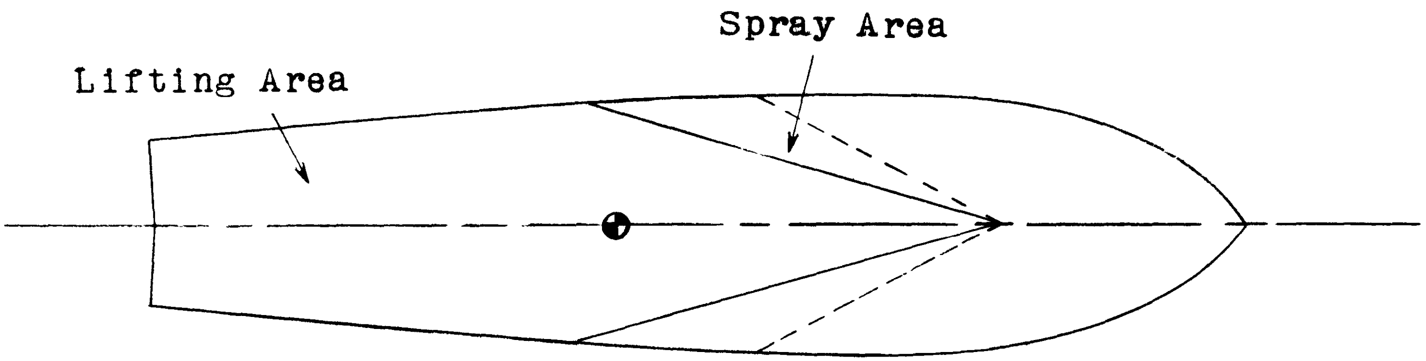

Figure 1a - Conventional Planing Boat

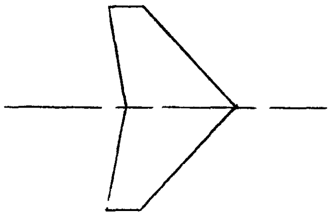

Figure 1b - Hydrofoil

	Planing Boat	Hydrofoil
C_L	0.02	0.20
Aspect Ratio	0.50	3.00
Camber	No	Yes
Taper Ratio	0.50	0.30
L/D	6.00	9.00
Lifting Area	350 ft^2	35 ft^2

Figure 1 - Comparison of Design Characteristics and Efficiency (L/D) for a Conventional Planing Boat and a Hydrofoil (Gross Weight 50,000 Pounds, Speed 50 Knots)

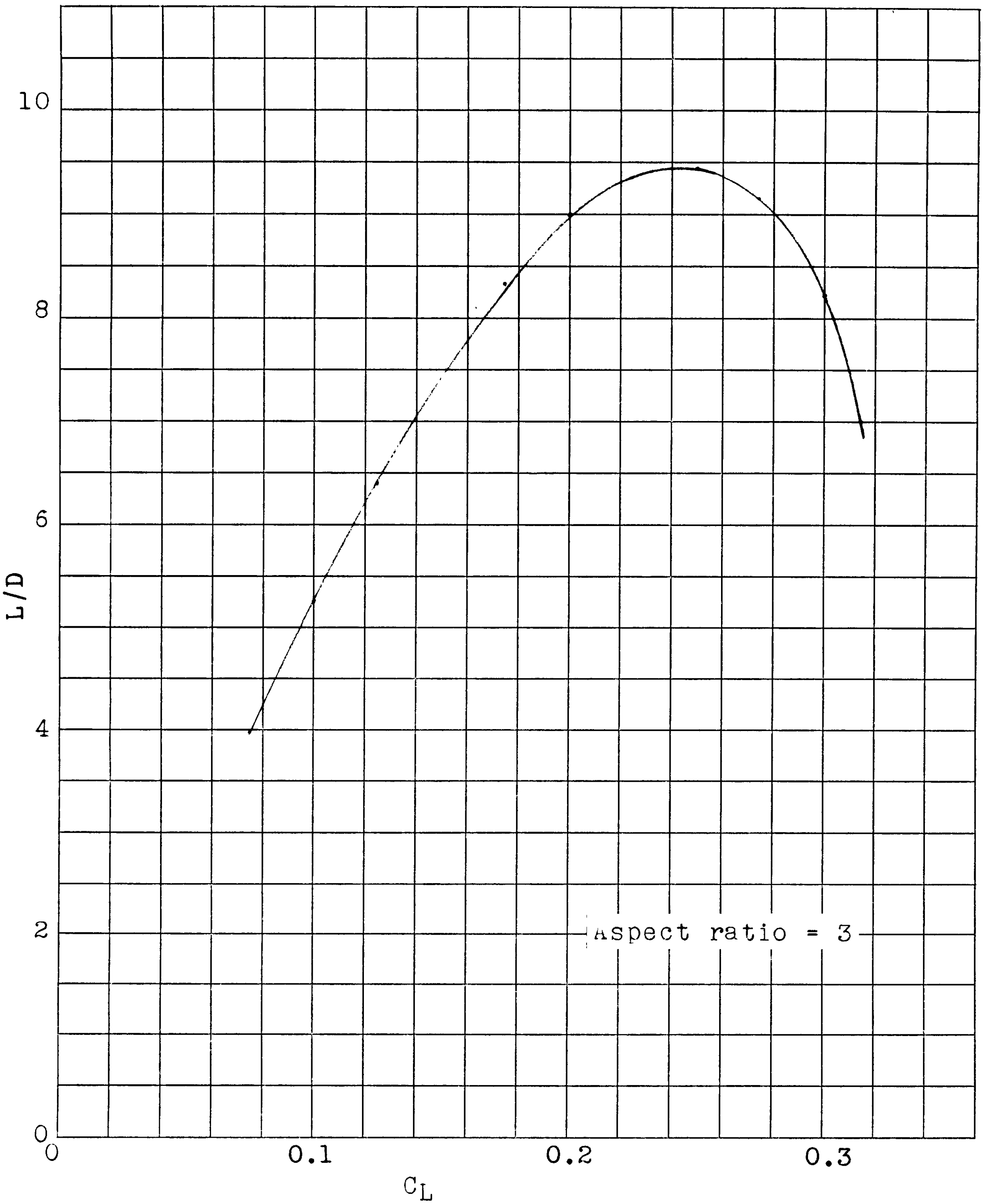

Figure 2 - Lift-Drag Ratio versus Lift Coefficient for a Typical Hydrofoil-Strut-Nacelle Configuration

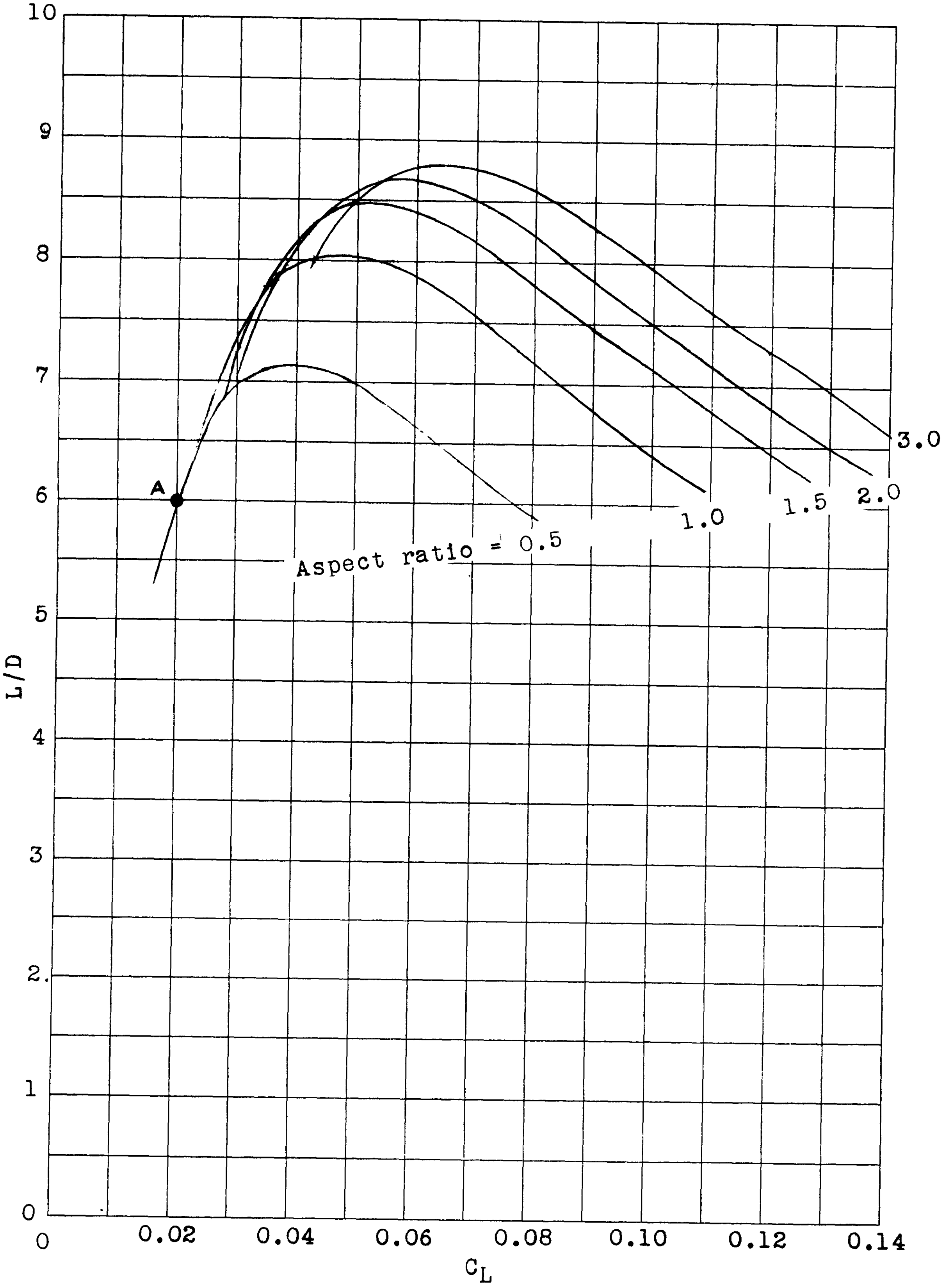

Figure 3 - Lift-Drag Ratio versus Lift Coefficent for Planing Hulls of Various Aspect Ratios (12.5 Degree Deadrise, 0.0004 ΔC_f)

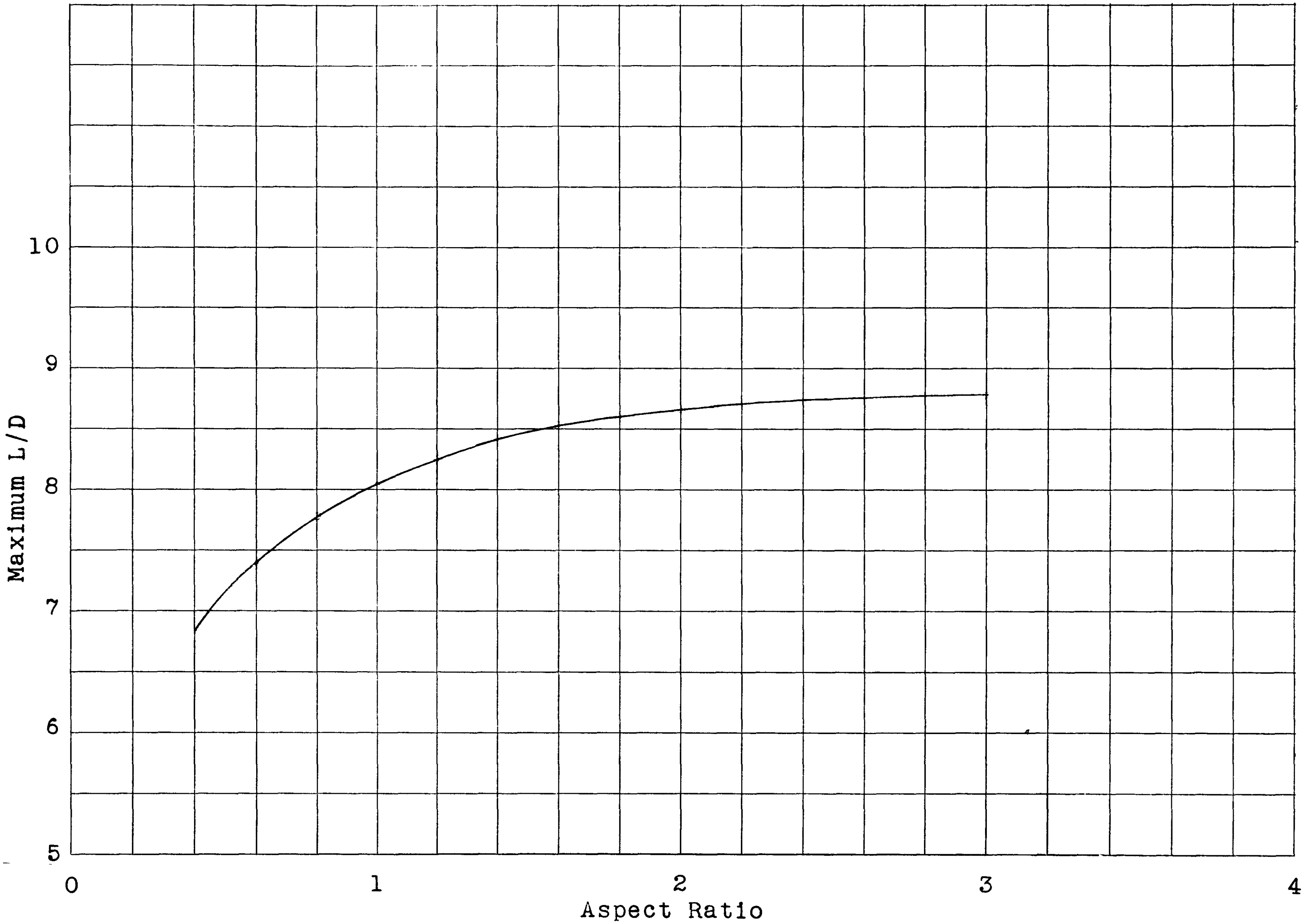

Figure 4 - Maximum Lift-Drag Ratio versus Aspect Ratio for Planing Hulls Having 12.5-Degree Deadrise and 0.0004 ΔC_f

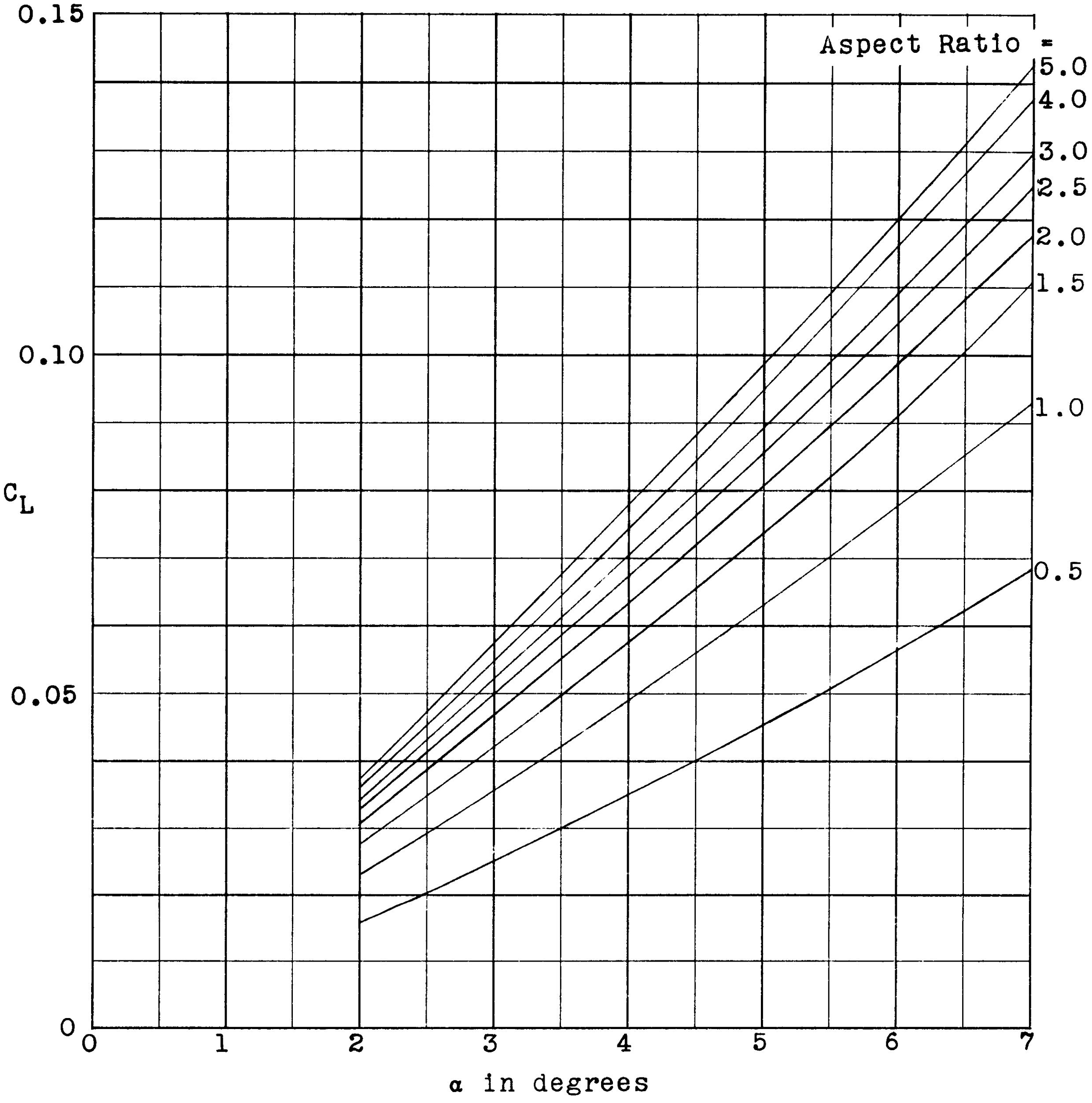

Figure 5 - Lift Coefficient versus Angle of Attack for Planing Hulls of Various Aspect Ratios. (12.5 Degree Deadrise)

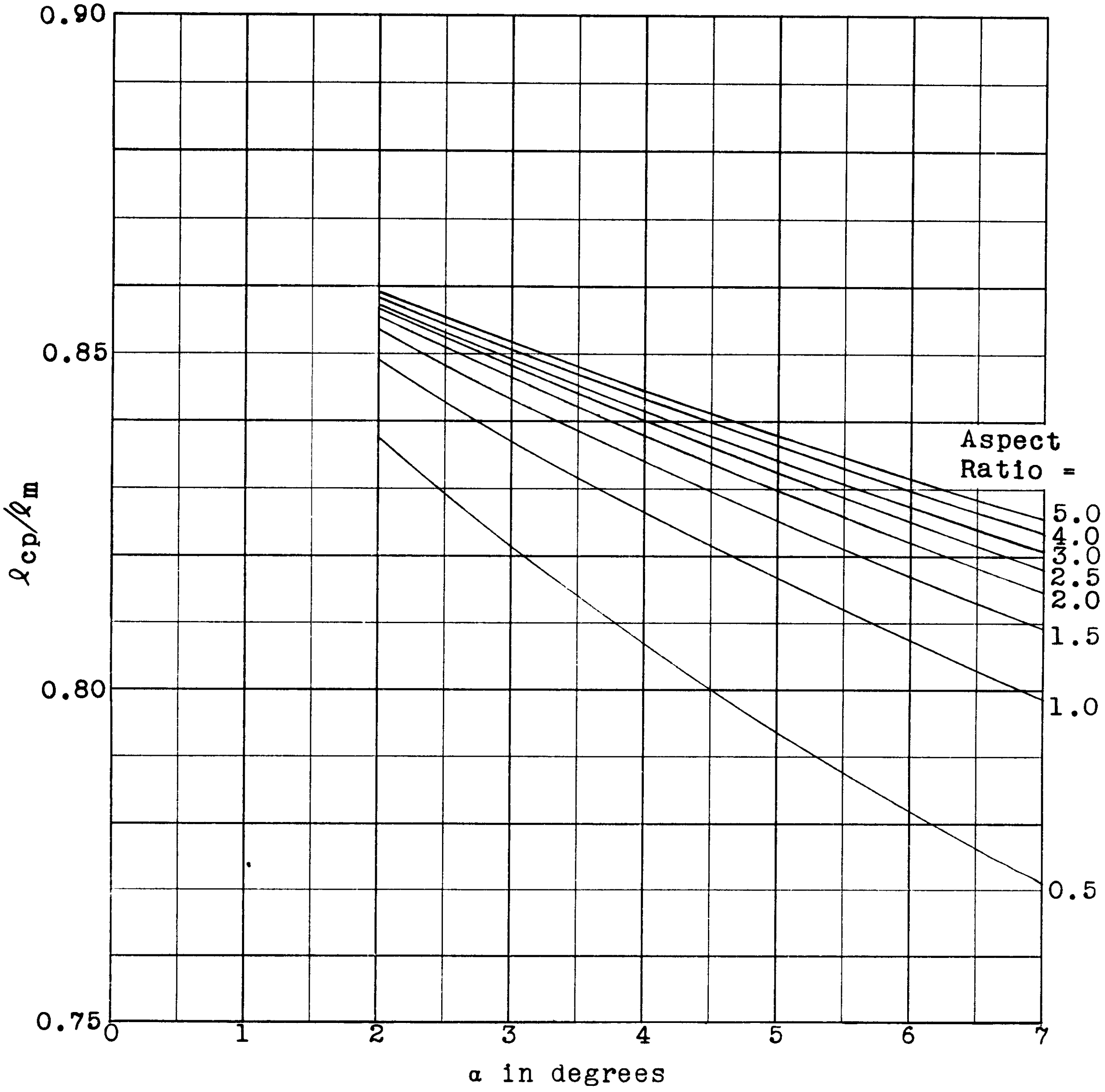

Figure 6 - Center-of-Pressure/Mean-Wetted-Length Ratio versus Angle of Attack for Planing Hulls of Various Aspect Ratios (12.5 Degree Deadrise)

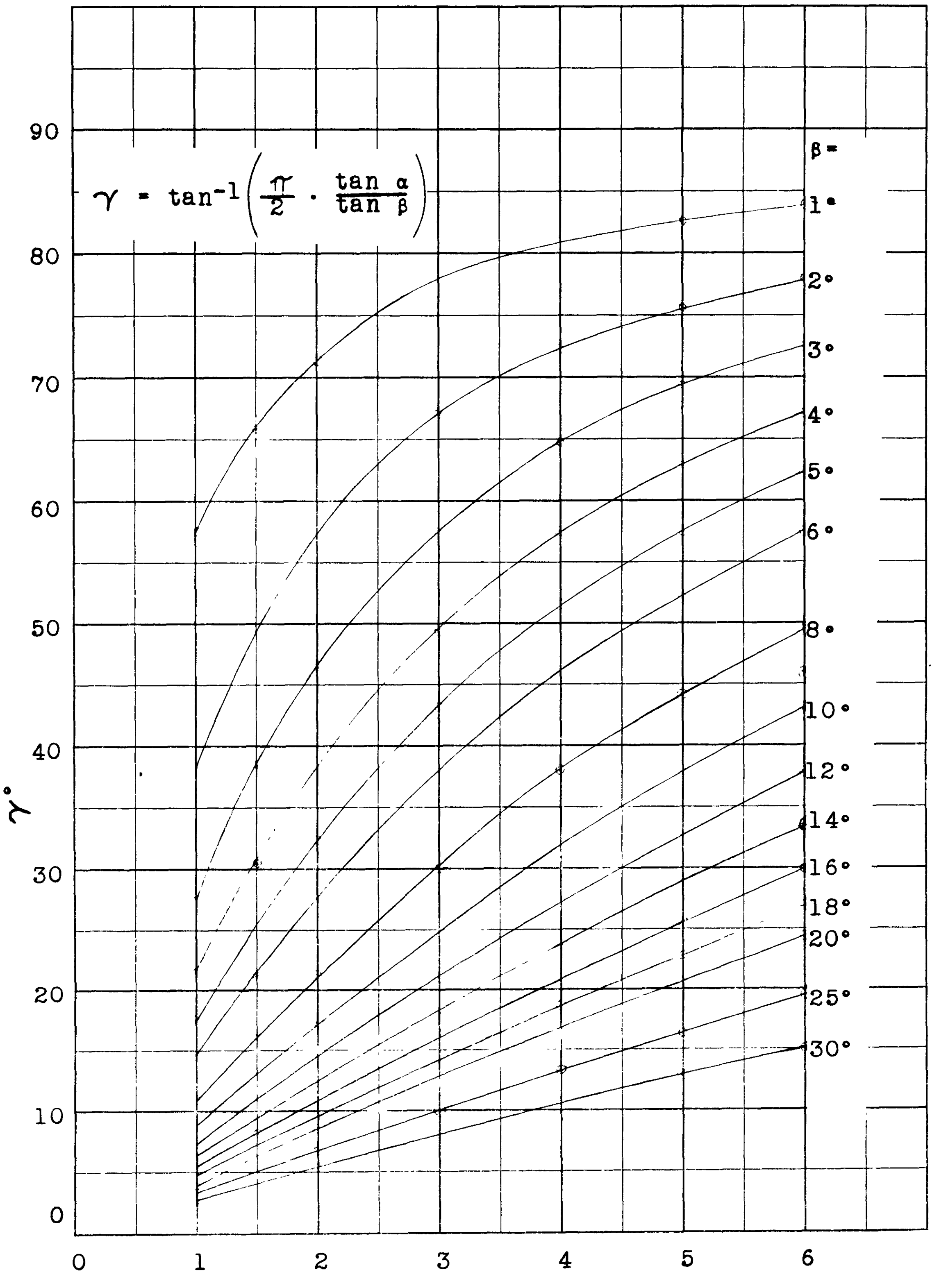

Figure 7 - Angle γ between Stagnation Line and Centerline in Plan View.

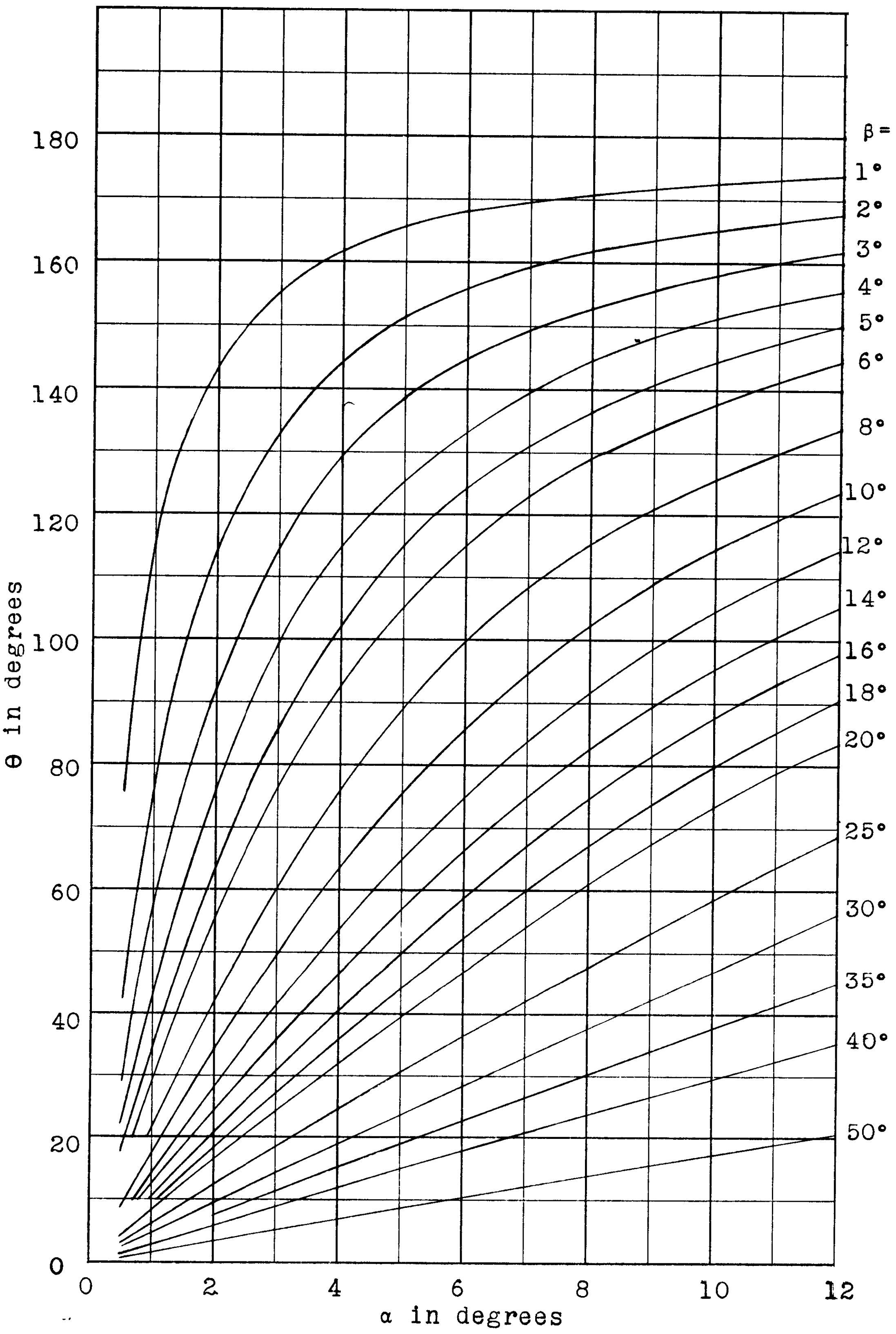

Figure 8 - Angle θ between Spray Direction and Centerline in Plan View.

Dimension	Definition	Value
b	Span of lifting surface	15.6 ft
ℓ_m	Mean geometric chord of lifting surface	7.8 ft
ℓ_{cp}	Distance of center of pressure forward of trailing edge of surface	6.6 ft
γ°	Angle of stagnation line with centerline in plan view	24 deg
θ	Angle of spray direction with the centerline in plan view	47.5 deg

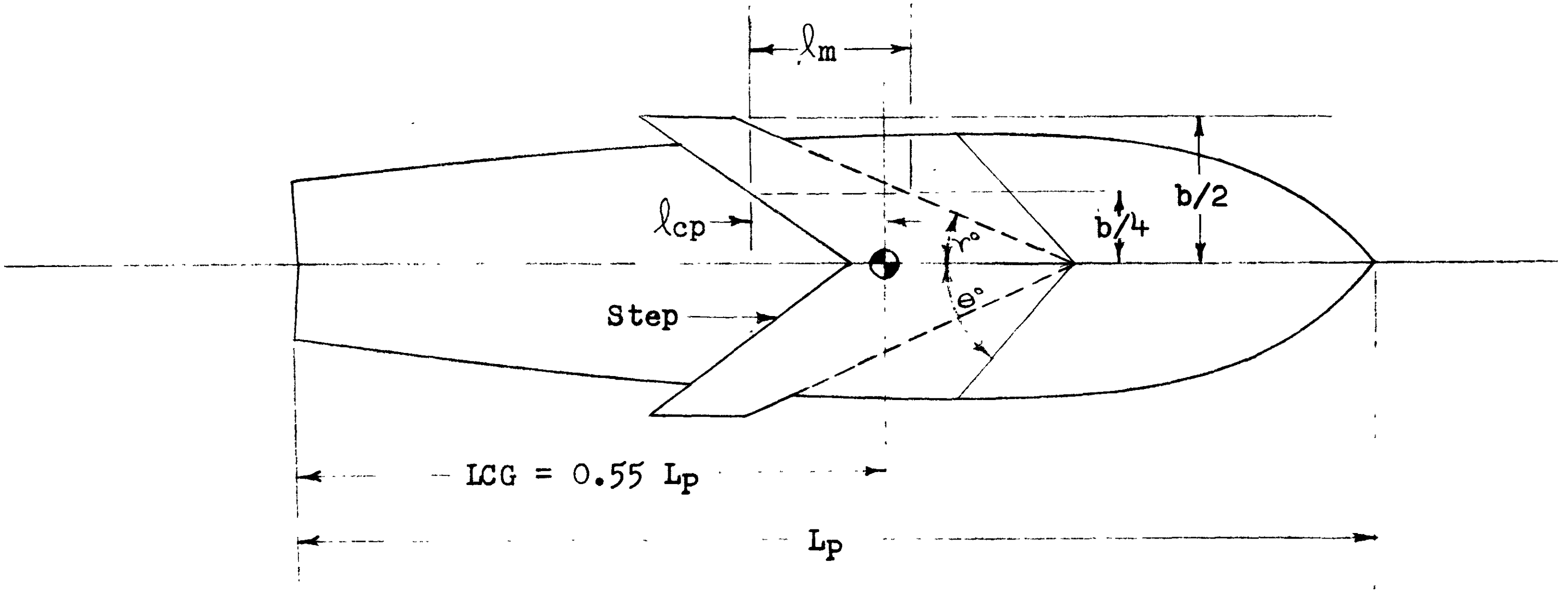

Figure 9 - Plan View of Planing Hull with Optimized Lifting Surface

Gross Weight 50,000 Pounds   Deadrise 12.5 Degrees
Speed 50 Knots   Aspect Ratio equals 2

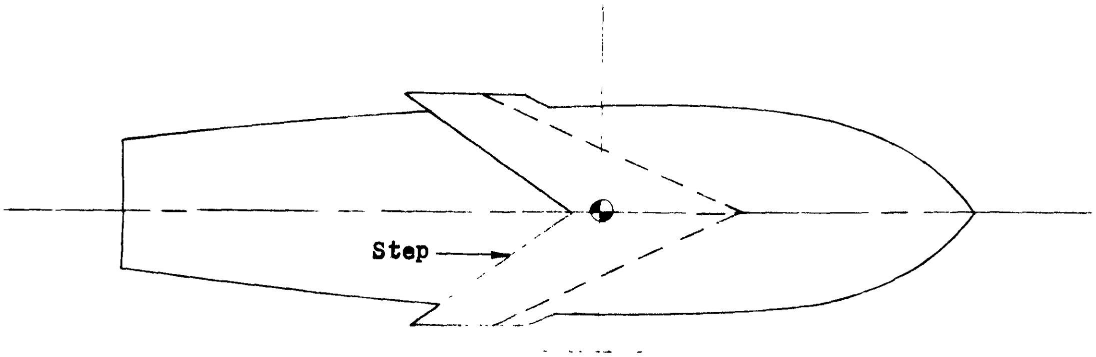

Figure 10a - Local Extensions Added to Planing Bottom
(Flat on Bottom and Curved on Top)

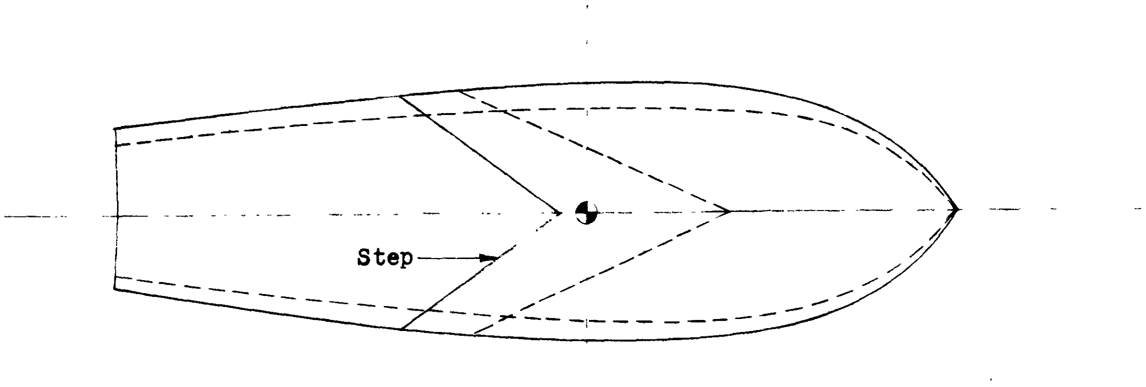

Figure 10b - Chine Width Increased throughout Hull Length

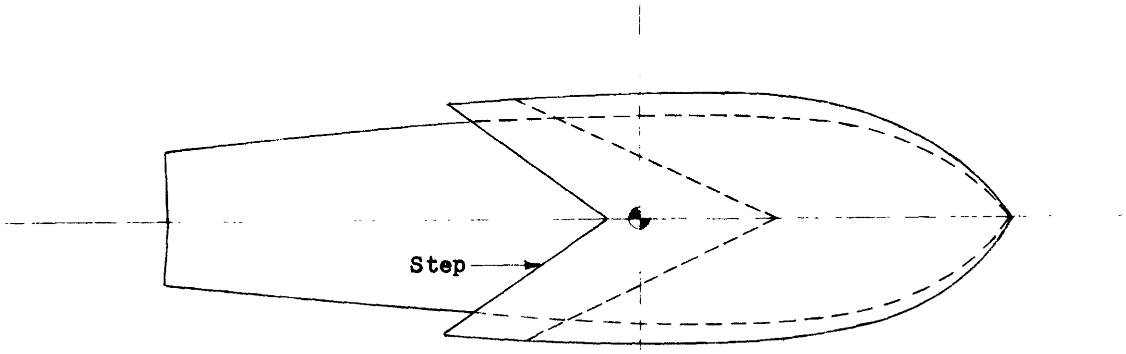

Figure 10c - Chine Width Increased Back to Step

Figure 10 - Alternative Modifications to Provide the Specified Lifting Surface Width

INITIAL DISTRIBUTION

Copies		
15	CHBUSHIPS	
	3	Tech Lib (Code 210-L)
	1	Lab Mgt Div (Code 320)
	1	App Res Div (Code 340)
	2	Prelim Des (Code 420)
	2	Hull Des (Code 440)
	2	Sci & Res (Code 442)
	4	Boats & Small Craft (Code 449)
1	COMDT, U.S. Coast Guard	
2	CO, U.S. Army Transportation Research Command, Fort Eustis	
	1	Attention Tech Intelligence Br
	1	Attention Mr. Richard W. Black
2	DIR, Davidson Lab, SIT, Hoboken	
2	ADMIN, Webb Inst of Naval Arch, Glen Cove Attention Prof. Thomas M. Curran	
2	Head, Dept of NAME, MIT, Cambridge	
2	Head, Dept of NAME, Univ of Michigan, Ann Arbor	
2	Aerojet-General Corporation, Washington Attention Mr. A. Markel	
1	Aircraft Armaments Inc., Cockeysville, Md.	
1	AVCO Corp., Wilmington Attention Capt. F. X. Forest	
1	DIR, Hudson Lab, Dobbs Ferry	
1	Fluid Dynamics Research Lab, Collins Radio Co., Cedar Rapids	
1	Sparkman and Stephans, Inc., New York Attention Mr. G. Gilbert Wyland	
1	Bell Aerosystems Co., Buffalo, New York	
1	Boeing Airplane Co., Seattle	
2	Chris-Craft Corp., Pompano Beach Attention Mr. E. L. Eckfield	

2	Gibbs and Cox, Inc.
1	General Dynamics/Convair, San Diego Attention Mr. R. H. Oversmith
2	Grumman Aircraft Eng Corp
2	Hydronautics, Inc
2	Lockheed-California Co., Burbank
1	Republic Aviation Corp., Farmingdale Attention Mr. Joseph G. Koelbel, Jr.
1	Owens Yacht Division, Brunswick Corp Attention Mr. David D. Beach
1	United Aircraft Corporate Systems Center, Farmington, Conn. Attention Mr. Henry A. Arnold
1	Cdr. E. Venning Jr., USN Quarters "P" Norfolk Naval Shipyard, Portsmouth
20	DDC

David Taylor Model Basin. Report 1902.
A LIFTING SURFACE APPROACH TO PLANING BOAT DESIGN, by Eugene P. Clement. Sep 1964. 19p. illus., graphs, diagrs., refs. UNCLASSIFIED

The utilization of a design approach for a planing boat similar to that followed in the design of a hydrofoil boat or an airplane leads to a new, more efficient type of planing boat configuration. The lift-drag ratio of the new configuration is approximately 50 percent greater than that of the conventional stepless planing boat.

1. Planing boats--Configuration
2. Planing boats--Design
I. Clement, Eugene P.

David Taylor Model Basin. Report 1902.
A LIFTING SURFACE APPROACH TO PLANING BOAT DESIGN, by Eugene P. Clement. Sep 1964. 19p. illus., graphs, diagrs., refs. UNCLASSIFIED

The utilization of a design approach for a planing boat similar to that followed in the design of a hydrofoil boat or an airplane leads to a new, more efficient type of planing boat configuration. The lift-drag ratio of the new configuration is approximately 50 percent greater than that of the conventional stepless planing boat.

1. Planing boats--Configuration
2. Planing boats--Design
I. Clement, Eugene P.

David Taylor Model Basin. Report 1902.
A LIFTING SURFACE APPROACH TO PLANING BOAT DESIGN, by Eugene P. Clement. Sep 1964. 19p. illus., graphs, diagrs., refs. UNCLASSIFIED

The utilization of a design approach for a planing boat similar to that followed in the design of a hydrofoil boat or an airplane leads to a new, more efficient type of planing boat configuration. The lift-drag ratio of the new configuration is approximately 50 percent greater than that of the conventional stepless planing boat.

1. Planing boats--Configuration
2. Planing boats--Design
I. Clement, Eugene P.

David Taylor Model Basin. Report 1902.
A LIFTING SURFACE APPROACH TO PLANING BOAT DESIGN, by Eugene P. Clement. Sep 1964. 19p. illus., graphs, diagrs., refs. UNCLASSIFIED

The utilization of a design approach for a planing boat similar to that followed in the design of a hydrofoil boat or an airplane leads to a new, more efficient type of planing boat configuration. The lift-drag ratio of the new configuration is approximately 50 percent greater than that of the conventional stepless planing boat.

1. Planing boats--Configuration
2. Planing boats--Design
I. Clement, Eugene P.

David Taylor Model Basin. Report 1902.
A LIFTING SURFACE APPROACH TO PLANING BOAT DESIGN, by Eugene P. Clement. Sep 1964. 19p. illus., graphs, diagrs., refs. UNCLASSIFIED

The utilization of a design approach for a planing boat similar to that followed in the design of a hydrofoil boat or an airplane leads to a new, more efficient type of planing boat configuration. The lift-drag ratio of the new configuration is approximately 50 percent greater than that of the conventional stepless planing boat.

1. Planing boats--Configuration
2. Planing boats--Design
I. Clement, Eugene P.