$T_q = \frac{V}{\sqrt{L}} = 3{,}358\ F_n$

$F_n = T_q \cdot 0{,}2978$

Series 64 Resistance Experiments on High-Speed Displacement Forms

gilt für: $\frac{L}{\nabla^{1/3}} = 8{,}59 - 17{,}26$

By Hugh Y. H. Yeh[1]

The speed-length ratios of displacement-type surface ships in the past were limited to under 2.0. In order to perform projected tactical missions, however, the Navy needs ships of much higher speeds resulting in speed-length ratios of 2.0 or above. To gain information in this respect, 27 models of conventional hull forms designated "Series 64" were designed, constructed, and tested at the David Taylor Model Basin. This paper reports the results of the bare hull resistance tests of Series 64 models.

In the process of determining the horsepower necessary to fulfill speed requirements, the naval architect will at some time have to refer to the data published in the various technical publications for guidance. Extremely useful are those data which contain the results of experiments on methodical series of model tests, in which the design parameters are varied systematically one at a time. These series also serve as a yardstick in judging the performance characteristics of new designs. For instance, at the David Taylor Model Basin, we customarily compare the resistance characteristics of all new models with those of the Taylor Standard Series [1][2] or Series 60 [2] models. If the resistance characteristics are inferior to those of the comparable series, unless restricted by the other requirements, such as stability, and so on, it is anticipated that improvement of the hull form can be achieved.

The speed-length ratios of displacement-type surface ship series data published in the past were limited to under 2.0. Power requirements increase rapidly above the speed-length ratio of 1.5 and, if a ship were designed to operate about that speed-length ratio, the conventional marine machinery weight would be more than the payload. Since the need of speed-length ratios higher than 1.5 was not acute, it was thought impractical to consider ships which operated at speed-length ratios over 1.5. In order to perform projected tactical missions, however, the Navy needs ships of much higher speeds resulting in speed-length ratios of 2.0 or above.

$F_n = 0{,}6$

[1] David Taylor Model Basin, Washington, D. C.

[2] Numbers in brackets designate References at end of paper.

Presented at the December 9, 1964 Meeting of the Chesapeake Section of The Society of Naval Architects and Marine Engineers.

Wave resistance was believed to be the main cause for this surge in resistance which inspired a number of novel designs [3,4] to reduce wave resistance, such as Shark Ship, Escort Research Ship, and others.

The lack of a standard makes the task of judging the performance of these new designs very difficult. To remedy this deficiency, the David Taylor Model Basin, in 1959, under its Fundamental Hydromechanics Research Program, initiated a series of experiments on a high-speed, low-wave drag form. Since no data were available on conventional displacement-type surface ships at high speed, it was decided that exploratory studies should start with conventional hull forms before going into any novel type of ship forms.

After the preliminary investigation, 27 models of conventional hull forms (designated "Series 64") were designed, constructed, and tested. This paper reports the results from the bare-hull resistance tests of this series of models.

Choice of Hull Form for Parent Model

In order to develop a good high-speed displacement-type surface ship hull form for the parent model, it would be highly desirable to draw guidance from existing test data on ships which have comparable characteristics. As mentioned previously, there is little information available on ships which operate at the speeds for which we were aiming. Fortunately, at the David Taylor Model Basin, we do have considerable test data available on moderately high-speed displacement-type surface ships (speed-length ratios as high as 3.6). These data were collected and compared in the selection of hull forms. To ensure fair comparison, all test data obtained with speed-length ratios higher than 1.0 were

$F_n = 1{,}07$

Nomenclature

A_x = maximum sectional area
B_x = beam at maximum sectional area
C_F = frictional resistance coefficient = $R_F/\frac{1}{2}\rho S v^2$
ΔC_F = correlation allowance
C_r = residuary resistance coefficient = $R_r/\frac{1}{2}\rho S v^2$
$C_r^* = R_r/\frac{1}{2}\rho A_x v^2$
C_t = total resistance coefficient = $R_t/\frac{1}{2}\rho S v^2$
H_x = draft at maximum sectional area
L = length at designed waterline, ft
R_F = frictional resistance, lb
R_r = residuary resistance, lb
R_t = total resistance, lb
S = wetted surface, sq ft
V = speed, knots
v = speed, fps
Δ = displacement in tons of 2240 lb and in salt water having a weight density corresponding to a volume of 34.977 cu ft/ton
ρ = mass density of water, lb sec^2/ft^4
ν = kinematic viscosity of water, ft^2/sec

$\frac{L}{\nabla^{1/3}} = \frac{100}{\sqrt[3]{\frac{\nabla}{(0{,}01 \cdot L)^3}}}$

calculated using current calculating procedures [5].
In selecting the criterion for comparison, consideration is given to the following parameters: ©, C_r, and R_r/Δ. $/\Delta$ was finally selected on the basis that it gives a earer picture of the relationship between residuary sistance and displacement. Primary consideration comparing hull forms was given to high-speed perrmance with a probable penalty at lower speed.

This comparison resulted in the selection of two models, TMB Models 3474 and 3548, both of which exhibited exceptionally good performance at high speeds.

Two new models, TMB Models 4783 and 4783-1, were constructed using Models 3474 and 3578 as guides in developing the lines. These new models differed only in the afterbody chine line; that is, Model 4783 had a hard chine or knuckle and Model 4783-1 had a soft or round chine.

When bare-hull resistance tests were conducted for these two new models, the results indicated that Model 4783-1 had the better overall performance; above the speed-length ratio of 2.6, both performed considerably better than either Model 3474 or Model 3548. Therefore, Model 4783-1 was chosen as the parent for the series and data for this model are given in Fig. 1.

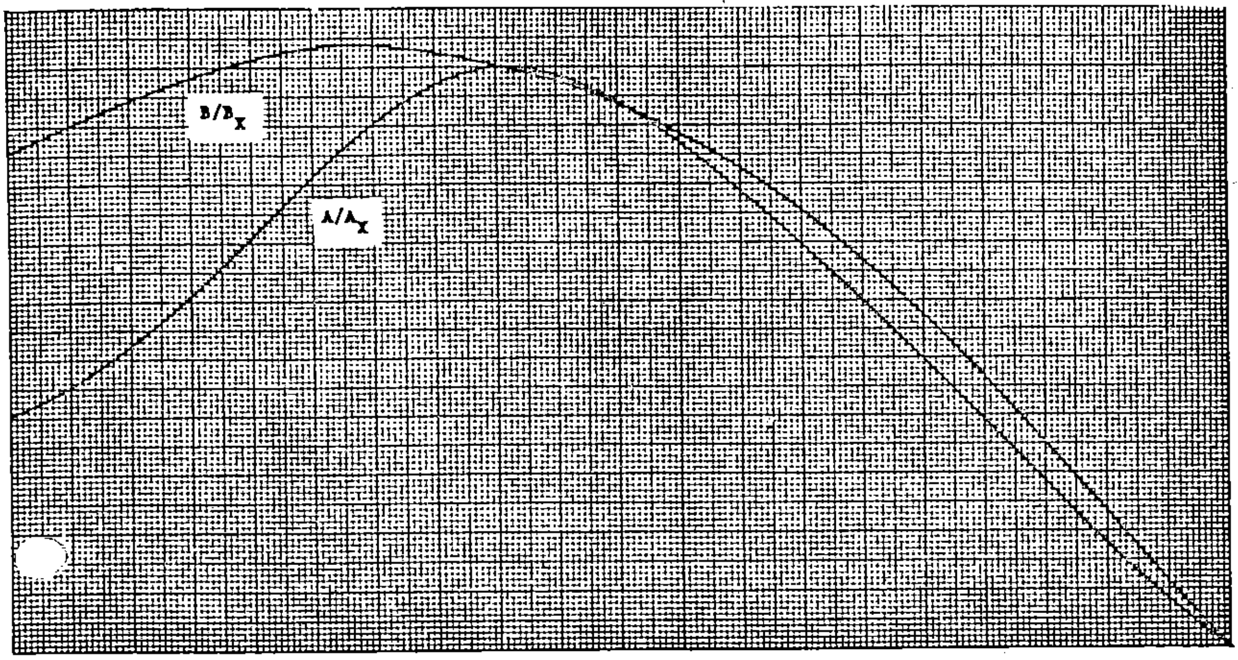
SHIP AND MODEL DATA
FOR
[illegible]
MODEL 4783-1

PPENDAGES: NONE

DIMENSIONS	SHIP	MODEL	L W L COEFFICIENTS			
ENGTH (LWL) ft		10.0	C_B	0.450	C_{WF}	0.541
ENGTH (LBP) ft		10.0	C_P	0.630	C_{WA}	0.981
EAM (B_X) ft		1.0	C_X	0.714	L_E/L	0.600
RAFT (H) in.		4.0	C_W	0.761	L_X/L	0
ISPL IN LBS (F.W.)		94.0	C_{PF}	0.518	L_P/L	0.400
VETTED SURF. SQ. FT.		10.38	C_{PA}	0.815	L/B	10.000
INES TMB P-522-4783-01			C_{PE}	0.568	B_X/H	3.000
CB/L_{WL} = 0.566 AFT OF F.P.			C_{PR}	0.710	$\Delta/(.01L)^3$	42.853
CF/L_{WL} = 0.601 AFT OF F.P.			C_{PV}	0.591	$S/\sqrt{\Delta L}$	15.825
.L ENTRANCE HALF ANGLE = 7.0			C_{PVA}	0.609	f	0
			C_{PVF}	0.522	t	1.227

Selection of Parameters

Because Series 64 is an exploratory series, it was decided that in the initial stages, a minimum number of models would be used; therefore, only a limited number of parameters could be studied. If the results of this



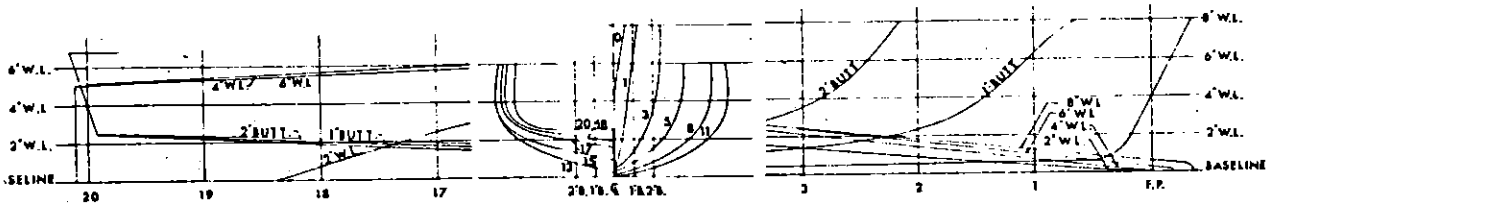
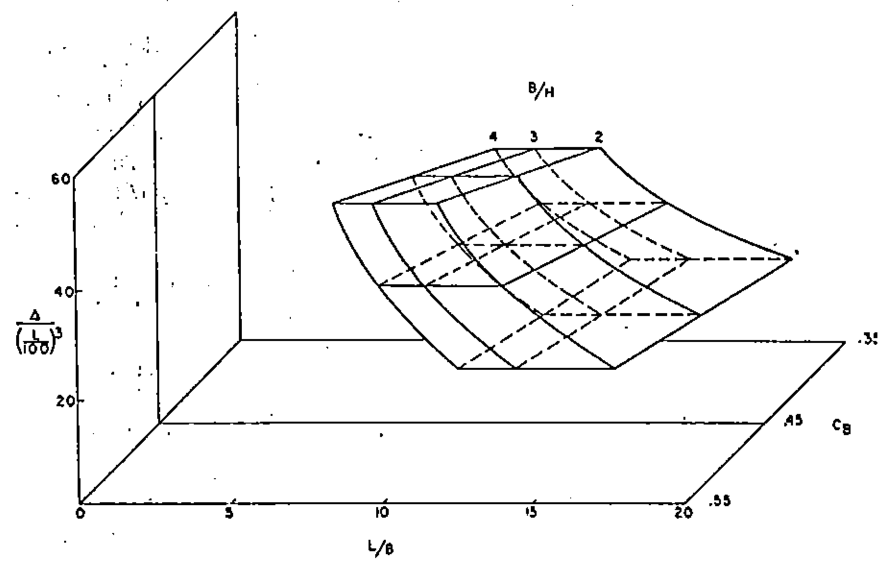


Fig. 1

Achtung: $\frac{\Delta}{(L:0,01)}$ gilt für Seewass



$$M = \frac{L}{\nabla^{1/3}} = \frac{100}{\sqrt[3]{\frac{\Delta}{(L\cdot 0{,}01)^3}\cdot 35{,}006}}$$

$$M = \frac{30{,}5695}{\sqrt[3]{\frac{\Delta}{L\cdot 0{,}01}}}$$

Fig. 2 Variation of Series 64 models

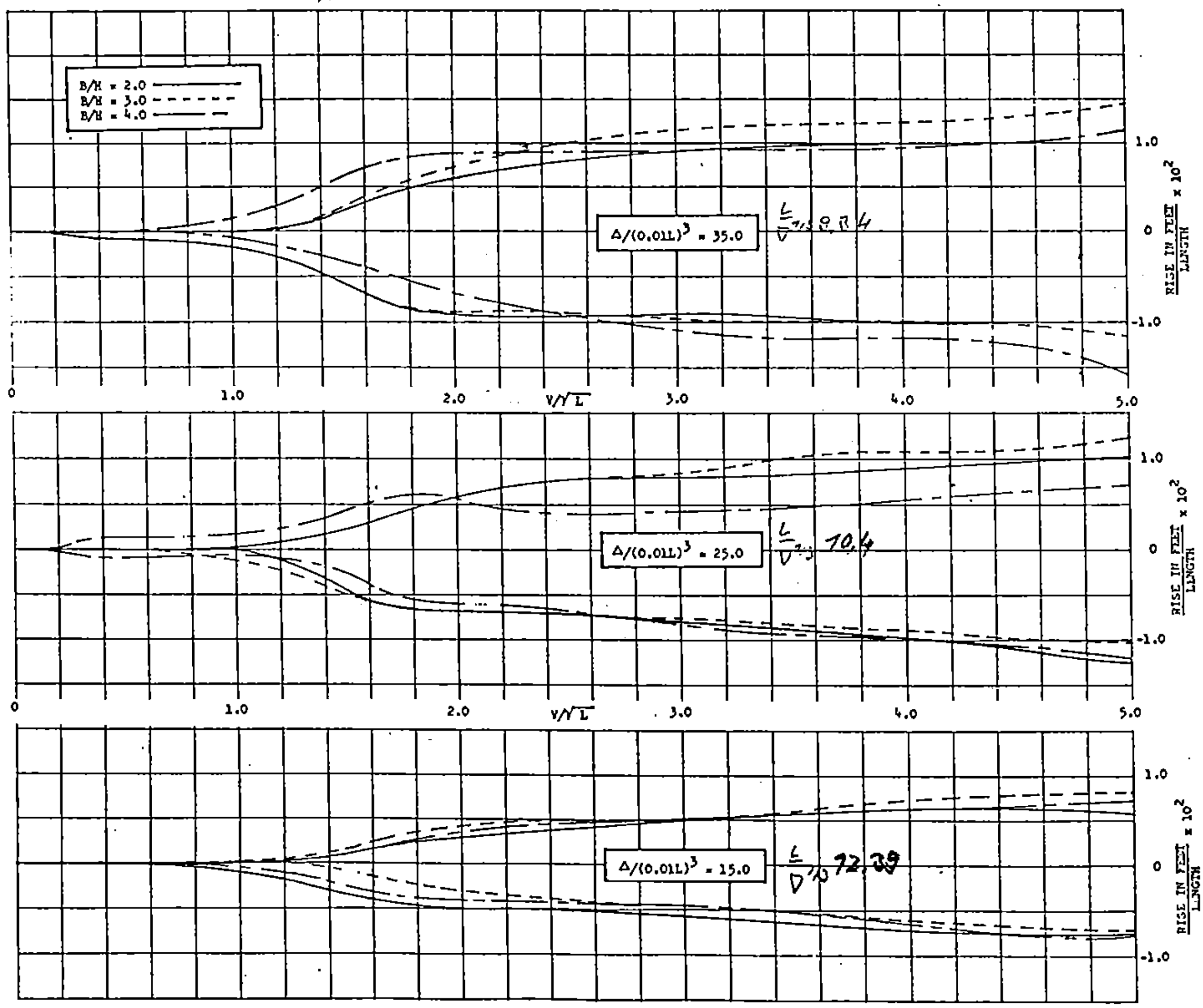


Fig. 3 Changes of bow and stern levels with speed for David Taylor Model Basin Series 64 models. Block coefficients of models are 0.35

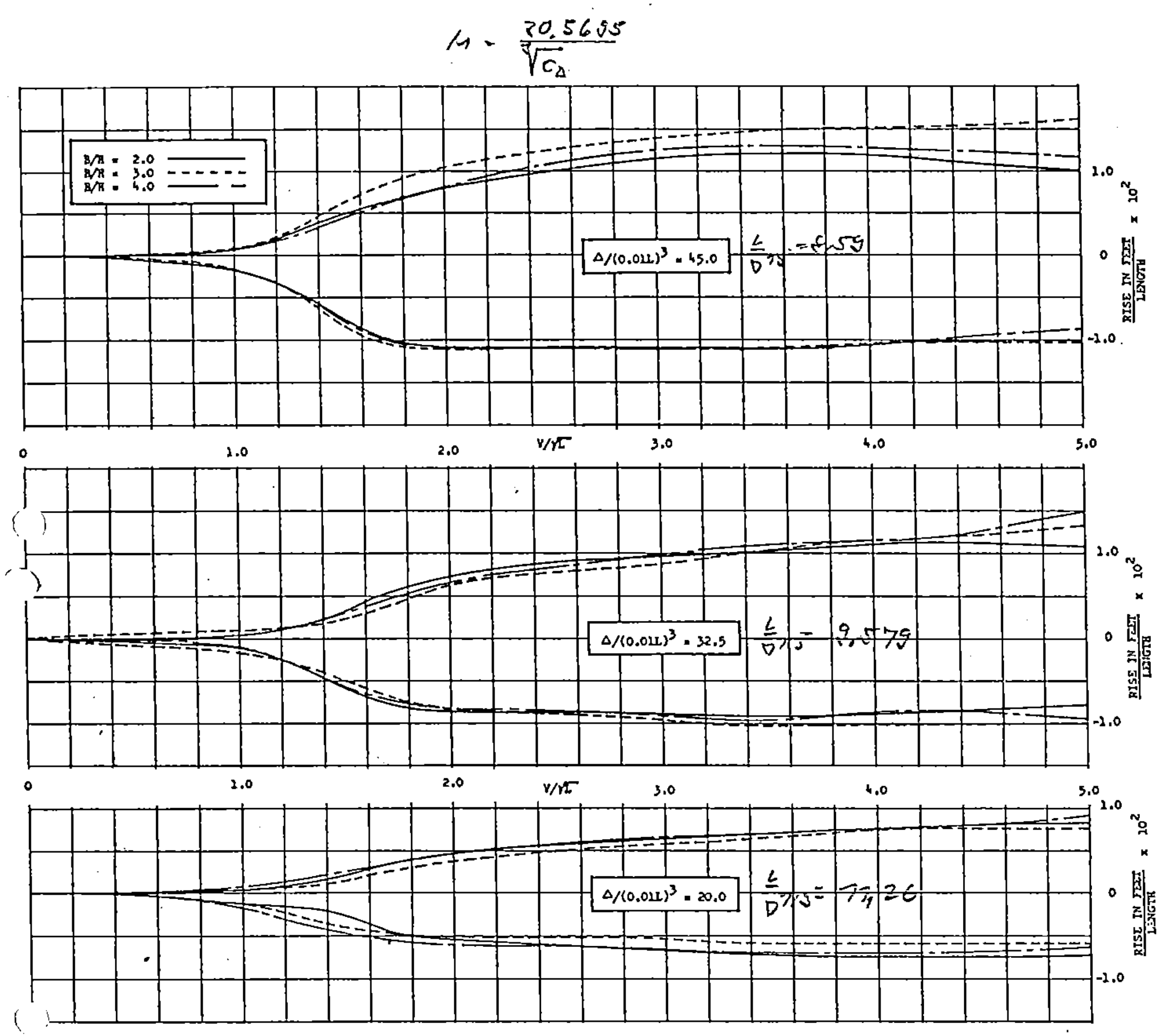


Fig. 4 Changes of bow and stern levels with speed for David Taylor Model Basin Series 64 models. Block coefficients of models are 0.45

study indicate that this is the correct approach, the series can be expanded by adding other parameters.

Three parameters, B/H, $\Delta/(0.01L)^3$, and C_B, were selected. Three models for each parameter may not adequately describe the effect of change of the parameter, but they should be enough to indicate the trend of the effect of the change. With this in view, the minimum number of 27 models was decided upon.

To include all basic dimensions with only three parameters, the choice naturally centered at block coefficient, C_B, longitudinal coefficient, C_P, maximum sectional area coefficient, C_X, beam-draft ratio, B/H, length-beam ratio L/B, and displacement-length ratio, $\Delta/(0.01L)^3$. Owing to the relationship of $C_X = C_B/C_P$, only two of these three parameters needed to be considered. Similarly, any ratio among $\Delta/(0.01L)^3$, B/H, and L/B could be expressed in terms of the other two ratios by the relationship of

$$\Delta/(0.01L)^3 = C_B/K(L/B)^2(B/H)$$

where $K = 34.977 \times 10^{-6}$.

Taylor's 'Speed and Power of Ships'' [1] indicates that the higher the speed-length ratio, the smaller the effect upon resistance of varying the longitudinal coefficient. Consequently, after careful examination of the contours of residuary resistance, in pounds per ton of displacement, the block coefficient C_B was selected as one of the parameters in preference to the longitudinal coefficient C_P. This selection, however, does not

$M = \frac{30,5685}{\sqrt[3]{C_\Delta}}$

Table 1 Model Data for Series 64 Models

$\frac{L}{\nabla^{1/3}}$	MODEL No.	C_B	C_X	$\frac{B}{H}$	$\frac{\Delta}{(0.01L)^3}$	L/B	B IN.	H IN.	A_X SQ. IN.	S SQ. FT.	$S/\sqrt{\Delta L}$	C_{PV}	C_{PVF}	C_{PVA}	$\frac{1}{2}\alpha_E$ DEG
8,04	4787	0.55	0.873	2	55	11.956	10.037	5.018	43.96	11.388	15.355	0.723	0.744	0.639	5.5
8,93	4788	0.55	0.873	2	40	14.020	8.559	4.280	31.98	9.711	15.355	0.723	0.744	0.639	4.7
10,45	4789	0.55	0.873	2	25	17.734	6.767	3.384	19.99	7.678	15.355	0.723	0.744	0.639	3.7
8,04	4790	0.55	0.873	3	55	9.762	12.292	4.097	43.96	11.503	15.510	0.723	0.744	0.639	6.7
8,93	4791	0.55	0.873	3	40	11.447	10.483	3.494	31.98	9.809	15.510	0.723	0.744	0.639	5.8
10,45	4792	0.55	0.873	3	25	14.479	8.288	2.763	19.99	7.755	15.510	0.723	0.744	0.639	4.5
8,04	4793	0.55	0.873	4	55	8.454	14.194	3.548	43.96	11.903	16.050	0.723	0.744	0.639	7.8
8,99	4794	0.55	0.873	4	40	9.914	12.104	3.026	31.98	10.151	16.050	0.723	0.744	0.639	6.6
10,45	4795	0.55	0.873	4	25	12.540	9.569	2.392	19.99	8.025	16.050	0.723	0.744	0.639	5.2
8,59	4796	0.45	0.714	2	45	11.956	10.037	5.018	35.97	10.411	15.520	0.591	0.609	0.522	5.5
9,57	4797	0.45	0.714	2	32.5	14.069	8.529	4.265	25.98	8.848	15.520	0.591	0.609	0.522	4.7
11,26	4798	0.45	0.714	2	20	17.934	6.691	3.346	15.99	6.941	15.520	0.591	0.609	0.522	3.7
8,59	4799	0.45	0.714	3	45	9.762	12.292	4.097	35.97	10.616	15.825	0.591	0.609	0.522	6.7
9,57	4800	0.45	0.714	3	32.5	11.487	10.446	3.482	25.98	9.022	15.825	0.591	0.609	0.522	5.8
11,26	4801	0.45	0.714	3	20	14.643	8.195	2.732	15.99	7.077	15.825	0.591	0.609	0.522	4.5
8,59	4802	0.45	0.714	4	45	8.454	14.194	3.548	35.97	11.109	16.561	0.591	0.609	0.522	7.8
9,58	4803	0.45	0.714	4	32.5	9.948	12.062	3.016	25.98	9.441	16.561	0.591	0.609	0.522	6.6
11,26	4804	0.45	0.714	4	20	12.682	9.462	2.366	15.99	7.406	16.561	0.591	0.609	0.522	5.2
9,34	4805	0.35	0.556	2	35	11.956	10.037	5.018	27.98	9.907	16.746	0.460	0.475	0.407	5.5
10,4	4806	0.35	0.556	2	25	14.146	8.483	4.242	19.99	8.373	16.746	0.460	0.475	0.407	4.7
12,39	4807	0.35	0.556	2	15	18.264	6.570	3.285	11.99	6.486	16.746	0.460	0.475	0.407	3.7
9,34	4808	0.35	0.556	3	35	9.762	12.292	4.097	27.98	10.089	17.053	0.460	0.475	0.407	6.7
10,4	4809	0.35	0.556	3	25	11.551	10.389	3.463	19.99	8.526	17.053	0.460	0.475	0.407	5.8
12,39	4810	0.35	0.556	3	15	14.913	8.047	2.682	11.99	6.604	17.053	0.460	0.475	0.407	4.5
9,34	4811	0.35	0.556	4	35	8.454	14.194	3.548	27.98	10.644	17.992	0.460	0.475	0.407	7.8
10,4	4812	0.35	0.556	4	25	10.004	11.996	2.999	19.99	8.996	17.992	0.460	0.475	0.407	6.6
12,39	4813	0.35	0.556	4	15	12.915	9.292	2.323	11.99	6.968	17.992	0.460	0.475	0.407	5.2

L = 10'0" $L_E / L = 0.60$ $L_R / L = 0.40$ LCF/LWL = 0.601 AFT F.P. LCB/LWL = 0.5656 AFT F.P.

$C_P = 0.63$ $C_{PF} = 0.518$ $C_{PA} = 0.815$ $C_{PE} = 0.568$ $C_{PR} = 0.710$

$C_W = 0.761$ $C_{WF} = 0.541$ $C_{WA} = 0.981$ f = 0 t = 1.227

preclude the use of the longitudinal coefficient as a variable in future investigations.

From the same contours, the minimum residuary resistance tends to move toward the higher longitudinal coefficients as the speed increases. Since the parent model has a longitudinal coefficient of 0.63, and it appears to be in good agreement with that indicated by the Taylor contours, the value of 0.63 was used throughout the series. This, of course, does not mean this value of 0.63 was an optimum value of longitudinal coefficient for this type of hull form. With constant C_P and selected C_B, C_X will be fixed automatically.

Since displacement is an excellent indicator of payload, $\Delta/(0.01L)^3$ was chosen as one parameter. Also, because naval architects were accustomed to seeing B/H in all previous contours, the natural selection was B/H in preference to L/B.

Range of Parameters

In the data of existing models, which were compiled in the search for the hull form to be used as the parent model for high-speed, displacement surface ships, the block coefficients varied considerably. The values of 0.35 to 0.55, however, covered most of the ships; therefore, block coefficients of 0.35, 0.45 and 0.55 were selected. Based on the same compilation, the beam-draft ratios of 2, 3 and 4 also were established.

In the development of a reasonably good hull form

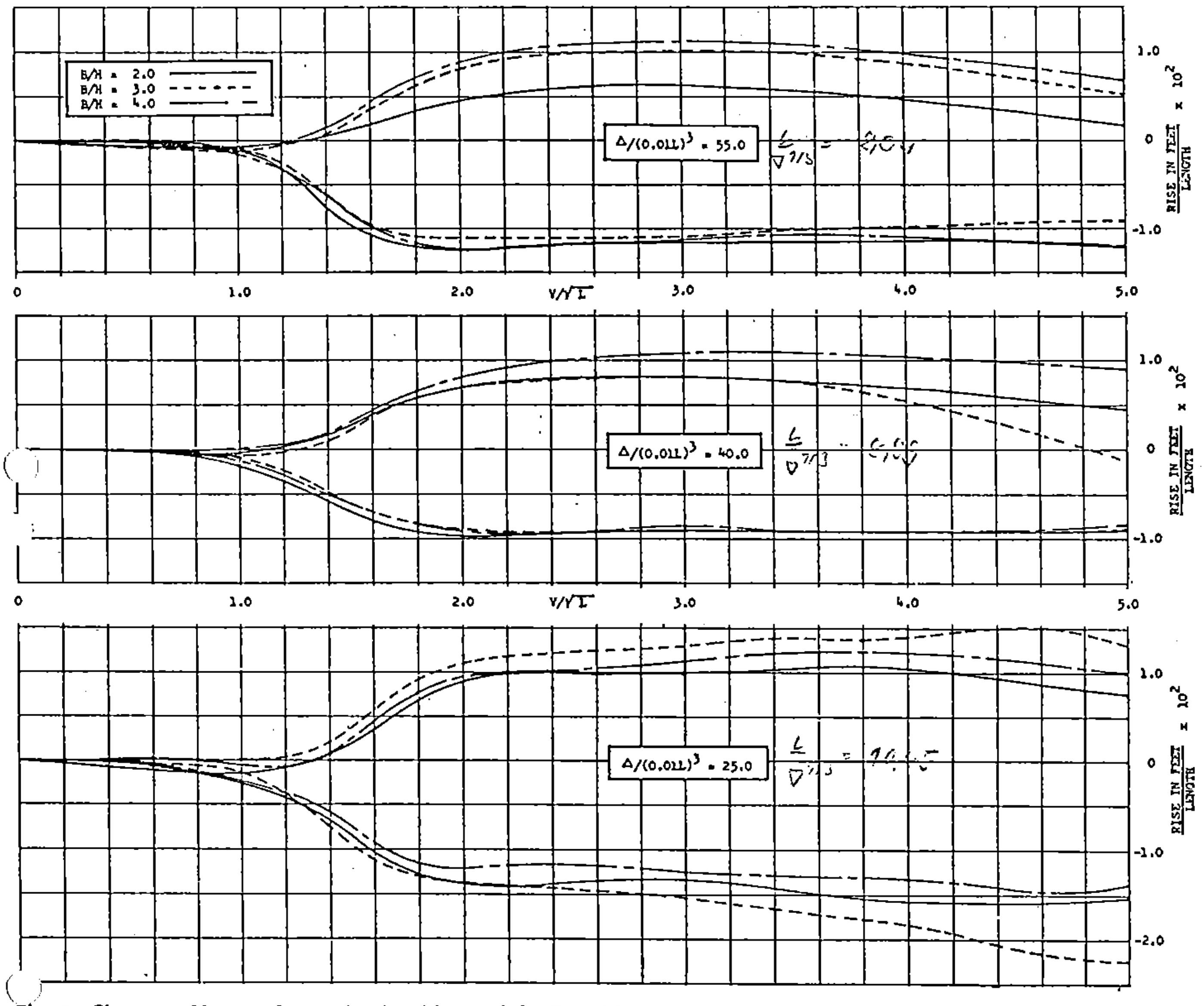


Fig. 5 Changes of bow and stern levels with speed for David Taylor Model Basin Series 64 models. Block coefficients of models are 0.55

with high-speed performance characteristics, it was not possible to obtain a set of displacement-length ratios applicable to all three block-coefficient models. However, it was possible to select values for each block-coefficient model so that the effects of changing displacement-length ratio overlapped as the block coefficients varied. The total range of displacement-length ratios is from 15.0 to 55.0 with the smallest values applicable to the lowest block-coefficient models.

The maximum section-area coefficients for each block-coefficient model were determined by the following relationship:

$$C_X = C_B/C_P$$

Since $C_P = 0.63$, C_X became 0.873, 0.714 and 0.556 for block-coefficient models of 0.55, 0.45 and 0.35, respectively.

The grid in Fig. 2 shows the relationship of each model to other models in the series.

Characteristics of Series 64 Models

The Series 64 models have fine entrance angles; half-angles of entrance ($\frac{1}{2}\alpha_e$) amount to 3.7 to 7.8 deg. There is no sharp curvature at the shoulder, and the maximum beam does not occur until Station 14 and then it reduces gradually to Station 20.

The stems are sloped downward and aft, the angle between FP and stem is in the order of 25 to 30 deg, with forefoot cut away.

Owing to the wide range of C_X, the shape of the sec-

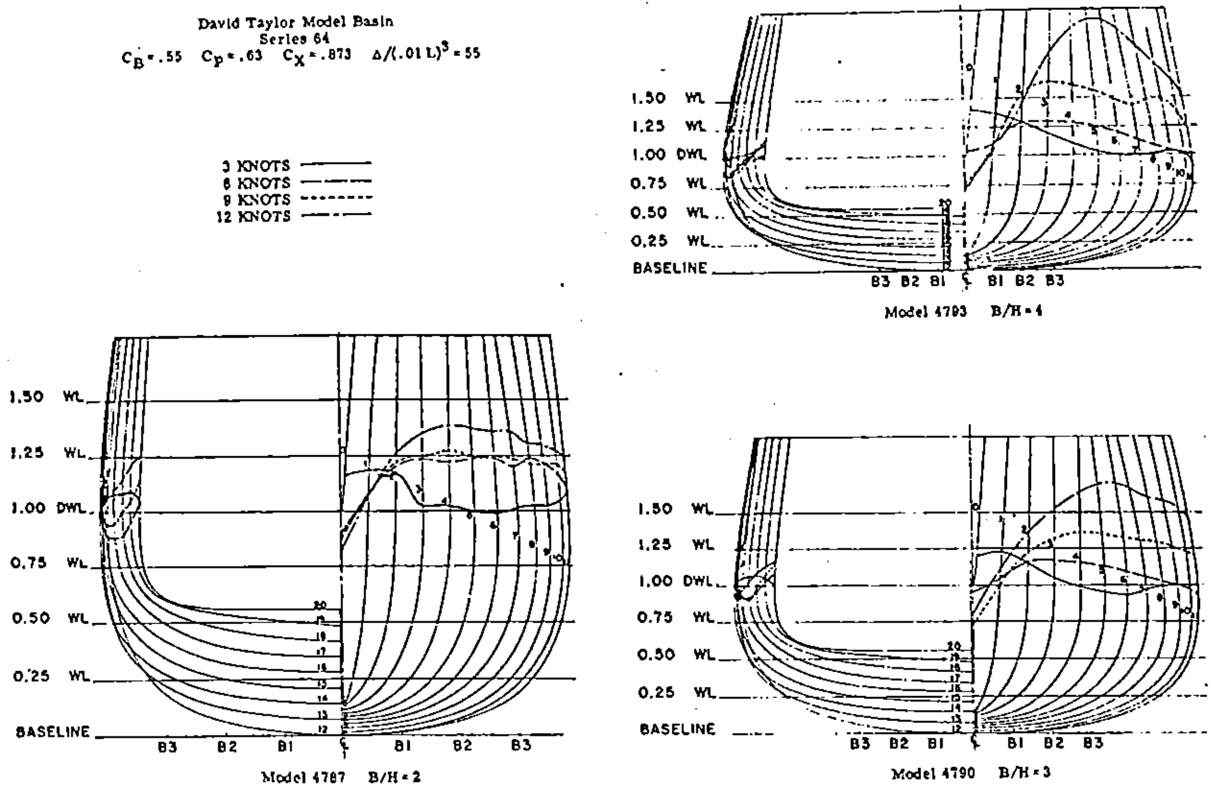


Fig. 6

Figs. 6–14 Body plans and wave profiles

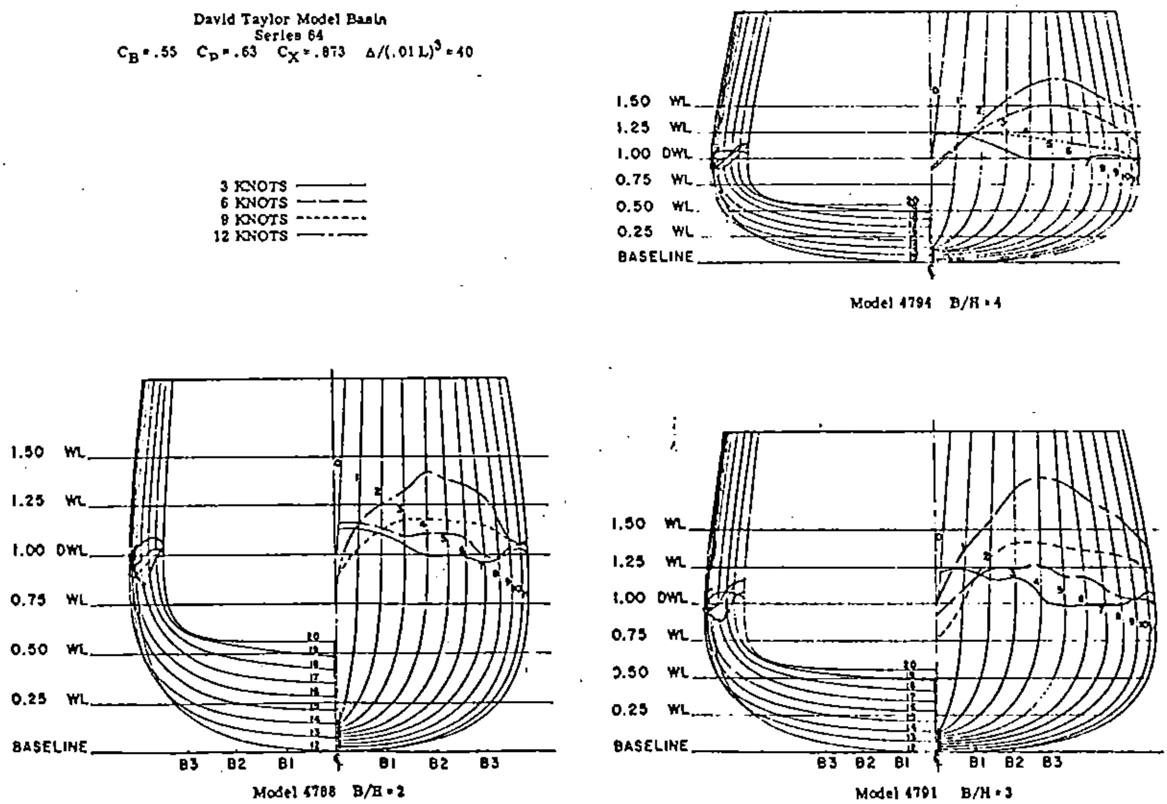


Fig. 7

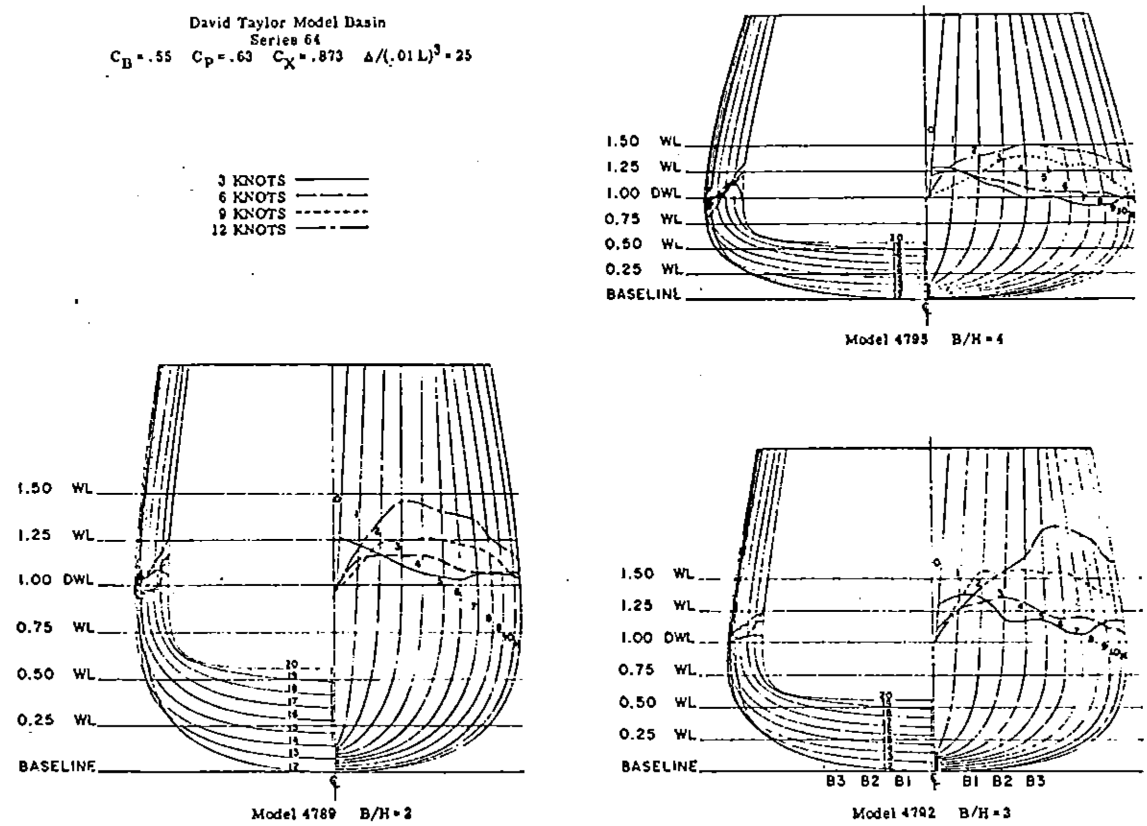

David Taylor Model Basin
Series 64
C_B = .55 C_P = .63 C_X = .873 Δ/(.01 L)^3 = 25
3 KNOTS
6 KNOTS
9 KNOTS
12 KNOTS
1.50 WL
1.25 WL
1.00 DWL
0.75 WL
0.50 WL
0.25 WL
BASELINE
Model 4795 B/H = 4
Model 4789 B/H = 2
B3 B2 B1 ℄ B1 B2 B3
Model 4792 B/H = 3

Fig. 8

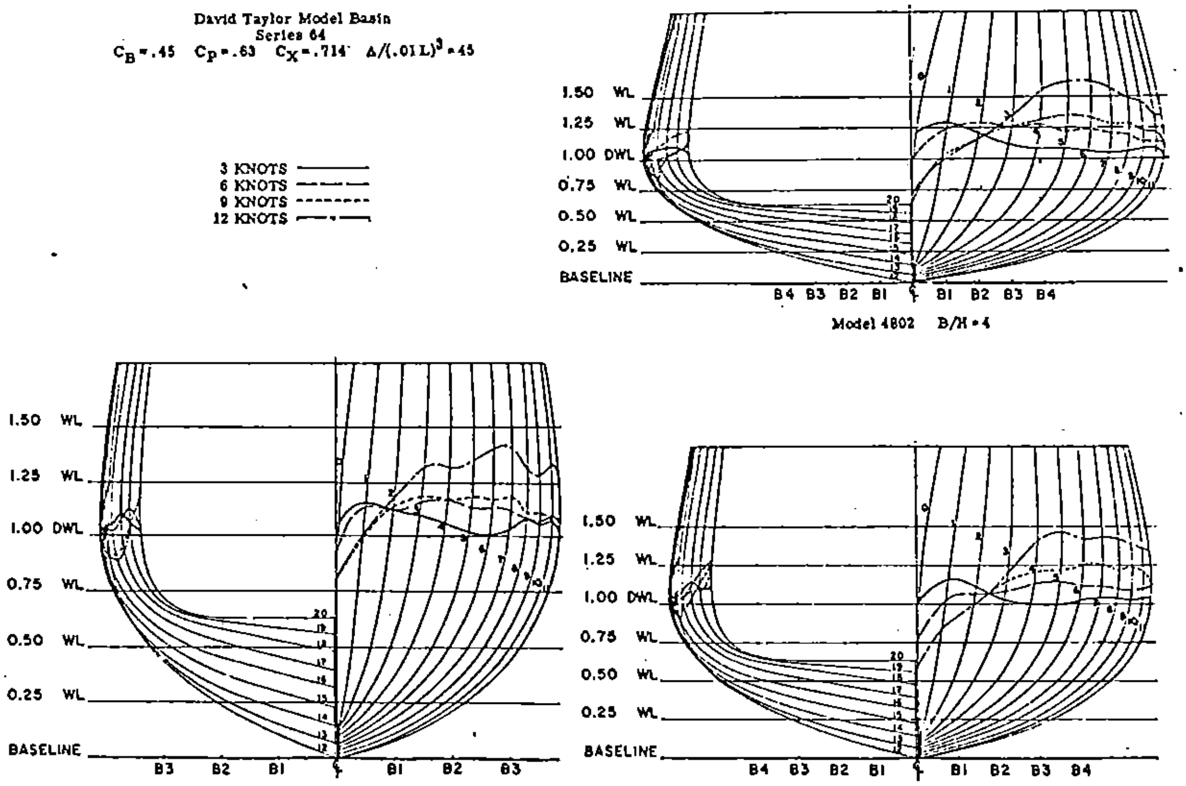

David Taylor Model Basin
Series 64
C_B = .45 C_P = .63 C_X = .714 Δ/(.01 L)^3 = 45
3 KNOTS
6 KNOTS
9 KNOTS
12 KNOTS
1.50 WL
1.25 WL
1.00 DWL
0.75 WL
0.50 WL
0.25 WL
BASELINE
B4 B3 B2 B1 ℄ B1 B2 B3 B4
Model 4802 B/H = 4
B3 B2 B1 ℄ B1 B2 B3
Model 4796 B/H = 2
B4 B3 B2 B1 ℄ B1 B2 B3 B4
Model 4799 B/H = 3

Fig. 9

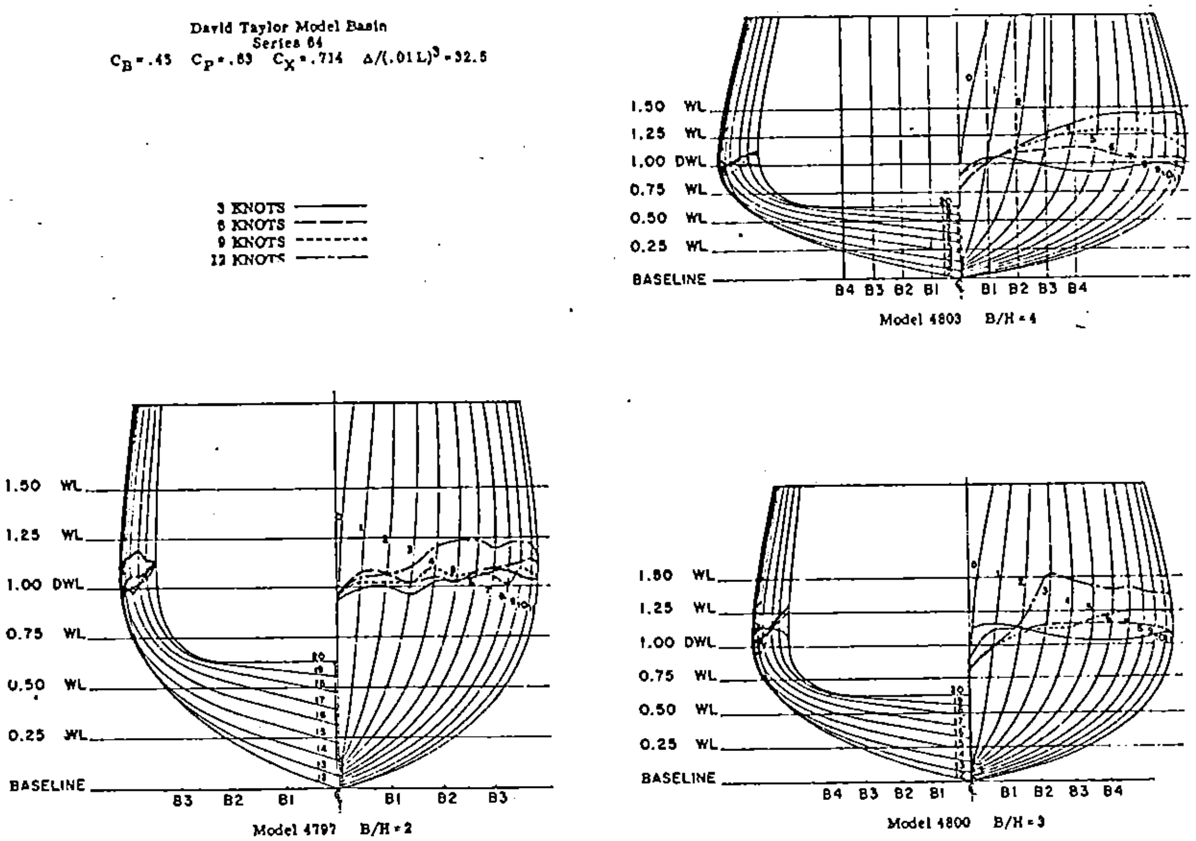

David Taylor Model Basin
Series 64
C_B = .45 C_P = .63 C_X = .714 Δ/(.01 L)³ = 32.5
3 KNOTS
6 KNOTS
9 KNOTS
12 KNOTS
1.50 WL
1.25 WL
1.00 DWL
0.75 WL
0.50 WL
0.25 WL
BASELINE
B4 B3 B2 B1 ℄ B1 B2 B3 B4
Model 4803 B/H = 4
B3 B2 B1 ℄ B1 B2 B3
Model 4797 B/H = 2
Model 4800 B/H = 3

Fig. 10

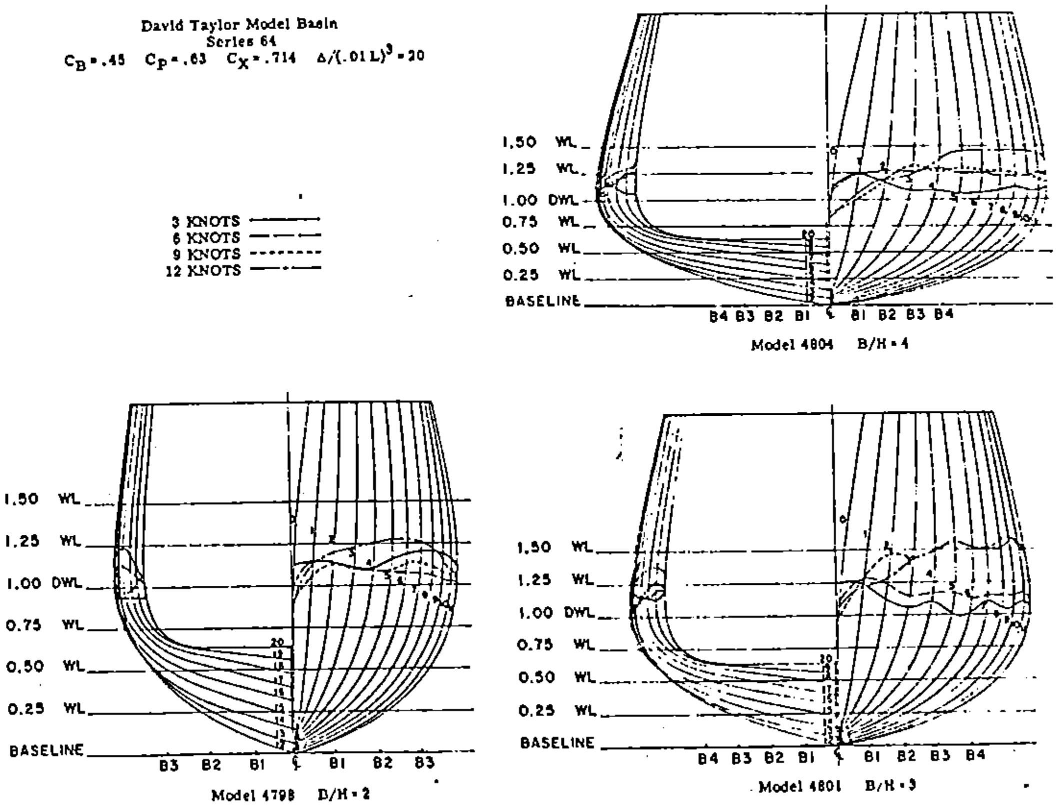

David Taylor Model Basin
Series 64
C_B = .45 C_P = .63 C_X = .714 Δ/(.01 L)³ = 20
3 KNOTS
6 KNOTS
9 KNOTS
12 KNOTS
1.50 WL
1.25 WL
1.00 DWL
0.75 WL
0.50 WL
0.25 WL
BASELINE
B4 B3 B2 B1 ℄ B1 B2 B3 B4
Model 4804 B/H = 4
B3 B2 B1 ℄ B1 B2 B3
Model 4798 B/H = 2
Model 4801 B/H = 3

Fig. 11

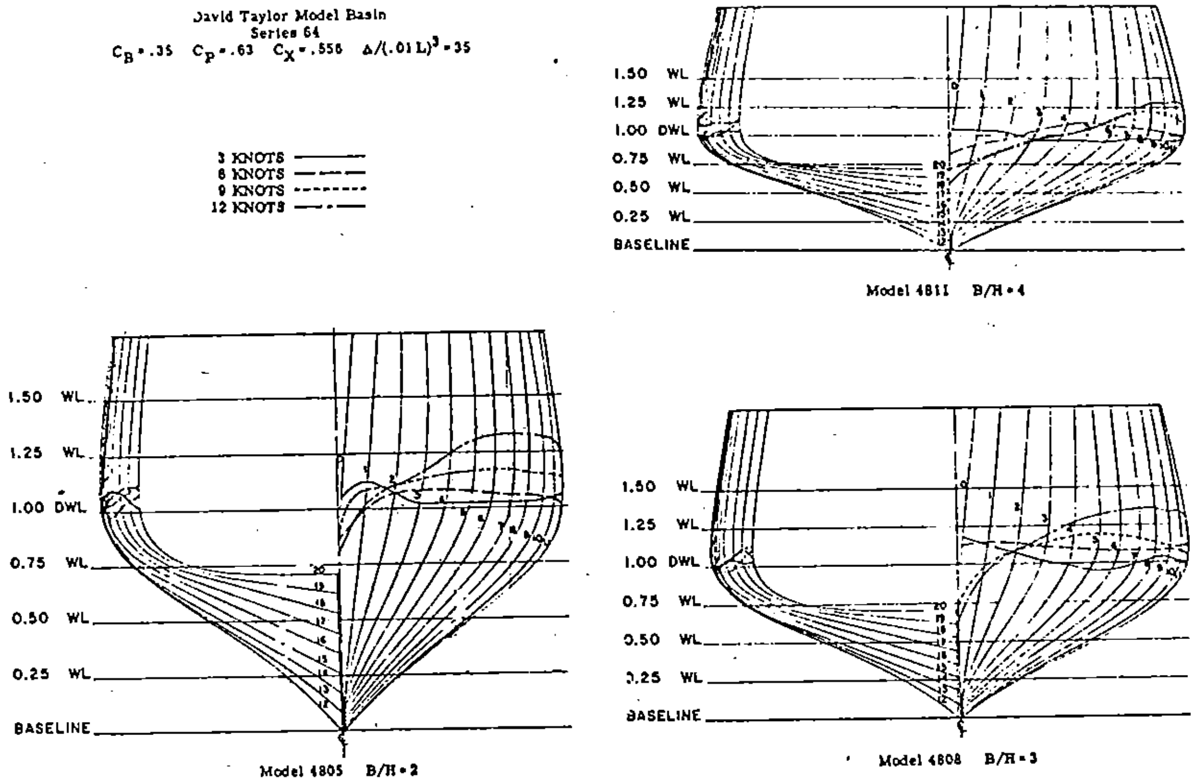

David Taylor Model Basin
Series 64
$C_B = .35$ $C_P = .63$ $C_X = .556$ $\Delta/(.01L)^3 = 35$
3 KNOTS
6 KNOTS
9 KNOTS
12 KNOTS
1.50 WL
1.25 WL
1.00 DWL
0.75 WL
0.50 WL
0.25 WL
BASELINE
Model 4811 B/H = 4
Model 4805 B/H = 2
Model 4808 B/H = 3

Fig. 12

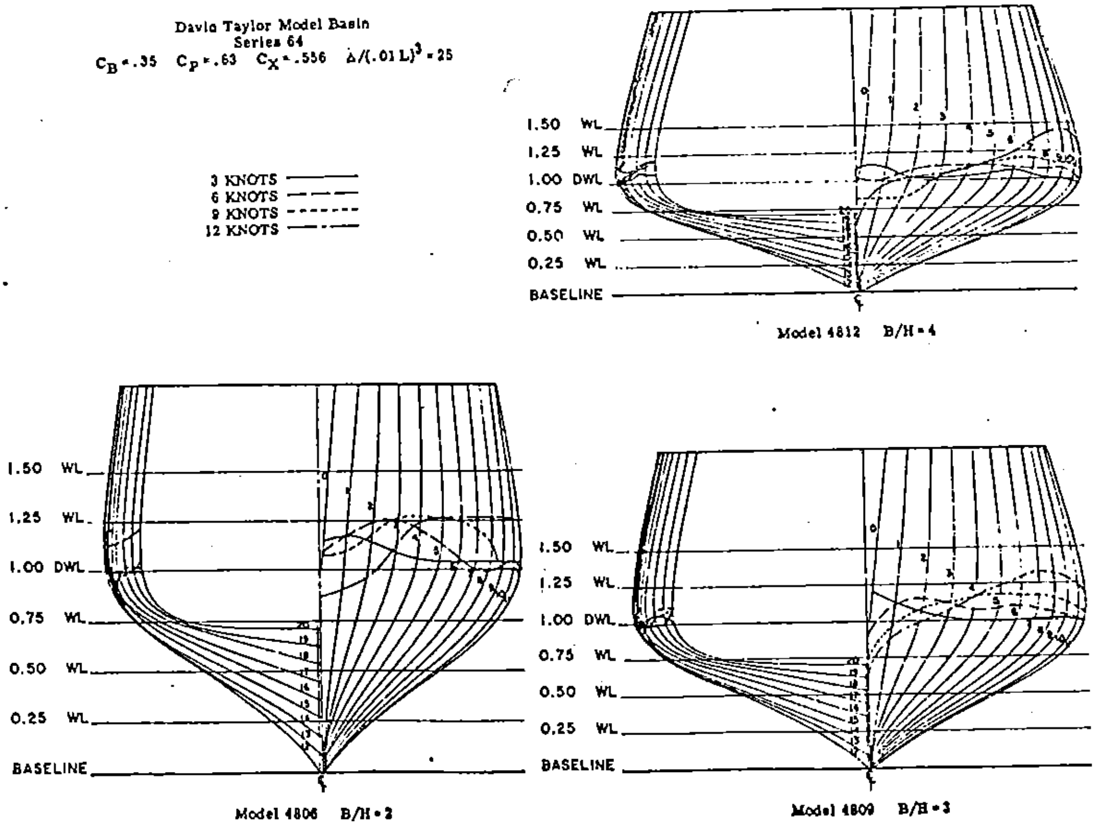

David Taylor Model Basin
Series 64
$C_B = .35$ $C_P = .63$ $C_X = .556$ $\Delta/(.01L)^3 = 25$
3 KNOTS
6 KNOTS
9 KNOTS
12 KNOTS
1.50 WL
1.25 WL
1.00 DWL
0.75 WL
0.50 WL
0.25 WL
BASELINE
Model 4812 B/H = 4
Model 4806 B/H = 2
Model 4809 B/H = 3

Fig. 13

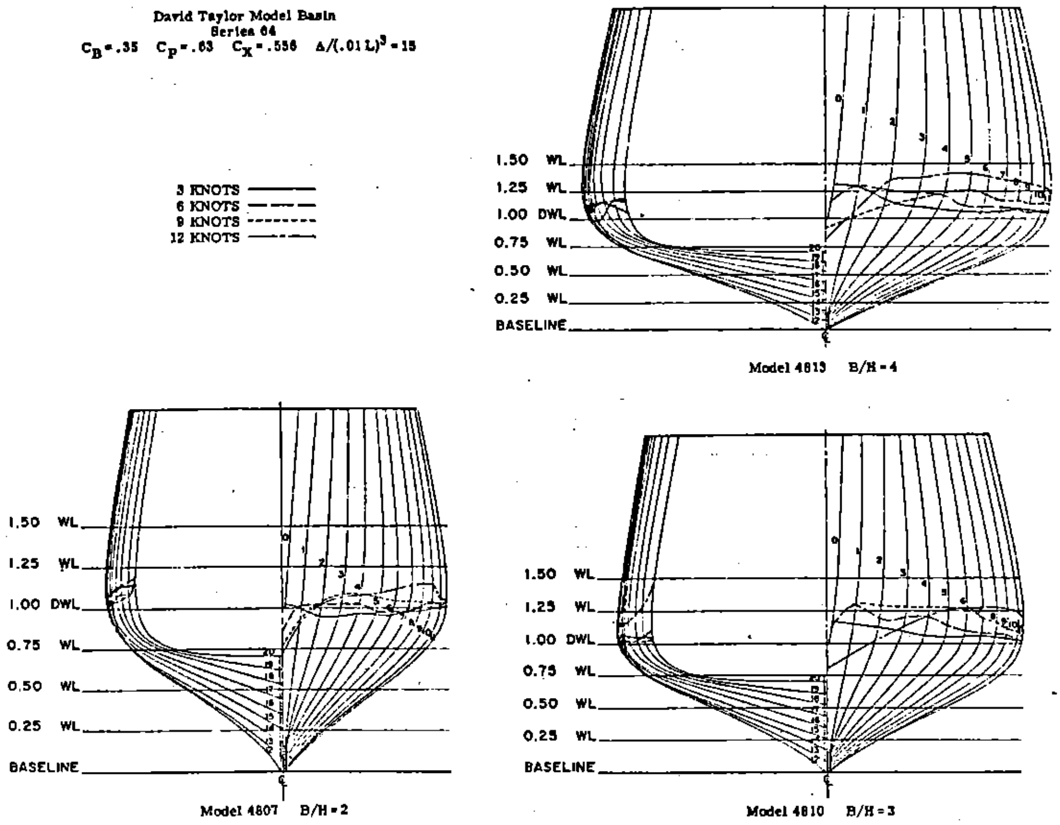


Fig. 14

tions varies from extreme U to extreme V, with no sharp bilge radius in either case. None of the models has parallel middlebodies, but they all have maximum section located at Station 12.

The stern is wide and flat below the design waterline, the buttocks are straight lines at the afterbody, and the transom is immersed with sharp cutoff at the end.

The sectional area (A/A_X), dimensionless beam (B/B_X), and centerline profile contours (H/H_X) are kept the same for all models and, therefore, the locations of longitudinal center of buoyancy, LCB, and longitudinal center of flotation, LCF, are the same for all models.

Data for all models are given in Table 1; all coefficients used are defined as in reference [6].

Resistance Tests of Series 64 Models

All models were made of wood and were 10 ft long at the design waterline. Tests were conducted by towing the models at the center of flotation in the DTMB deep-water basin, which has a cross section 51.0 ft wide and 22.0 ft deep. Models were free to pitch, heave, and roll but were restricted in yaw. When tests were conducted in calm water, resistance was measured by using towing dynamometers as described in [7], with model speeds ranging from 1.0 to 16.0 knots.

As a result of past experiences with models of this type of hull form, experiments were conducted without turbulence simulation.

Change of level at forward and aft perpendiculars was measured during the tests and results are given as percentages of length in Figs. 3 to 5. It should be noted that all models, both bow and stern, settled at low speeds, $V/\sqrt{L}$ below 1.2, the bow more so than the stern. After the speed-length ratio of 1.2 was reached, the bow began to climb and the stern began to settle more and more rapidly until about the speed-length ratio of 2.0, then they held at more or less the same position for the remainder of the speeds tested.

Wave profiles at model speeds of 3, 6, 9 and 12 knots, corresponding to speed-length ratios of 0.95, 1.90, 2.85 and 3.80, were recorded and traced on body plans, Figs. 6 through 14. Notice that at a corresponding speed the wave height reduces as the $\Delta/(0.01L)^3$ reduces.

Resistance test results were reduced to residuary resistance in pounds per ton of displacement R_r/Δ, using the Schoenherr formulation.

Only the data obtained from speed-length ratios of 1.0 to 5.0 are given as contours of R_r/Δ against displacement-length ratio at 0.20 speed-length ratio intervals in Figs. 15 through 23; those values of $V/\sqrt{L}$ between 0.20 and 0.80 are included in Tables 2 through 4.

The test results are also shown in Figs. 24 through 26 as C_r to a base of speed-length ratio; those values of $V/\sqrt{L}$ between 0.20 and 0.80 are included in Tables 5 through 7. Above a speed-length ratio of 3.0, they were also plotted as C_r'' against a speed-length ratio, where

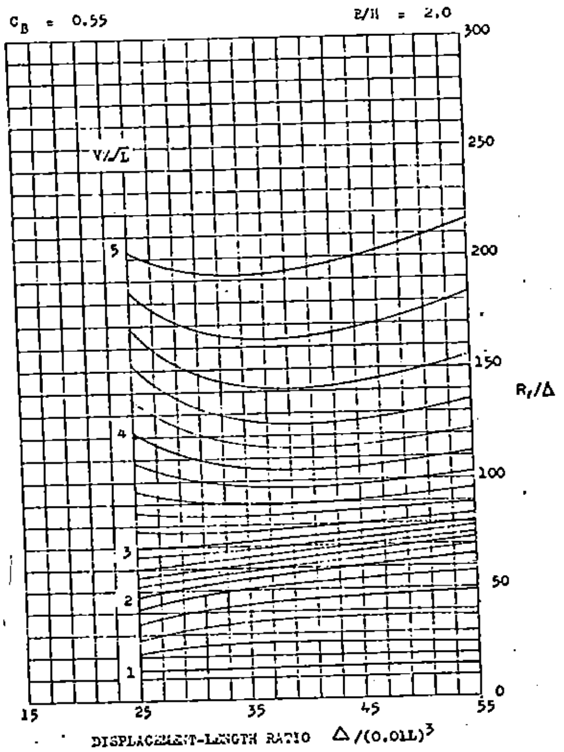


Fig. 15

Figs. 15–23 Contours of resistance in pounds per ton of displacement

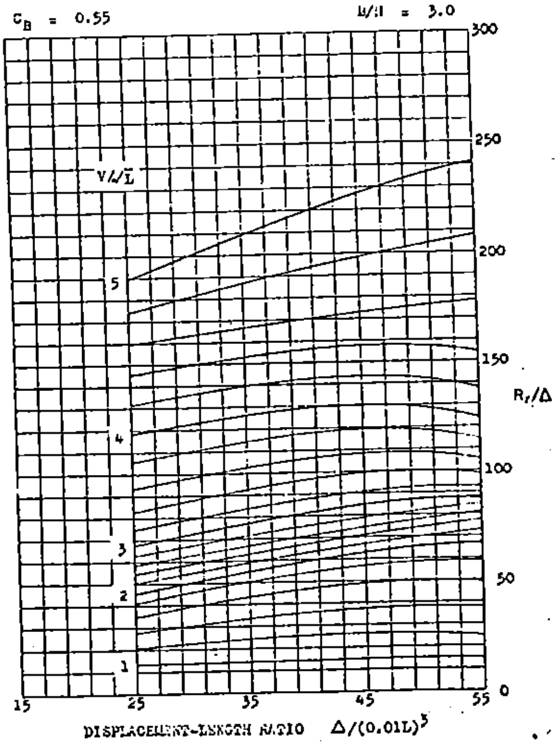


Fig. 16

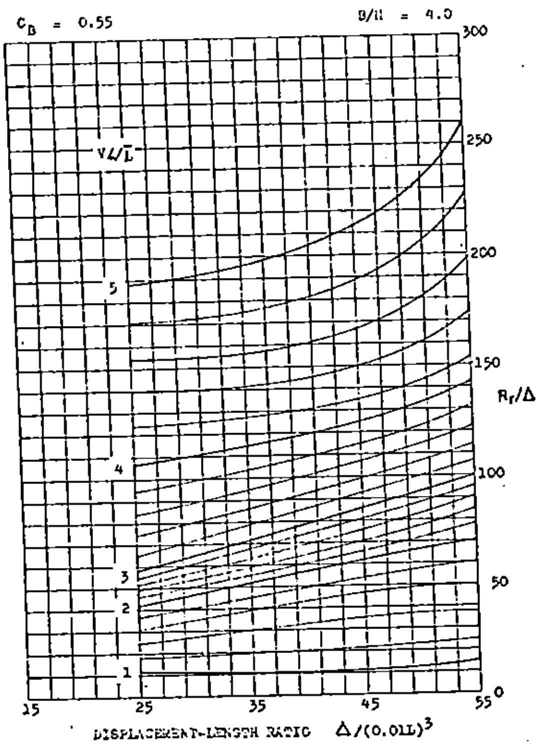


Fig. 17

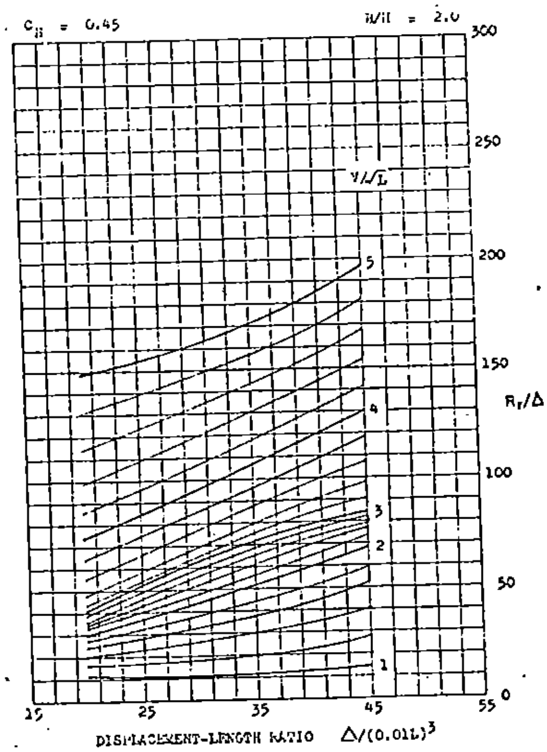


Fig. 18

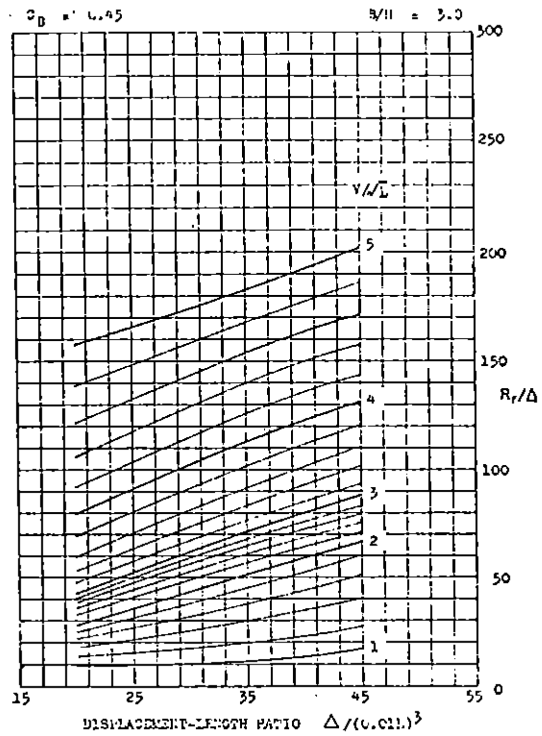


Fig. 19

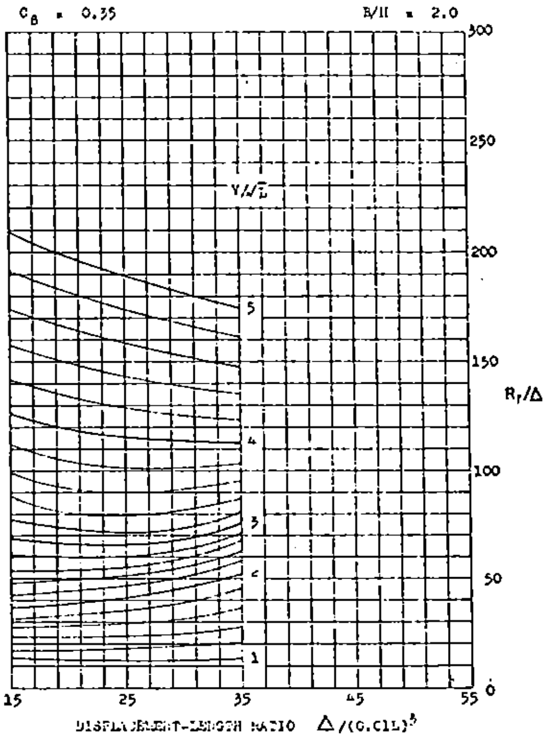


Fig. 21

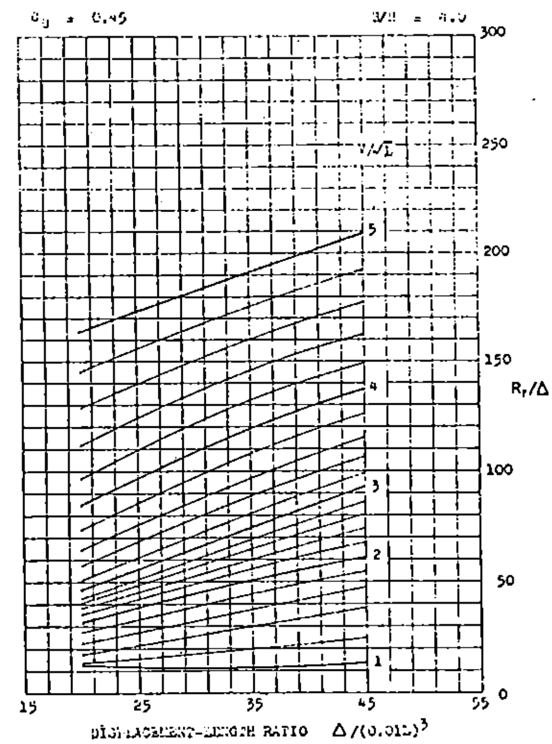


Fig. 20

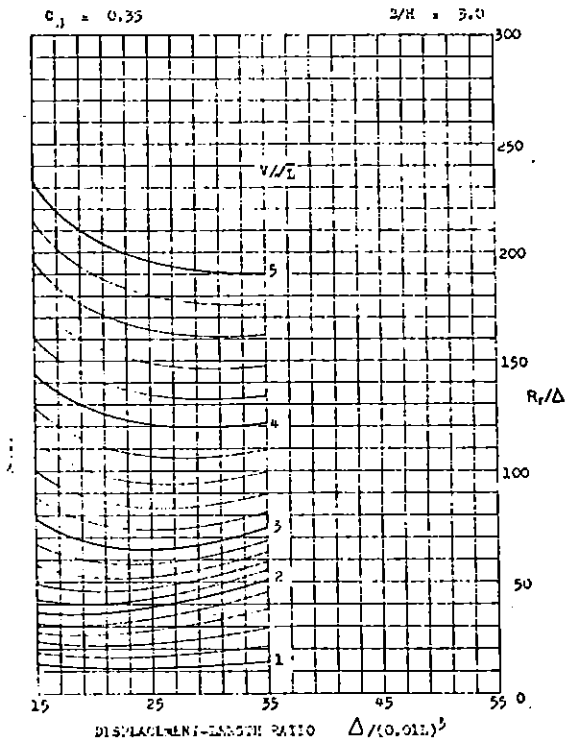


Fig. 22

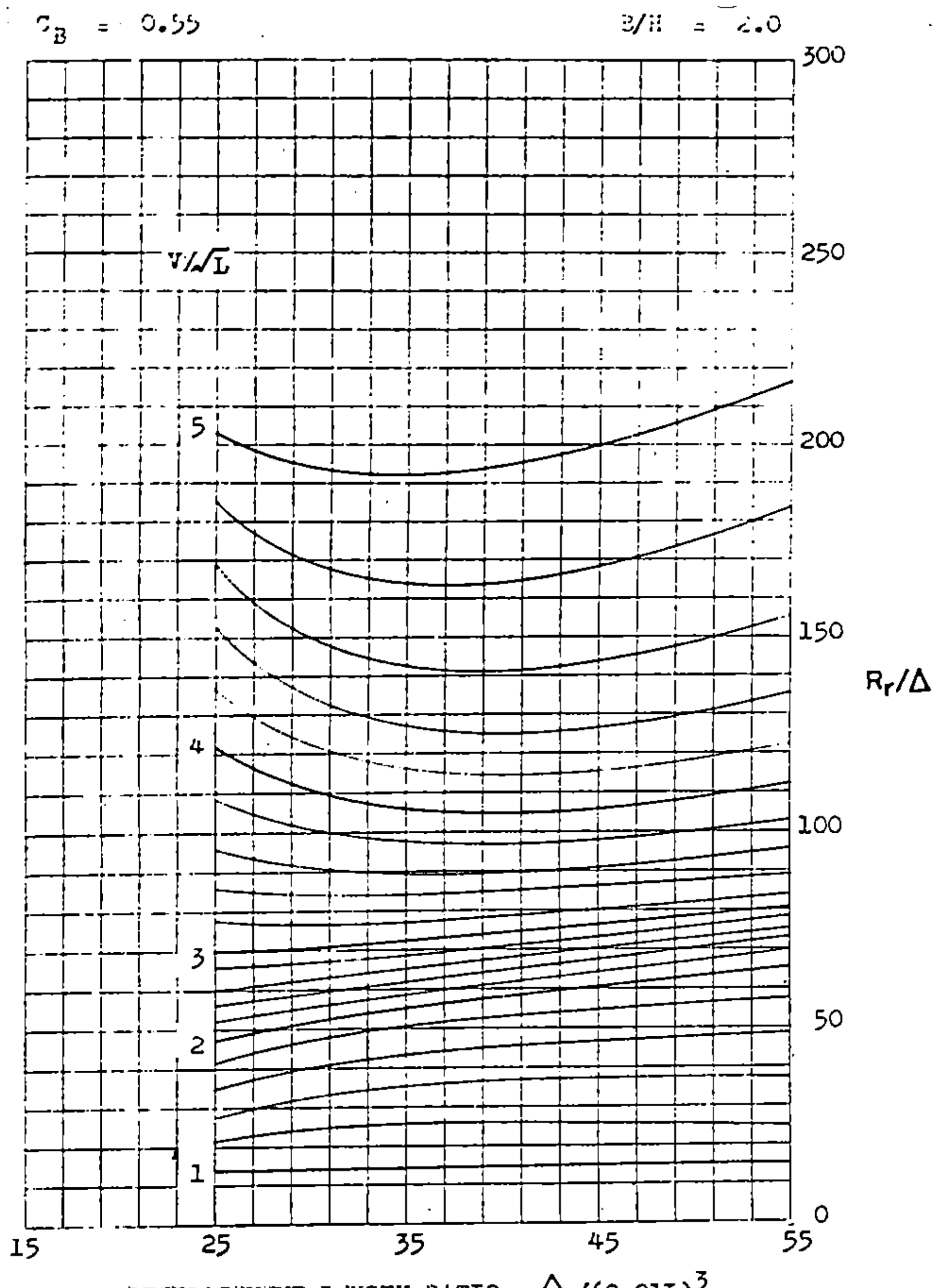


Fig. 15

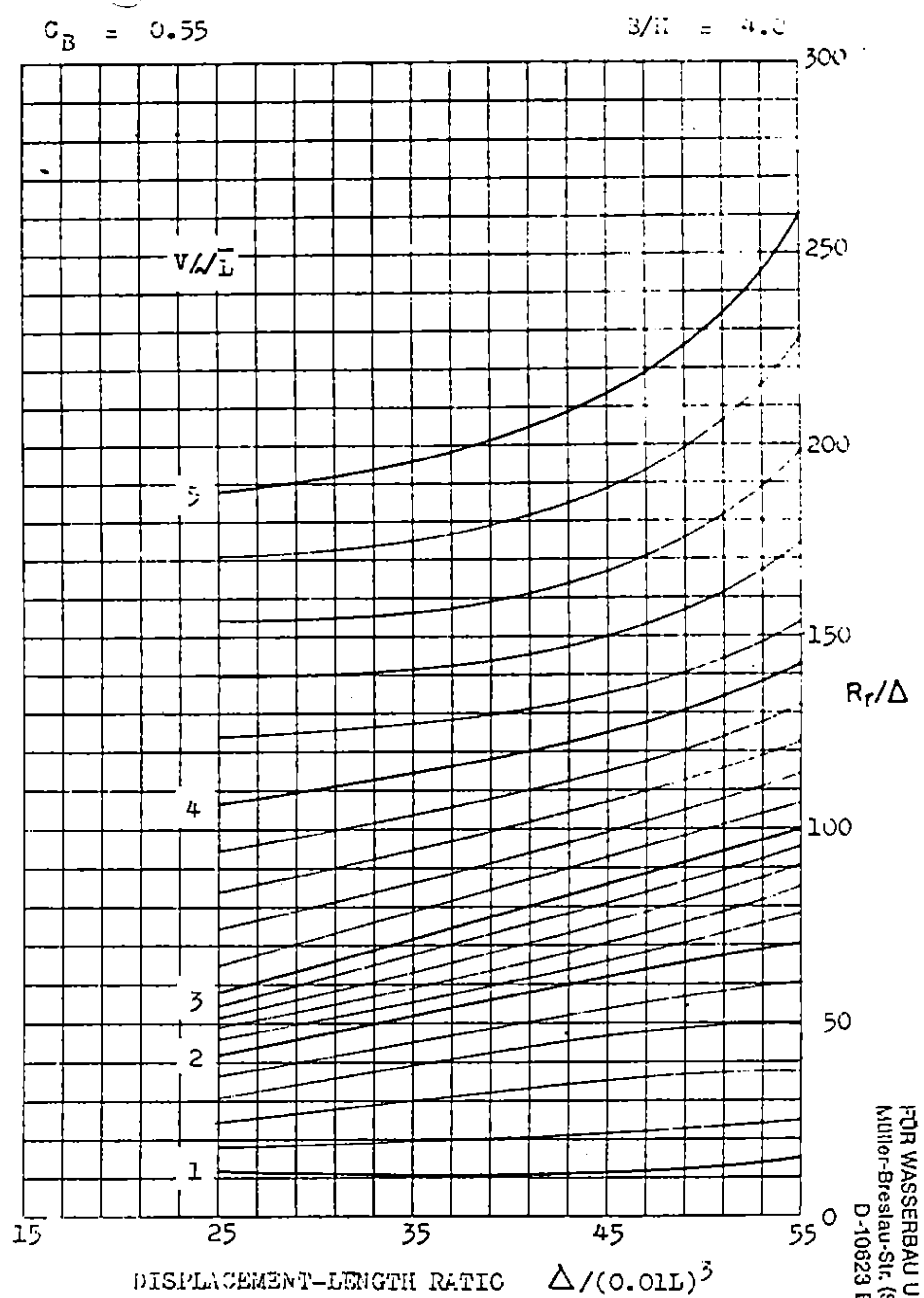
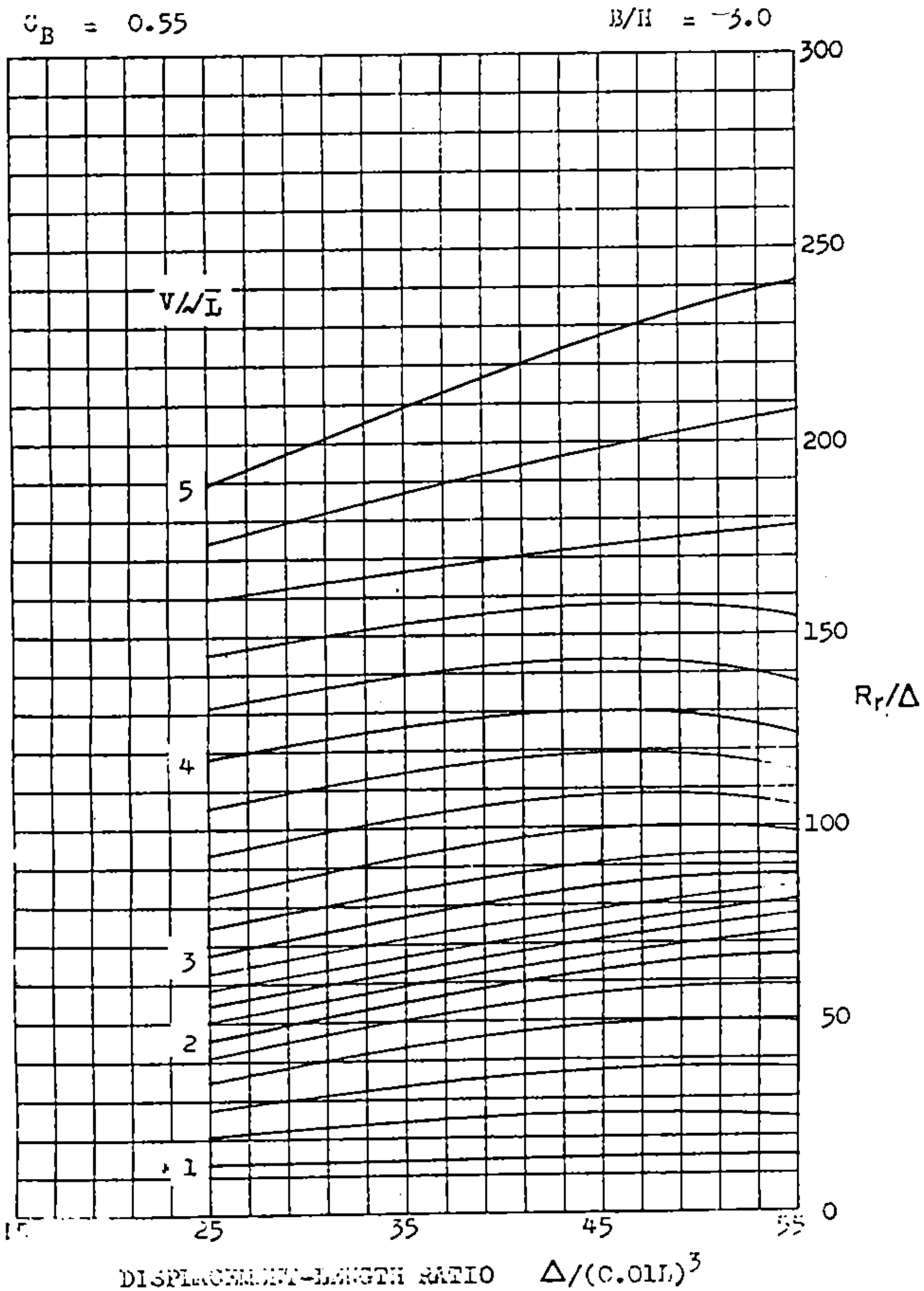


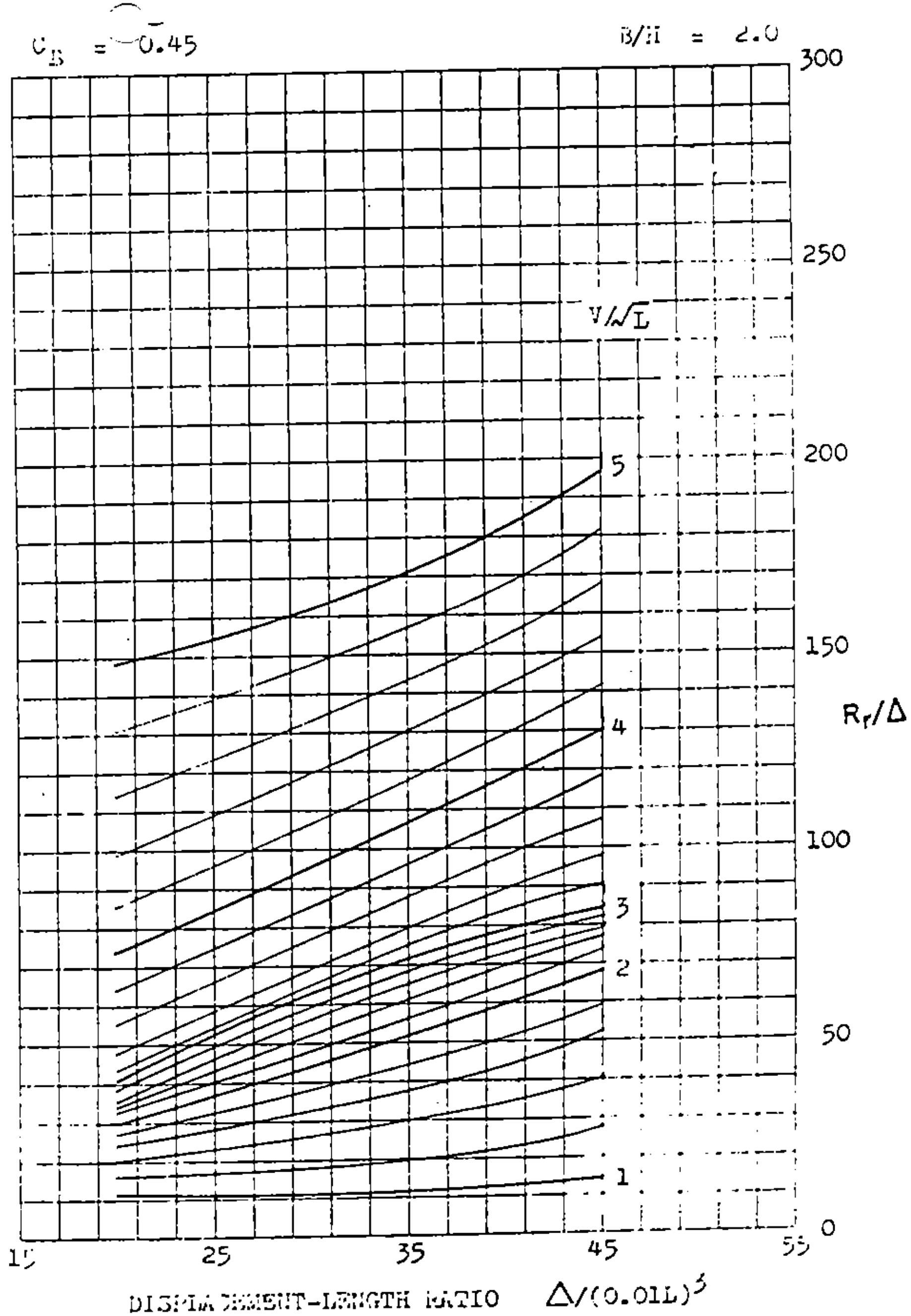
Fig. 17

Figs. 15–23 Contours of resistance in pounds per



C_B = 0.55
B/H = 3.0
V/√L
5
4
3
2
1
300
250
200
150
100
50
0
R_r/Δ
15
25
35
45
55
DISPLACEMENT-LENGTH RATIO $\Delta/(0.01L)^3$

Fig. 16



C_B = 0.45
B/H = 2.0
V/√L
5
4
3
2
1
300
250
200
150
100
50
0
R_r/Δ
15
25
35
45
55
DISPLACEMENT-LENGTH RATIO $\Delta/(0.01L)^3$

Fig. 18

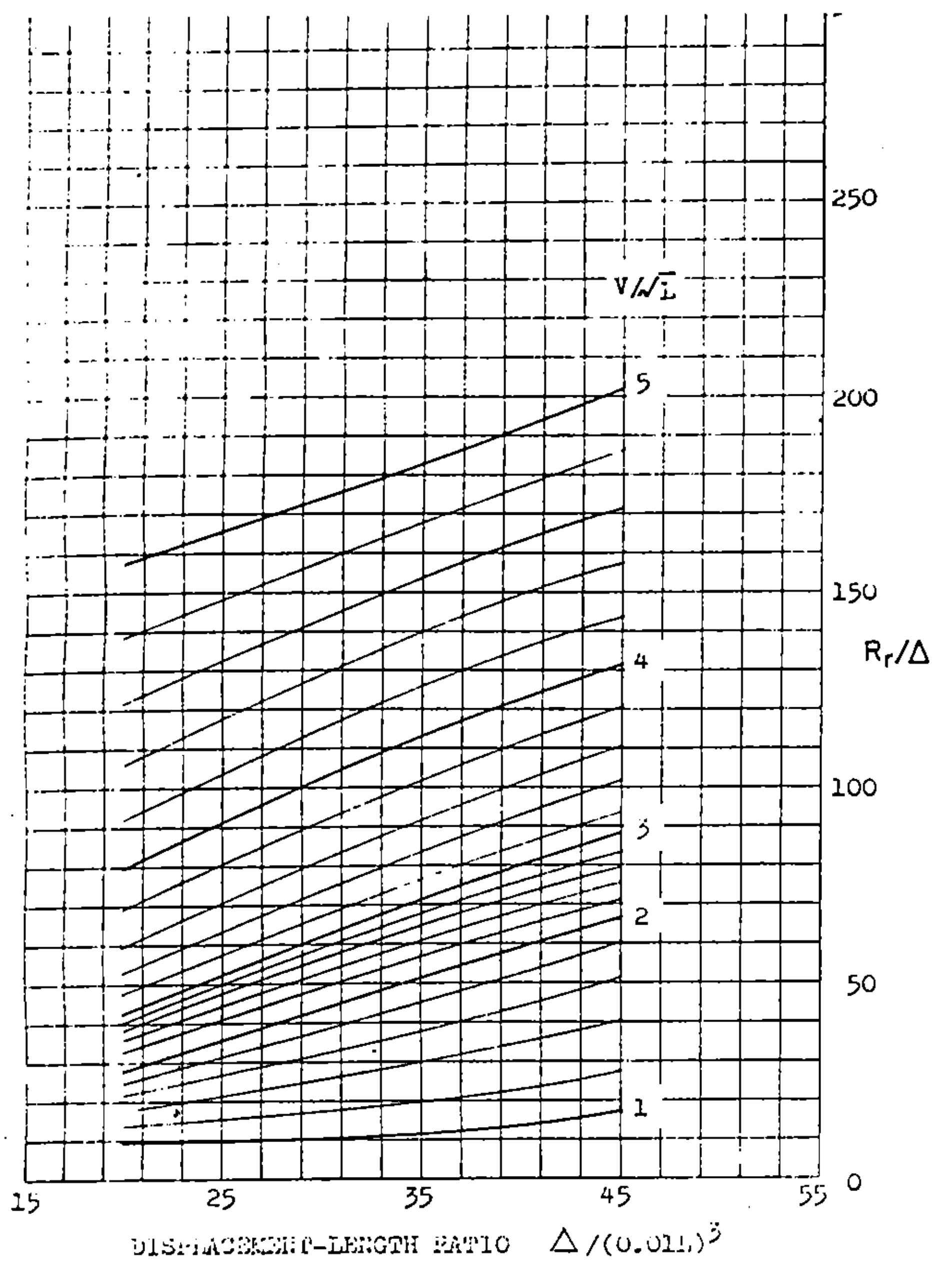

V/√L
5
4
3
2
1
250
200
150
100
50
0
R_r/Δ
15
25
35
45
55
DISPLACEMENT-LENGTH RATIO Δ/(0.01L)³

Fig. 19

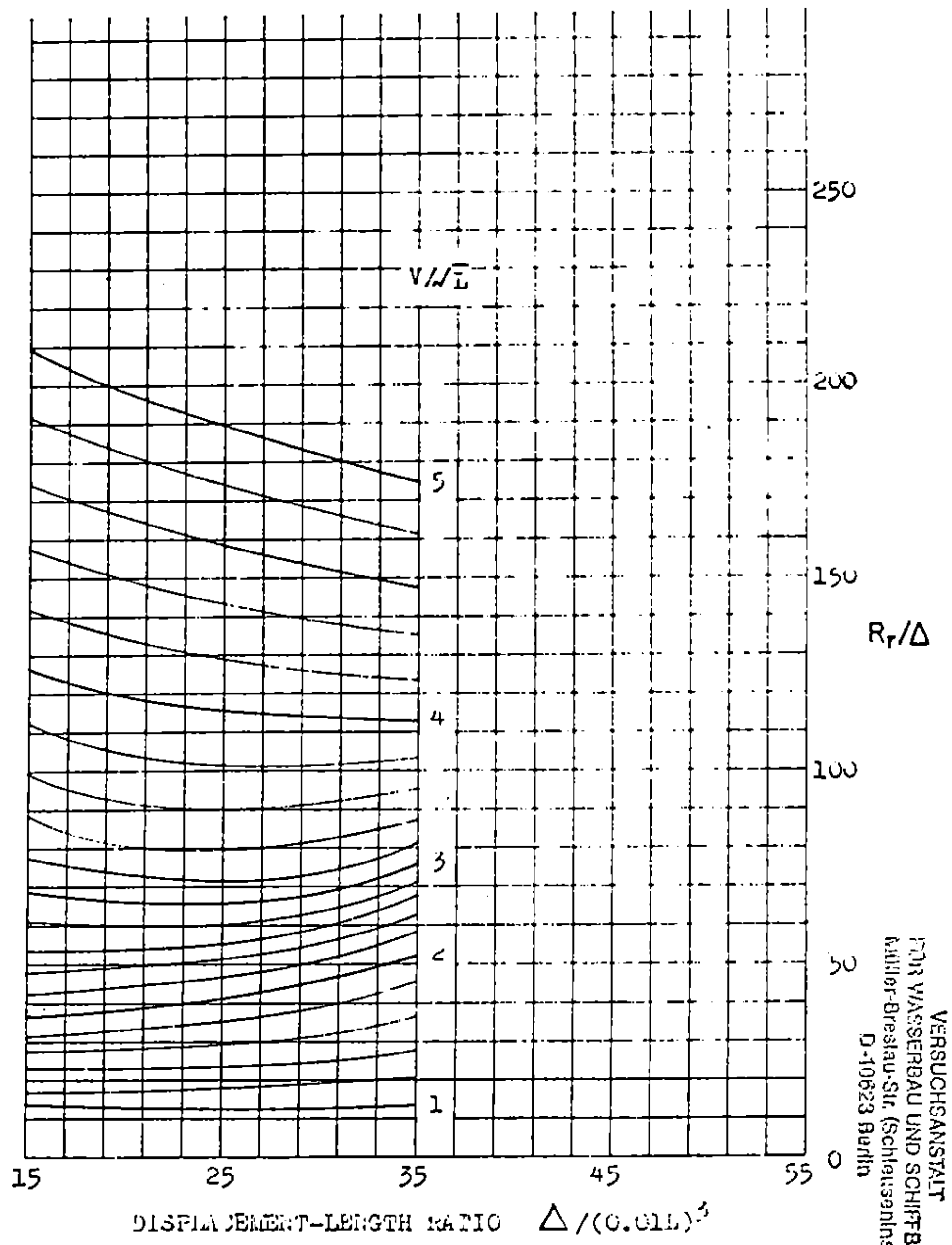
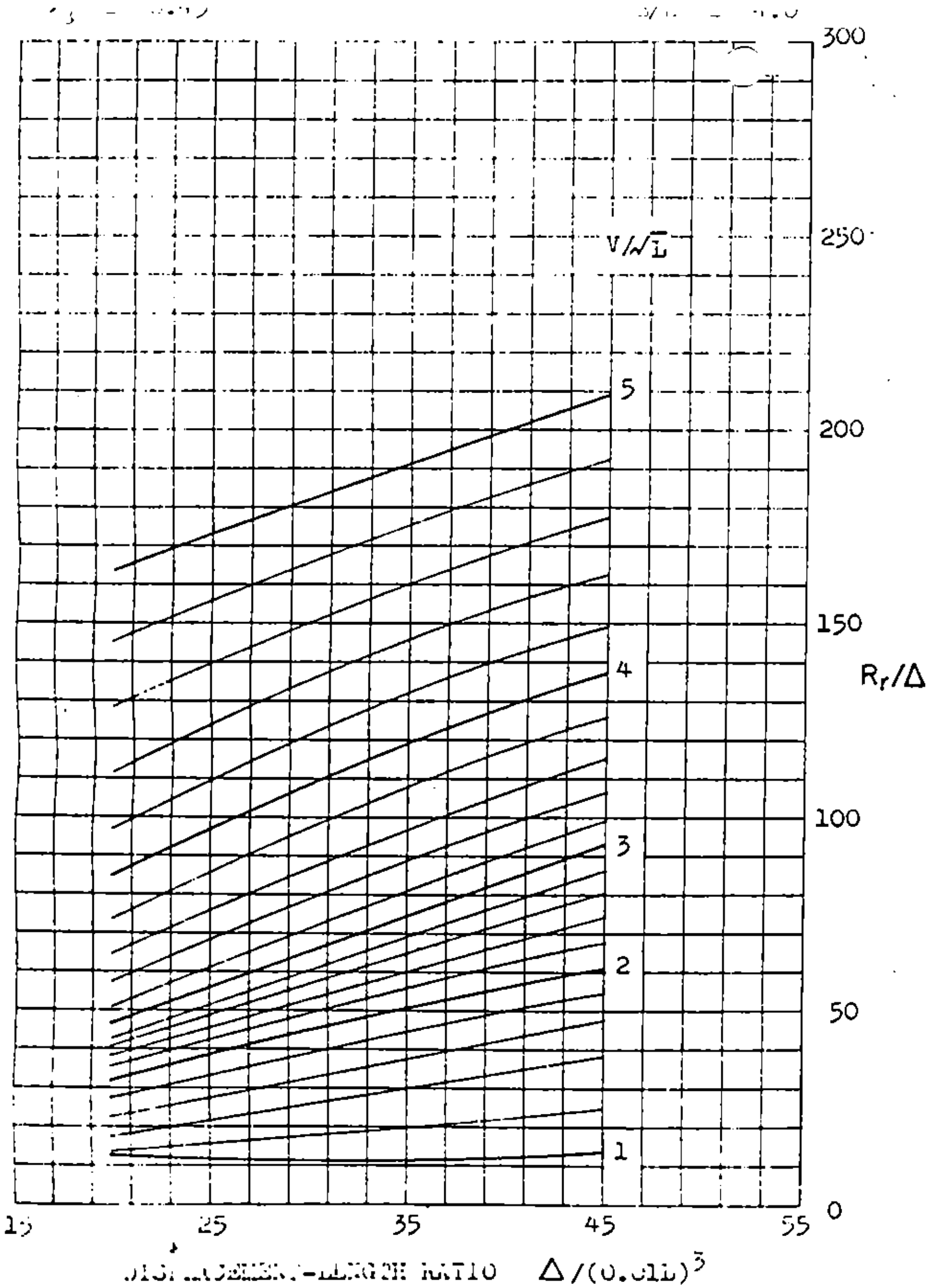
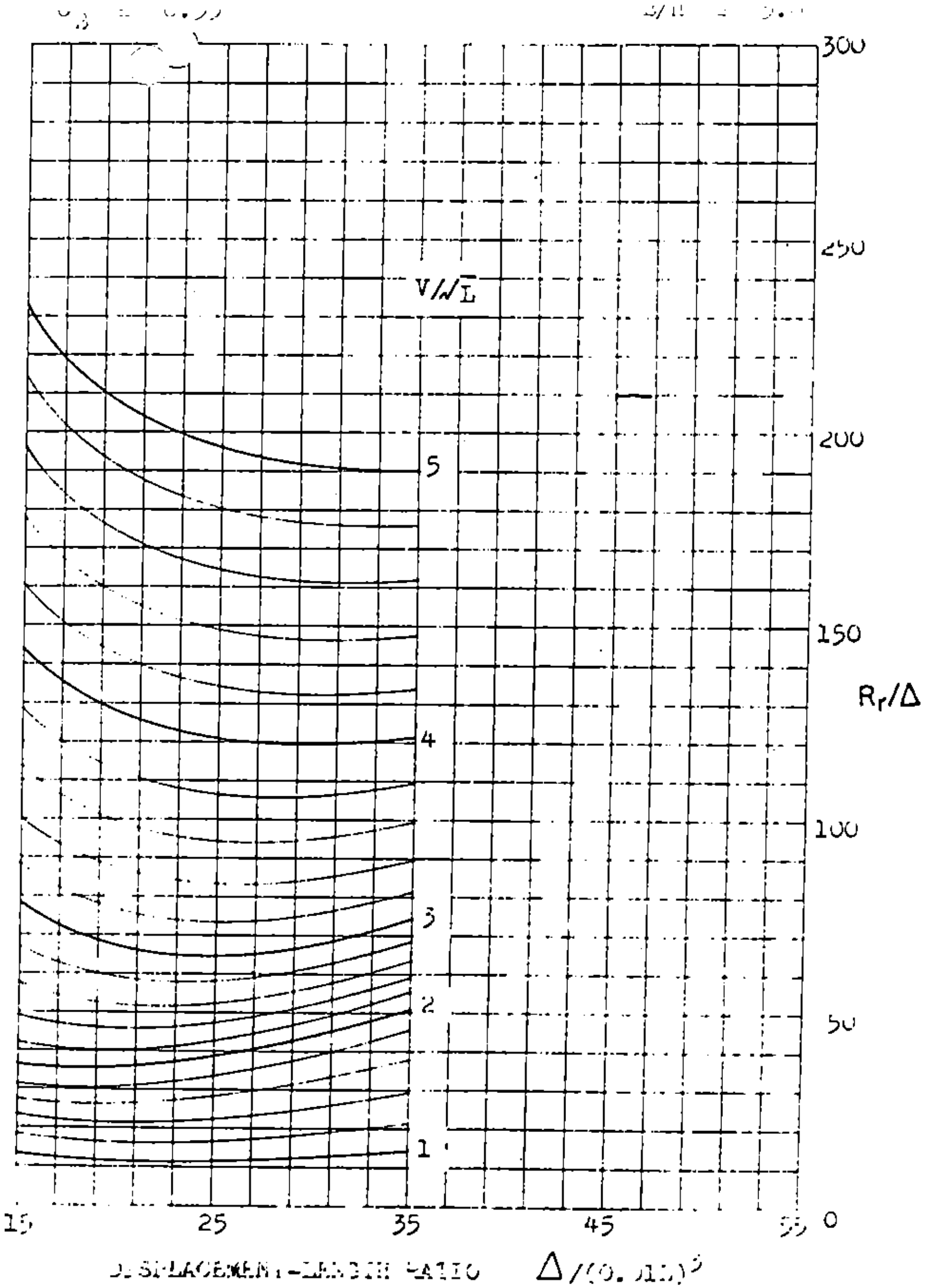

V/√L
5
4
3
2
1
250
200
150
100
50
0
R_r/Δ
15
25
35
45
55
DISPLACEMENT-LENGTH RATIO Δ/(0.01L)³

Fig. 21



V/√L
5
4
3
2
1
300
250
200
150
100
50
0
R_r/Δ
15
25
35
45
55
DISPLACEMENT-LENGTH RATIO Δ/(0.01L)^3

Fig. 20



V/√L
5
4
3
2
1
300
250
200
150
100
50
0
R_r/Δ
15
25
35
45
55
DISPLACEMENT-LENGTH RATIO Δ/(0.01L)^3

Fig. 22

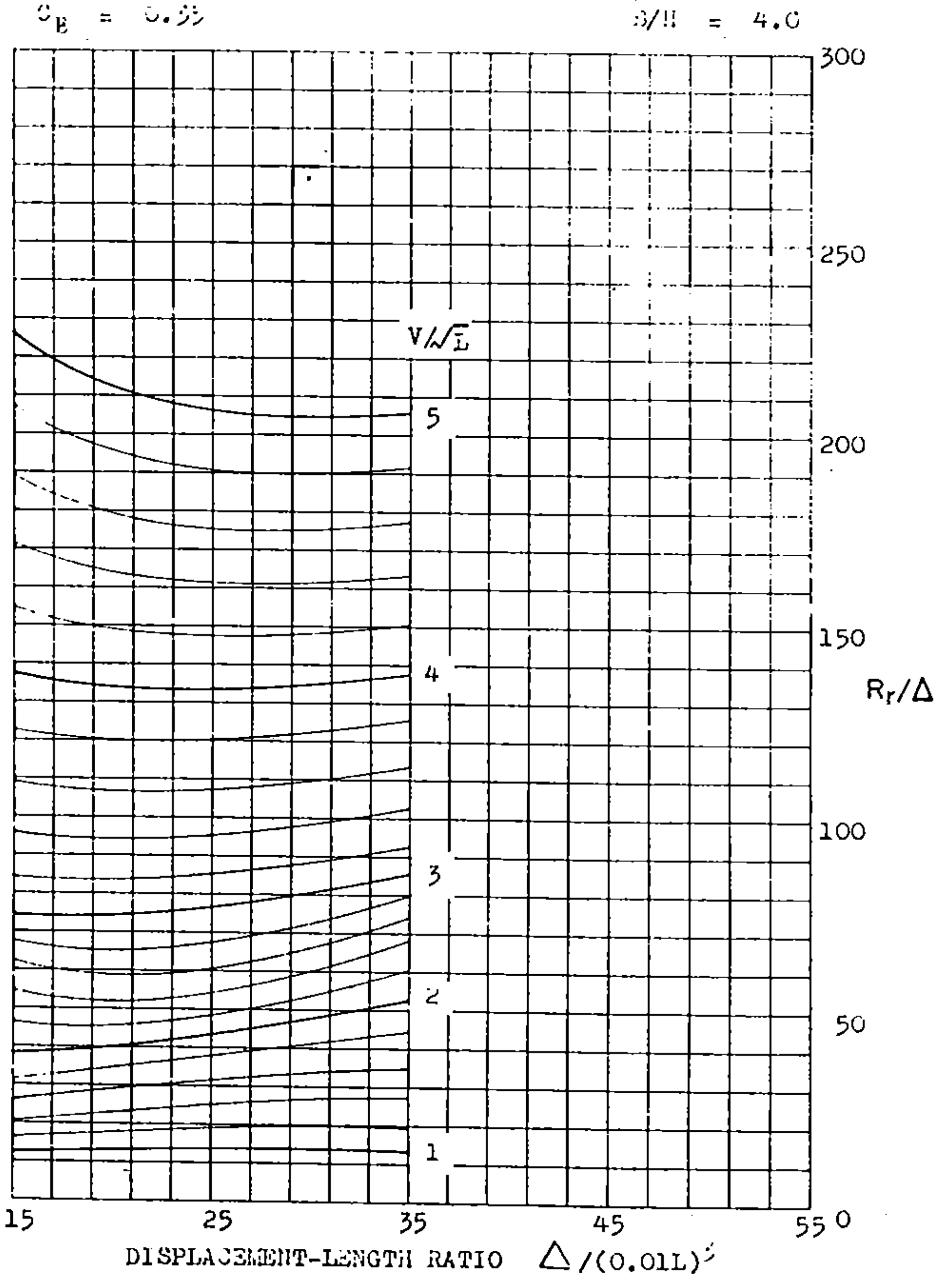

B/H = 4.0
V/√L
5
4
3
2
1
300
250
200
150
100
50
0
R_r/Δ
15
25
35
45
55
DISPLACEMENT-LENGTH RATIO △/(0.01L)

Fig. 23

Table 2 Residuary Resistance in Pounds Per Ton of Displacement for 0.55 Block Coefficient Models

$\frac{\Delta}{(.01L)^3}$	55			40			25		
$\frac{V}{\sqrt{L}}$ \ $\frac{B}{H}$	2	3	4	2	3	4	2	3	4
.20	.75	.75	.75	.77	.77	.77	.82	.82	.82
.40	2.62	2.62	2.62	1.54	1.54	1.28	2.06	2.06	2.06
.60	5.61	5.61	5.61	3.09	3.09	2.31	4.11	4.11	4.11
.80	10.28	10.28	10.28	6.94	6.94	4.37	7.40	7.40	6.99
1.00	14.96	14.96	14.96	14.40	14.40	10.54	13.16	13.16	11.52
1.20	24.87	24.87	24.87	25.45	25.45	20.31	21.39	20.98	17.69
1.40	37.40	37.40	37.40	36.77	35.74	32.91	27.97	27.56	24.27
1.60	48.80	48.99	49.18	45.25	46.28	43.19	34.55	34.55	30.85
1.80	57.96	58.90	60.02	52.96	54.25	49.36	41.14	40.72	36.61
2.00	65.26	66.94	70.31	58.10	59.13	57.08	46.89	45.66	41.95
2.20	69.93	72.92	78.53	61.70	63.25	60.93	51.83	50.18	46.07
2.40	73.48	77.41	85.26	64.53	66.85	64.79	56.36	54.71	49.36
2.60	75.91	81.15	90.87	67.36	70.96	69.16	60.47	58.41	51.42
2.80	78.34	84.52	95.36	70.44	75.59	74.30	65.41	62.53	54.30
3.00	80.78	87.88	99.85	74.04	81.24	78.67	69.93	67.46	58.00
3.20	83.95	92.74	106.39	78.67	87.93	85.36	77.34	74.46	64.99
3.40	88.82	98.73	114.06	84.33	96.16	92.30	85.56	82.68	74.04
3.60	95.17	105.64	122.66	89.99	106.18	100.53	95.84	93.38	83.92
3.80	102.84	114.06	132.01	96.93	117.24	109.01	108.60	105.31	94.61
4.00	112.19	123.41	143.04	104.64	129.00	119.04	121.76	118.47	106.54
4.20	122.29	135.75	153.50	114.15	142.43	130.35	136.57	131.64	124.00
4.40	135.37	154.07	174.00	125.72	156.00	144.49	152.20	145.21	139.50
4.60	155.38	178.19	198.50	141.41	169.90	160.00	168.66	159.61	154.50
4.80	183.62	208.11	228.00	164.03	193.00	180.00	185.11	174.01	171.00
5.00	216.90	241.21	260.00	194.88	218.50	203.00	203.21	189.22	188.00

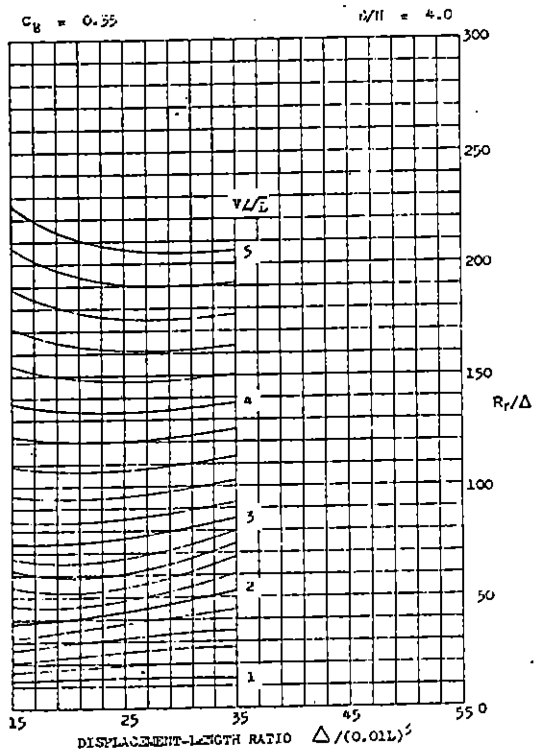


Fig. 23

Table 3 Residuary Resistance in Pounds Per Ton of Displacement for 0.45 Block Coefficient Models

$\frac{\Delta}{(.01L)^3}$	45			32.5			20		
$\frac{V}{\sqrt{L}}$ \ $\frac{B}{H}$	2	3	4	2	3	4	2	3	4
.20	.91	.91	.91	.95	.95	.95	1.54	1.54	1.54
.40	2.51	2.51	2.51	2.85	2.53	2.22	3.08	2.57	3.08
.60	5.26	5.48	5.26	5.70	5.06	4.11	6.17	5.14	6.17
.80	9.60	10.51	9.83	8.23	7.91	6.64	8.74	7.20	9.26
1.00	14.85	17.14	13.71	11.08	10.76	11.08	11.31	9.77	12.86
1.20	27.65	27.65	24.91	18.67	18.67	18.67	15.43	13.37	13.37
1.40	40.22	40.22	38.16	27.53	27.53	27.53	20.05	17.48	17.48
1.60	50.28	51.42	47.76	34.81	34.81	34.81	24.17	21.60	22.11
1.80	59.42	60.10	54.85	41.14	41.14	41.14	27.25	24.68	27.25
2.00	68.33	66.50	61.02	47.46	47.46	47.46	29.82	28.80	31.88
2.20	73.59	71.53	67.42	52.53	52.53	52.53	32.39	32.91	35.48
2.40	77.24	75.87	74.04	56.96	56.64	56.32	34.45	35.99	38.05
2.60	79.99	79.76	80.44	60.75	60.12	60.44	35.99	38.05	40.11
2.80	82.27	83.64	86.61	64.24	63.29	64.55	38.05	40.11	42.68
3.00	84.56	88.21	93.01	67.40	66.77	69.93	40.11	42.16	46.28
3.20	90.50	93.70	99.18	70.25	71.51	75.94	43.19	47.31	50.91
3.40	98.27	101.47	106.50	74.68	78.47	83.22	47.82	52.96	57.08
3.60	107.41	110.38	115.18	82.27	86.70	91.45	55.02	59.65	64.28
3.80	118.38	120.66	125.69	90.82	96.51	102.21	63.76	68.90	73.53
4.00	129.81	131.64	137.12	101.26	107.90	113.92	73.53	79.70	84.33
4.20	141.69	143.98	149.23	112.33	120.56	126.89	85.36	92.04	96.67
4.40	154.26	157.46	162.94	124.99	134.17	140.50	98.73	105.93	111.07
4.60	167.97	171.40	177.57	138.28	148.41	155.05	113.64	121.35	128.04
4.80	181.68	186.25	192.88	152.20	162.96	170.56	130.61	138.83	145.00
5.00	196.31	202.02	209.34	166.13	178.47	186.69	148.09	157.34	163.52

Table 4 Residuary Resistance in Pounds Per Ton of Displacement for 0.35 Block Coefficient Models

$\frac{\Delta}{(.01L)^3}$	35			25			15		
$\frac{V}{\sqrt{L}}$ \ $\frac{B}{H}$	2	3	4	2	3	4	2	3	4
.20	.59	.59	.59	.82	.82	.82	.68	.68	.68
.40	1.47	1.47	1.47	1.64	1.64	1.64	2.06	2.06	2.06
.60	4.70	4.40	4.11	4.11	4.52	4.94	4.80	5.48	4.80
.80	7.64	8.23	7.93	7.40	6.99	8.23	8.23	9.60	8.91
1.00	13.22	14.10	13.22	12.34	11.52	13.16	13.03	13.71	12.34
1.20	19.98	21.16	19.39	18.10	16.86	18.92	17.82	18.51	16.45
1.40	27.91	29.38	27.03	23.86	22.62	25.09	23.31	23.31	20.57
1.60	36.73	37.90	34.97	29.62	28.38	31.26	27.42	27.42	26.05
1.80	45.84	45.25	44.07	35.38	33.73	37.84	31.54	31.54	31.54
2.00	52.30	50.54	52.89	41.14	38.67	43.19	36.34	35.65	38.39
2.20	58.18	55.23	60.82	46.90	42.78	48.54	42.51	42.51	46.62
2.40	62.88	59.35	68.17	51.01	47.31	54.30	47.99	49.36	54.85
2.60	67.29	63.47	74.34	55.12	52.24	60.88	53.48	57.59	62.39
2.80	71.11	68.46	79.92	60.06	58.00	67.87	61.02	67.19	67.87
3.00	75.81	74.34	85.80	65.82	64.58	76.10	68.56	78.16	74.73
3.20	81.10	81.10	92.85	71.58	73.22	85.15	77.47	88.44	84.33
3.40	87.85	89.62	102.55	79.80	83.51	95.85	88.44	100.10	95.98
3.60	95.20	99.31	113.42	90.09	94.61	107.78	99.41	113.81	109.01
3.80	103.43	109.89	125.46	101.61	106.95	120.53	112.44	128.89	122.72
4.00	112.83	121.35	137.51	115.18	120.53	133.69	126.84	143.98	137.80
4.20	123.70	133.99	150.44	128.76	134.51	147.27	141.92	160.43	154.94
4.40	135.16	147.80	163.66	143.56	148.91	161.25	157.69	178.26	171.40
4.60	147.80	161.90	177.47	158.37	164.54	175.65	174.14	196.08	189.22
4.80	161.31	176.00	191.58	174.00	180.18	190.87	191.97	214.59	207.05
5.00	174.83	190.40	205.97	189.64	196.22	206.09	209.79	233.79	226.25

Table 5 Residuary Resistance Coefficients, $C_r \times 10^3$, for 0.55 Block Coefficient Models

$\frac{\Delta}{(.01L)^3}$	55			40			25		
$\frac{V}{\sqrt{L}}$ \ $\frac{B}{H}$	2	3	4	2	3	4	2	3	4
.20	3.187	3.155	3.049	2.803	2.775	2.682	2.364	2.340	2.262
.40	2.788	2.760	2.668	1.401	1.387	1.118	1.477	1.462	1.413
.60	2.655	2.629	2.540	1.246	1.233	1.192	1.313	1.300	1.256
.80	2.738	2.711	2.620	1.576	1.561	.950	1.329	1.316	1.201
1.00	2.549	2.524	2.439	2.093	2.072	1.466	1.512	1.497	1.266
1.20	2.943	2.914	2.815	2.569	2.543	1.961	1.707	1.657	1.350
1.40	3.251	3.219	3.111	2.822	2.624	2.334	1.640	1.600	1.361
1.60	3.249	3.228	3.132	2.569	2.601	2.346	1.551	1.535	1.325
1.80	3.049	3.067	3.020	2.376	2.409	2.118	1.459	1.430	1.242
2.00	2.780	2.823	2.866	2.111	2.127	1.984	1.347	1.298	1.153
2.20	2.462	2.542	2.645	1.853	1.880	1.750	1.230	1.179	1.046
2.40	2.174	2.267	2.413	1.628	1.670	1.564	1.124	1.080	.942
2.60	1.914	2.025	2.192	1.448	1.510	1.422	1.028	.983	.836
2.80	1.703	1.819	1.983	1.306	1.387	1.318	.958	.907	.761
3.00	1.529	1.647	1.809	1.196	1.299	1.215	.883	.853	.708
3.20	1.397	1.528	1.693	1.117	1.236	1.159	.868	.827	.698
3.40	1.309	1.441	1.609	1.060	1.197	1.110	.850	.814	.705
3.60	1.251	1.375	1.543	1.009	1.179	1.078	.850	.820	.712
3.80	1.214	1.333	1.490	.976	1.168	1.050	.864	.830	.720
4.00	1.195	1.301	1.458	.951	1.158	1.034	.874	.842	.732
4.20	1.181	1.298	1.419	.941	1.162	1.027	.889	.849	.772
4.40	1.192	1.343	1.466	.944	1.160	1.038	.903	.853	.791
4.60	1.251	1.421	1.530	.971	1.156	1.051	.916	.858	.803
4.80	1.358	1.524	1.613	1.035	1.206	1.086	.923	.859	.816
5.00	1.478	1.628	1.696	1.133	1.258	1.130	.934	.861	.827

Table 6 Residuary Resistance Coefficients, $C_r \times 10^3$, for 0.45 Block Coefficient Models

$\frac{\Delta}{(.01L)^3}$	45			32.5			20		
$\frac{V}{\sqrt{L}}$ \ $\frac{B}{H}$	2	3	4	2	3	4	2	3	4
.20	3.486	3.419	3.267	3.077	3.017	2.884	3.922	3.847	3.676
.40	2.396	2.350	2.246	2.307	2.011	1.682	1.961	1.602	1.838
.60	2.227	2.278	2.087	2.051	1.788	1.388	1.743	1.424	1.633
.80	2.287	2.457	2.195	1.667	1.571	1.261	1.389	1.122	1.378
1.00	2.266	2.564	1.960	1.435	1.368	1.345	1.150	.974	1.225
1.20	2.929	2.872	2.472	1.680	1.648	1.575	1.089	.926	.885
1.40	3.130	3.069	2.783	1.820	1.785	1.706	1.040	.889	.850
1.60	2.995	3.004	2.667	1.762	1.728	1.652	.960	.841	.823
1.80	2.797	2.774	2.420	1.646	1.614	1.542	.855	.760	.801
2.00	2.605	2.487	2.180	1.538	1.508	1.441	.758	.718	.759
2.20	2.319	2.210	1.991	1.406	1.379	1.318	.680	.678	.699
2.40	2.045	1.970	1.837	1.282	1.250	1.188	.608	.623	.630
2.60	1.804	1.765	1.701	1.165	1.130	1.086	.541	.561	.565
2.80	1.600	1.596	1.579	1.062	1.026	1.000	.493	.510	.519
3.00	1.433	1.466	1.477	.971	.943	.944	.453	.467	.490
3.20	1.348	1.368	1.384	.889	.888	.901	.429	.461	.474
3.40	1.296	1.313	1.318	.837	.863	.874	.421	.456	.470
3.60	1.264	1.274	1.270	.823	.850	.857	.431	.459	.473
3.80	1.250	1.250	1.244	.815	.850	.860	.449	.476	.485
4.00	1.237	1.231	1.225	.820	.857	.865	.467	.497	.502
4.20	1.225	1.221	1.209	.825	.869	.874	.492	.520	.522
4.40	1.215	1.216	1.203	.837	.881	.811	.518	.546	.547
4.60	1.211	1.212	1.199	.847	.891	.890	.546	.572	.576
4.80	1.203	1.209	1.196	.856	.899	.899	.576	.601	.600
5.00	1.198	1.209	1.197	.861	.907	.907	.602	.628	.623

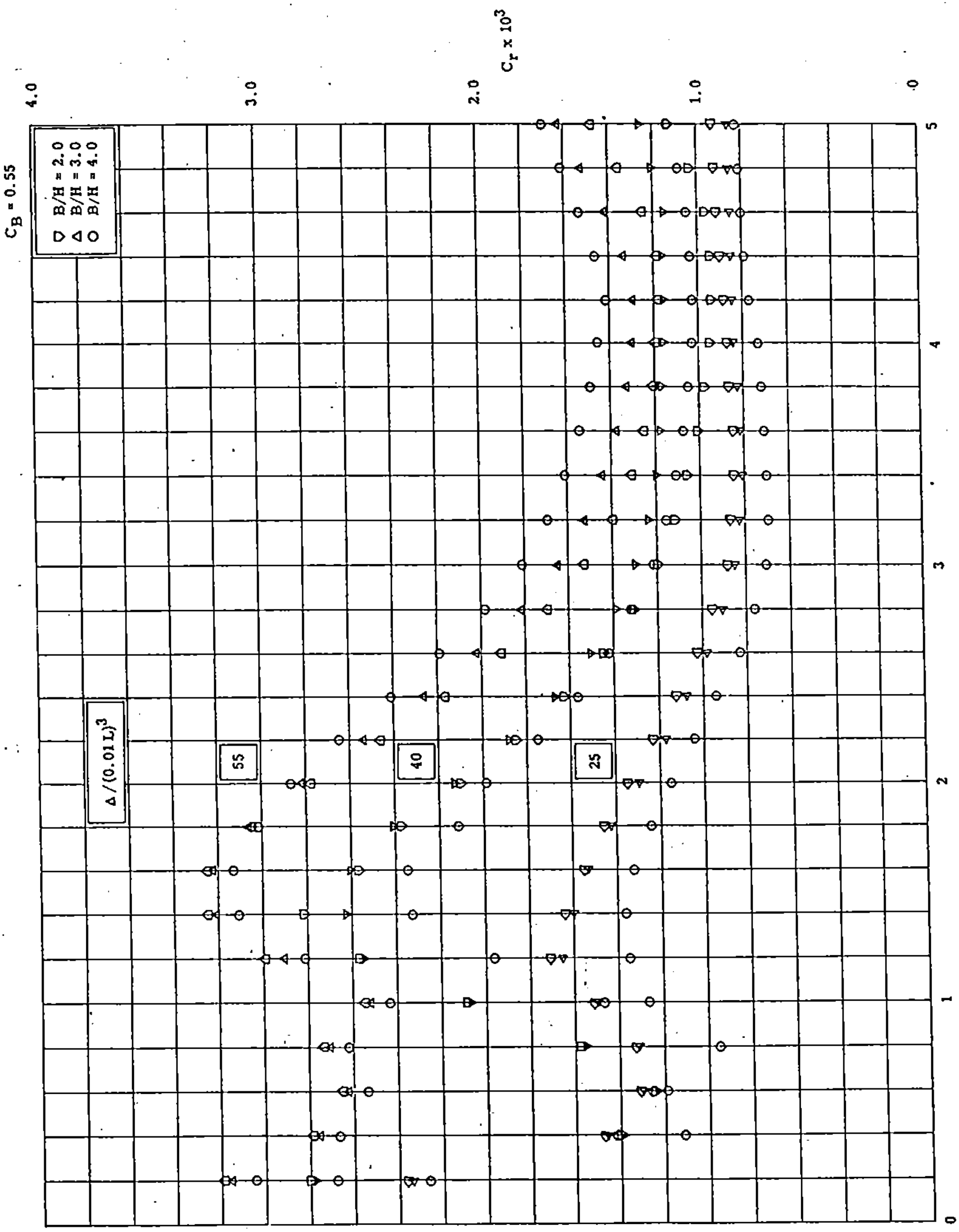


Fig. 24

Figs. 24–26 Residuary-resistance coefficients, $C_r = R_r/1/2\rho SV^2$

Table 7 Residuary Resistance Coefficients, $C_r \times 10^4$, for 0.35 Block Coefficient Models

$\frac{\Delta}{(.01L)^3}$	35			25			15		
$\frac{V}{\sqrt{L}}$ \ $\frac{B}{H}$	2	3	4	2	3	4	2	3	4
.20	1.832	1.799	1.702	2.168	2.129	2.017	1.399	1.374	1.302
.40	1.145	1.124	1.063	1.084	1.064	1.008	1.049	1.030	.977
.60	1.628	1.499	1.323	1.204	1.300	1.345	1.068	1.221	1.013
.80	1.488	1.574	1.476	1.219	1.131	1.261	1.049	1.202	1.058
1.00	1.648	1.726	1.531	1.300	1.192	1.291	1.063	1.099	.937
1.20	1.730	1.798	1.560	1.324	1.212	1.289	1.010	1.030	.868
1.40	1.775	1.835	1.597	1.282	1.194	1.255	.970	.953	.797
1.60	1.788	1.812	1.582	1.219	1.147	1.197	.874	.858	.773
1.80	1.764	1.710	1.575	1.150	1.077	1.145	.794	.780	.739
2.00	1.630	1.546	1.531	1.083	1.000	1.059	.741	.714	.729
2.20	1.498	1.397	1.455	1.021	.915	.983	.717	.704	.732
2.40	1.361	1.261	1.371	.933	.850	.924	.680	.687	.723
2.60	1.241	1.149	1.274	.859	.800	.883	.646	.683	.701
2.80	1.131	1.069	1.181	.807	.765	.849	.635	.687	.658
3.00	1.050	1.011	1.104	.770	.742	.829	.622	.696	.631
3.20	.987	.969	1.050	.736	.740	.815	.617	.692	.626
3.40	.947	.949	1.027	.727	.748	.813	.624	.694	.631
3.60	.916	.938	1.013	.732	.755	.815	.626	.704	.639
3.80	.893	.932	1.006	.741	.766	.818	.635	.715	.646
4.00	.879	.928	.995	.758	.779	.819	.647	.721	.654
4.20	.874	.930	.988	.769	.788	.819	.656	.729	.667
4.40	.870	.934	.979	.781	.796	.817	.665	.738	.672
4.60	.871	.937	.971	.789	.805	.814	.672	.743	.679
4.80	.873	.935	.963	.796	.809	.812	.680	.746	.683
5.00	.872	.932	.954	.799	.812	.808	.685	.749	.687

C_r is defined as $R_r/\frac{1}{2}\rho A_x v^2$, in Figs. 27 through 29.

It should be understood that in no way is it claimed that these models possess an optimum hull form. Yet the results indicate that this series does fulfill its mission.

The dropping off of residuary-resistance coefficients and the close spacings of R_r/Δ contours between the speed-length ratio of 2.0 and 3.0 mean that a small increase in horsepower will bring a higher return in speed in this speed range than in any other speed range, except at the very low speeds.

The leveling off of the residuary-resistance coefficients and their magnitudes after the speed-length ratio of 3.0 indicates that the wave resistance is no longer an important factor. The frictional resistance, however, remains the dominant factor, and its magnitude is about twice as large as the form drag. In some cases, the residuary coefficients have only the values of the correlation allowances. Therefore, for ships designed to operate at speed-length ratios over 3.0, it is highly desirable to keep the wetted surface to the minimum.

Application of Results

The bare-hull resistance of a comparable Series 64 hull form can be estimated by using one of the following methods:

1 $\text{EHP} = R_t v/550$

$$R_t = R_F + R_r$$

$$R_T = \tfrac{1}{2}\rho S v^2 (C_F + \Delta C_F) + \frac{R_r}{\Delta}\Delta$$

2 $\text{EHP} = R_t v/550$

$$= (\tfrac{1}{1100}) S \rho v^3 (C_F + \Delta C_F + C_r)$$

It is recommended that the comparable Series 64 wetted surface, which can be estimated from Fig. 30, using either the curves or the empirical formula, be used in the calculations. The American Towing Tank Conference 1947 friction line (Schoenherr line) is recommended for calculating frictional resistance. If this line is not used, allowance should be made to account for the

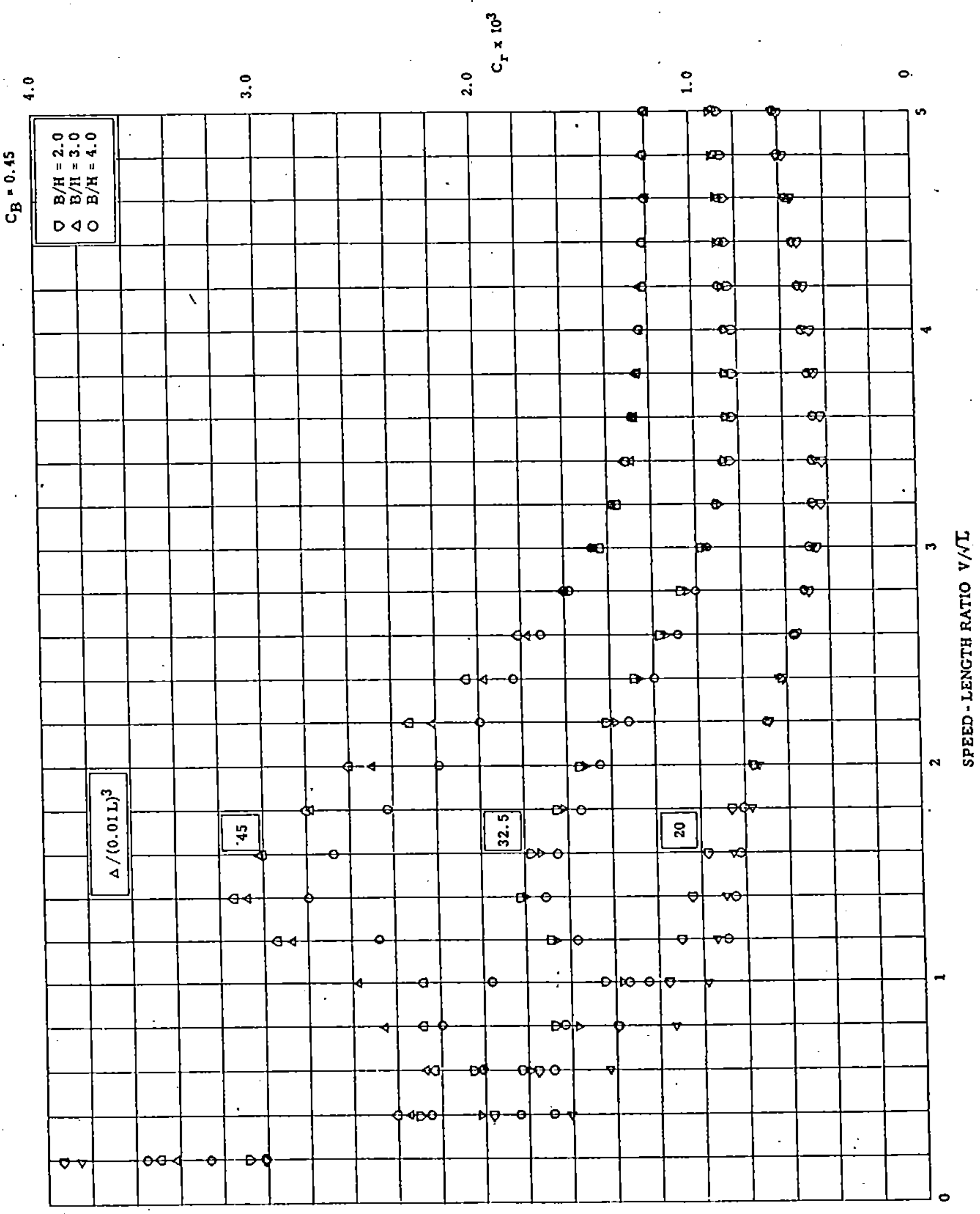
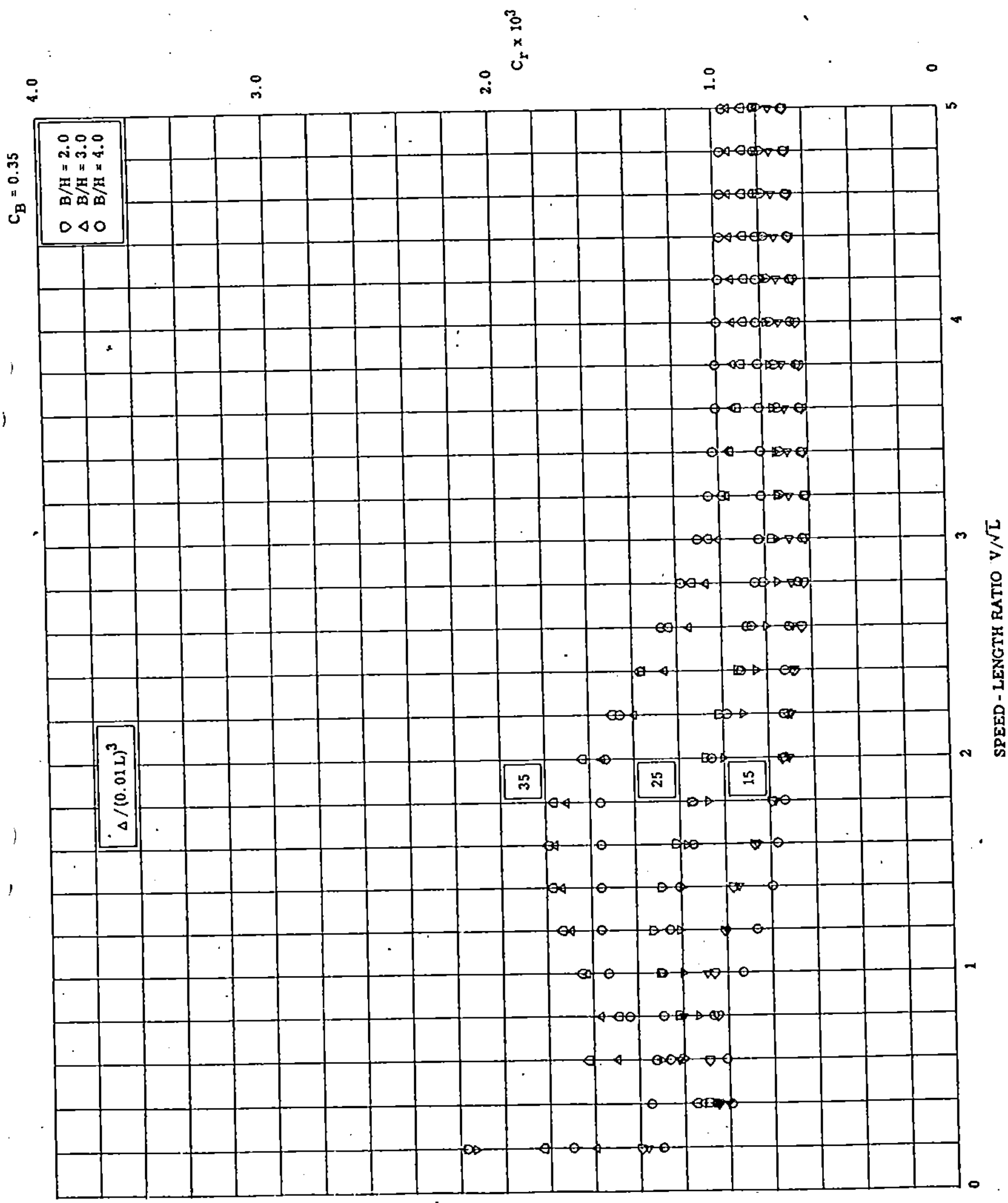

C_B = 0.45
▽ B/H = 2.0
◁ B/H = 3.0
○ B/H = 4.0
$C_r \times 10^3$
4.0
3.0
2.0
1.0
0
$\Delta/(0.01L)^3$
45
32.5
20
0
1
2
3
4
5
SPEED - LENGTH RATIO $V/\sqrt{L}$

Fig. 25



$C_B = 0.35$
B/H = 2.0
B/H = 3.0
B/H = 4.0
$C_r \times 10^3$
4.0
3.0
2.0
1.0
0
$\Delta/(0.01L)^3$
35
25
15
SPEED - LENGTH RATIO $V/\sqrt{L}$
0
1
2
3
4
5

Fig. 26

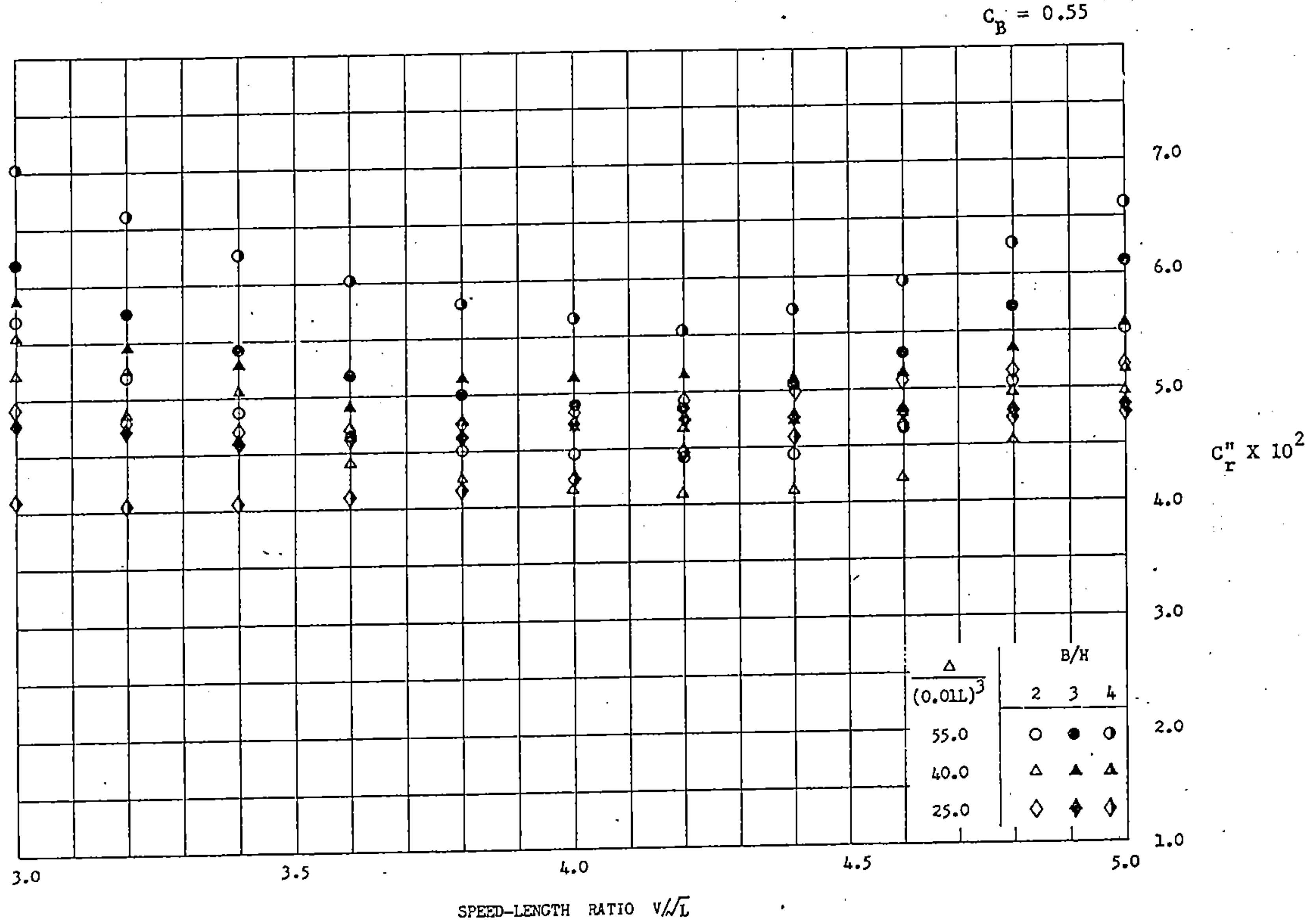
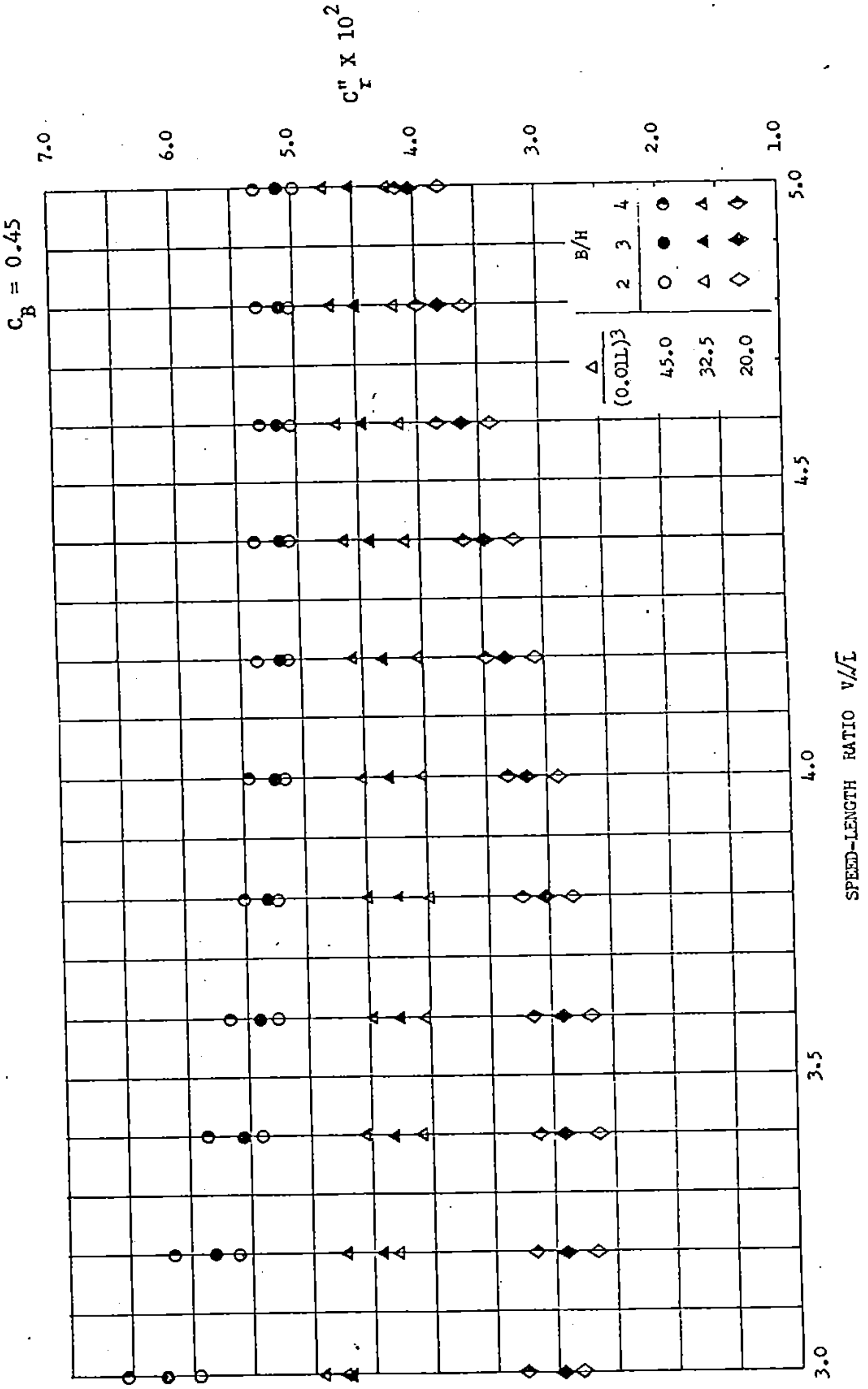


Fig. 27

Figs. 27–29 Drag coefficients, $C_r'' = R_r/1/2\rho A_x v^2$



$C_B = 0.45$
$C_r'' \times 10^2$
7.0
6.0
5.0
4.0
3.0
2.0
1.0
B/H
2
3
4
$\frac{\Delta}{(0.01L)^3}$
45.0
32.5
20.0
5.0
4.5
4.0
3.5
3.0
SPEED-LENGTH RATIO V/√L

Fig. 28

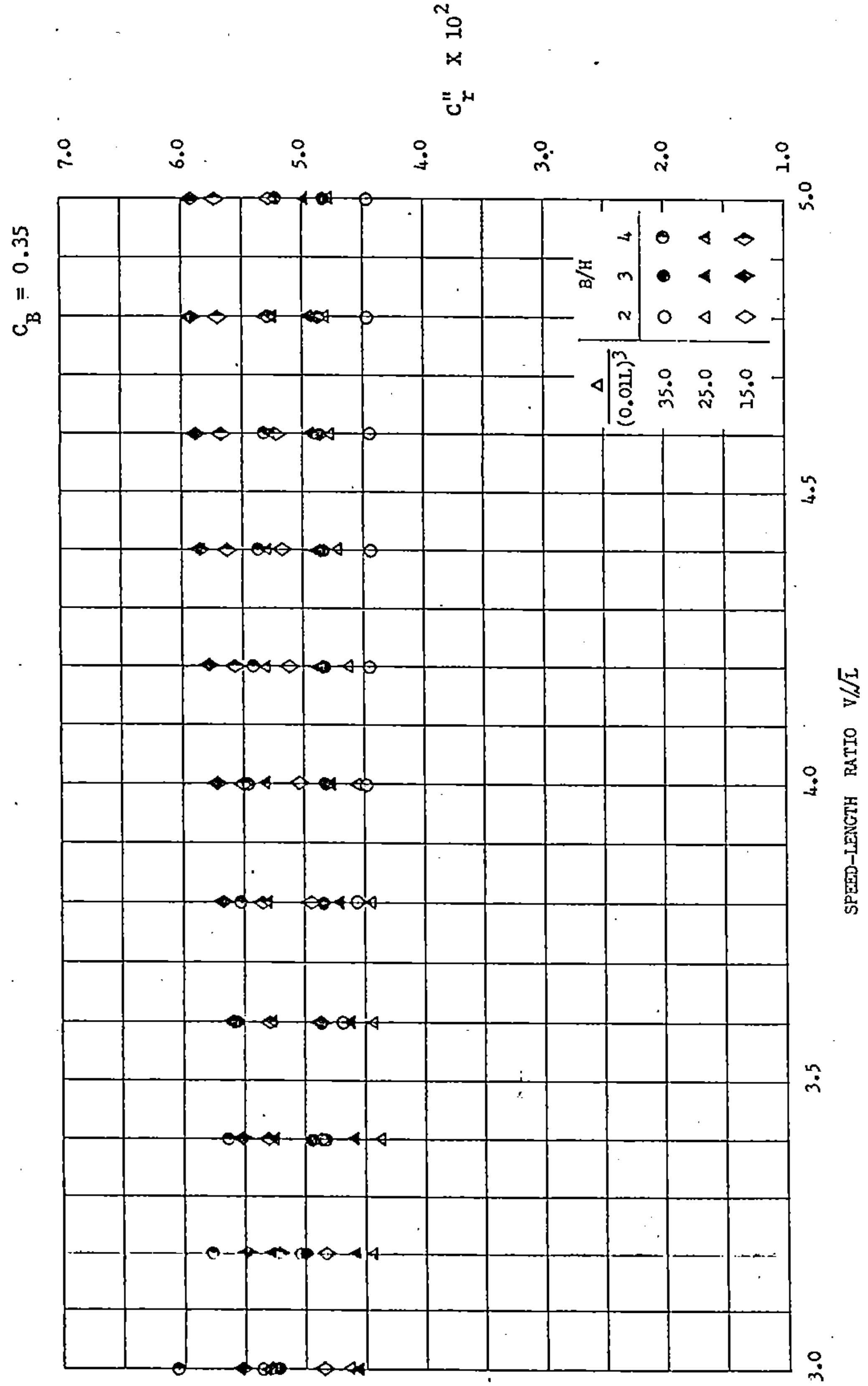

$C_B = 0.35$
$C''_r \times 10^2$
7.0
6.0
5.0
4.0
3.0
2.0
1.0
B/H
2
3
4
Δ / (0.01L)^3
35.0
25.0
15.0
5.0
4.5
4.0
3.5
3.0
SPEED-LENGTH RATIO V/√L

Fig. 29

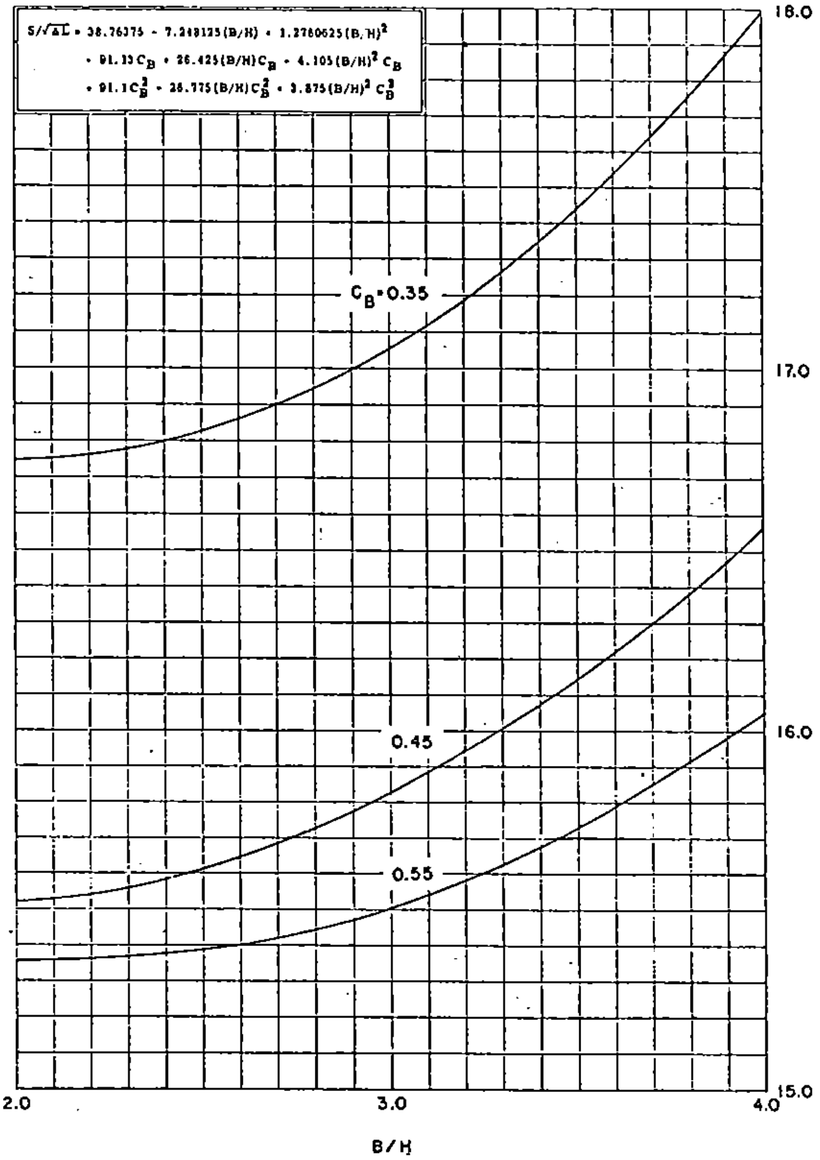


Fig. 30 Wetted-surface coefficients of Series 64 models

difference in the model frictional resistance which was used in deriving the C_r and R_r/Δ-values.

The correlation allowances, ΔC_F, recommended by reference [8] for destroyer-type hull forms are from 0.0004 to 0.0008, depending on the type of paint used.

To obtain R_r/Δ or C_r-values, a three-way interpolation is involved, first between $\Delta/(0.01L)^3$ values at each block coefficient within each B/H, then at constant $\Delta/(0.01L)^3$ across the B/H, and finally at each $\Delta/(0.01L)^3$ and B/H across the block coefficient. This process is repeated for every $V/\sqrt{L}$-value required. This interpolation is a tedious process and results thus obtained may or may not be consistent. Therefore, these data were programmed on the Burroughs E101 desk-size electronic digital computer using $\Delta/(0.01L)^3$, B/H, and C_B as variables at every 0.20 $V/\sqrt{L}$-value from 0.20 to 5.0.

Comment

The series as a whole fulfills its mission in calm water; however, its seakeeping quality has been questioned. To ascertain their behavior in waves, a limited number of Series 64 models have been tested. The results of these tests have not yet been analyzed. If the results of these seakeeping tests prove to be acceptable, the extension of the series is highly recommended.

Acknowledgments

The work described in this paper represents the efforts of many people, and it is difficult to recognize them all adequately. The experimental work was sponsored by the Bureau of Ships Fundamental Hydromechanics Research Program carried on at the David Taylor Model Basin. The tests were conducted and the data were

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Particularly, the author is appreciative of the efforts and advice of Dr. K. E. Schoenherr, former head of the Hydromechanics Laboratory, Mr. J. B. Hadler, head of the Ship Powering Division, Mr. G. R. Stuntz, then-head of the Speed and Power Branch, and Mr. A. L. Beal, head of the Research and Development Section where the program was carried out. Also the author is indebted to Mr. R. Bauman for model drafting work.

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Sulfur and Sea Salt Attack of Turbine Blades

(*Continued from page 247*)

removal of salt by evaporation and the lower is probably because of the temperature being too low for reaction.

In all the laboratory work it was observed that salt vapors had little or no effect and for attack to take place it was necessary for solid or molten salt to be present.

The aluminized coatings used on all specimens and blades were deposited by a pack aluminizing treatment and afterwards heat treated in an inert atmosphere to diffuse the layer. The final layer is 0.002 to 0.003 in. thick. Similar coatings can be produced by dip aluminizing followed by heat treatment but the pack method has been found more easily controllable. In either case heat treatment is essential as the coating formed is both hard and brittle. If used as aluminized, cracking and spalling are liable to occur.