

AD-R122 851

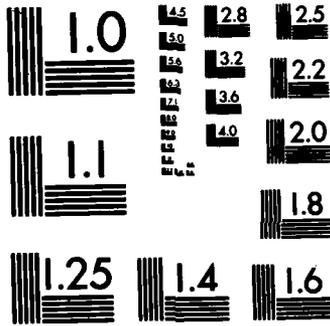
THEORY OF HIGH SPEED DISPLACEMENT SHIPS WITH TRANSOM
STERNS(U) HYDRONAUTICS INC LAUREL MD M P TULIN ET AL.
SEP 82 TR-8035-1 N00014-80-C-0669

1/1

UNCLASSIFIED

F/G 13/10 NL

						END						
						FORM						
						+						
						ONE						

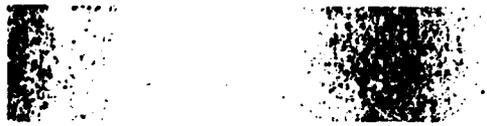
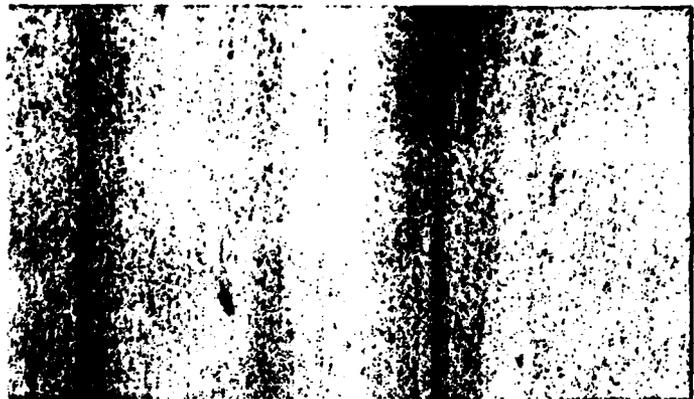


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

12

==

AD A 122851



DWG FILE COPY

SEARCHED
SERIALIZED
JAN 03 1983
E

HYDRONAUTICS, incorporated research in hydrodynamics

Research, consulting, and advanced engineering in the fields of NAVAL and INDUSTRIAL HYDRODYNAMICS. Offices and Laboratory in the Washington, D. C., area: Pindell School Road, Howard County, Laurel Md.

HYDRONAUTICS, Incorporated

TECHNICAL REPORT
8035-1

THEORY OF HIGH SPEED DISPLACEMENT
SHIPS WITH TRANSOM STERNS

by

Marshall P. Tulin*
C. C. Hsu

September, 1982

Prepared for
Office of Naval Research
Under
Contract No. N00014-80-C-0669
NR 062-596

JAN 5 1983

* Present Address: Dept. of Mechanical and Environmental Engineering
University of California, Santa Barbara, CA 93106

1

20. the resistance, at high speed, may be greatly reduced through proper after-body design. A comparison of calculated results with the experimental results of NSRDC Series 64 shows good agreement and lends credence to the theory.

TABLE OF CONTENTS

	<u>Page No.</u>
INTRODUCTION	1
THEORY	4
SOLUTION	8
RESULTS	12
EXTENSIONS	16
SUMMARY AND CONCLUSIONS	17

Accession For	
NTIS GRA&I	<input checked="" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By _____	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A	



RE: Distribution Statement
Unlimited per Dr. Robt. E. Whitehead,
ONR/Code 432

INTRODUCTION

There is considerable interest in high speed displacement ships. These are characterized by high length-beam ratios, sharp bows, and flat sterns terminating in a transom. Such ships have been constructed for naval purposes, for example the German WWII Jaguar boats and their derivative the current Israeli missile boats, originally French built. All of these ships are reported to combine high surface speed with excellent seakeeping characteristics.

Systematic tests of conventional high speed forms were carried out at the David Taylor Model Basin and reported by H.Y.H. Yeh in 1964, Reference 1. These tests, comprising a series of 27 models, involved systematic variation in beam-draft ($B/H = 2,3,4$) and block coefficient ($C_B = 0.35,0.45,0.55$); the resulting length-beam ratios varied from about 8.5 to 18.0; the transoms were in general very full, their width being not too much smaller than the maximum beam.

The test results show a very significant residuary coefficient at the highest speed-length ratios, often exceeding 50 percent of the residuary pertaining at a speed length ratio (V/\sqrt{L}) of 1.5, where wave resistance may be expected to be a maximum, see Figures 1A and 1B.

These results, taken together with the very fact of the wide transom stern evolution in design, raises some extraordinarily interesting questions concerning the hydrodynamics of these ships:

1) Since wave resistance is generally believed to decrease rapidly at high V/\sqrt{L} toward a value of zero, what exactly is the nature of the very large measured residuaries at high V/\sqrt{L} ? Spray? Other??

2) Why are open sterns (transoms) desirable at high speeds?

After all, for submerged slender bodies, there is generally a positive form drag associated with open sterns.

Planing vessels have been rather extensively treated and rather good methods based on theory exist for the prediction of their performance, References 2 and 3; and the nature of their resistance (spray and "induced") is fairly well understood for slender surfaces, Reference 4. Strangely enough, however, there does not seem to exist any theory pertaining to the flow about high speed displacement ships, aside from preliminary theoretical considerations, such as those of Ogilvie, Reference 5. Nor is there a theory of transoms, except for the numerical calculations of Van Eseltine and Haussling, Reference 6. We certainly have not found answers to the two most interesting and important questions 1) and 2) above. Pertinent theory might not only answer these questions but provide methods for optimizing design, especially of the transom.

In view of this situation, the senior author initiated a theoretical study of slender high speed displacement ships under ONR Contract N00014-80-C-0669, with the results described below.

The theory is asymptotic to $V/\sqrt{L} = \infty$ (no gravity), and assumes $B/H = O(2)$ and $B/L \ll 1.0$. All of these conditions seem realized in the high speed tests of Reference 1.

Most important, it is pointed out at the outset that the solution to the problem is not unique and that the physically realizeable solution involves in general, a "wake" flow behind the ship which carries energy and therefore results in resistance. This resistance is in general reduced by widening a suitable transom, and may in fact be annulled by a suitable transom with a width at the waterline equal to the ship's maximum beam.

The theory is given analytical form and reduced finally to a boundary value problem in the cross flow plane, which must be solved for each cross section of the ship. A computer program is utilized to solve this problem and rather extensive calculations of resistance made for ships comprising Series 64, Reference 1. The results are excellent at the highest values of B/H and not bad for other values.

The results seem important; they suggest: a) that the greatest part of resistance of high speed displacement ships is due to the stern (we call it "stern-induced" resistance) and not to spray! b) that the "stern-induced" resistance may be eliminated through proper after-body design, and that the very existence of transoms lies in their ability to reduce such resistance; c) that the usual wave resistance problem is not completely posed, that the solution is not unique, and that the solution normally taken in existing theory, at least at high speeds, may result in physically unrealizable solutions.

Finally we point out that the theory may be applied to ships with yaw, and suggest that a sideforce linear in yaw results at high speed and can be calculated.

Directions for extension of the theory are pointed out.

THEORY

We are concerned here with slender ships ($B/H = O(2)$; $B/L \ll 1$) operating at "high" speeds ($U_0^2/gL \gg 1$). We assume that the effects of viscosity are secondary. Consequently:

1) On the free surface, where $p = \text{constant}$, the speed q is everywhere the same and equal to the approach velocity, U_0 far ahead of the ship. ($q = \sqrt{U^2 + v^2 + w^2}$ where $U = U_0 + u$, v and w are the (x,y,z) components of velocity, and where $u,v,w = \phi_{x,y,z}$).

2) $\nabla^2 \phi = 0$ everywhere and $\nabla^2 \phi \approx \phi_{yy} + \phi_{zz} = 0$; therefore $\phi = R[\Psi(x; z + iy)]$. $q \approx U_0 + \phi_x$.

3) The free surface may be taken in the $(x-z)$ plane (i.e. at $y \equiv 0$).

4) On the free surface, $y = 0$: $\phi_x = 0$, or $\phi(x, 0, z) = \phi(z)$.

5) The free surface consists of four separate regions, see Figure 2, a plan view. The entire free surface is S and the intersection of S and the hull is N , which defines the waterline shape. In S_0 , the region outside the maximum beam: $\phi = 0$, since $\phi(-\infty, 0, z) \equiv 0$. In S_1 , the forward shadow of the ship: $\phi = 0$, except in a narrow boundary near N which is the spray region S_s . In the narrow boundary layer S_s the flow on S_1 (where $w = 0$) adjusts itself very rapidly to the condition on N where

$$w \approx \pm \frac{U_0}{2} \frac{db}{dx} ;$$

($b(x)$ is the local beam of the waterplane). Physically, this adjustment is experienced as a thin spray sheet. In S_2 , the rear shadow of the ship there are two distinct possibilities:

- i) $\phi = 0$
 ii) $\phi_z(x, z) = \phi_z(x_N; z)$, where $\phi_z(x_N; z) \approx U_0 \frac{dz_N}{dx} = \pm \frac{1}{2} U_0 \frac{db}{dx}$ [1]

The former possibility (i) would again require a narrow boundary layer along N wherein the lateral flow would adjust itself from its value on the hull to the value $w = 0$ in the shadow. But the resulting solution requires (in this approximation) that flow detach from the hull with infinite vertical velocity and move downward to reach the water level downstream. In Figure 3 the free surface shape is shown schematically for a section of the bow and of the stern, according to both i) and ii) above. The "inverted spray" solution indicated by i) would lead to a narrow but high sheet of water between the hull and the wake surface everywhere along the stern and is not observed in practice, while the "smooth" flow indicated by ii) seems typical of observation. We therefore choose ii). This choice is equivalent to imposing the Kutta condition at the trailing edge of a slender wing or planing surface of waterline shape N .

6) As a result of ii), there exists in the entire rear shadow of the hull, prescribed values of w on the free water surface in S_2 , see Figure 4.

7) On the hull surface:

$$\nabla (U_0 x + \phi) \cdot \vec{n} = 0 \quad [2]$$

where \vec{n} is the outer normal (vector) at any point on the hull,

and is given by:

$$\vec{n} = (n_x; n_y; n_z) = (\sin\beta; -\cos\beta \cos\alpha; \cos\beta \sin\alpha)$$

where β is the angle between the vector $n_z + i n_y$ and n , and is given by (the subscript M refers to points on the hull):

$$\tan\beta = \cos\alpha \cdot \frac{\partial y_M}{\partial x}$$

or,

$$n_x = - \left[n_y \frac{\partial y_M}{\partial x} - n_z \frac{\partial z_M}{\partial x} \right] \quad [3]$$

Finally, assuming $\phi_x/U_0 \ll 1$, Equation [2] yields:

$$\phi_y|_M = U_0 \frac{\partial y_M}{\partial x}; \quad \phi_z|_M = U_0 \frac{\partial z_M}{\partial x} \quad [4]$$

or, assuming in addition that $\cos\beta \approx 1$:

$$\phi_n = U_0 \left[\cos\alpha \frac{\partial y_M}{\partial x} - \sin\alpha \frac{\partial z_M}{\partial x} \right] \quad [5]$$

8) Finally, in view of 1-7 above, the problem is reduced to a set of two dimensional potential problems in the cross flow plane as shown in Figure 5. Notice that the problem may be replaced by another which is equivalent, in which the hull beneath the water surface is augmented by its reciprocal above the surface, such that the equivalent body is source free in the far field, and may be represented by a dipole distribution; the flow is thus essentially wing-like. In this representation the surface S_2 comprises a trailing vortex wake, and condition ii) of paragraph 5 is mathematically equivalent to the imposition

of the trailing edge Kutta condition in the case of a slender wing, as noted earlier. The representation of the hull and its reciprocal involves additional vorticity. At the transom, the hull (plus reciprocal vorticity) plus free surface wake is shed into the ships wake (plus its reciprocal) and manifests both the lift acting on the hull (vertical momentum in the wake) and the stern-induced resistance of the hull (kinetic energy in the cross flow).

9) The narrow spray region S_2 corresponds to the leading edge region on a slender flat wing. In the latter case, the inability of the flow to follow the wing (go around the leading edge) leads to loss of leading edge suction and therefore to a resistance which is non-zero in the case of separation at the leading edge. The non-zero value of leading edge suction follows from the nature of the singularity at the leading edge of the flat wing

$$(\psi' = w - iv \sim \frac{1}{\sqrt{\zeta}}, \text{ where } \zeta = z + iy) .$$

In the case of a displacement ship with a vertical side at N, then it can be shown that $\psi' \sim \ln \zeta$ and that the waterline suction and therefore the spray resistance is zero in the present approximation. This surprising conclusion would seem to be borne out by our later comparison of predicted stern-induced resistance with experiments.

SOLUTION

The flow about the ship, according to 2) above, can be described by a complex potential,

$$\Psi = \Psi(x; y, z) = \phi + i\psi$$

where Ψ is an analytical function of $\zeta = z + iy$. The complex velocity is:

$$\frac{d\Psi}{d\zeta} = \Psi'(x; y, z) = w - iv$$

and the velocity field is given by,

$$\nabla(U_0 x + \phi) = [U_0 + \phi_x; \phi_y; \phi_z] = [U_0 + \phi_x; -I(\Psi')'; R(\Psi')] .$$

The complex velocity at each value of x may be represented in terms of a distribution of a suitable Green's function:

$$\Psi'(x; \zeta) = \int \frac{Q(x; \zeta_1)}{2\pi} G(\zeta, \zeta_1) d\zeta_1$$

$$M(x) + M^*(x) \quad [6]$$

where $Q(x; \zeta_1)$ represents the strength of the singularity distribution due to the presence of the ship equivalent boundary, $M + M^*$. A suitable Green's function in the present problem is the source:

$$G(\zeta, \zeta_1) = \frac{1}{\zeta - \zeta_1}$$

so that Q is the complex source strength.

The contour M includes the submerged hull M_ℓ and its reciprocal M_u , and M^* includes the vortex sheet on the free surface S_2 , Figure 5, where $\zeta_u = \bar{\zeta}_\ell$, the overbar indicating the complex conjugate.

If Q_ℓ is the source strength on M_ℓ , and Q_u on M_u , then $Q_u = \bar{Q}_\ell$ satisfies the boundary condition on S_0 ($w=0$). Equation [6] may thus be written:

$$\Psi'(x; \zeta) = \frac{1}{2\pi} \int_{M_\ell} \left\{ \frac{Q d\zeta_1}{(\zeta - \zeta_1)} - \frac{\bar{Q} d\bar{\zeta}_1}{(\zeta - \bar{\zeta}_1)} \right\} + \frac{i}{2\pi} \int_{M^*} \frac{\gamma dz_1}{(\zeta - z_1)} \quad [7]$$

Since the integral on M_ℓ contributes not at all to w on M^* , then on S_2 :

$$\gamma(z_1) = -2w(z_1), \text{ the latter being prescribed by [1].}$$

Now, it is possible to show that,

$$-ie^{i\alpha} \Psi' = \phi_n - i\phi_s \quad [8]$$

where s is the counterclockwise direction along the hull M_ℓ .

Combining [7] and [8]:

$$R \left\{ -\frac{ie^{i\alpha}}{2\pi} \int_M \left\{ \frac{Q d\zeta_1}{(\zeta - \zeta_1)} - \frac{\bar{Q} d\bar{\zeta}_1}{(\zeta - \bar{\zeta}_1)} \right\} - \frac{e^{i\alpha}}{\pi} \int_{M^*} \frac{w(x; z_1) dz_1}{(\zeta - z_1)} \right\} = \phi_n(\zeta) \quad [9]$$

for all ζ on M_ℓ . Since $\phi_n(\zeta)$ is known in terms of the hull shape, see Equation [5], this represents an integral equation for $Q(x; \zeta)$.

The effects of the body shape and stern wake on S may be decoupled by seeking:

$$Q = m + i\gamma$$

where

$$R \left\{ - \frac{ie^{i\alpha}}{2\pi} \int_{M_\ell} \left\{ \frac{m d\zeta_1}{(\zeta - \zeta_1)} - \frac{m d\bar{\zeta}_1}{(\zeta - \bar{\zeta}_1)} \right\} \right\} = \phi_n(\zeta) \quad [10]$$

for all ζ on M_ℓ .

$$R \left\{ \int_{M_\ell} \left\{ \frac{\gamma d\zeta_1}{(\zeta - \zeta_1)} + \frac{\gamma d\bar{\zeta}_1}{(\zeta - \bar{\zeta}_1)} \right\} - 2 \int_{M^*} \frac{w(x; z_1) dz_1}{(\zeta - z_1)} \right\} = 0$$

so that the body boundary conditions in the absence of shed vorticity are satisfied entirely by the hull source distribution, m ; and the effect of the shed vorticity is represented by an additional induced vorticity distribution, γ . These integral equations, of the Neumann type, can be solved numerically for $Q(\zeta)$ on M_ℓ .

To the slender body approximation, Bernoulli's equation becomes:

$$p = -\frac{1}{2}\rho(u^2 + v^2 + w^2) - \rho U_0 \frac{\partial \phi}{\partial x} \approx -\rho U_0 \frac{\partial \phi}{\partial x} \quad [11]$$

The incremental lift (dL_f) and resistance (dD) may be determined from knowledge of the pressure acting on a transverse slice:

$$\frac{dL_f}{dx} = \int_{M_\ell} p dz = -\rho U_0 \int_{M_\ell} \frac{\partial \phi}{\partial x} dz \quad [12]$$

$$\frac{dD}{dx} = - \int p n_x dz \approx \rho U_o \int \frac{\partial \phi}{\partial x} \frac{\partial \phi}{\partial n} dz \quad [13]$$

The total lift and resistance may then be approximated by:

$$L_f = \int_0^L \frac{dL_f}{dx} dx \approx -\rho U_o \int_{M_\ell} \phi dz \Big|_0^L \quad [14]$$

$$D = \int_0^L \frac{dD}{dx} dx \approx \rho U_o \int_{M_\ell} \phi \frac{\partial \phi}{\partial n} dz \Big|_0^L$$

[15]

$$-\rho U_o \int_0^L \int_{M_\ell} \phi \frac{\partial}{\partial x} \left(\frac{\partial \phi}{\partial n} \right) dz dx$$

RESULTS

Extensive numerical studies have been made for ships of the form:

$$y_m(x, z) = -h(x) \left[1 - \left(\frac{z}{b} \right)^2 \right]^{n_1} \quad [16]$$

with

$$b = b_0 \left(\frac{x}{L} \right)^{n_2} \left(1 - n_6 \frac{x}{L} \right)^{n_3} \quad [17]$$

$$h = h_0 \left(\frac{x}{L} \right)^{n_4} \left(1 - n_7 \frac{x}{L} \right)^{n_5} \quad [18]$$

The parameter n_1 characterizes the fullness of the ship's cross-section. Parameters n_2 , n_3 , and n_6 govern the waterline profiles. Parameters n_4 , n_5 , and n_7 determine the draft variations. Calculations of both the lift and resistance have been made. However, in the following only the resistance results, which are of particular interest, will be discussed in some detail. The parameters n_1 , n_2 , ... etc are varied from a parent ship of the form:

$$n_1 = 0.4, \quad n_2 = 1.0, \quad n_3 = 0.5, \quad n_4 = 0.25$$

$$n_5 = 0.5, \quad n_6 = 0.87, \quad n_7 = 0.9$$

$$\frac{L}{B} = 10, \quad \frac{B}{H} = 4.0$$

where B and H are the maximum beam and draft of the ship. In these Figures, the resistance has been nondimensionalized by $\frac{1}{2} \rho U_0^2 B^2$ and given by

$$C_D = \frac{D}{\frac{1}{2}\rho U_0^2 B^2} = C_{D_1} + C_{D_2} \quad [19]$$

in which C_{D_1} and C_{D_2} represent the contributions by the source (hull alone) and the vorticity (trailing wake caused) distributions respectively. The resistances due to source distributions (C_{D_1}) are generally small, so that the resistance calculated is largely "stern induced", accompanying the trailing wake from the aft waterline.

The dependence of C_D on ship cross section fullness is shown in Figure 6. The values of C_D are small for ships of very full cross section and increase with increase in n_1 until it reaches a maximum and then decrease with further increase in n_1 . The effects of the parameters n_2 and n_3 (which determine the fullness of the waterline profile) on C_D are given in Figures 7 and 8. The resistances are smaller for finer bows (larger n_2) and fuller sterns (smaller n_3). The values of C_D with various parameter n_4 and n_5 which largely determine the draft variations near the bow and stern respectively are shown in Figure 9 and 10 and are smaller for higher rake bows (smaller n_4) and sharper keel-rise sterns (larger n_5). Although the effect is small over most of the range. In Figure 11, the strong variations of C_D with parameter n_6 which dictates the location of maximum beam is given. The resistance is smaller for the location of maximal beam nearer to the stern. The effect of n_7 , which determine the draft near stern, on C_D is shown in Figure 12. The resistance is smaller for shallower sterns (larger n_7). The dependence of C_D on length-beam and beam-draft ratios is shown in Figures 13 and 14. The resistances are seen to decrease with increasing in length-beam and beam-draft ratio.

The variations in resistances, except for parameters n_3 and n_6 , are moderate for various parameter changes. The resistances are very sensitive to the variations in n_3 and n_6 , as can be seen in Figure 8 and Figure 11. The resistance can be reduced substantially if the maximum beam can be moved more toward the stern (by decreasing n_6). If the changes in beam near the stern can be made more gradual (by decreasing n_3), the resistance can also be drastically reduced. These results seem to indicate that superior ship resistance characteristics at high speed may be achieved by proper shaping the waterline profiles around the stern.

These results are consistent with the fact that a waterline with maximum beam at the transom and with zero slope there ($db/dx = 0$) will not create a trailing wake and will therefore be free of resistance C_{D_2} . In fact $\phi_n \equiv 0$ at every point on the transom then $C_{D_1} = 0$ too.

Numerical calculations for ship forms very similar to those of Series 64 high-speed displacement forms, Reference 1 are also made. The values of various parameters for these computations are given below:

$$n_2 = 0.975, n_3 = 0.525, n_4 = 0.25, n_6 = 0.865$$

$$\left. \begin{array}{l} n_1 = 0.275, n_5 = 0.485, n_7 = 0.91 \\ n_1 = 0.65, n_5 = 0.525, n_7 = 0.954 \end{array} \right\} \text{for } C_B(\text{block coefficient}) = \left\{ \begin{array}{l} 0.55 \\ 0.45 \end{array} \right.$$

These series of displacement hulls have the same waterline profiles but have different draft variations for different block coefficients. Comparisons between the calculations and the experimental residual resistance data (non-dimensionalized by $\frac{1}{2}\rho U_0^2 B^2$) measured at the speed length of five by Yeh (Reference

1) are shown in Figures 15a and 15b. The results are generally in good agreement, and especially for $B/H = 3.0$ and 4.0 . Certainly the results would lend general confidence to both the theoretical developments and method of calculation.

EXTENSIONS

The theory presented here applies in the limit of very high speeds. A decrease in Froude number will involve both hydrostatic and wave sources of resistance. The hydrostatic effect on the transom is easily estimated. The waves must be the subject of additional theory, and an asymptotic theory (wavenumber small) suggests itself and could prove effective in the regime of high but finite speeds.

As noted in the introduction, a sideforce linear in yaw or sideslip develops due to the trailing wake and can be calculated.

The case of unsteady motions of the ship can be treated by the same kind of theory, possibly including motions in waves with forward speed (high speed limit).

And, finally, some of the startling results of the present paper deserve experimental verification. In that case, trim should also be calculated using the present results.

SUMMARY AND CONCLUSIONS

1) A theory has been developed and reduced to computation which applies to displacement ships in the limit of very high speeds.

2) Transom sterns may be treated.

3) The theoretical treatment is based on treating the hull as finite in beam and draft, but slender. It seems especially appropriate in the case of high speed ships which typically have large length/beam ratios.

4) In considering the consequences of the constant pressure condition on the free surface at high speeds it is revealed that two essentially different conditions can be imposed in the region aft of the maximum beam of the ship (in its shadow). One of these involves a thin sheet of water flowing rapidly down all along the aft waterline (inverted spray), and is discarded as physically unreal. The other involves a smooth flow at the aft waterline and a trailing wake (horizontal velocities on the free surface in the shadow). It seems physically realizable and corresponds to flows satisfying the Kutta condition at the trailing edge of slender wings.

5) Calculations are made for ships of a highly variable parametric form (seven constants) and the results given.

6) The trailing wake results in substantial residuary resistance at high speeds for normal waterline shapes. This is a completely new finding.

7) This residuary is typically reduced by widening the transom and is minimized by taking the maximum beam at the transom with sides there parallel to the flow direction. A shallow draft at the transom is also indicated.

8) A comparison of calculated results with the experimental results of NSRDC Series 64 shows good agreement, especially at the larger values of B/H (3 and 4) and lends credence to the theory.

9) Extensions are indicated.

REFERENCES

1. Yeh, H. Y. H., "Series 64 Resistance Experiments on High-Speed Displacement Forms," Marine Tech., Vol. 2, No. 3, 1965.
2. Shuford, C. L., Jr., "A Theoretical and Experimental Study of Planing Surfaces Including Effect of Cross Section and Planform," NACA TN 3939, 1957.
3. Hsu, C. C., "On the Motions of High Speed Planing Craft," HYDRONAUTICS, Incorporated Technical Report 603-1, May 1967.
4. Tulin, M. P., "The Theory of Slender Surfaces Planing at High Speed," Schiffstechnik, 4, 1956, 125-133.
5. Ogilvie, T. F., "Non-Linear High-Froude-Number Free-Surface Problems," J. Engineering Math., 1, 1967, 215-235.
6. Van Eseltine, R. T., and Haussing, H. J., "Flow About Transom Sterns," The Third International Conference on Numerical Ship Hydrodynamics, June 1981, Paris, France.

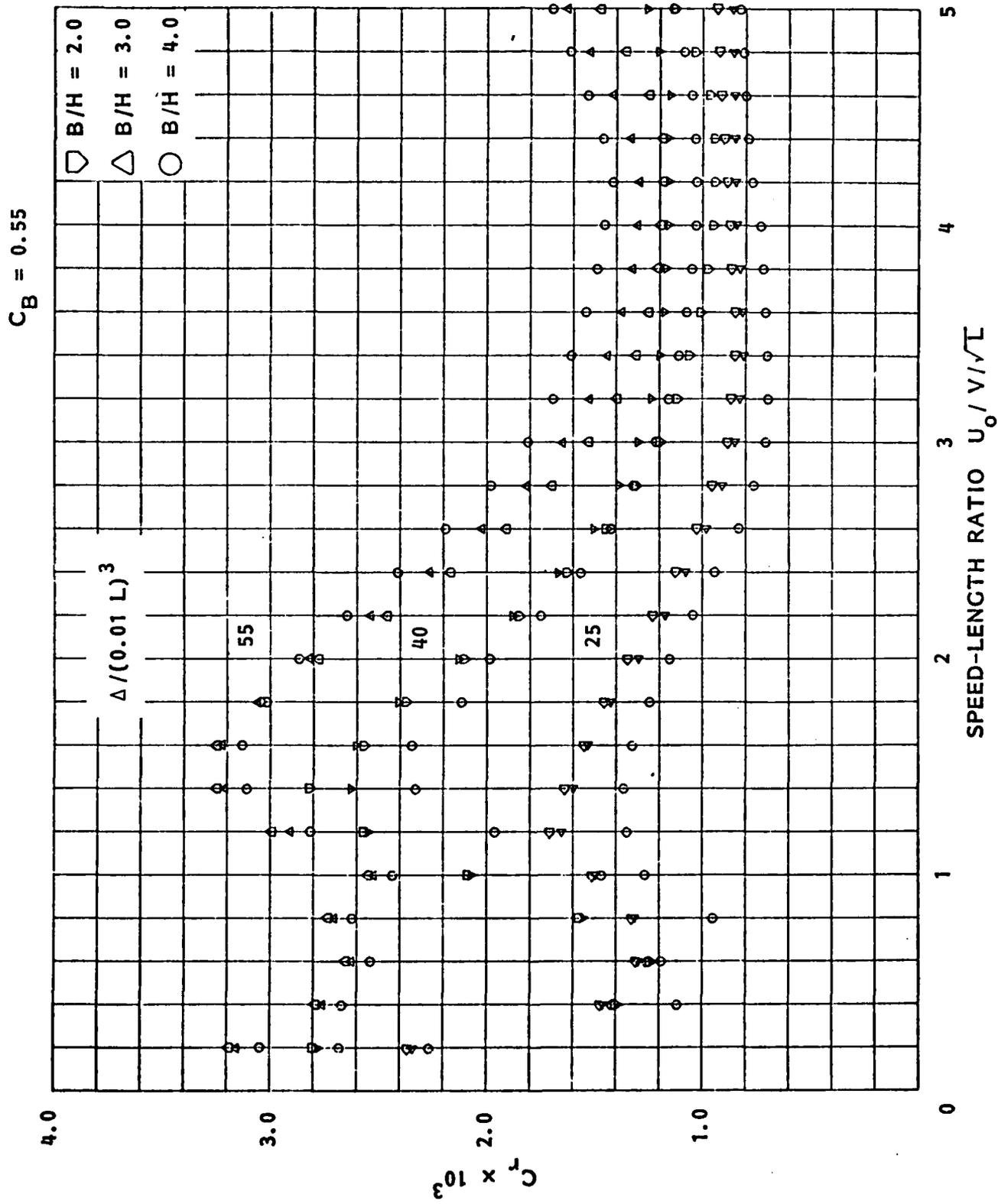


FIGURE 1A RESIDUARY-RESISTANCE COEFFICIENTS, $C_r = R_r / 1/2 \rho S V^2$

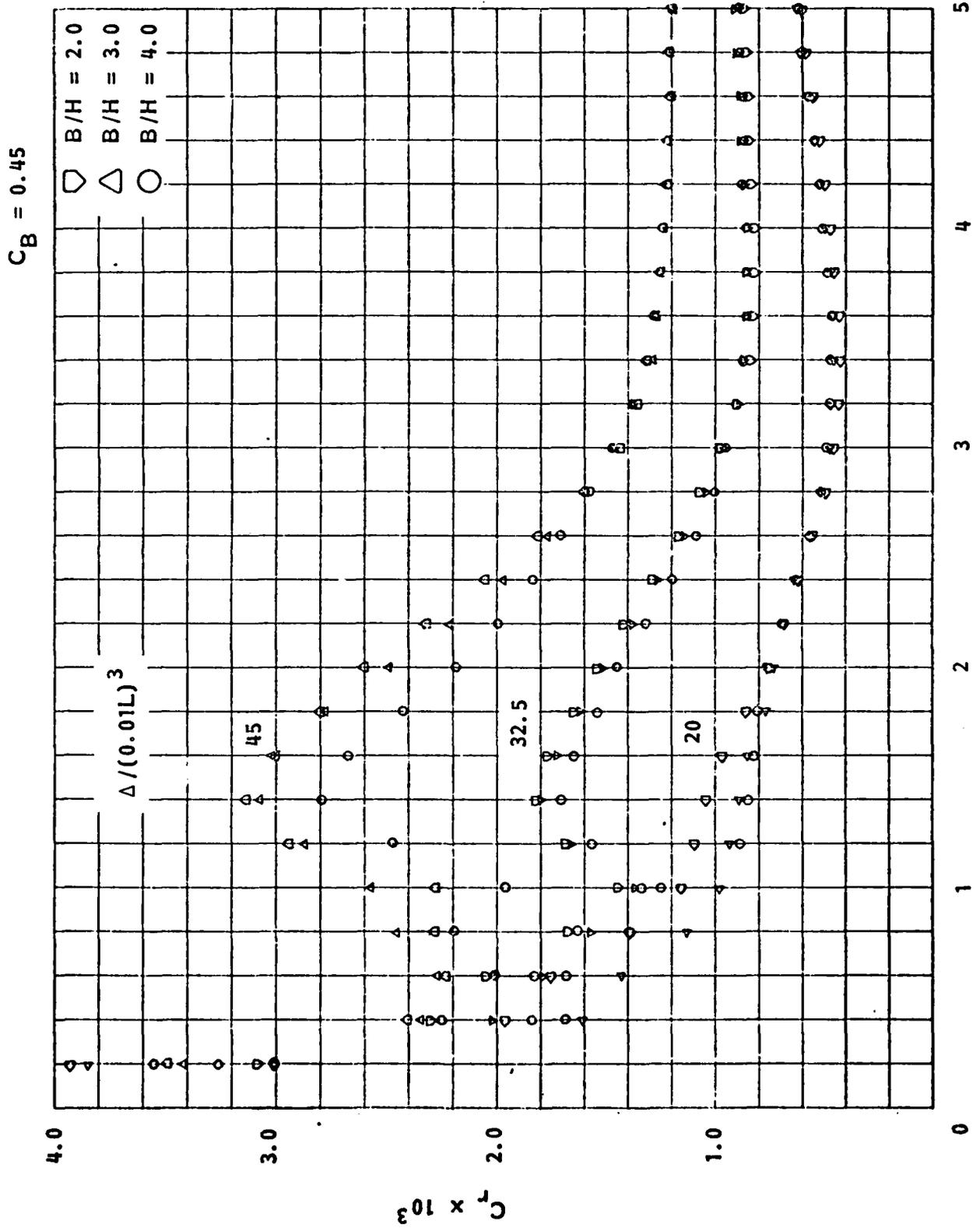


FIGURE 1B SPEED-LENGTH RATIO V/\sqrt{L}

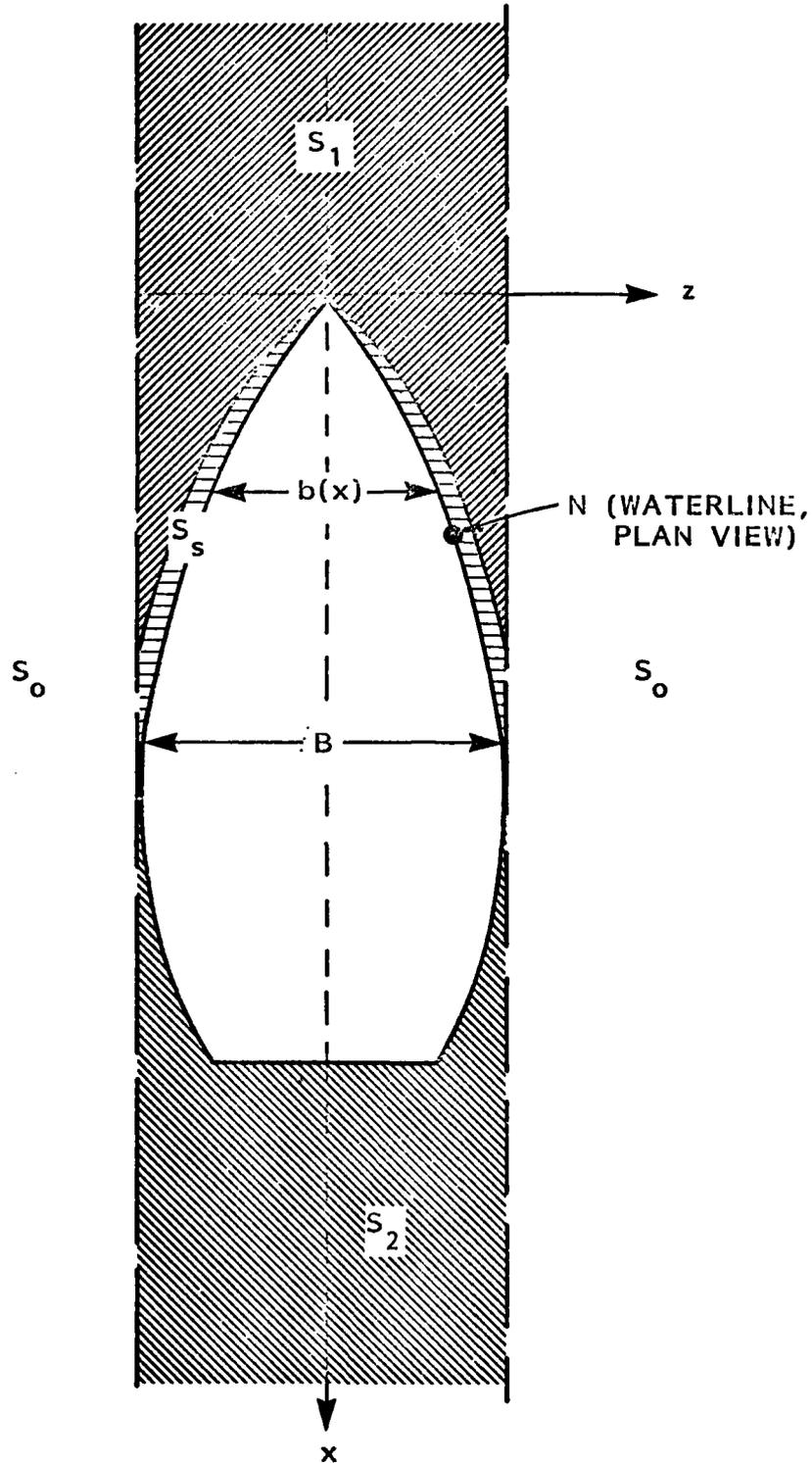


FIGURE 2 - FREE SURFACE REGIONS - HIGH SPEED SHIP

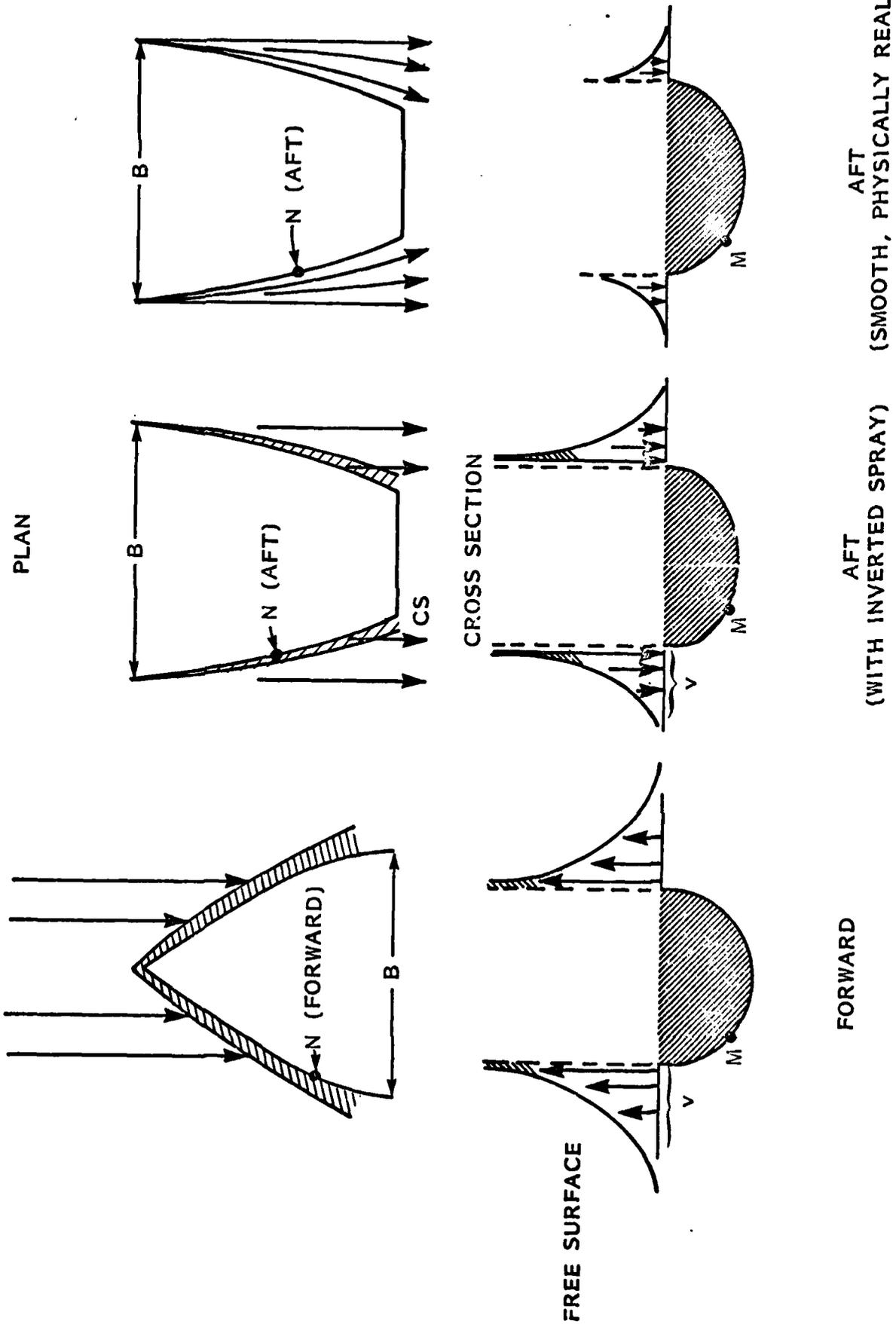


FIGURE 3 - SCHEMATIC OF STREAMLINES AND FREE SURFACE SHAPE

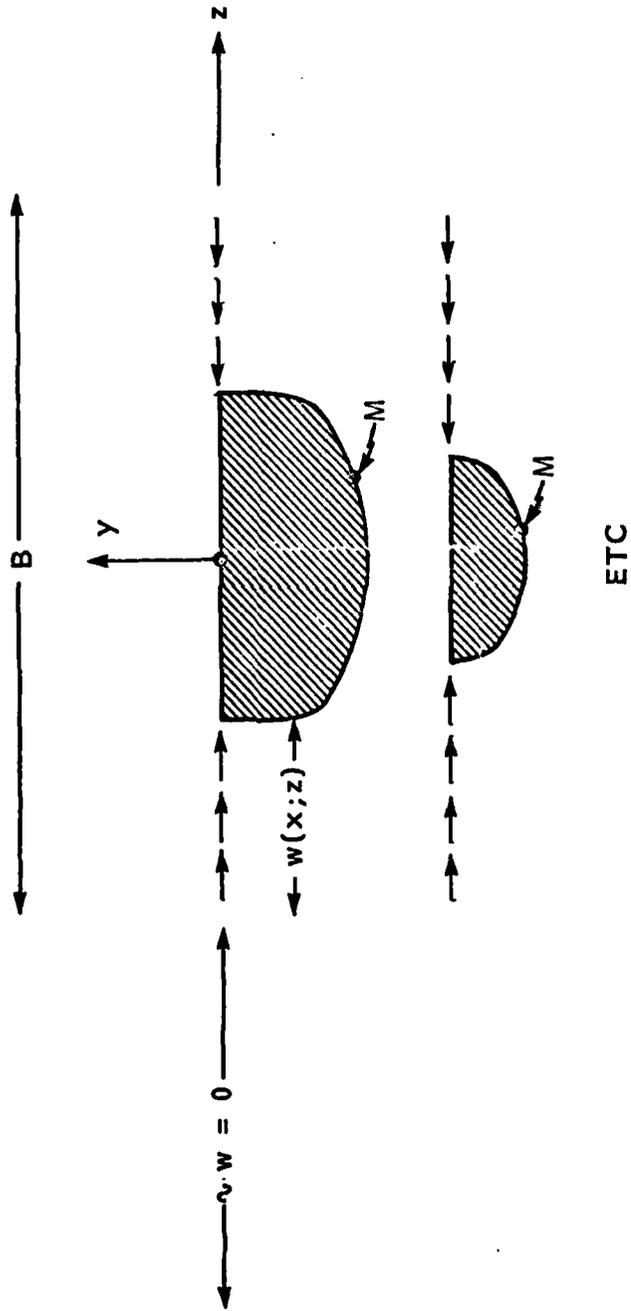


FIGURE 4 - TYPICAL AFT CROSS-SECTIONS SHOWING TRANSVERSE VELOCITIES ($y \equiv 0$) IN REAR SHADOW OF HULL

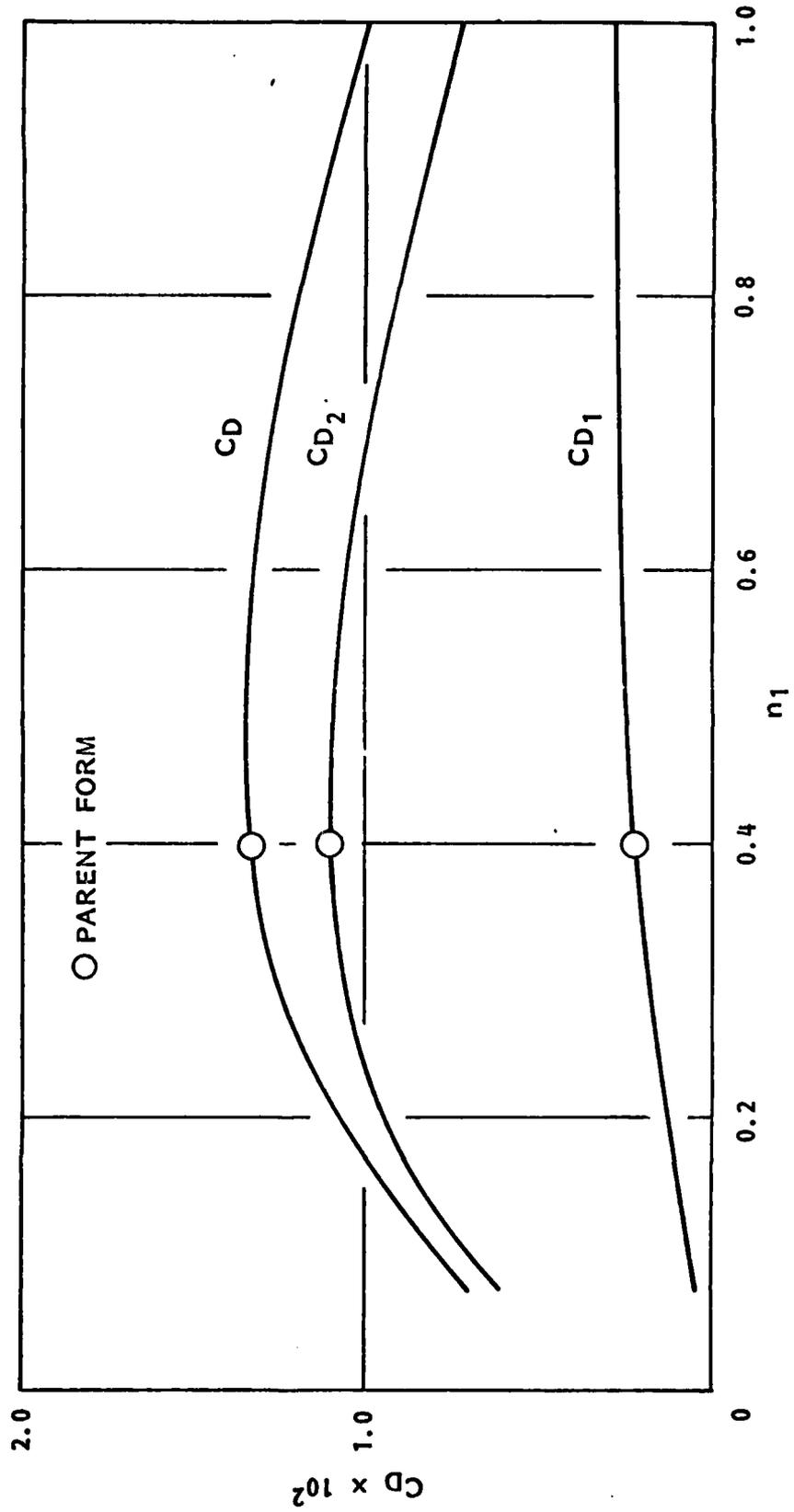


FIGURE 6 C_D Vs n_1

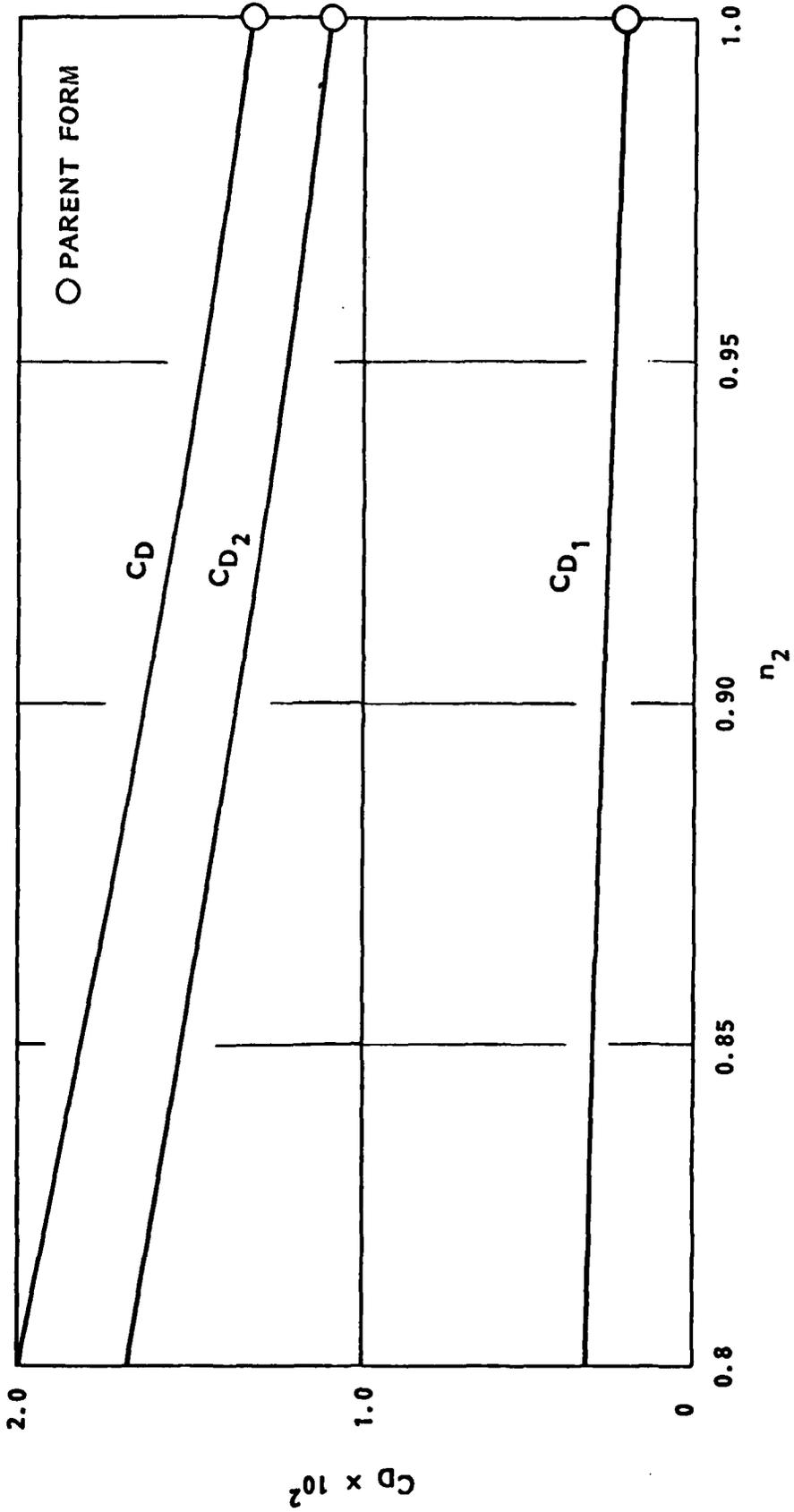


FIGURE 7 C_D Vs n_2

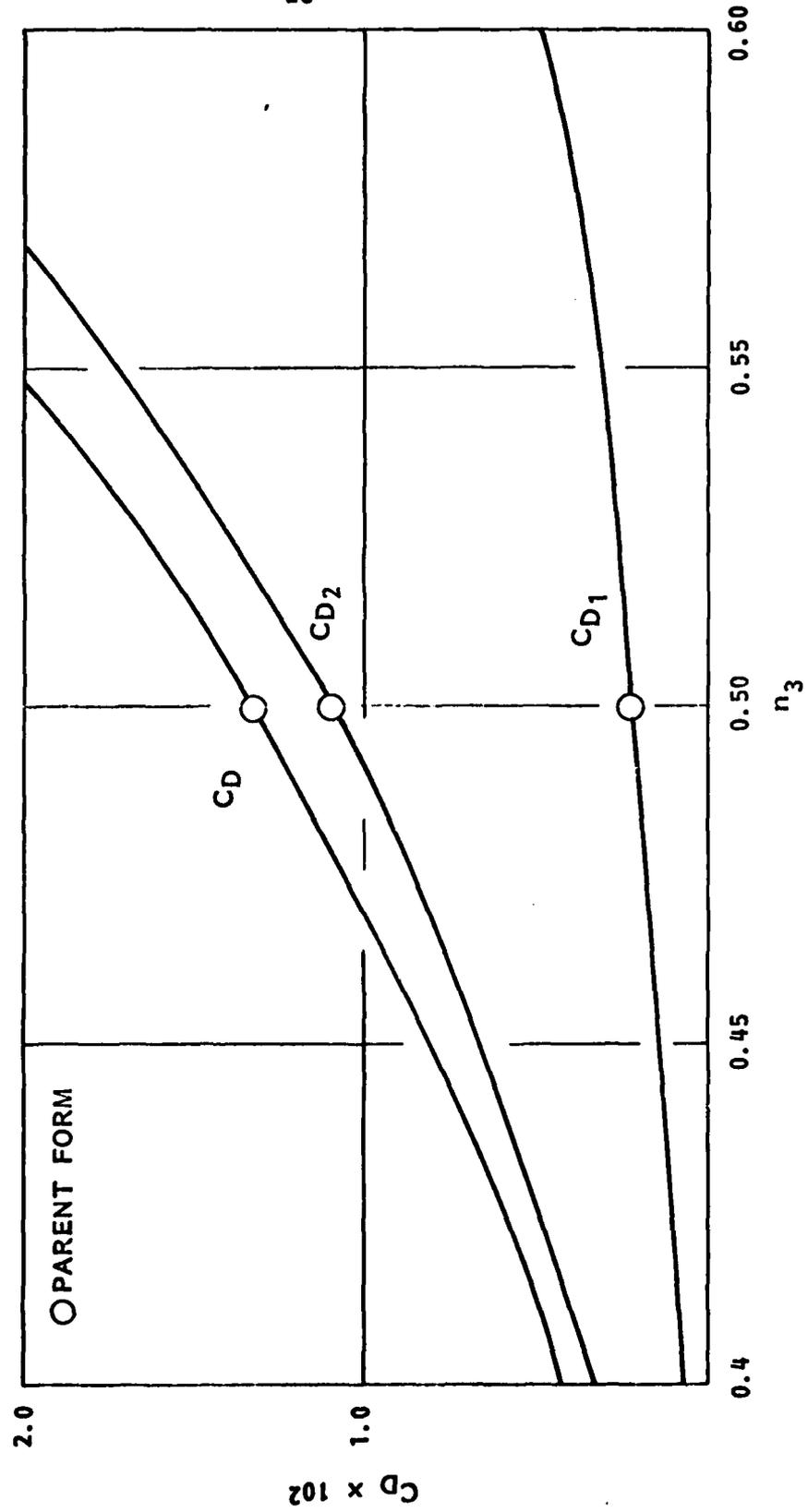


FIGURE 8 C_D Vs n_3

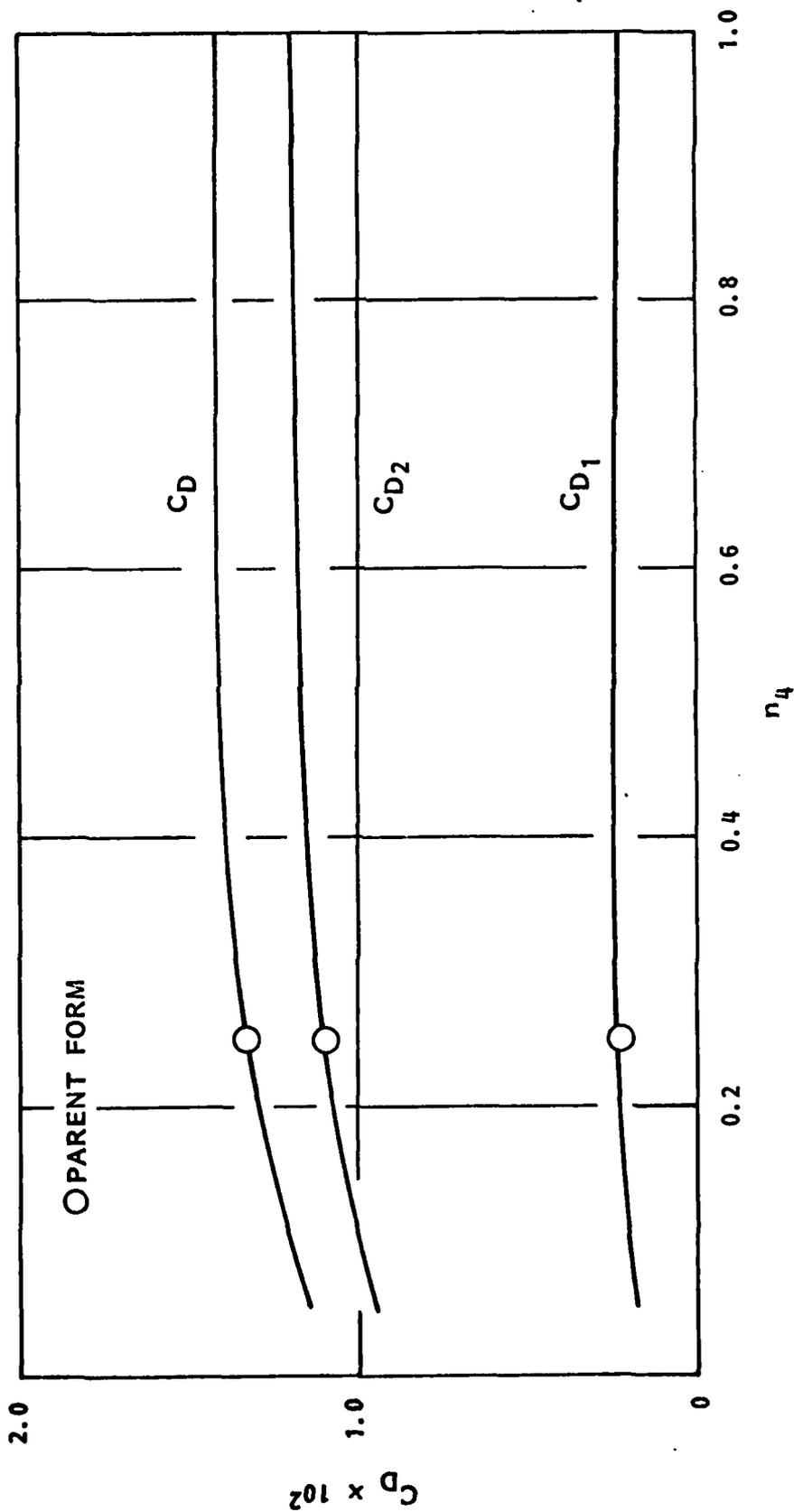


FIGURE 9 C_D Vs n_4

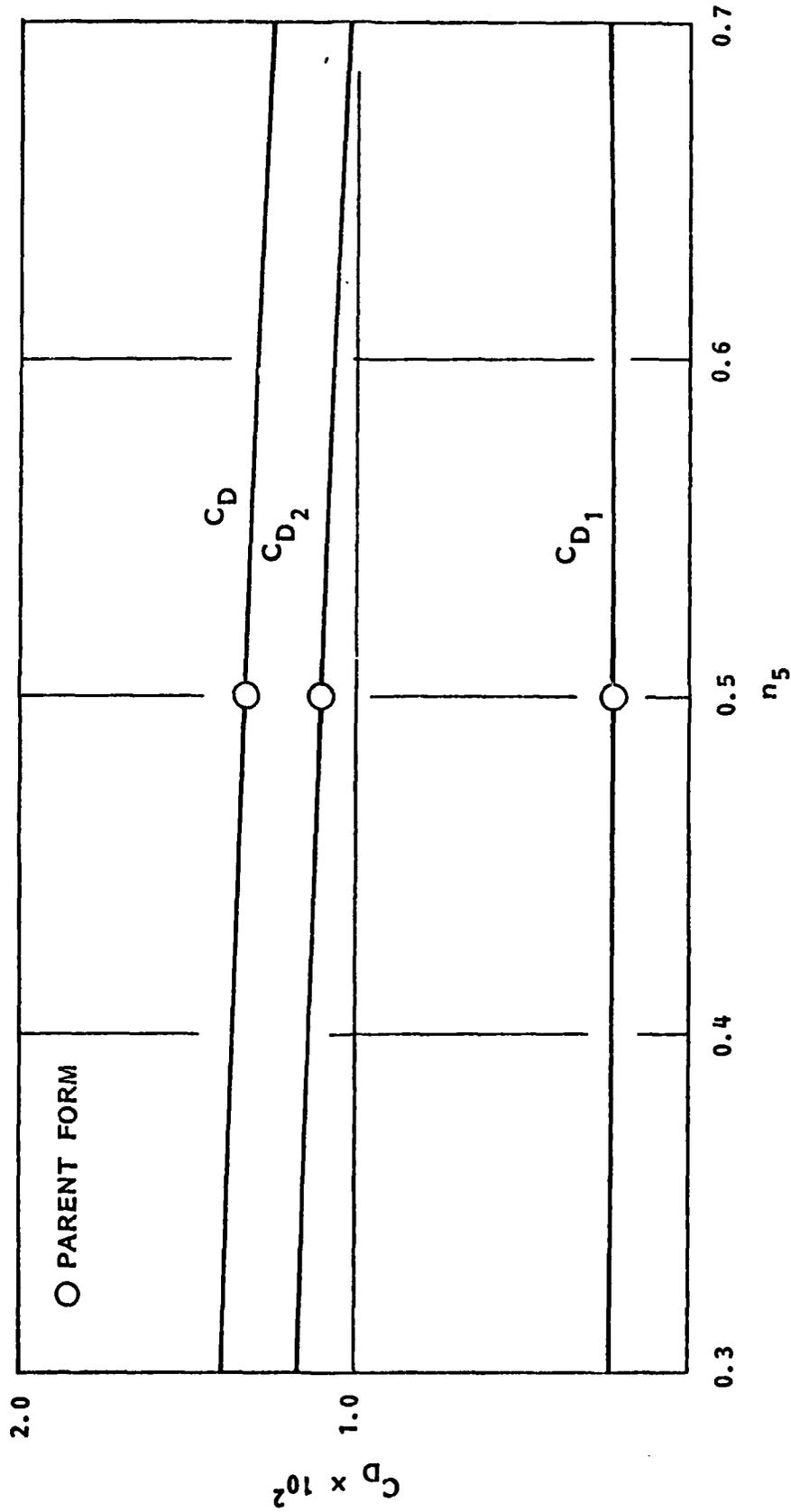


FIGURE 10 C_D Vs n_5

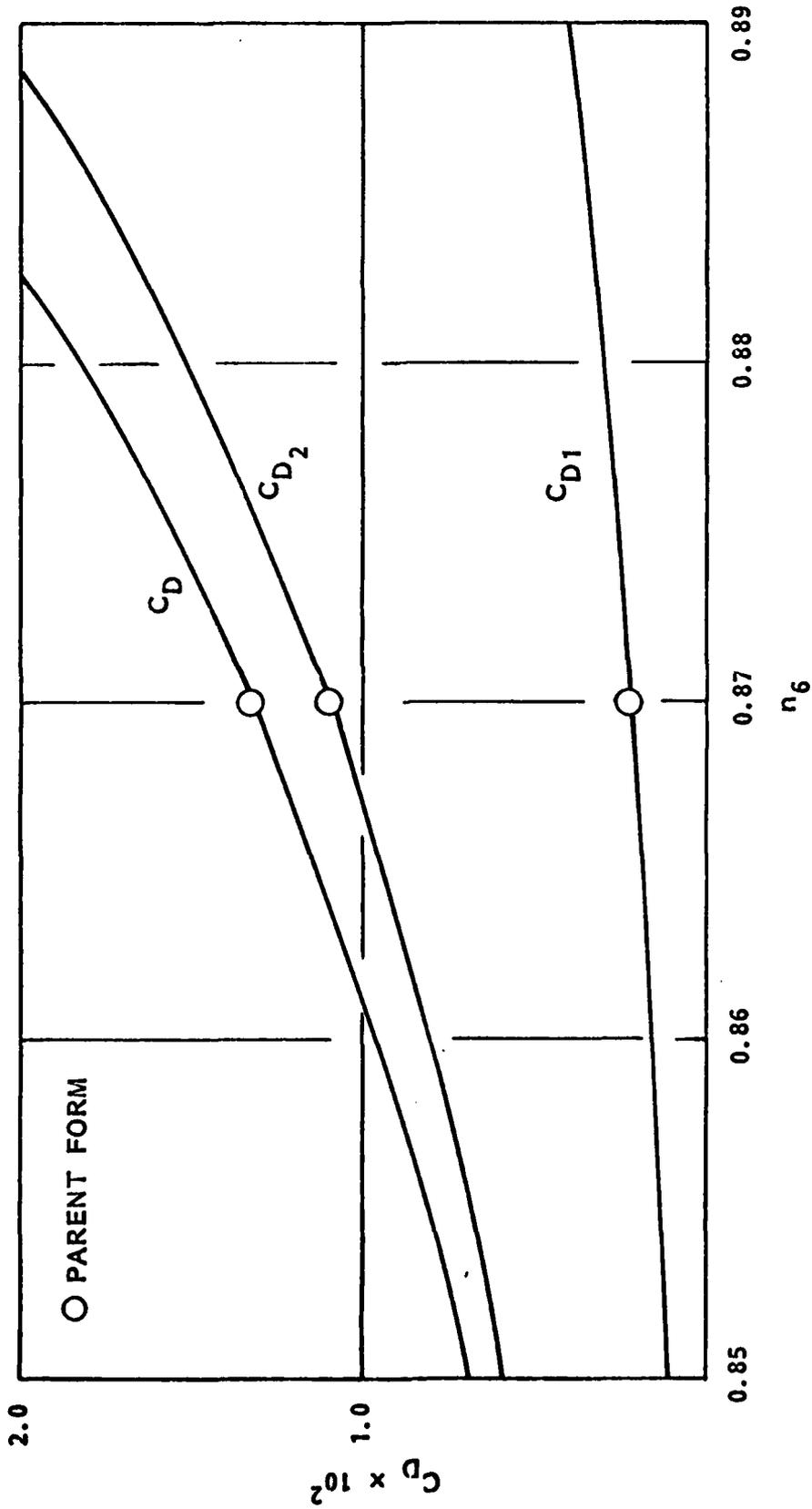


FIGURE 11 C_D Vs n_6

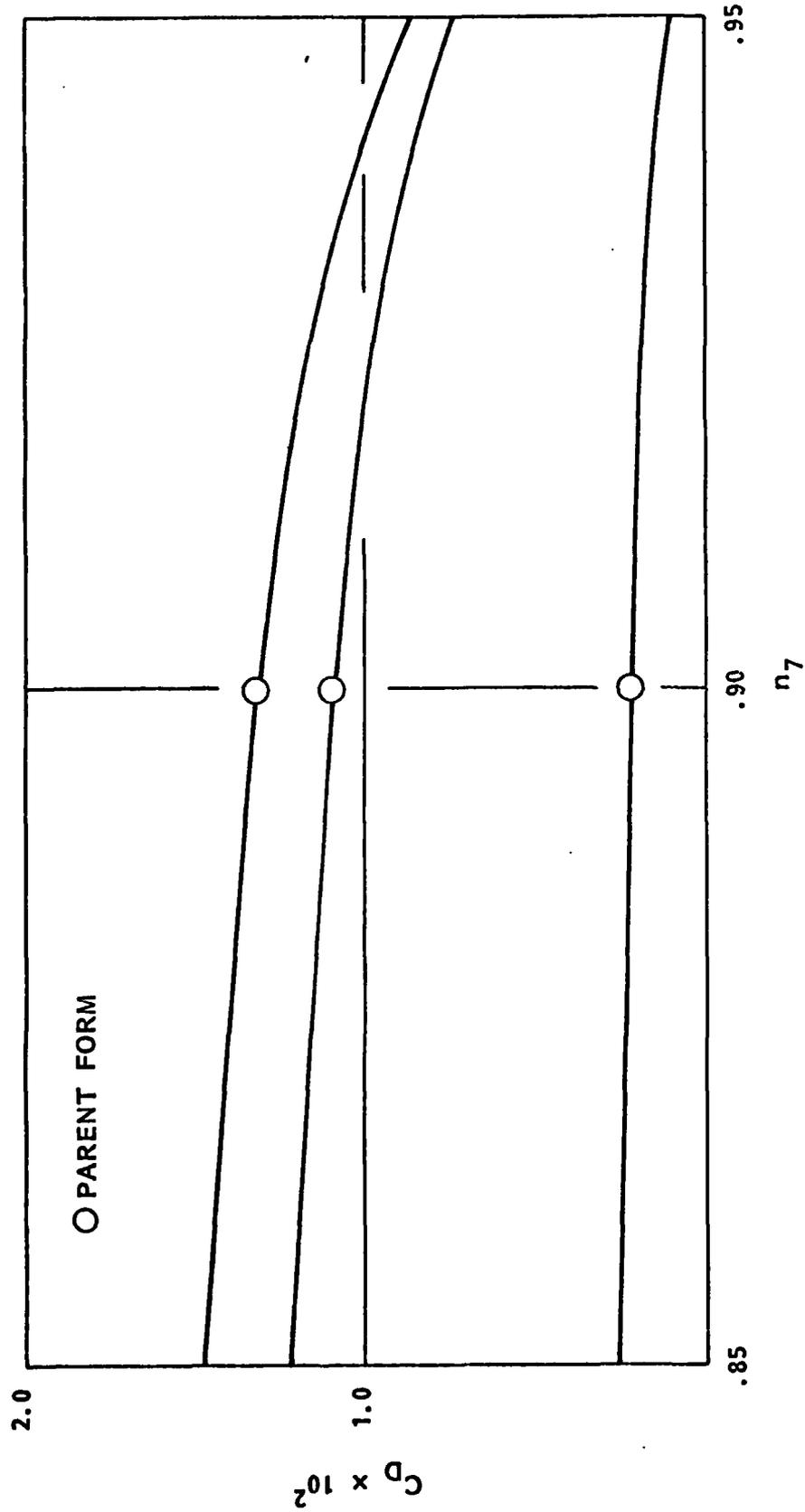


FIGURE 12 C_D Vs n^7

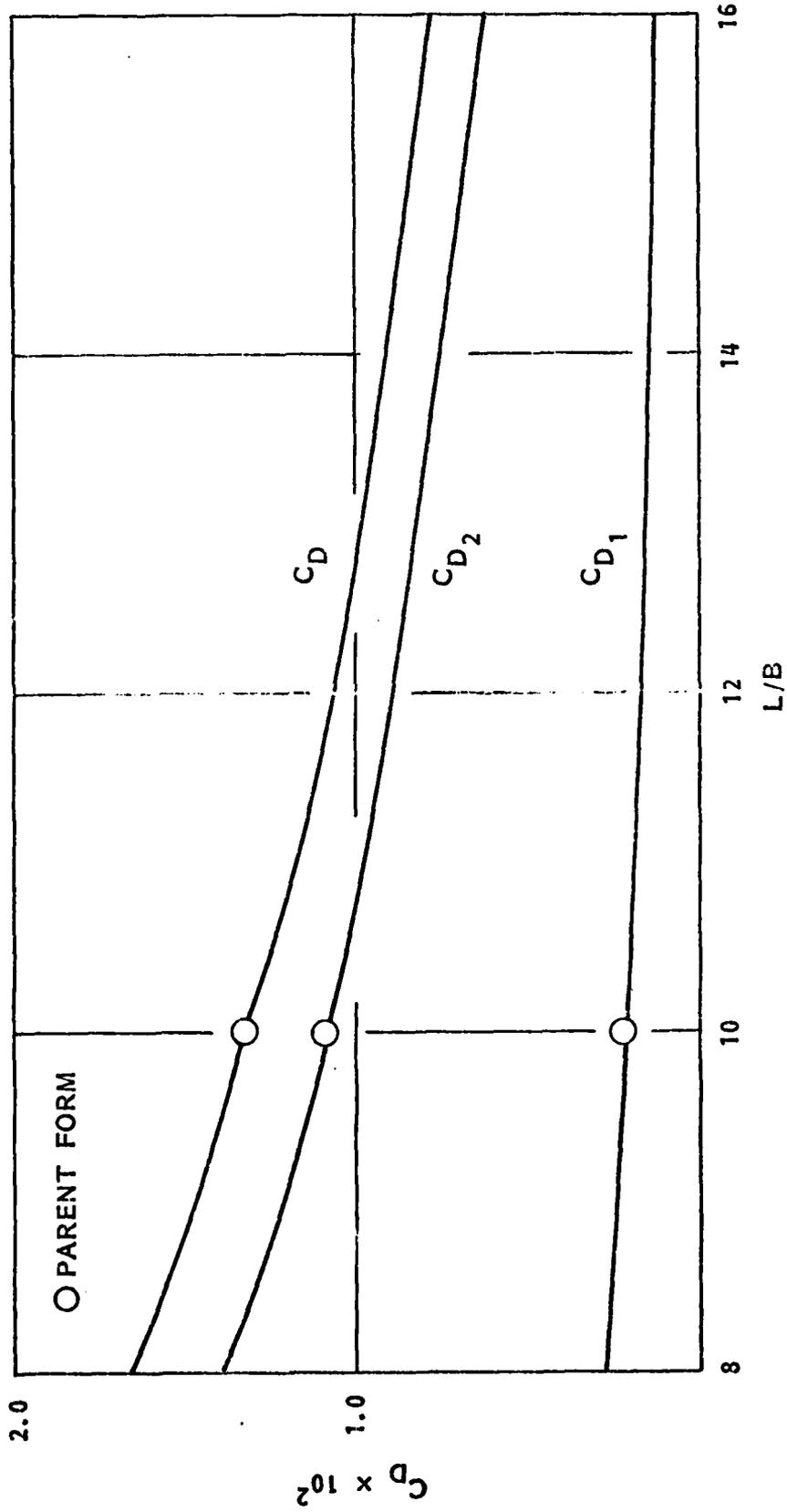


FIGURE 13 C_D Vs L/B

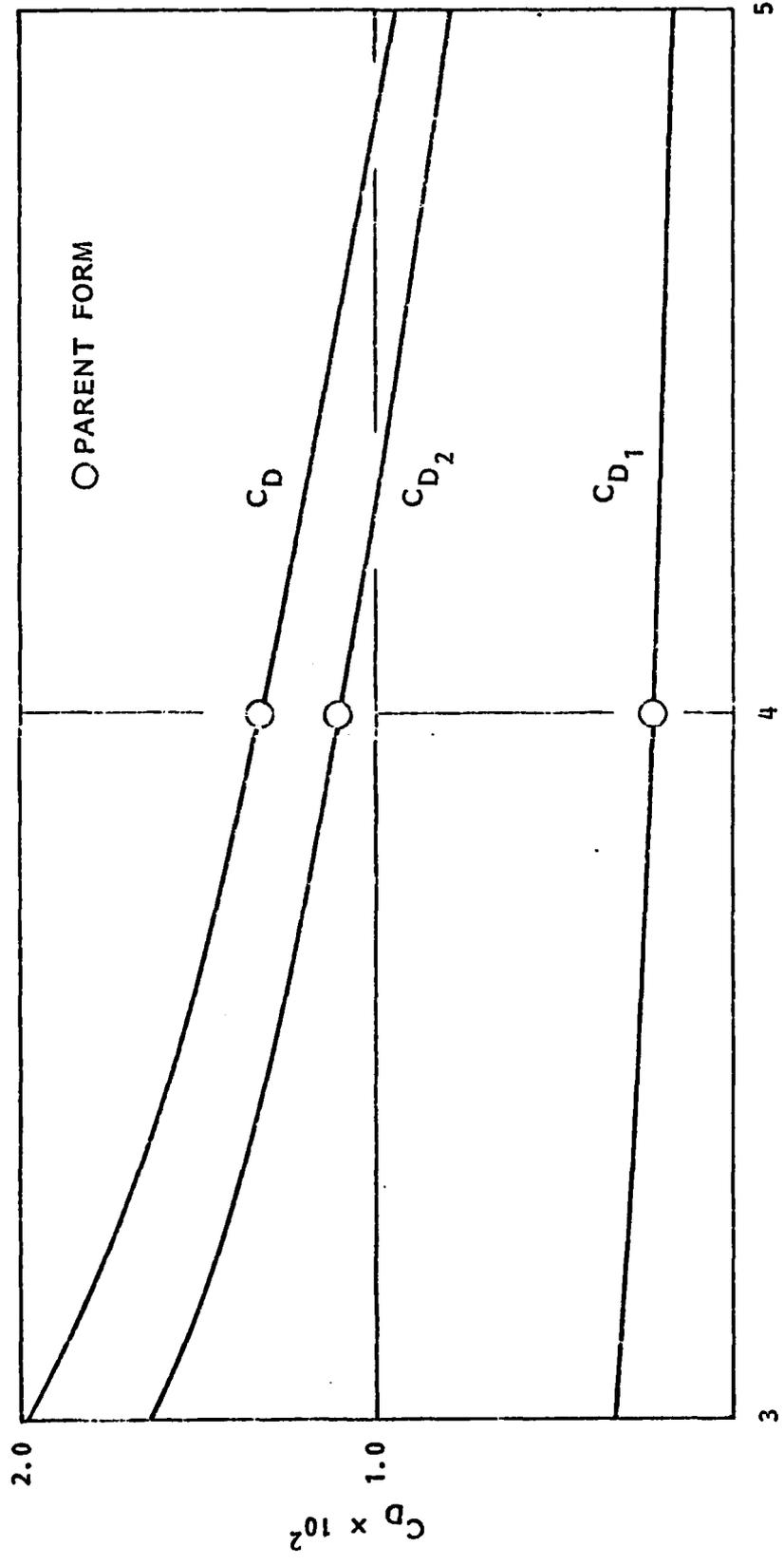


FIGURE 14 C_D Vs B/H

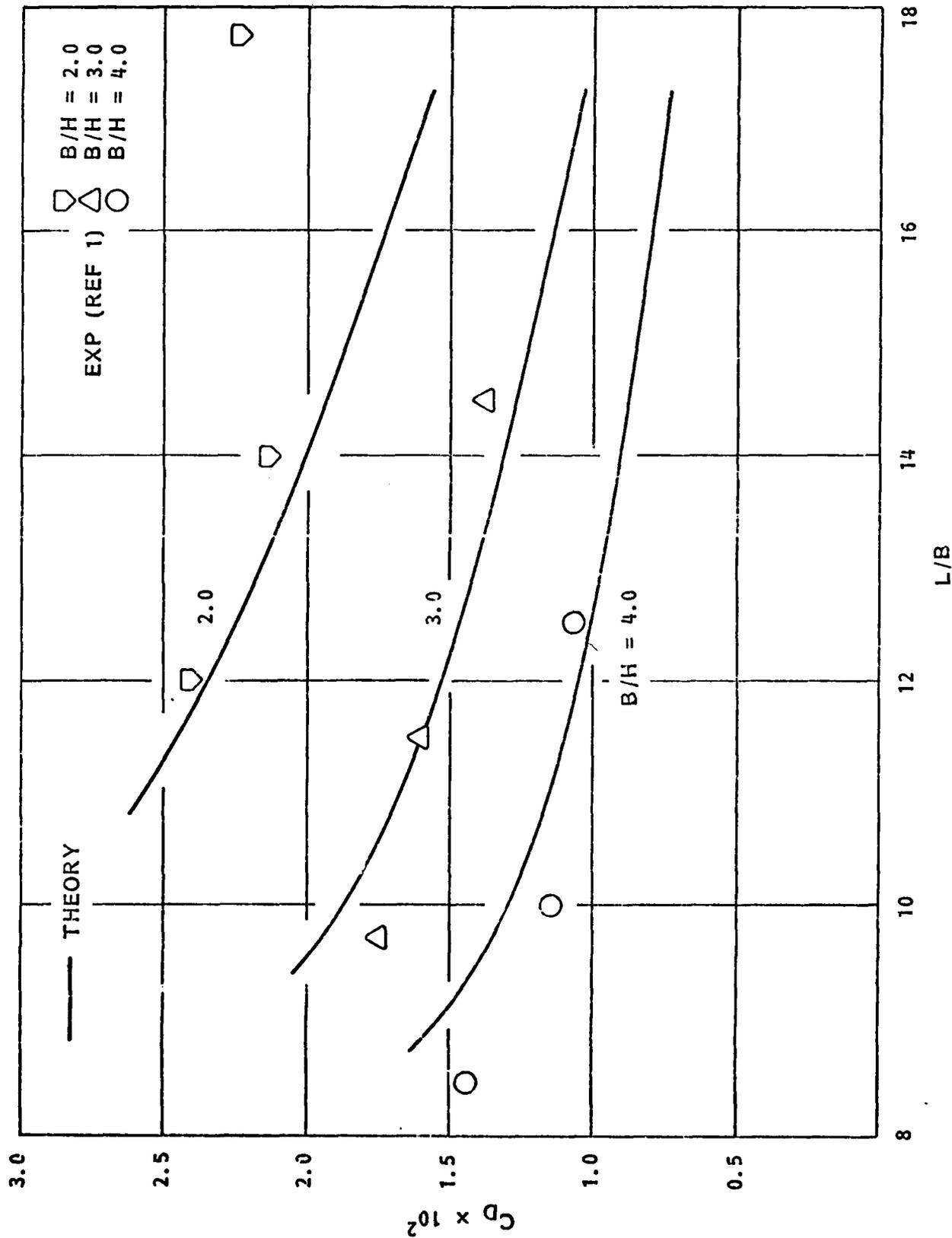


FIGURE 15a COMPARISONS WITH EXPERIMENTS, BLOCK COEFFICIENT = 0.55

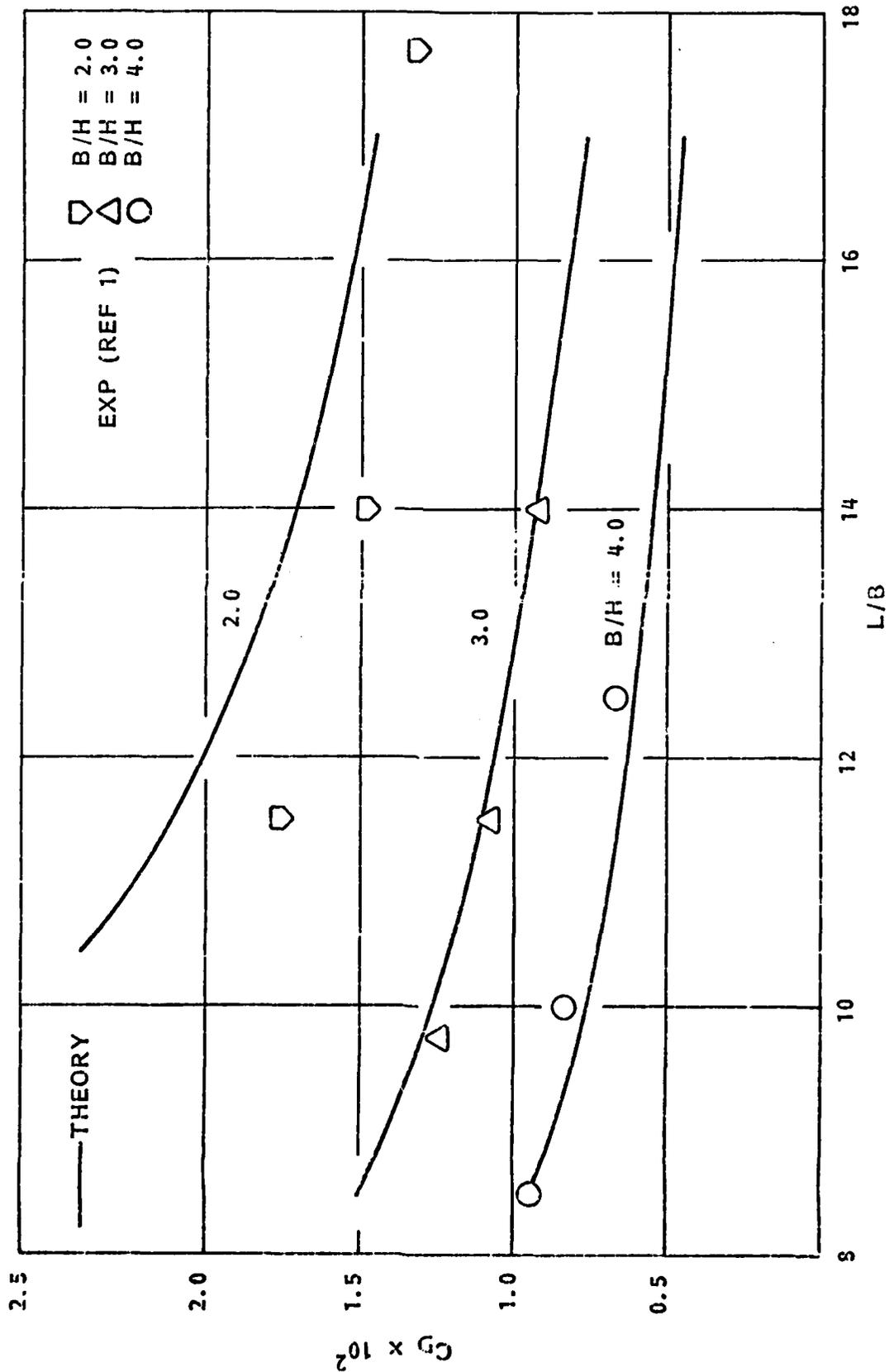


FIGURE 15b CONTINUED, BLOCK COEFFICIENT = 0.15

DISTRIBUTION LIST FOR UNCLASSIFIED
TECHNICAL REPORTS AND REPRINTS ISSUED UNDER
CONTRACT N00014-78-C-0014 TASK 062-596

All addressees receive one copy unless otherwise specified.

Defense Technical Information Center
Cameron Station
Alexandria, VA 22314 12 copies

Professor Bruce Johnson
U.S. Naval Academy
Engineering Department
Annapolis, MD 21402

Library
U.S. Naval Academy
Annapolis, MD 21402

Technical Library
David W. Taylor Naval Ship Research
and Development Center
Annapolis Laboratory
Annapolis, MD 21402

Professor C. -S. Yih
The University of Michigan
Department of Engineering Mechanics
Ann Arbor, MI 48109

Professor T. Francis Ogilvie
Massachusetts Institute of Technology
Department of Ocean Engineering
Cambridge, MA 02139

Office of Naval Research
Code 211
800 N. Quincy Street
Arlington, VA 22217

Office of Naval Research
Code 438
800 N. Quincy Street
Arlington, VA 22217 3 copies

Office of Naval Research
Code 473
800 N. Quincy Street
Arlington, VA 22217

NASA Scientific and Technical
Information Facility
P. O. Box 8757
Baltimore/Washington International
Airport
Maryland 21240

Professor Paul M. Naghdi
University of California
Department of Mechanical Engineering
Berkeley, CA 94720

Librarian
University of California
Department of Naval Architecture
Berkeley, CA 94720

Professor John V. Wehausen
University of California
Department of Naval Architecture
Berkeley, CA 94720

Library
David W. Taylor Naval Ship Research
and Development Center
Code 522.1
Bethesda, MD 20084

Mr. Justin H. McCarthy, Jr.
David W. Taylor Naval Ship Research
and Development Center
Code 1540
Bethesda, MD 20084

Dr. William B. Morgan
David W. Taylor Naval Ship Research
and Development Center
Code 1500
Bethesda, MD 20084

Director
Office of Naval Research Eastern/Central
Regional Office
Building 114, Section D
606 Summer Street
Boston, MA 02210

Library
Naval Weapons Center
China Lake, CA 93555

Technical Library
Naval Surface Weapons Center
Dahlgren Laboratory
Dahlgren, VA 22418

Technical Documents Center
Army Mobility Equipment Research Center
Building 315
Fort Belvoir, VA 22060

Technical Library
Webb Institute of Naval Architecture
Glen Cove, NY 11542

Dr. J. P. Breslin
Stevens Institute of Technology
Davidson Laboratory
Castle Point Station
Hoboken, NJ 07030

Professor Louis Landweber
The University of Iowa
Institute of Hydraulic Research
Iowa City, IA 52242

R. E. Gibson Library
The Johns Hopkins University
Applied Physics Laboratory
Johns Hopkins Road
Laurel, MD 20810

Lorenz G. Straub Library
University of Minnesota
St. Anthony Falls Hydraulic Laboratory
Minneapolis, MN 55414

Library
Naval Postgraduate School
Monterey, CA 93940

Technical Library
Naval Underwater Systems Center
Newport, RI 02840

Engineering Societies Library
345 East 47th Street
New York, NY 10017

The Society of Naval Architects and
Marine Engineers
One World Trade Center, Suite 1369
New York, NY 10048

Technical Library
Naval Coastal System Laboratory
Panama City, FL 32401

Professor Theodore Y. Wu
California Institute of Technology
Engineering Science Department
Pasadena, CA 91125

Director
Office of Naval Research Western Regional
Office
1030 E. Green Street
Pasadena, CA 91101

Technical Library
Naval Ship Engineering Center
Philadelphia Division
Philadelphia, PA 19112

Army Research Office
P. O. Box 12211
Research Triangle Park, NC 27709

Editor
Applied Mechanics Review
Southwest Research Institute
8500 Culebra Road
San Antonio, TX 78206

Technical Library
Naval Ocean Systems Center
San Diego, CA 92152

ONR Scientific Liaison Group
American Embassy - Room A-407
APO San Francisco 96503

Librarian
Naval Surface Weapons Center
White Oak Laboratory
Silver Spring, MD 20910

Defense Research and Development Attache
Australian Embassy
1601 Massachusetts Avenue, NW
Washington, DC 20036

Librarian Station 5-2
Coast Guard Headquarters
NASSIF Building
400 Seventh Street, SW
Washington, DC 20591

Library of Congress
Science and Technology Division
Washington, DC 20540

Dr. A. L. Slafkosky
Scientific Advisor
Commandant of the Marine Corps
Code AX
Washington, DC 20380

Maritime Administration
Office of Maritime Technology
14th & E Streets, NW
Washington, DC 20230

Maritime Administration
Division of Naval Architecture
14th & E Streets, NW
Washington, DC 20230

Dr. G. Kulin
National Bureau of Standards
Mechanics Section
Washington, DC 20234

Naval Research Laboratory
Code 2627
Washington, DC 20375 6 copies

Library
Naval Sea Systems Command
Code 09GS
Washington, DC 20362

Mr. Thomas E. Peirce
Naval Sea Systems Command
Code 03512
Washington, DC 20362

Oceanographer of the Navy.
200 Stovall Street
Alexandria, VA 22332

Office of Naval Research
Code 481
800 N. Quincy Street
Arlington, VA 22217

Professor Richard W. Miksad
The University of Texas at Austin
Department of Civil Engineering
Austin, TX 78712

Dr. Robert R. Long
The Johns Hopkins University
Department of Earth and
Planetary Sciences
Baltimore, MD 21218

Professor Owen M. Phillips
The Johns Hopkins University
Department of Earth and
Planetary Sciences
Baltimore, MD 21218

Professor C. C. Mei
Massachusetts Institute of Technology
Department of Civil Engineering
Cambridge, MA 02139

Professor David J. Benney
Massachusetts Institute of Technology
Department of Mathematics
Cambridge, MA 02139

Professor E. Mollo-Christensen
Massachusetts Institute of Technology
Department of Meteorology
Room 54-1722
Cambridge, MA 02139

Professor Justin E. Kerwin
Massachusetts Institute of Technology
Department of Ocean Engineering
Cambridge, MA 02139

Professor John W. Miles
University of California, San Diego
Institute of Geophysics and
Planetary Physics, A-025
La Jolla, CA 92093

Dr. E. W. Montroll
Physical Dynamics, Inc.
P. O. Box 556
La Jolla, CA 92038

Director
Scripps Institute of Oceanography
University of California
La Jolla, CA 92037

Dr. Steven A. Orszag
Cambridge Hydrodynamics, Inc.
54 Baskin Road
Lexington, MA 02173

Dr. Steven C. Crow
President, Poseidon Research
11777 San Vicente Blvd., Suite 641
Los Angeles, CA 90049

Professor Frederick K. Browand
University of Southern California
University Park
Department of Aerospace Engineering
Los Angeles, CA 90007

Professor John Laufer
University of Southern California
University Park
Department of Aerospace Engineering
Los Angeles, CA 90007

Professor T. N. Stevenson
University of Manchester
Department of the Mechanics of Fluids
Manchester M13 9PL, England

Professor Jin Wu
University of Delaware
College of Marine Studies
Newark, DE 19711

Professor R. C. MacCamy
Carnegie Institute of Technology
Department of Mathematics
Pittsburgh, PA 15213

Professor Norman J. Zabusky
University of Pittsburgh
Department of Mathematics and Statistics
Pittsburgh, PA 15260

Dr. Harvey Segur
Aeronautical Research Associates
of Princeton, Inc.
50 Washington Road
Princeton, NJ 08540

Professor J. T. C. Liu
Brown University
Division of Engineering
Providence, RI 02912

Professor C. H. Su
Brown University
Division of Applied Mathematics
Providence, RI 02912

Dr. Jack W. Hoyt
Naval Ocean Systems Center
Code 2501
San Diego, CA 92152

Professor Milton Van Dyke
Stanford University
Department of Aeronautics
and Astronautics
Stanford, CA 94305

Professor J. F. Thompson
Mississippi State University
Department of Aerophysics and
Aerospace Engineering
State College, MS 39762

Professor Richard L. Pfeffer
Florida State University
Geophysical Fluid Dynamics Institute
Tallahassee, FL 32306

Professor Ruby E. Krishnamurti
Florida State University
Department of Oceanography
Tallahassee, FL 32306

Professor Timothy W. Kao
The Catholic University of America
Department of Civil Engineering
Washington, DC 20064

Professor Phillip Mandel
Massachusetts Institute of Technology
Department of Ocean Engineering
Cambridge, MA 02139

Professor J. Nicholas Newman
Massachusetts Institute of Technology
Department of Ocean Engineering
Room 5-324A
Cambridge, MA 02139

Professor Ronald W. Yeung
Massachusetts Institute of Technology
Department of Ocean Engineering
Cambridge, MA 02139

Professor S. I. Pai
University of Maryland
Institute of Fluid Dynamics
and Applied Mathematics
College Park, MD 20742

Computation and Analyses Laboratory
Naval Surface Weapons Center
Dahlgren Laboratory
Dahlgren, VA 22418

Dr. Robert K. -C. Chan
JAYCOR
1401 Camino Del Mar
Del Mar, CA 92014

Professor K. E. Shuler
University of California, San Diego
Department of Chemistry
La Jolla, CA 92093

Professor Hsien-Ping Pao
The Catholic University of America
Department of Civil Engineering
Washington, DC 20064

Commander
Naval Oceanographic Office
Washington, DC 20373

Dr. J. O. Elliot
Naval Research Laboratory
Code 8310
Washington, DC 20375

Naval Research Laboratory
Code 8340
Washington, DC 20375

Naval Ship Engineering Center
Code 6110
Washington, DC 20362

Naval Ship Engineering Center
Code 6114
Washington, DC 20362

Naval Ship Engineering Center
Code 6136
Washington, DC 20362

Dr. Gary S. Deem
Bell Telephone Laboratories, Inc.
1 Whippany Road
Whippany, NJ 07981

Mr. D. Farmer
Naval Ocean Research and
Development Activity
Code 332
NSTL Station, MS 39522