THE UNIVERSITY OF MICHIGAN

College of Engineering

Department of Naval Architecture and Marine Engineering

Final Report

RESISTANCE OF CONVENTIONAL SHIP FORMS WITH LARGE BULBOUS BOWS

1. Series 60, $C_B = 0.60$
2. Series 60, $C_B = 0.70$

Tetsuo Takahei
Finn C. Michelsen
J. L. Moss

Project Director: R. B. Couch

Under contract with:

Department of Commerce
Maritime Administration
Contract No. MA-2564, Task III
Washington, D. C.

Administered through:
Office of Research Administration

July 1964
Ann Arbor

CONTENTS

TABLES

PART I

PART II

FIGURES

PART I

PART II

FIGURES (continued)

Part I. Series 60, $C_B = 0.60$

INTRODUCTION

In developing an efficient hull form, the naval architect automatically provides for beneficial interference between the bow, stern, and shoulders transverse wave systems. The addition of a bulbous bow, which generates large divergent and small transverse wave components, is aimed at cancelling the divergent component of the bow wave system.

Techniques for optimizing bulb designs are somewhat different for the two following cases: (a) a bulb fitted to an existing hull, and (b) a hull designed with an integral bulb. This part of the report deals with case (a), and the necessary techniques of fitting a bulb to an existing hull are explained. In this case, a series of five bulbs for Series 60, $C_B = 0.60$, hull form were designed and tested.

The most serious problem is that the location and amplitude of the divergent wave system of the bulbless hull are unknown. These, however, may be fairly accurately estimated. Wave contour maps are the best means of determining location and amplitude of waves. Simple photographs of wave patterns can be helpful. High quality photographs of wave patterns can be obtained by spreading a thin coating of fine aluminum powder on the water surface. The high reflective qualities of the powder, combined with stroboflash lights, yield distinct pictures of the rapidly fluttering wave pattern. See Fig. 1.

A quicker, but more approximate method, is to simply photograph the wave profile along the side of the model. However, the interference between the bow and shoulder wave systems tends to obscure the bow system.

Were it possible to represent mathematically conventional ship forms accurately, wave contours could be computed. This would permit more accurate determination of bulb size and location.

A bulb must be designed for a specific speed, since amplitudes of bulb and hull waves vary in opposite directions when ship speed is changed. However, an optimum bulb for a given speed will be effective, although to a lesser degree, over a wide range of speeds straddling the design speed. Therefore, it is not necessary to operate the ship at the specified speed in order to realize the benefits of the bulb. At speeds considerably lower than the design speed, the bulb is generally detrimental.

MODEL AND BULB DESIGNS

For this experimental research project on a large bow bulb fitted to a conventional ship hull, the Series 60, $C_B = 0.60$, $L_{BP}/\nabla^{1/3} = 6.165$, was chosen as being a typical hull form. The particulars of this hull are given in Table 1. Therefore, the design procedure followed is applicable to the design of bulbs for other conventional hull forms.

For a given set of principal dimensions, displacement and stability requirements, a hull with an integral bulb may be calculated. However, in this case, as indicated earlier, the quicker but more approximate, alternative method of fitting a bulb to an existing hull was adopted. The data in Table 2 of the characteristics of existing hulls with large bulbs was used as a basis. Five different bulbs were designed and tested when fitted to the Series 60, $C_B = 0.60$ hull form. The characteristics of these five bulbs are given in Table 3 and a description of each bulb follows.

Bulb B1 (Fig. 2) — This bulb was designed from the characteristics of C-201-F2 and also those of the "Kurenai-Maru" (see Table 2), taking into account design speed and the effects of ship's breadth and draft.

Bulb B2 (Fig. 3) B1 was modified so that no part of the bulb protruded below the baseline. In other aspects, B2 is similar to B1.

Bulb B3 (Fig. 4) Tests results with B1 and B2 showed that these bulbs over-cancelled, i.e., the counter-waves generated were too large. B3 was designed to create a smaller wave amplitude.

Bulb B4 (Fig. 5) The size of B3 was retained, but the center of B4 was positioned aft of the FP in order to determine longitudinal location effects.

Bulb B5 (Fig. 6) Both B3 and B4 were found to be still too large so that the waves generated over-cancelled. In addition the tests of B4 showed that longitudinal locations forward of the FP, instead of aft, are desirable for the bow in question. Therefore, the volume of B5 was decreased from that of B3 and B4, and its center was positioned forward of the FP but not as much so as in the first three designs.

Presumably, further alterations could optimize the bulb design. However, the intention here was not necessarily to find the most desirable bulb, but rather to show typical steps in design and testing in order to find the optimum bulb.

TEST PROCEDURE AND RESULTS

A 14 ft (L_{BP}) parent model was used in the tests. Resistance and propulsion test results have been reported previously. (Ref. 1).* Other than the bulbs, the rudder was the only appendage attached.

The tests were carried out at constant draft, so that the addition of the bulb increased both wetted area and displacement over that of the

---

* References listed at the end of this report.

bulbless hull. Turbulence was stimulated on the main hull by means of a 0.036 in. diameter trip wire placed 5 per cent of L_{BP} aft of the FP, and on the bulb by round studs 0.032 in. in diameter, 0.020 in. in height spaced 0.5 in. apart.* The protruding ends of the studs were squared off.

The test results were analyzed by The University of Michigan EHP computer program which makes a small blockage correction. (Ref. 2). The 1947 A.T.T.C. friction extrapolator was used to expand the data to a 600 ft L_{BP}, with a roughness allowance of $\Delta C_F = 0.0004$.

Figure 7 shows the sectional area curves for the bulbless hull and the hull when fitted with each of the five bulbs.

Figures 8 through 10 give the test results in terms of C_R, EHP and EHP per ton of displacement. Table 4 gives model resistance in lb corresponding to the bulbless hull and to the hull fitted with each of the five bulbs. Table 5 gives EHP and EHP per ton of displacement for a 600 ft L_{BP} for the bulbless hull and for the hull fitted with each of the five hulls. In addition, the latter gives the per cent increase in EHP due to the fitting of the bulb as compared to the bulbless hull. It should be pointed out that some ambiguity is introduced regarding C_R, since this coefficient is a function of wetted surface which is slightly different in each case. Instead of the wetted surface, the square of the constant characteristic length, either L_{WL} or L_{BP}, could have been used in the expression for C_R, but this would have been against accepted practice. Also in the present case, as wetted surface increased, so did displacement, and hence resistance. Only slight discrepancies result when

* The position of the line of studs on the bulb was determined by the bulb and cone with its apex located at the center of the bulb and apex half angle of 65 deg. This location of stimulation is the same as used on sphere drag tests in order to induce turbulent separation.

using the standard definition of C_R.

The test results are shown more strikingly in Figure 8. Bulb B5 is shown to decrease resistance, as compared to the bulbless hull, over a much broader range of speed than the other bulbs. However, the performance of B5 at high speeds is not as good as that of the first three bulbs. While bulbs B1, B2 and B3 over-cancelled, mainly because of their large size, B5 appears close to optimum with respect to both size and location. Bulb B5 may under-cancel owing to its small size.

Bulb B2 had the lowest resistance at the high speeds, but nearly the same as B5 at the trial speed of 23.54 knots. As shown in Table 5, the reductions in EHP were 5.1 and 5.0 per cent for B2 and B5 respectively at 24 knots. The latter figures reflect differences in wetted surface and displacement not shown in Fig. 8. At the trial condition, both B2 and B5 bulbs enable the ship to attain about one-quarter of a knot higher speed with the same power, assuming the same hull efficiency.

CONCLUSIONS

The bulb designs and tests reported herein were begun before analytical investigations of the hydrodynamic characteristics of the bulbless hull form were in progress. In view of the information about the bulbless hull form gained through analyses reported under Task 1, bulb B5 appears to be closely optimized within the limitations of the two-dimensional linearized wave-making resistance theory.

The next logical step would be to design a hull with an integral bulb based on the configuration of B5. By retaining the principal dimensions and displacement of the bulbless hull, further reduction in resistance in the design speed range should be expected.

Table 1

Bulbless Parent Model Characteristics

Series 60; $C_B = 0.60$

U of M Model No. 912

$L_{WL} = 14.235$ ft.

$L_{BP} = 14.000$ ft.

$B = 1.867$ ft.

$H = 0.747$ ft.

$B/L_{WL} = 0.131$

$H/L_{WL} = 0.0524$

$L_{BP}/\nabla^{1/3} = 6.165$

$C_B = 0.600$

$C_X = 0.977$

$C_P = 0.614$

$\frac{1}{2}\alpha = 7.0^\circ$

Design Speed: $V/\sqrt{L_{WL}} = 0.894$; $v/\sqrt{gL_{WL}} = 0.268$

Trial Speed: $V/\sqrt{L_{WL}} = 0.952$; $v/\sqrt{gL_{WL}} = 0.285$

Table 2

Existing Bulb Design Data

No.	Ship or Model	Main Hull Characteristics							$\frac{V}{\sqrt{L}}$ *	Bow Bulb Characteristics, per Cent						Remarks
		Δ	L	B/L	H/L	C_B	$L/\nabla^{1/3}$	$1/2\alpha_E$		a_o/L	$\delta\nabla/\nabla$	$\delta S/S$	A_B/A_X	h/L	ℓ/L	
1	C-101-F1	—	—	0.0904	0.068	—	6.30	12.5	0.85	2.6	2.13	4.41	21.0	4.0	4.0	Streamline form, rocker bottom
2	C_{FK}-101-F1	—	—	0.0904	0.060	0.627	6.66	12.5	0.85	2.6	2.51	4.89	25.0	4.0	4.0	Streamline form, flat bottom
3	C_{FK}-101-F2	—	—	0.0904	0.060	0.627	6.66	12.5	—	2.8	4.60	6.99	40.5	4.8	5.3	Streamline form, flat bottom
4	C-201-F2	—	—	0.121	0.074	—	5.52	18.0	0.90	3.3	4.06	9.96	22.1	5.4	6.0	Streamline form, rocker bottom
5	$M44_F$-BB1	—	—	0.210	0.12	0.548	3.18	26.5	0.95	4.3	4.35	9.60	27.4	7.5	5.0	Fishing boat
6	UF3(x UF7)F1	—	—	0.152	0.060	0.580	4.34	19.0	0.93	3.0	1.95	3.09	20.0	4.2	-2.0	Streamline form, simulated high-speed freighter
7	Railway Ferry	—	—	0.157	0.040	0.545	5.02	—	0.90	2.0	2.02	3.18	20.1	3.0	1.0	Modified streamline form
8	Ocean. Research Ship	642	147	0.224	0.065	0.486	3.90	13.0	1.00	2.5	1.92	4.64	16.5	5.0	1.3	
9	Kurenai Maru	2,333	262	0.168	0.049	0.526	4.60	11.0	1.10	1.9	1.96	3.88	16.8	2.5	1.9	Passenger coaster
10	Jap. Escort Ship	2,890	378	0.116	0.031	0.511	8.13	7.7	1.10	1.6	1.87	4.22	25.6	3.1	3.1	

*$L=L_{BP}$=length between perpendiculars, ft

B=beam, ft

H=mean draft, ft

C_B=block coefficient

$1/2\alpha_E$=half angle of entrance at LWL

∇=volume of displ. of hull without bulb

$\delta\nabla$=incr. of volume of displ. due to bulb

S=wetted surf. of main hull without bulb

S=incr. of wetted surf. due to bulb

Δ=displacement, long tons

V=speed in knots

a_o=mean radius of bulb=(width + height)/4

h=depth of bulb center below LWL

ℓ=longitudinal distance of bulb center from FP(+ forward, -aft)

A_B=transverse sectional area of bulb at its center

A_X=main hull midship sectional area

Table 3

Bulb Characteristics

No.	a_o/L %	h/L %	ℓ/L %	$\delta\nabla/\nabla$ %	$\delta S/S$ %	A_B/A_X %
B1	2.05	4.05	2.74	1.91	4.54	19.5
B2	1.95	3.72	2.68	1.95	4.40	17.1
B3	1.84	3.68	1.20	1.42	3.20	16.9
B4	1.90	3.68	-1.90	1.10	1.39	14.6
B5	1.44	4.15	0.60	0.79	1.79	11.3

Remarks: Negative values of ℓ/L indicates a center of bulb location aft of F.P.

$L = L_{BP}$

Table 4
Model Resistance

$\frac{V^*}{\sqrt{L}}$	v, ft/sec	Pounds Resistance					
		Bare Hull	B1	B2	B3	B4	B5
0.3	1.912	0.43	0.48	0.54	0.53	0.54	0.52
0.4	2.549	0.82	0.97	1.00	0.96	0.92	0.90
0.5	3.187	1.131	1.53	1.58	1.49	1.45	1.30
0.6	3.824	1.89	2.11	2.19	2.05	2.09	1.92
0.7	4.460	2.55	2.76	2.86	2.73	2.75	2.52
0.8	5.097	3.31	3.58	3.57	3.42	3.49	3.27
0.9	5.736	4.65	5.00	4.96	4.92	4.86	4.59
1.0	6.372	7.02	6.56	6.66	6.79	6.75	6.58
1.1	7.009	8.80	7.94	8.09	8.03	8.19	8.08
1.2	7.647	--	9.46	--	--	--	--
Test Water Temp. $^{\circ}F$		70	71	71	72	70	68

* $L = L_{WL}$

Table 5

EHP and EHP/Δ for L_{BP}=600 ft

V_K	$\frac{V}{\sqrt{L}}$ *	EHP						EHP/Δ						% EHP Change Due To Bulb**				
		Bare Hull	B1	B2	B3	B4	B5	Bare Hull	B1	B2	B3	B4	B5	B1	B2	B3	B4	B5
12	0.486	2,250	2,900	3,000	2,930	2,820	2,630	0.0854	0.1080	0.1117	0.1096	0.1059	0.0990	28.9	33.3	30.2	25.3	16.9
13	0.526	2,870	3,630	3,790	3,650	3,580	3,300	0.1089	0.1352	0.1411	0.1366	0.1344	0.1242	26.5	32.1	27.2	24.7	15.0
14	0.567	3,620	4,450	4,620	4,450	4,400	4,000	0.1374	0.1657	0.1720	0.1665	0.1652	0.1506	22.9	27.6	22.9	21.5	10.5
15	0.607	4,490	5,390	5,640	5,380	5,380	4,820	0.1704	0.2007	0.1884	0.2013	0.2020	0.1815	20.0	25.6	19.8	19.8	7.3
16	0.648	5,450	6,410	6,730	6,380	6,470	5,710	0.2068	0.2387	0.2506	0.2387	0.2429	0.2150	17.6	23.5	17.1	18.7	4.8
17	0.688	6,620	7,610	7,980	7,420	7,670	6,780	0.2512	0.2834	0.2971	0.2777	0.2879	0.2553	15.0	20.6	12.1	15.9	2.4
18	0.729	7,960	9,070	9,350	8,700	9,000	8,030	0.3021	0.3378	0.3481	0.3256	0.3379	0.3023	13.9	17.4	9.3	13.0	0.9
19	0.769	9,480	10,800	10,900	10,200	10,530	9,600	0.3598	0.4022	0.4058	0.3817	0.3953	0.3614	13.9	15.0	7.6	11.1	1.3
20	0.810	11,300	13,090	12,850	12,170	12,380	11,580	0.4288	0.4875	0.4784	0.4554	0.4647	0.4360	15.8	13.7	7.7	9.6	2.5
21	0.850	13,780	15,870	15,380	14,700	14,660	14,190	0.5230	0.5910	0.5726	0.5501	0.5503	0.5369	15.2	11.6	6.7	6.4	3.0
22	0.891	17,400	19,200	18,480	18,100	17,980	17,540	0.6603	0.7150	0.6880	0.6773	0.6750	0.6623	10.3	6.2	4.0	3.3	0.8
23	0.931	22,390	23,100	22,200	22,230	22,200	21,610	0.8497	0.8602	0.8265	0.8318	0.8334	0.8136	3.2	-0.9	-0.7	-0.9	-3.5
24	0.972	28,000	27,150	26,580	26,600	27,040	26,600	1.0626	1.0111	0.9896	0.9954	1.0151	1.0015	-3.1	-5.1	-5.0	-3.4	-5.0
25	0.012	33,680	31,100	30,850	30,900	31,900	31,400	1.2780	1.1580	1.1485	1.1563	1.1975	1.1822	-7.7	-8.4	-8.3	-5.3	-6.8
Δ=displacement in S.W. @ 59°F								26,349	26,852	26,863	26,723	26,639	26,557					

*$L=L_{WL}$

** + when bulbous bow is inferior, - when bulbous bow is superior

Design Speed

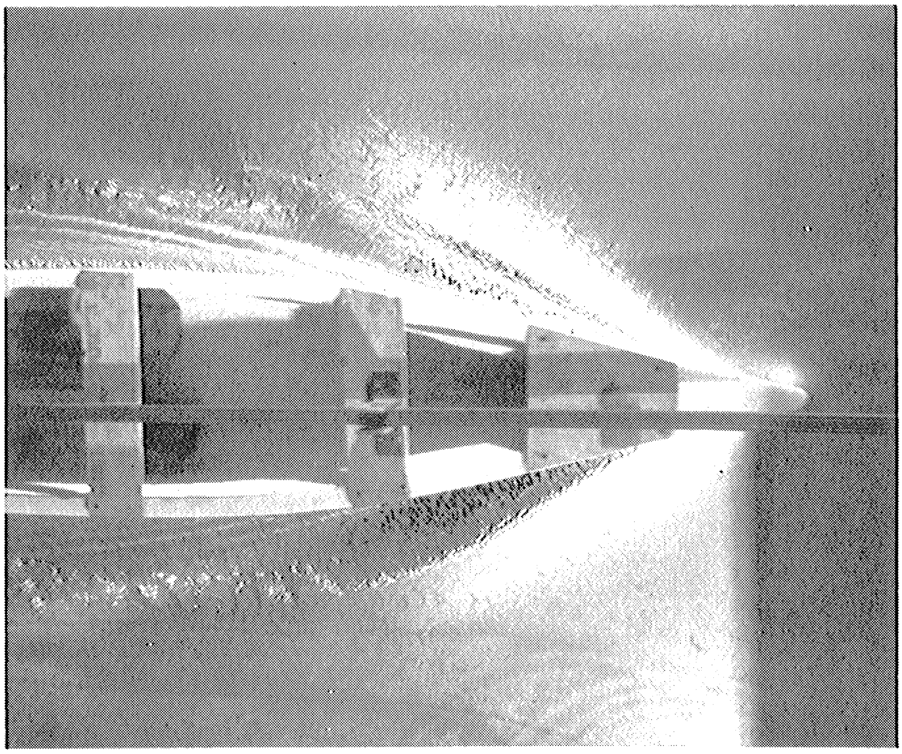
V_K=22.08 knots

$V/\sqrt{L}$=0.894

Trial Speed

V_K=23.51 knots

$V/\sqrt{L}$=0.952



Note: This photograph was obtained using the aluminum powder technique.

Fig. 1. Wave pattern of high speed cargo liner model.

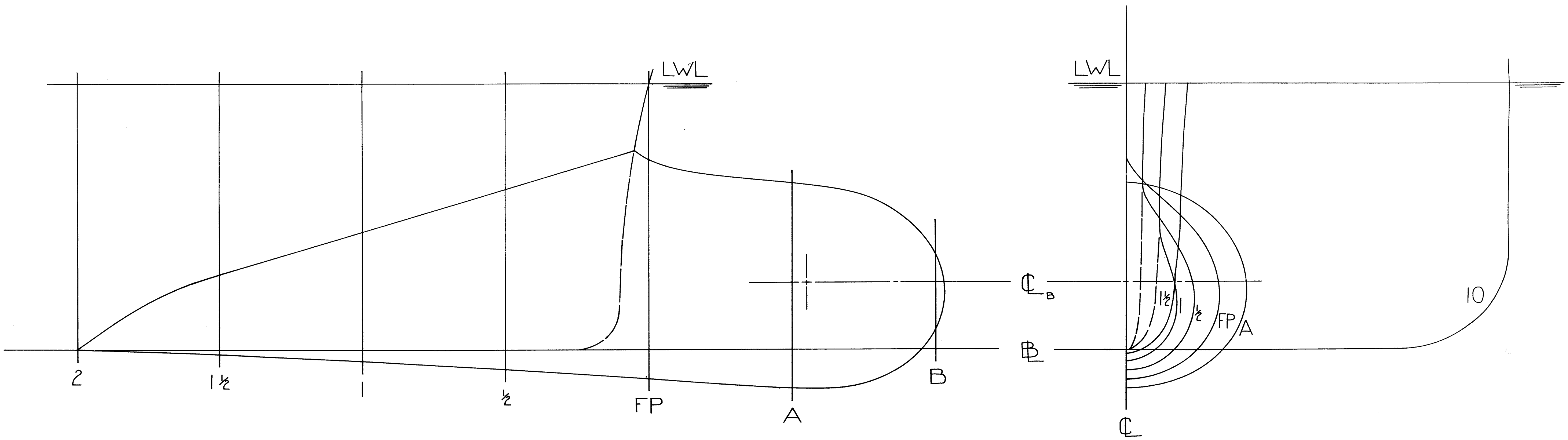


Fig. 2. Bulb Bl lines.

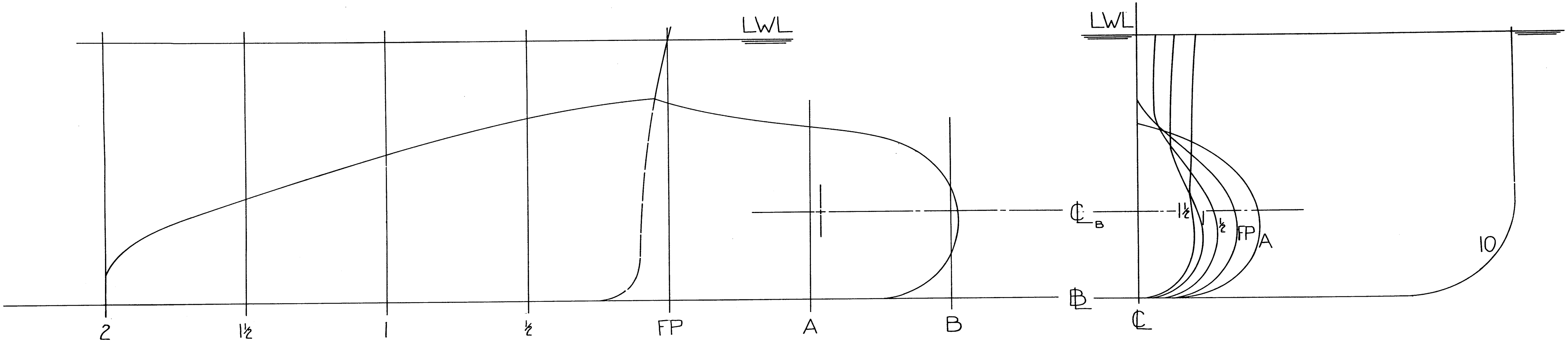


Fig. 3. Bulb B2 lines.

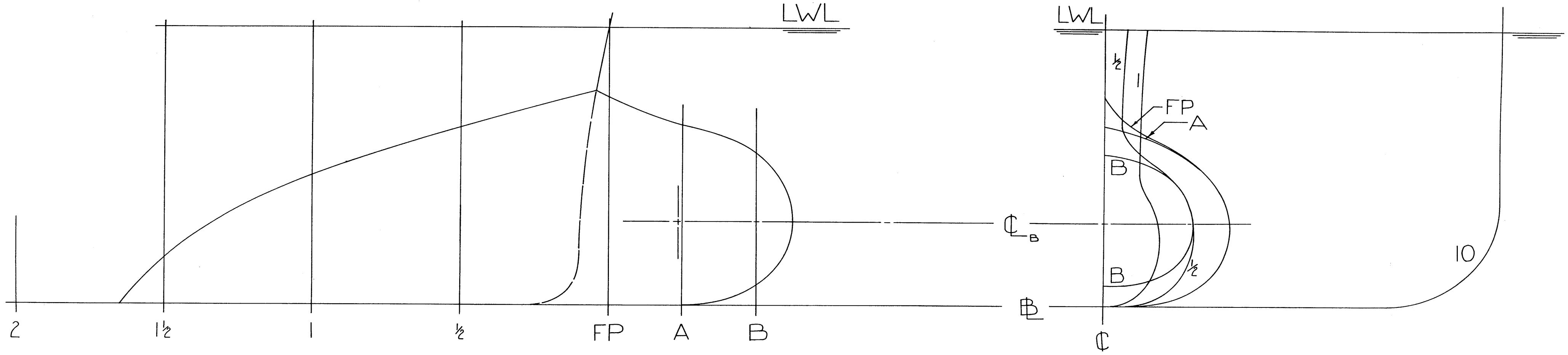


Fig. 4. Bulb B3 lines.

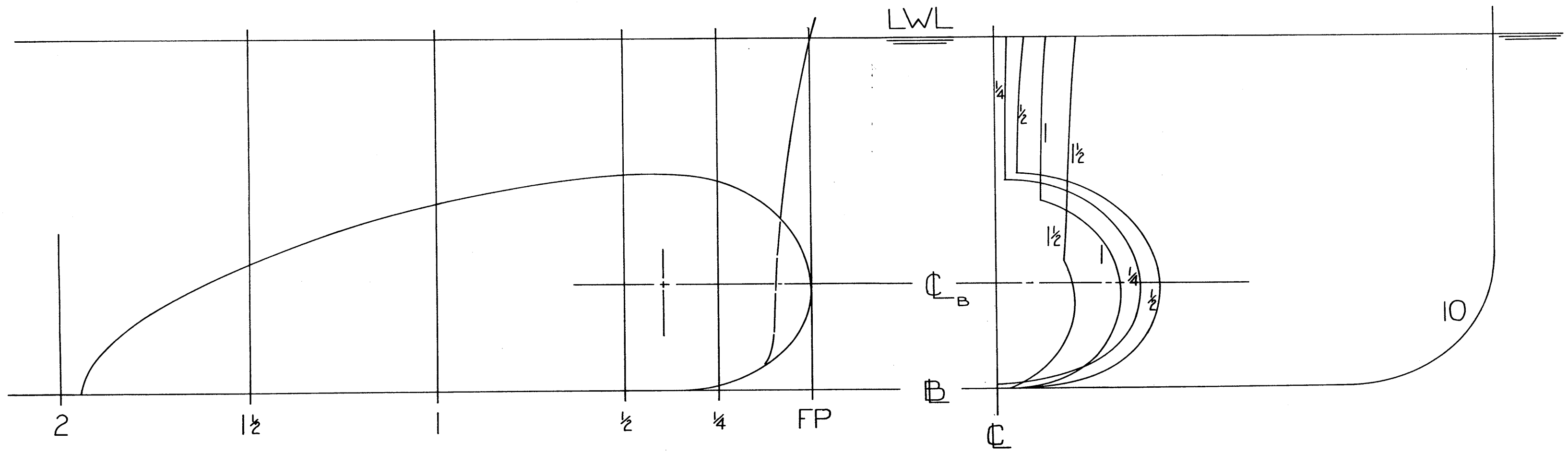


Fig. 5. Bulb B4 lines.

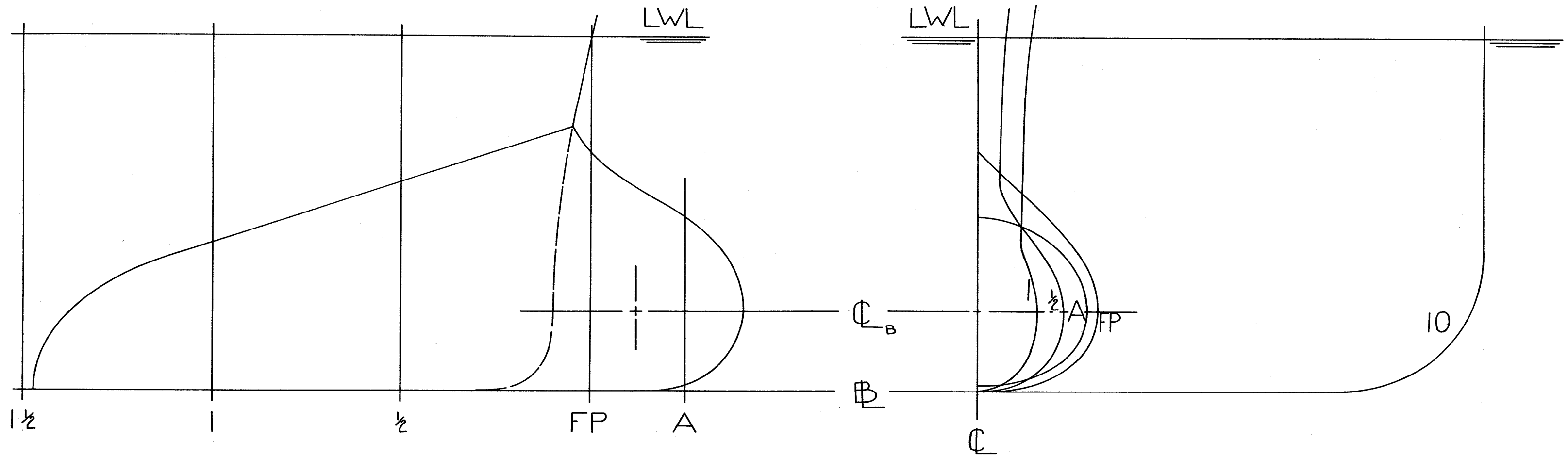


Fig. 6. Bulb B5 lines.

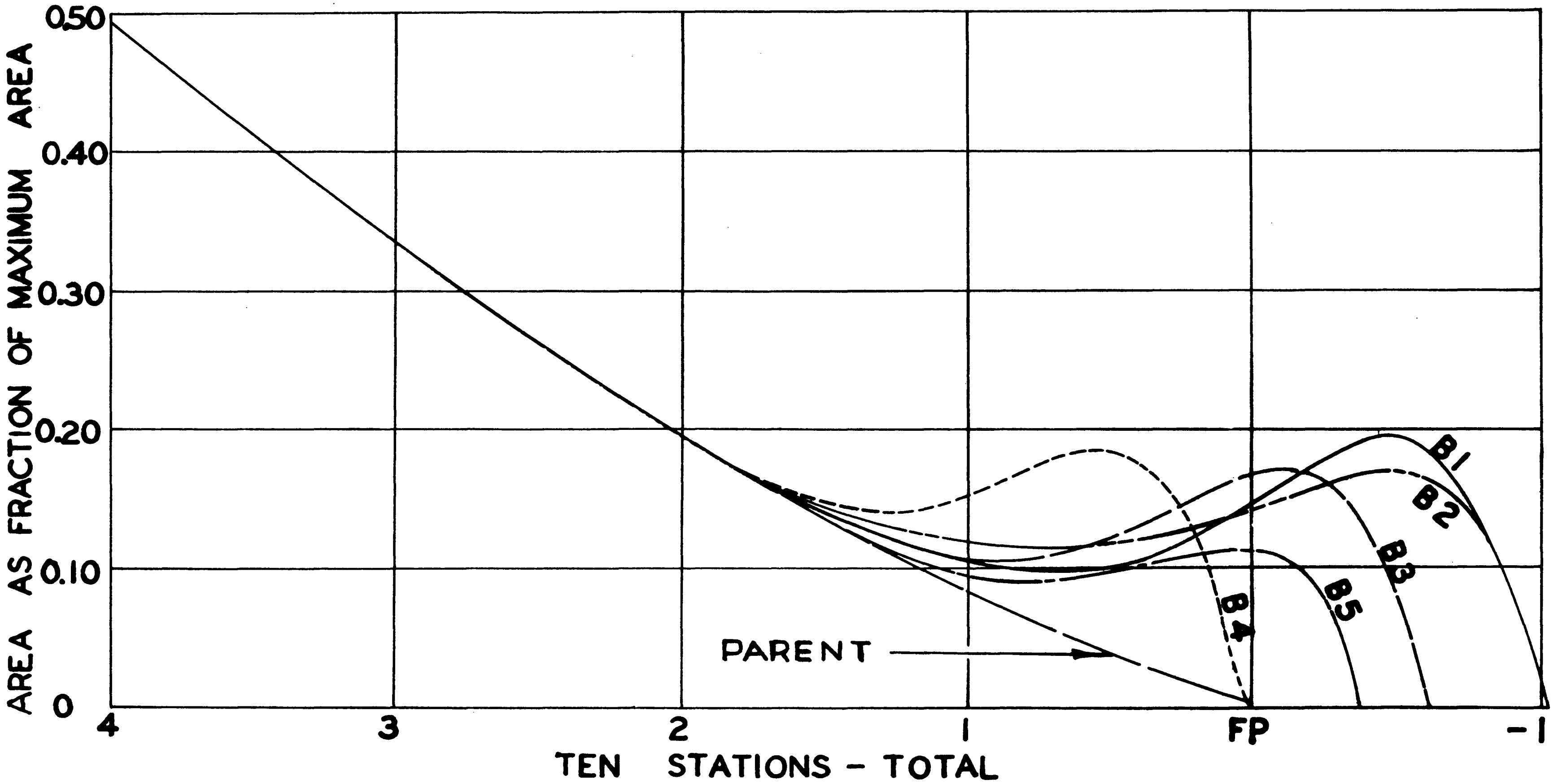


Fig. 7. Sectional area curves, bulbless parent and parent fitted with B1-B5 bulbs.

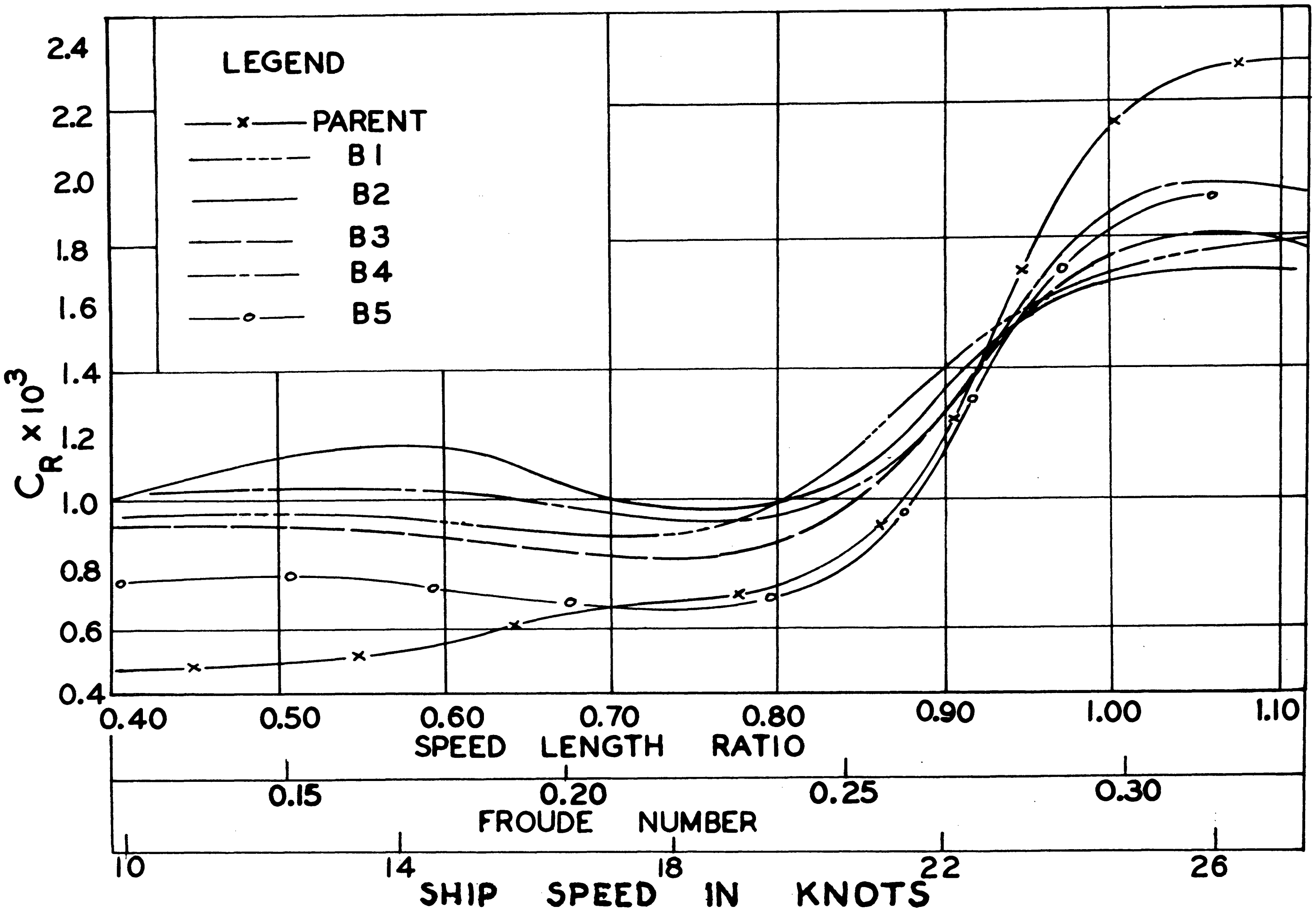


Fig. 8. C_R curves, bulbless parent and parent fitted with B1-B5 bulbs.

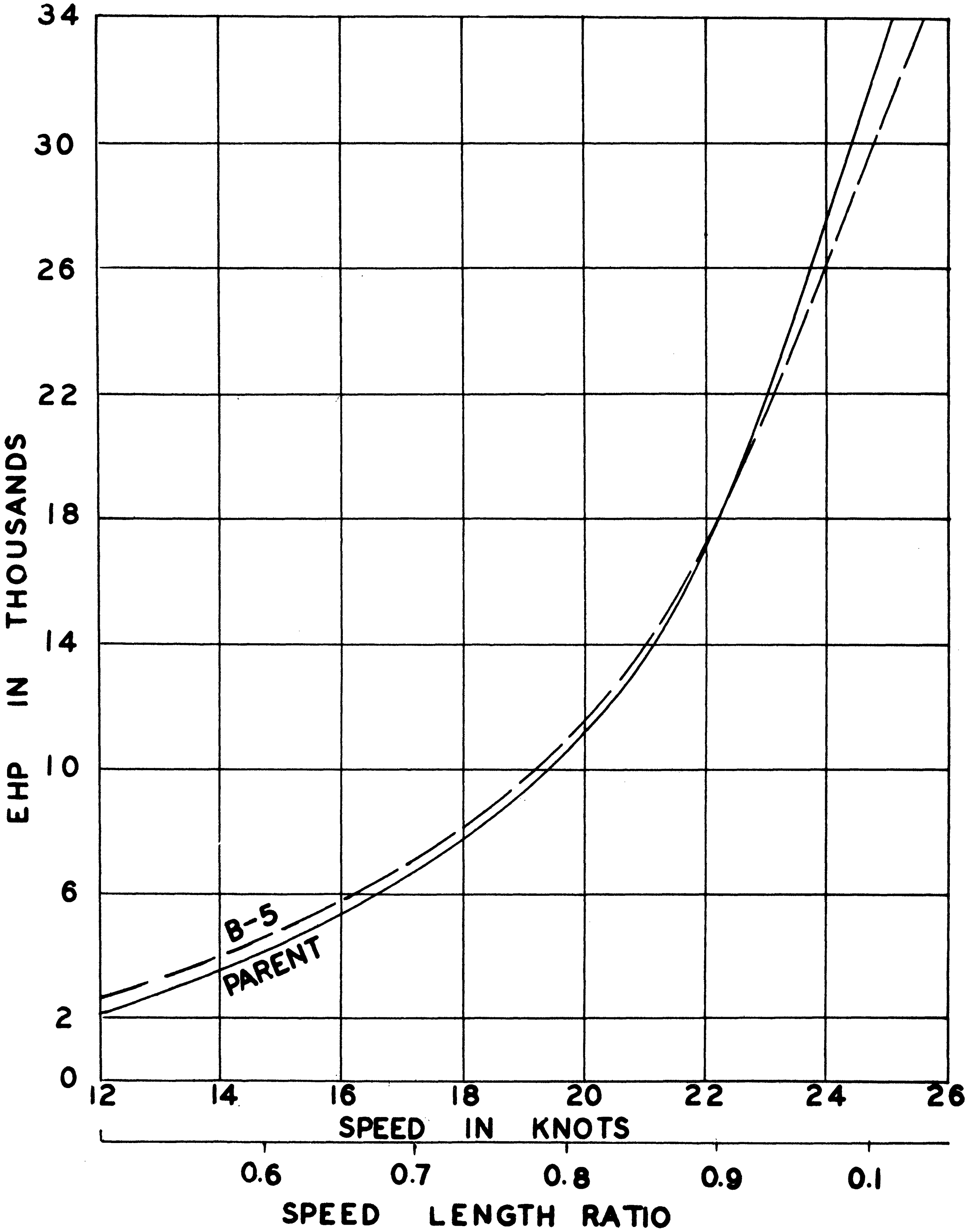


Fig. 9. EHP curves L_{BP} = 600 ft for bulbless parent and parent fitted with B5 bulb.

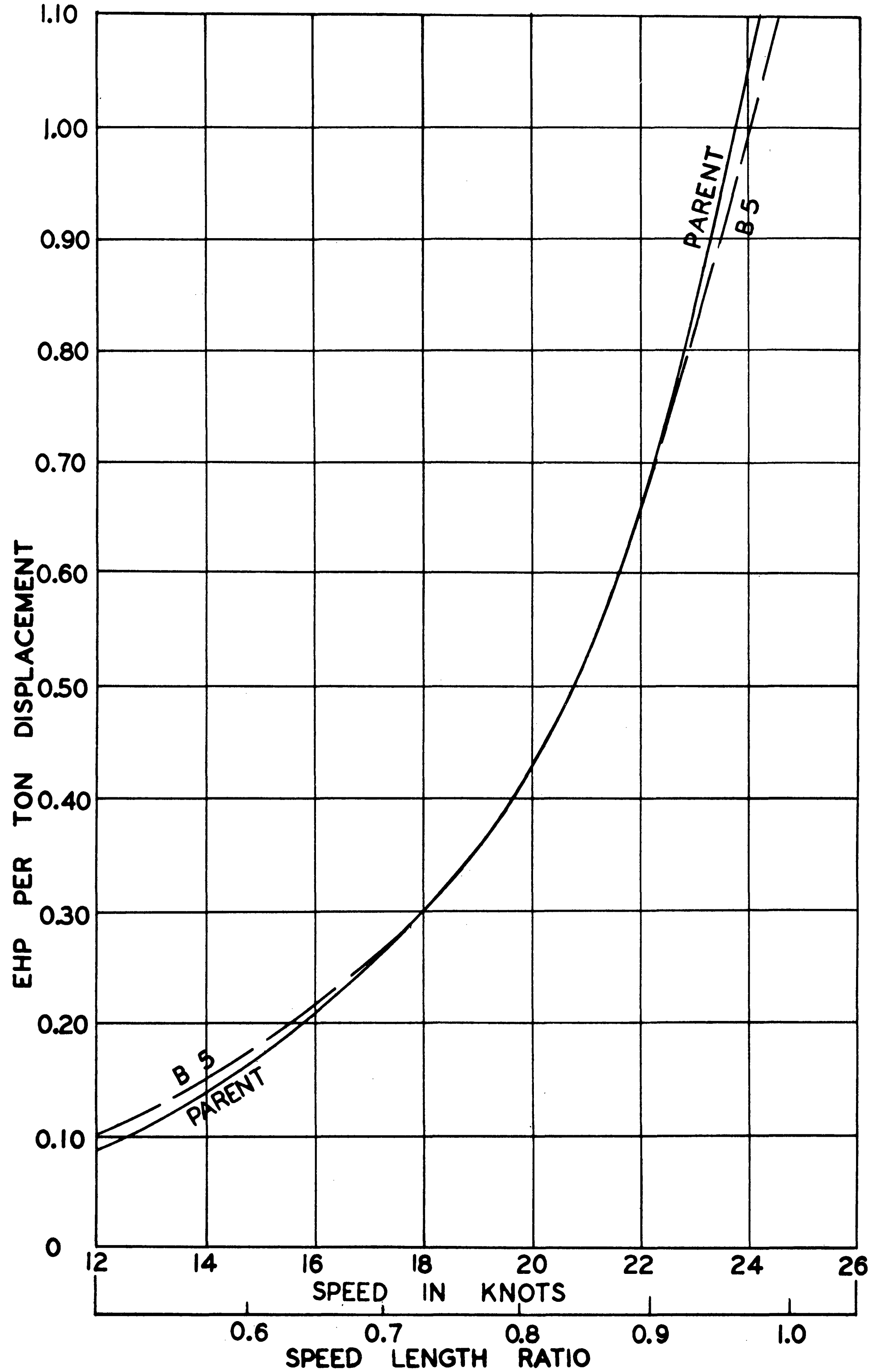


Fig. 10. EHP/Δ curves L_{BP} = 600 ft for bulbless parent and parent fitted with B5 bulb.

Part II. Series 60, C_B = 0.70

INTRODUCTION

In the first part of this report the purpose and necessary techniques of incorporating a bow bulb to ship's hulls are explained. In addition, the results of fitting a bulb to an existing hull of conventional form are presented.

This report describes a second attempt to design a large bulbous bow for a conventional merchant ship form. In this case the following procedures and conditions were investigated:

(a) The two approaches of incorporating a bow bulb, mentioned in the first part of this report, were used in combination.

(b) Different size fillets were used behind the bow bulb to fair it into the main hull to ascertain how this would affect form drag.

(c) Tests at the ballast load of 60 per cent of full load were carried out, in addition to those at 100 per cent of full load. This was done realizing the importance of ship's resistance in the ballast condition.

MODEL AND BULB DESIGNS

In this second attempt to design a large bulbous bow for a conventional merchant ship, the Series 60, $C_B = 0.70$, $L/\nabla^{1/3} = 5.944$, was chosen as being a typical hull form. The dimensions and characteristics of the corresponding bulbless parent (U. of M. Model No. 902A*, Fig. 11) are given in Table 6.

*Model 902A was used earlier at the University of Michigan to investigate a systematic set of variations on the Series 60, $C_B = 0.70$, $L/\nabla^{1/3} = 5.944$ hull form (D.T.M.B. Model No. 4259). These variations consisted of three conventional bulbous bows of three, six and nine per cent area (Model Nos. 902B, 902C and 902D respectively), which were compared with the bulbless parent form of Model 902A. The results of this investigation are reported in the publication of ref. 3.

The bow bulb chosen for these experimental investigations was designed by the waveless hull theory. Its dimensions and characteristics are near the optimum for minimizing the wave resistance of the parent hull. The size of this bulb was characterized by a sectional area at its center (A_B) of 11 per cent that of the midship sectional area of the main hull (A_X) and a mean radius (a_o) of 1.6 per cent of the length between perpendiculars (L_{BP}) of the bulbless parent hull. These bulb features are very close to those of bulb B5 of the first part of this report, which proved to be superior to the four other bulbs tried with the Series 60, C_B = 0.60 hull form. The same bulb was incorporated in the former model numbers 902A, 902C and 902D of ref. 3. The new models 902A-B1 and 902A-B1M were alterations of model 902A, and 902C-B1 and 902D-B1 were respectively alterations of models 902C and 902D. The general characteristics of the new models with their integrated bulb are given in Table 7 and brief descriptions follow.

Model 902A-B1 (Fig. 12):

In this model the bow bulb center was placed forward of the FP and faired into the main hull by means of a regular size fillet.

Model 902A-B1M (Fig. 13):

Here also the bulb center was placed forward of the FP, but as compared to model 902A-B1 it was faired into the main hull using a larger fillet, to ascertain whether the form drag of the bulb could thus be reduced, especially in the ballast condition. Because of its larger fillet, this model had slightly greater volumes of displacement both in the full load and ballast condition as compared to those of model 902A-B1. However, the wetted surfaces for both loading conditions were the same as for the latter model.

Model 902C-B1 (Fig. 14):

In this model the bow bulb center was placed forward of the FP and faired into the main hull using a regular size fillet. The volumes of displacement for both the full load and ballast conditions and the wetted surface for the full load conditions were slightly less than those for model 902A-B1. However, the wetted surface for the ballast condition was slightly greater than the corresponding value for the latter model.

Model 902D-B1 (Fig. 15):

Here the bow bulb center was placed at the FP. The volumes of displacement, both in the full load and ballast conditions, were the same as those of model 902C-B1 and the wetted surfaces for the two loading conditions, while slightly greater, were practically the same as those for the latter.

Wave-making resistance is mainly influenced by the geometry of the ship's entrance or by the shape of the sectional area curve forward. Figure 16 shows the sectional area curves for the models described previously, including that for the bulbless parent hull.

TEST PROCEDURE AND RESULTS

A 12.5 ft (L_{BP}) parent model was used in these tests. Resistance test results for this model were reported previously in ref. 3. In the new tests, other than the bulbs, the rudder was the only appendage attached.

Regular resistance tests were carried out with each of the five models of Tables 6 and 7 for two loading conditions, i.e., full load, and ballast at a displacement of 60 percent that of full load. Throughout each condition the drafts were kept constant in all models at the values shown in Table 6 for model 902A. Because of this, the displacement and wetted surface of the five models were slightly different during the tests, as shown in Tables 6 and 7. However, the effect of these differences on the resistance results may be justly disregarded.

Turbulence was stimulated in the way described on page 6 of the report.

Test results were analyzed also in the manner explained on page 6.

Figures 17 through 20 give the test results in terms of C_R and EHP. Tables 8 and 9 give resistance in lb for models corresponding to their parent bulbless hull and to the four other hulls with bulbous bow. Tables 10 and 11 give EHP for a 600 ft L_{BP} for the bulbless hull and for each of the four hulls with integrated bow bulbs.

Photographs were taken of the wave profile alongside models 902A and 902A-B1M, and comparing these pictures, the difference of wave profile due to the bulb was investigated. Figures 21 through 23 show the wave profile for the full load condition and Figs. 24 through 26 show it for the ballast condition.

DISCUSSION OF RESULTS AND CONCLUSIONS

The C_R curves of Fig. 17, for the full load condition, shows clearly that 902A-B1 is the best of all models. The reductions in resistance shown by the latter model over the bulbless parent are 28 per cent at the designed service speed and 19 per cent at the trial speed. The other three bulbous bow models, 902D-B1, 902C-B1 and 902A-B1M, show reductions in C_R of decreasing magnitude in the latter order.

Two facts which follow seem worth mentioning. (a) The order of increasing fullness of the entrance was given by 902D, 902C, and 902A. The latter fitted with the B1 bulb, model 902A-B1, yielded the least C_R values. This fact shows the importance of the proper combination of main hull and bulb. In other words, the optimum configuration of bulbous bow should be figured out from the very first step of the hull design, instead of fitting a bulb to a conventional hull form. (b) Models 902A-B1 and 902A-B1M differ in that the latter had a larger fillet to fair the bow bulb into the main hull. It could have been expected that the larger fillet would decrease form drag and thus yield a lower resistance. The test results, however, indicate that with a larger fillet behind the bulb the residuary resistance is increased both in the full load and ballast condition. The tests, in addition, show that even a substantial hollowness behind the bulb need not produce serious separation drag.

The C_R curves for the ballast condition (displacement 60 per cent that at full load) are shown on Fig. 18. None of the bulbous bow models suceeded in getting lower C_R values than the bulbless parent hull in this condition. Again, the least resistance of the latter models was given by 902A-B1.

The EHP values evaluated for a ship of 600 ft L_{BP} are shown in Fig. 19 for the full load condition and on Fig. 20 for the ballast condition. The best model, 902A-B1, shows a reduction of EHP in the full load condition over the bulbless parent of 8.5 per cent at the service speed and 6.5 per cent at the trial speed. This trend is reversed in the ballast condition and model 902A-B1 shows an increase of 19 per cent over that of model 902A at a speed corresponding to 19 knots.

When considering both the full load and ballast conditions, a somewhat smaller bulb, say 8 per cent as defined on Table 7, seems desirable.

Table 6

Bulbless Parent Model Dimensions and Characteristics

Series 60, C_B=0.70

U. of M. Model No. 902A, Fig. 11, (see ref. 3)

L_{WL}=12.709 ft	B/H= 3.00	L_E/L_{BP}=0.42
L_{BP}=12.5 ft	L_{BP}/B= 7.00	L_X/L_{BP}=0.119
B= 1.786 ft	$L_{BP}/\nabla^{1/3}$= 5.944	L_R/L_{BP}=0.461
C_B= 0.700	α_E=11.6°	C_{PE}=0.642
C_X=0.986		C_{PR}=0.698
C_P=0.710		

Nomenclature:

L_E=length of entrance

L_X=length of parallel middle body

L_R=length of run

C_{PE}=prismatic of the entrance

C_{PR}=prismatic of the run

Loading Condition	Full Load	Ballast
Draft, ft	H=0.595 (even keel)	H_{fwd}= 0.25 H_{aft}=0.5625 Trim=0.3125
∇, ft^3	9.298	5.570
S, ft^2	28.499	23.037

*Ballast condition is at a displ. of 60% that of FL.

Design Speed: $V/\sqrt{L_{WL}}$=0.695 ; $v/\sqrt{gL_{WL}}$=0.207

Trial Speed: $V/\sqrt{L_{WL}}$=0.755 ; $v/\sqrt{gL_{WL}}$=0.225

Table 7

Large Bulbous Bow Models, Dimensions and Characteristics

Models		902A-B1	902A-B1M[a]	902C-B1	902D-B1[a]
Bulb Features, per cent					
A_B/A_X		11.0	11.0	11.0	11.0
a_o/L_{BP}		1.6	1.6	1.6	1.6
ℓ/L_{BP}		1.0[b]	1.0[b]	1.0[b]	0[c]
p/L_{BP}		2.6	2.6	2.6	1.6
h/H		75.5	75.5	75.5	75.5
Hull Features					
∇ ft^3	Full Load Cond.	9.353	9.372	9.298	9.298
	Ballast Cond.	5.618	5.632	5.579	5.579
S ft^2	Full Load Cond.	29.016	29.016	28.874	28.750
	Ballast Cond.	23.422	23.422	23.438	23.443

(a) Large fillets used behind the bulb to fair it into the main hull.

(b) Bulb center located at station A (see Figs. 12-14).

(c) Bulb center located at FP (see Fig. 15).

Explanations for Table 7

Notes:

1. Original models 902C and 902D had the same dimensions and characteristics listed in Table 1 for model 902A, except for S, $1/2\alpha_E$, and ∇ for the ballast condition.
2. Only the volume of the entrance of models 902A, 902C and 902D was redistributed to obtain models 902A-B1, 902A-B1M, 902C-B1 and 902D-B1.

Ship Nomenclature

L_{BP}=length between perpendiculars, ft

H=draft, ft

∇ =volume of displacement, ft^3

S=wetted surface, ft^2

A_X=midship sectional area, ft^2

Bow Bulb Nomenclature

a_o=mean radius, ft

ℓ =longitudinal position of bulb center (+ fwd., -aft from FP), ft

p=protruding length, ft

h=inmersion of bulb center, ft

A_B=sectional area at bulb center, ft^2

Table 3

Model Resistance - Full Load Condition

$\frac{V}{\sqrt{L}}$ *	v, ft/sec	Pounds Resistance				
		902A (Bulbless Parent)	902A-B1	902A-B1M	902C-B1	902D-B1
0.34	2.015	0.49	0.55	—	0.54	—
0.38	2.269	0.61	0.67	—	0.65	0.64
0.42	2.523	0.75	0.80	0.80	0.78	0.76
0.46	2.775	0.90	0.93	0.94	0.93	0.89
0.50	3.026	1.06	1.09	1.09	1.08	1.05
0.54	3.276	1.24	1.26	1.26	1.26	1.22
0.59	3.524	1.45	1.42	1.43	1.43	1.44
0.63	3.771	1.67	1.61	1.62	1.64	1.64
0.67	4.017	1.90	1.81	1.82	1.85	1.84
0.71	4.264	2.14	2.03	2.07	2.07	2.05
0.75	4.512	2.42	2.35	2.36	2.33	2.30
0.79	4.763	2.82	2.70	2.70	2.65	2.60
0.83	5.018	3.25	3.10	3.12	3.05	2.96
0.88	5.278	—	3.62	3.69	—	3.65
0.92	5.543	4.99	4.46	4.61	4.54	—
Test Water Temp. °F		72	72	74	72	73

$^{*}L = L_{WL}$

Table 9

Model Resistance - Ballast Condition

$\frac{V}{\sqrt{L}}$ *	v, ft/sec	Pounds Resistance				
		902A (Bulbless Parent)	902A-B1	902A-B1M	902C-B1	902D-B1
0.30	1.807	—	0.39	—	—	—
0.33	2.009	0.40	0.49	—	0.54	—
0.38	2.262	0.49	0.65	—	0.69	0.60
0.42	2.514	0.60	0.83	0.74	0.87	0.70
0.46	2.765	0.72	1.05	0.92	1.09	0.92
0.50	3.016	0.84	1.30	1.20	1.36	1.12
0.54	3.265	0.98	1.55	1.46	1.60	1.38
0.58	3.514	1.13	1.79	1.72	1.81	1.64
0.63	3.763	1.30	1.97	1.96	1.90	1.94
0.67	4.010	1.47	1.98	2.11	1.96	2.15
0.70	4.258	1.69	2.06	2.21	2.06	2.22
0.75	4.507	1.89	2.20	2.35	2.18	2.30
0.79	4.758	2.12	2.37	2.51	2.37	2.44
0.83	5.011	2.43	2.57	2.72	2.61	2.63
0.87	5.267	—	2.91	3.03	—	2.74
0.92	5.526	3.30	3.39	3.42	3.37	3.38
0.96	5.789	—	3.97	—	—	3.82
1.01	6.053	4.81	4.77	—	5.22	4.56
Test Water Temp. °F		72	72	74	72	73

*$L=L_{WL}$

Table 10

EHP for L_{BP}=600 ft - Full Load Condition

V_K	$\frac{V}{\sqrt{L}}$ *	EHP					% δEHP** vs 902A			
		902A	902A-B1	902A-B1M	902C-B1	902D-B1	902A-B1	902A-B1M	902C-B1	902D-B1
12	0.486	2,620	2,700	2,780	2,460	2,340	3.05	6.11	6.11	-10.61
13	0.526	3,380	3,470	3,500	3,380	3,380	2.66	3.55	0.00	0.00
14	0.567	4,270	4,280	4,270	4,270	4,390	-0.23	0.00	0.00	2.76
15	0.607	5,390	5,090	5,200	5,230	5,440	-5.57	-3.52	-2.97	0.92
16	0.648	6,670	6,170	6,260	6,350	6,600	-7.39	-6.15	-4.80	-1.05
17	0.688	8,060	7,400	7,570	7,620	7,700	-8.18	-6.08	-5.46	-4.47
18	0.729	9,660	8,940	9,230	9,100	9,100	-7.45	-4.45	-5.80	-5.80
19	0.769	11,880	11,130	11,310	10,990	10,970	-6.31	-4.80	-7.49	-7.66
20	0.809	14,830	13,800	13,990	13,430	13,230	-6.95	-5.66	-9.44	-12.09
21	0.850	18,160	17,000	17,310	16,600	16,250	-6.38	-5.23	-8.59	-10.51
Δ		28,632	28,802	28,857	28,632	28,632				

*$L=L_{WL}$, Δ=displacement in S.W. @ 59°F long tons

**+ when bulbous bow is inferior, - when bulbous bow is superior

Design Speed

V_K=17.1 knots

$V/\sqrt{L}$=0.695

Trial Speed

V_K=18.6 knots

$V/\sqrt{L}$=0.755

Table 11

EHP for L_{BP}=600 ft - Ballast Condition

V_K	$\frac{V}{\sqrt{L}}$ *	EHP					% δ EHP vs 902A			
		902A	902A-B1	902A-B1M	902C-B1	902D-B1	902A-B1	902A-B1M	902C-B1	902D-B1
12	0.486	2,060	3,730	3,400	4,070	3,000	81.1	65.0	97.6	45.6
13	0.526	2,670	5,100	4,700	5,310	4,570	91.0	76.0	98.9	71.2
14	0.567	3,340	6,420	5,950	6,600	5,970	92.2	78.1	97.6	78.7
15	0.607	4,170	7,750	7,450	7,490	7,490	85.9	78.6	79.6	79.6
16	0.648	5,100	8,380	8,750	8,030	8,720	64.3	71.6	57.5	71.0
17	0.688	6,220	8,700	9,700	8,690	9,770	39.9	55.9	39.7	57.1
18	0.729	7,450	9,610	10,640	9,530	10,440	29.0	42.8	27.9	40.1
19	0.769	8,990	10,800	11,800	10,700	11,280	20.1	31.3	19.0	25.5
20	0.809	10,780	12,130	13,120	12,300	12,540	12.5	21.7	13.7	16.3
21	0.850	13,130	14,040	15,020	14,220	14,250	6.9	14.4	8.3	8.5
△		17,152	17,300	17,341	17,180	17,178				

*$L+L_{WL}$, △ =displacement in S.W. @ 59°F long tons

**+ when bulbous bow is inferior, - when bulbous bow is superior

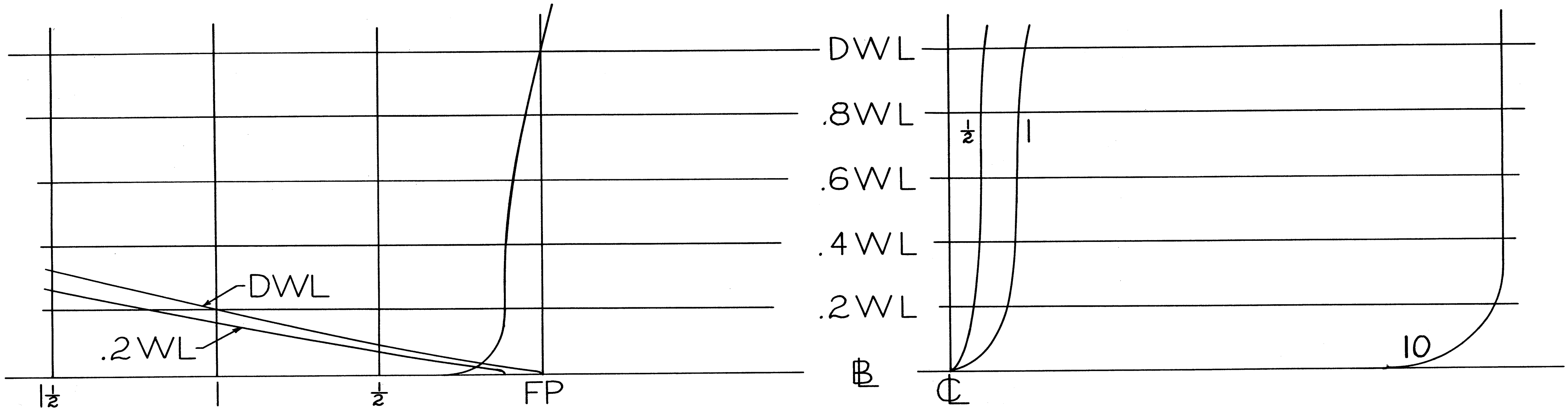


Fig. 11. Bulbless parent 902A bow lines.

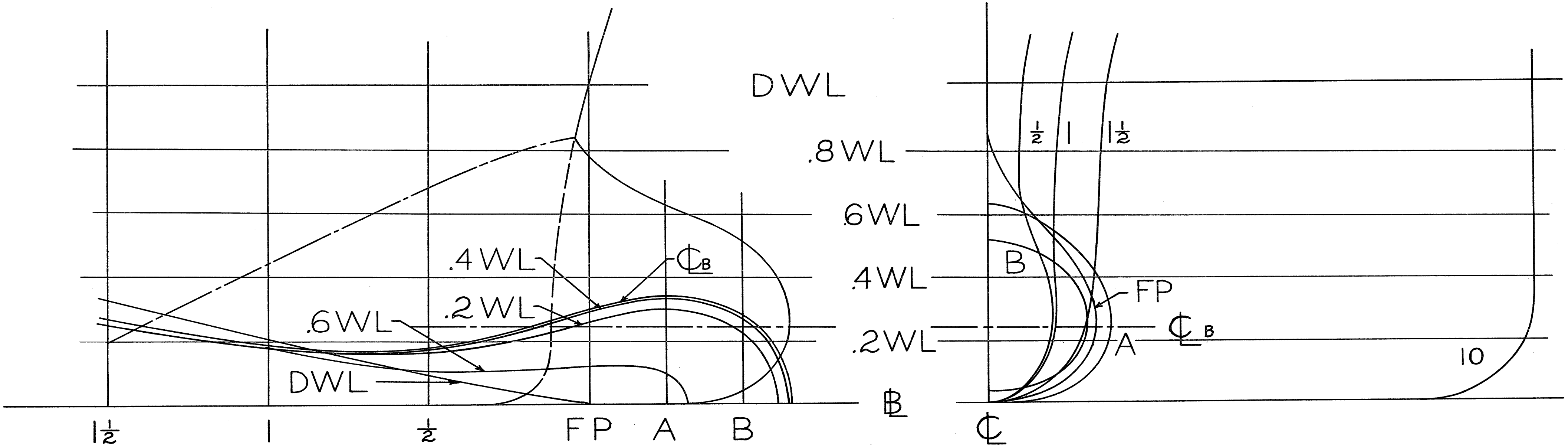


Fig. 12. Model 902A-B1 bulb lines.

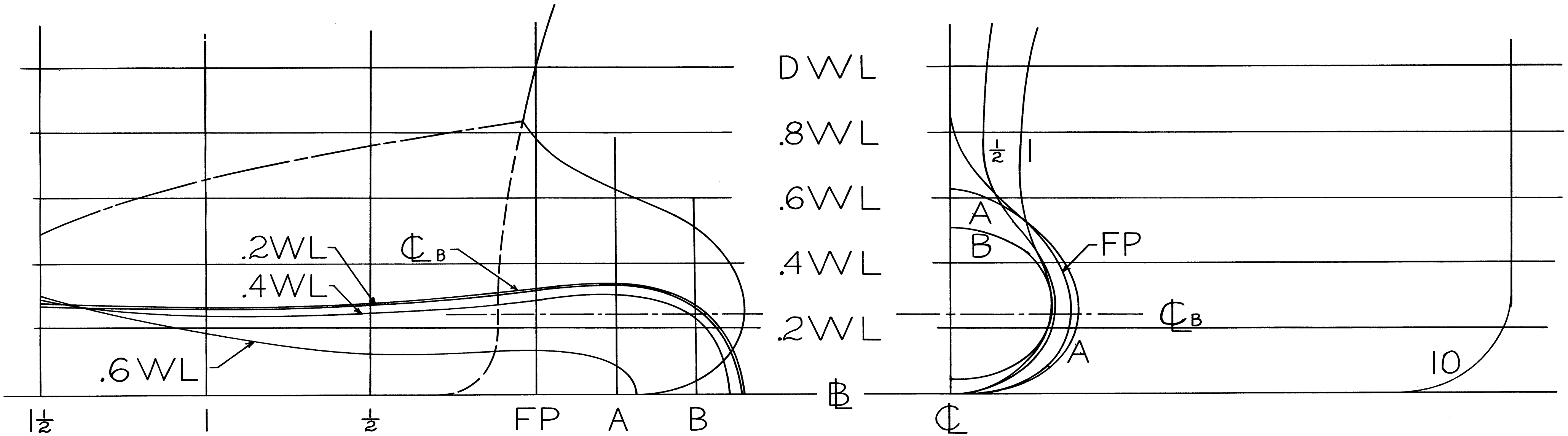


Fig. 13. Model 902A-B1M bulb lines.

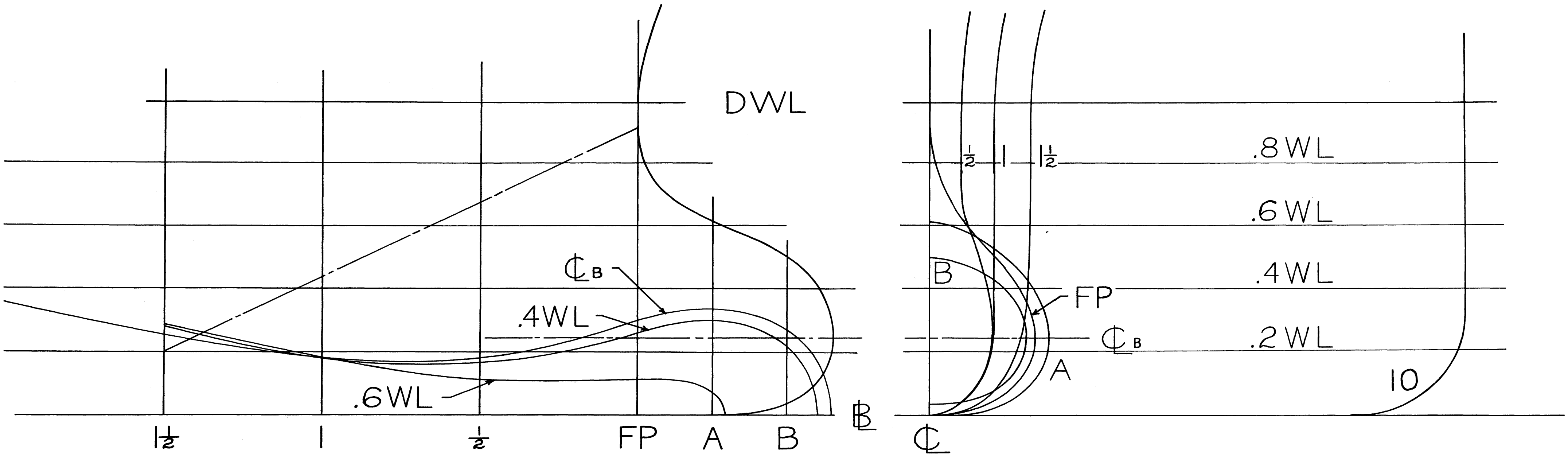


Fig. 14. Model 902C-B1 bulb lines.

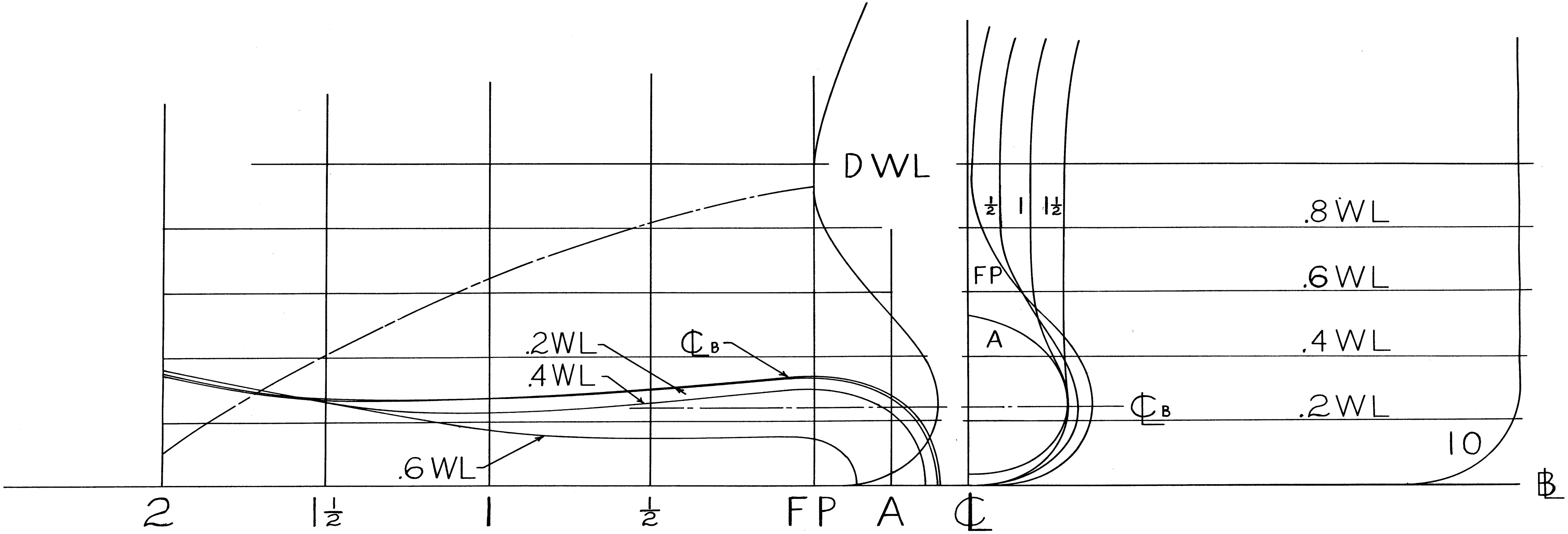


Fig. 15. Model 902D-B1 bulb lines.

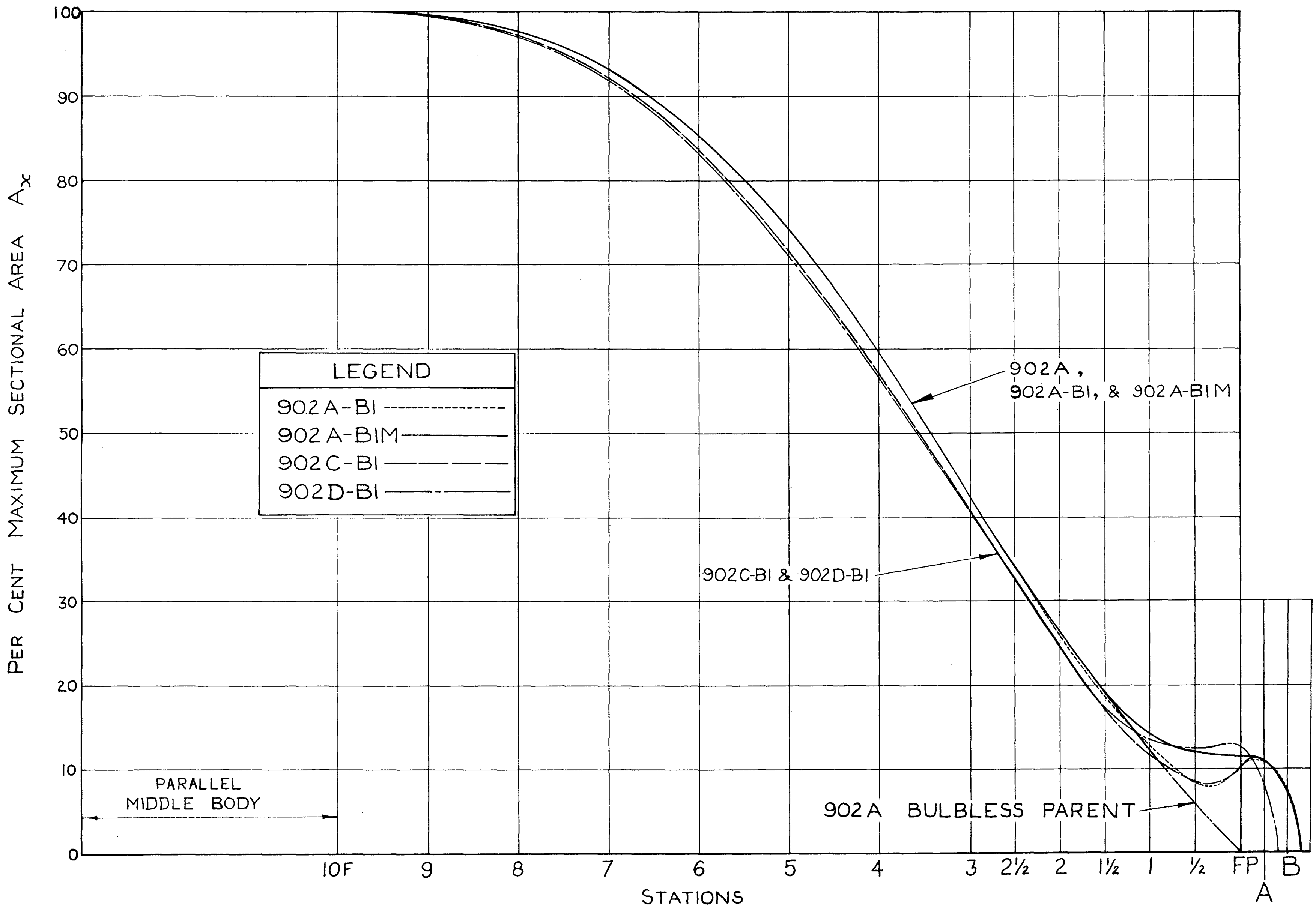


Fig. 16. Sectional area curves, 902A, 902A-B1, 902A-B1M, 902C-B1, and 902D-B1.

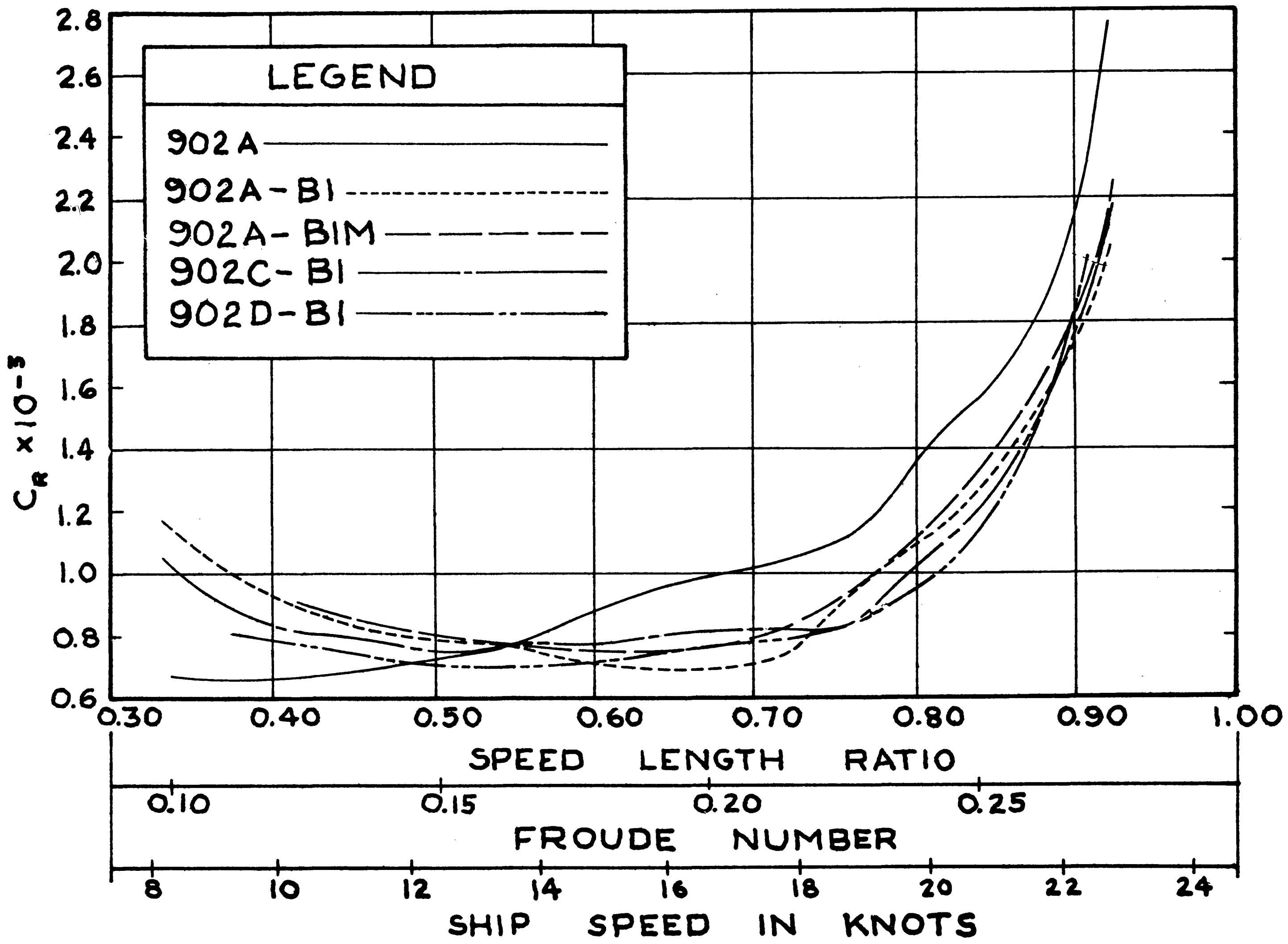


Fig. 17. C_R curves, full load condition.

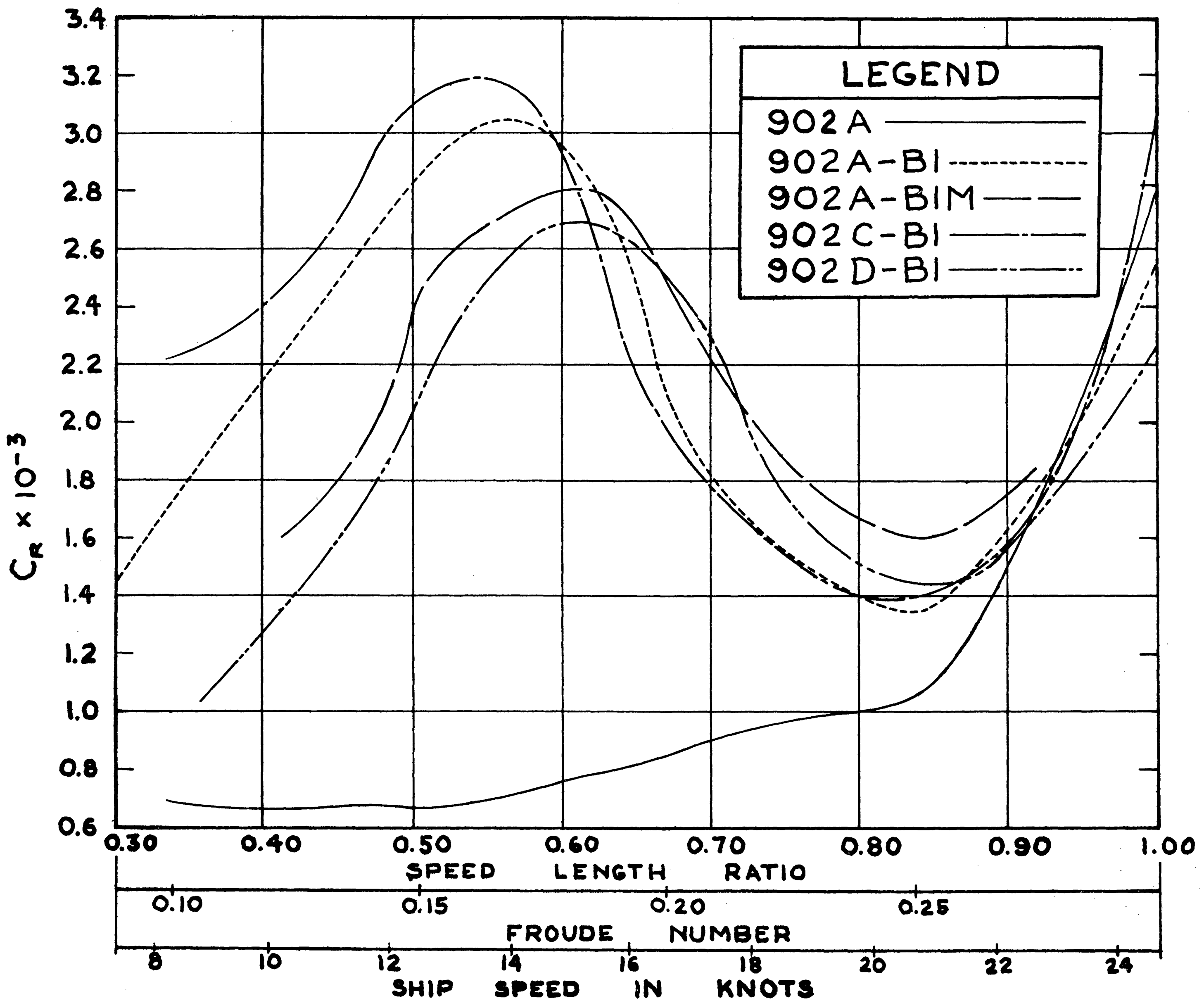


Fig. 18. C_R curves, ballast condition.

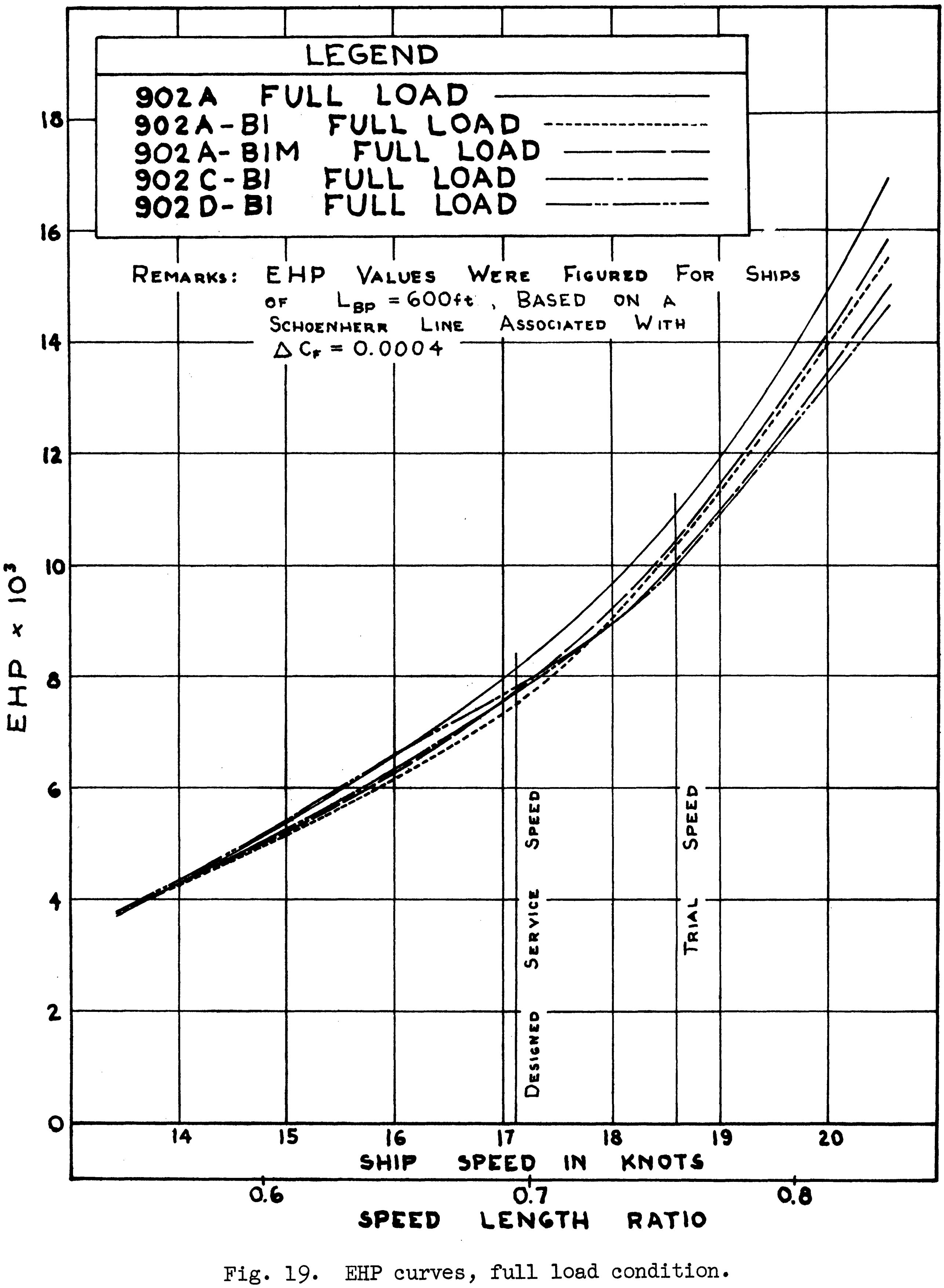


Fig. 19. EHP curves, full load condition.

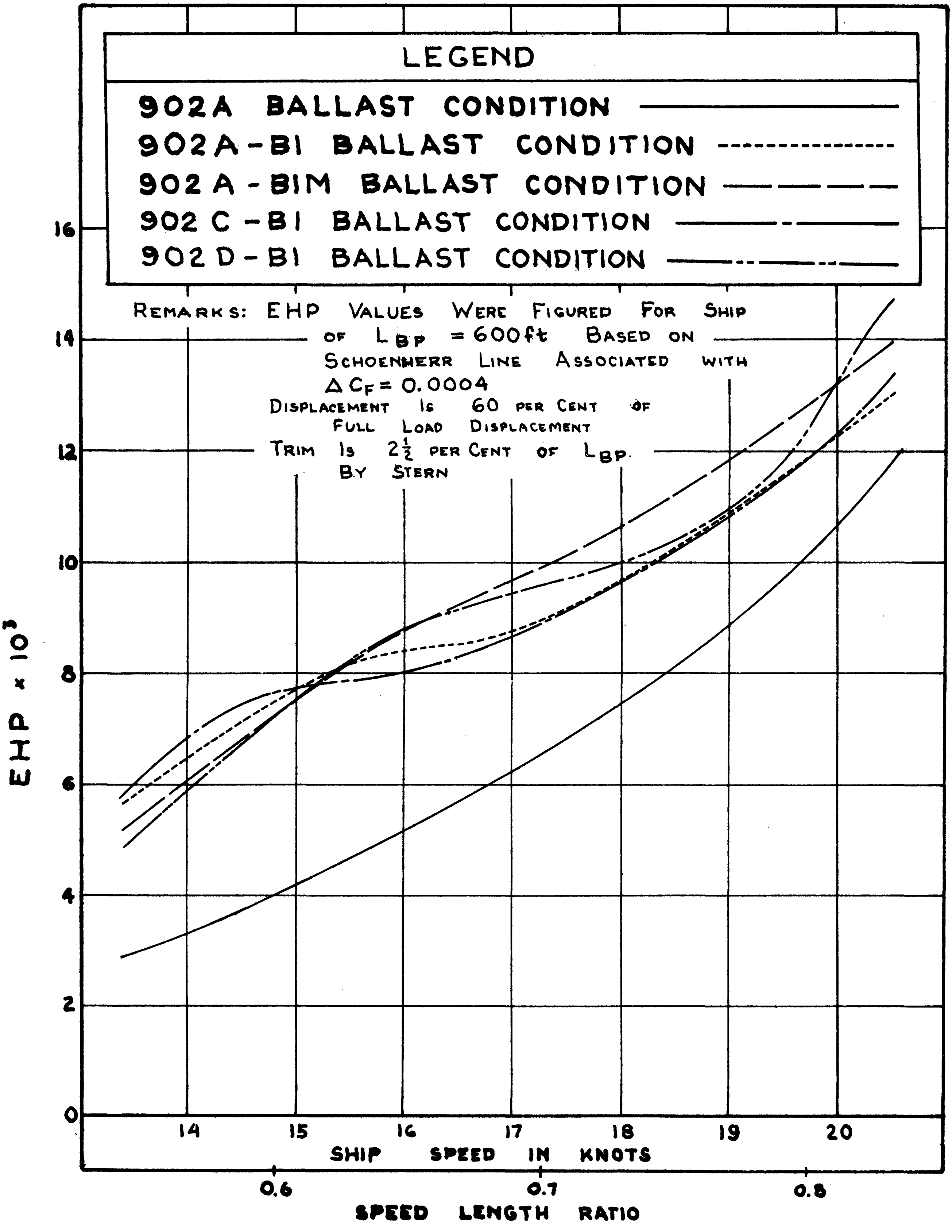


Fig. 20. EHP curves, ballast condition.

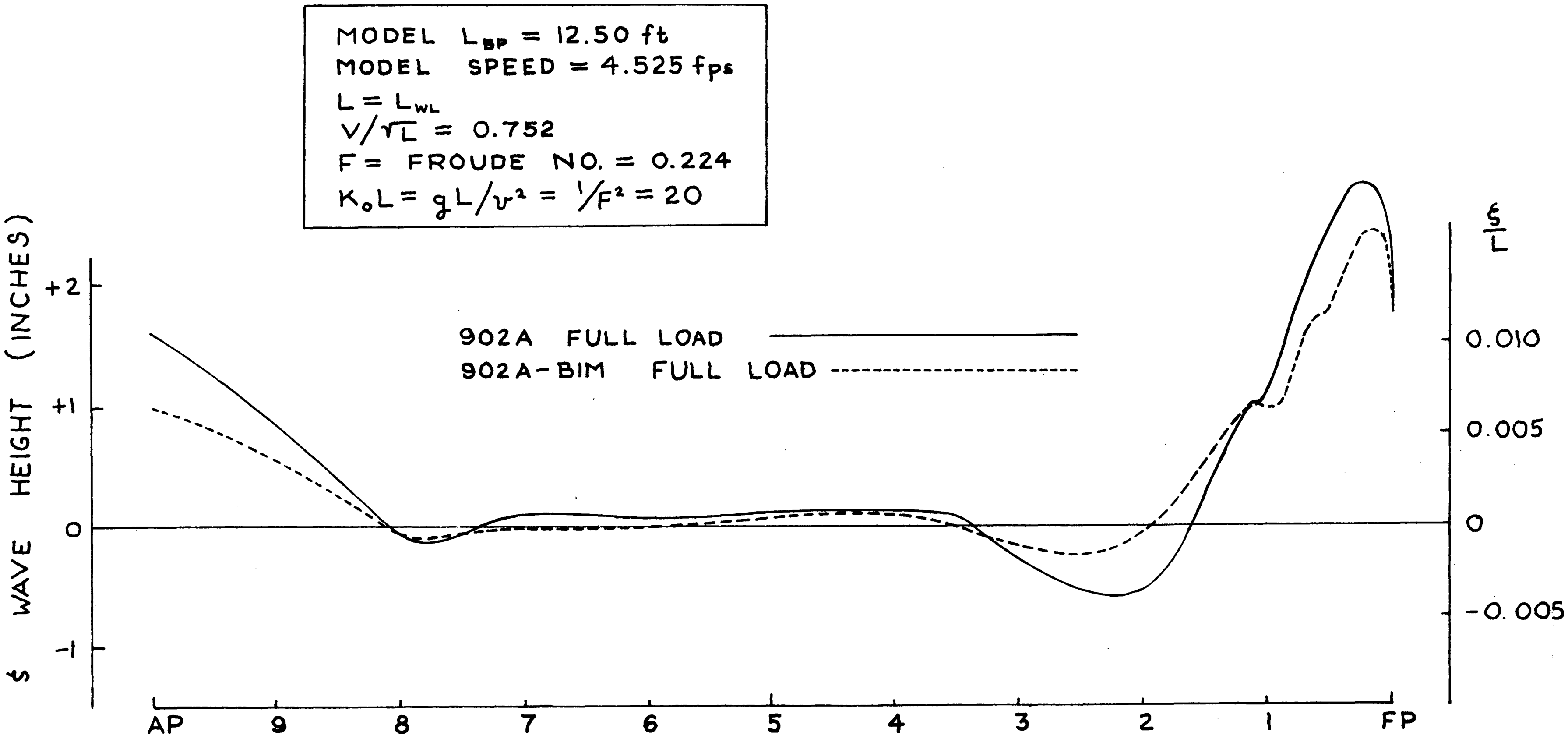


Fig. 21. Wave profile at 4.525 fps, full load condition.

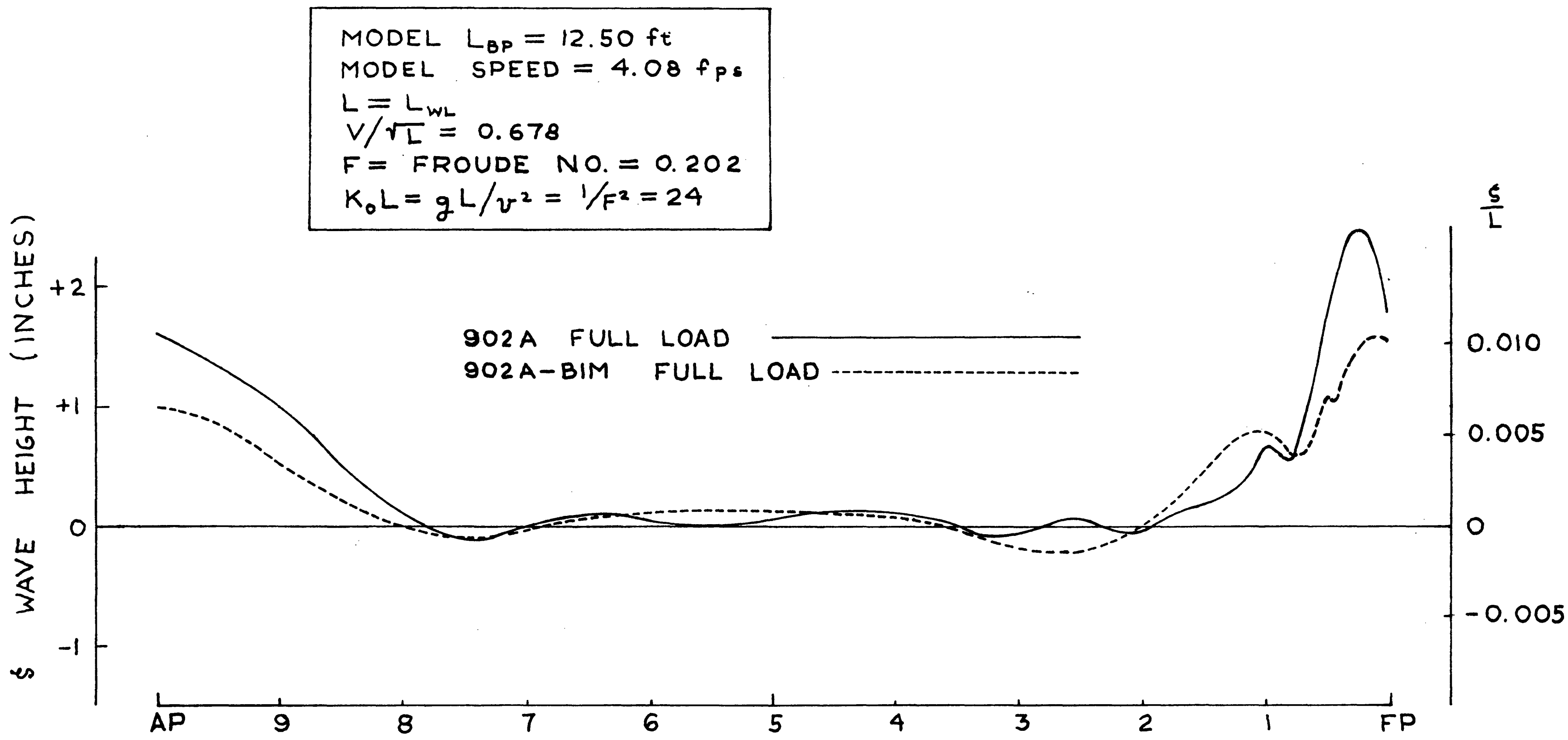


Fig. 22. Wave profile at 4.08 fps, full load condition.

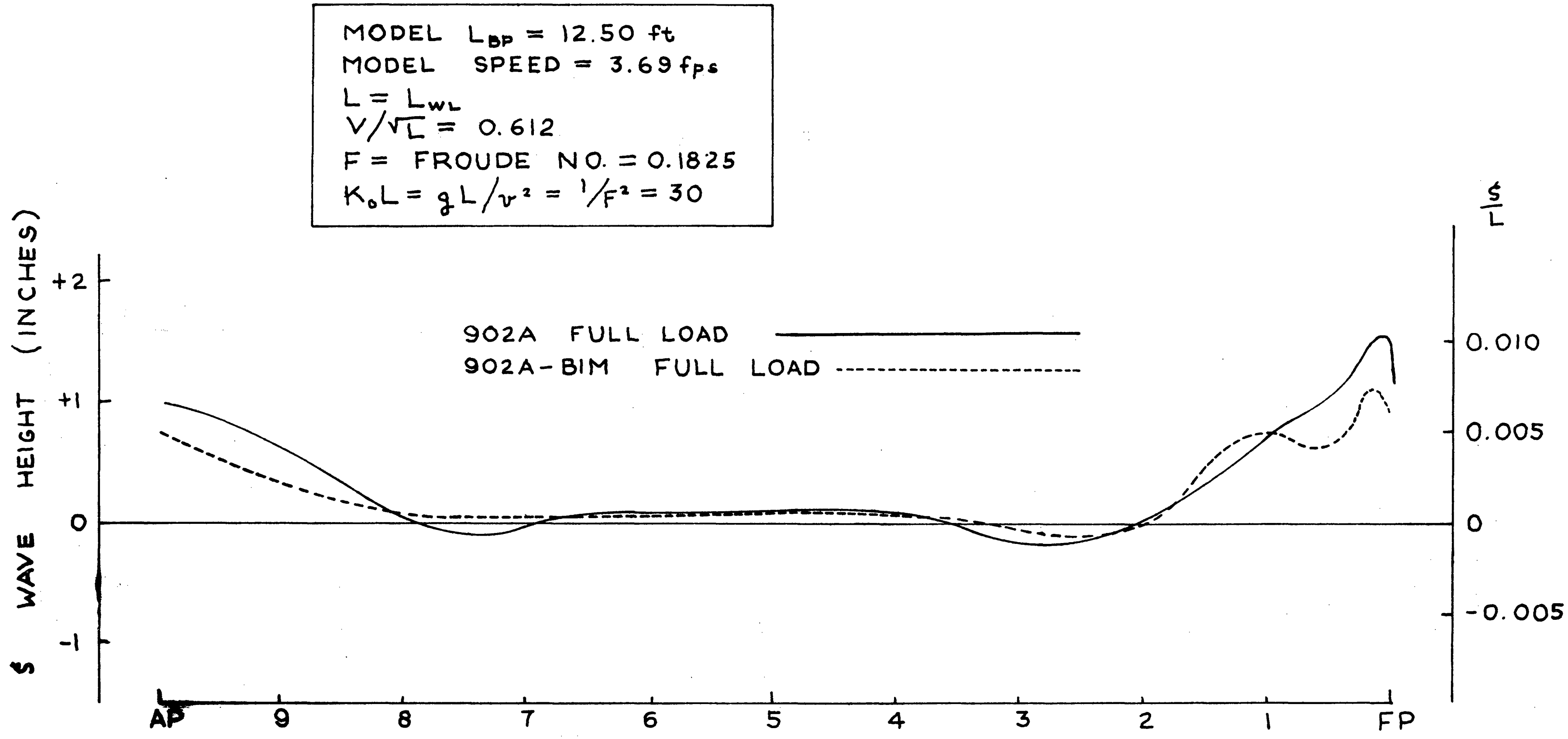


Fig. 23. Wave profile at 3.69 fps, full load condition.

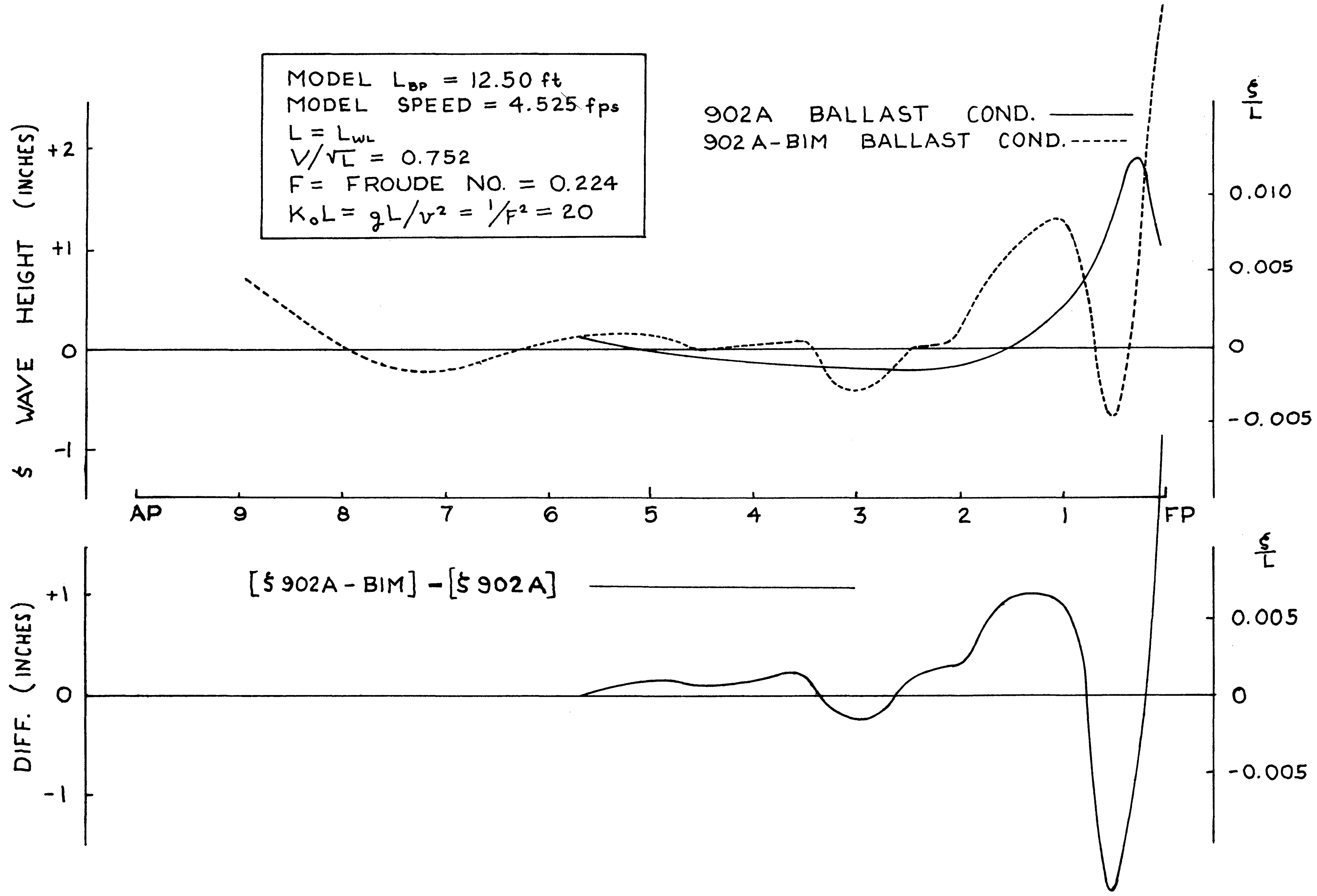


Fig. 24. Wave profile at 4.525 fps, ballast condition.

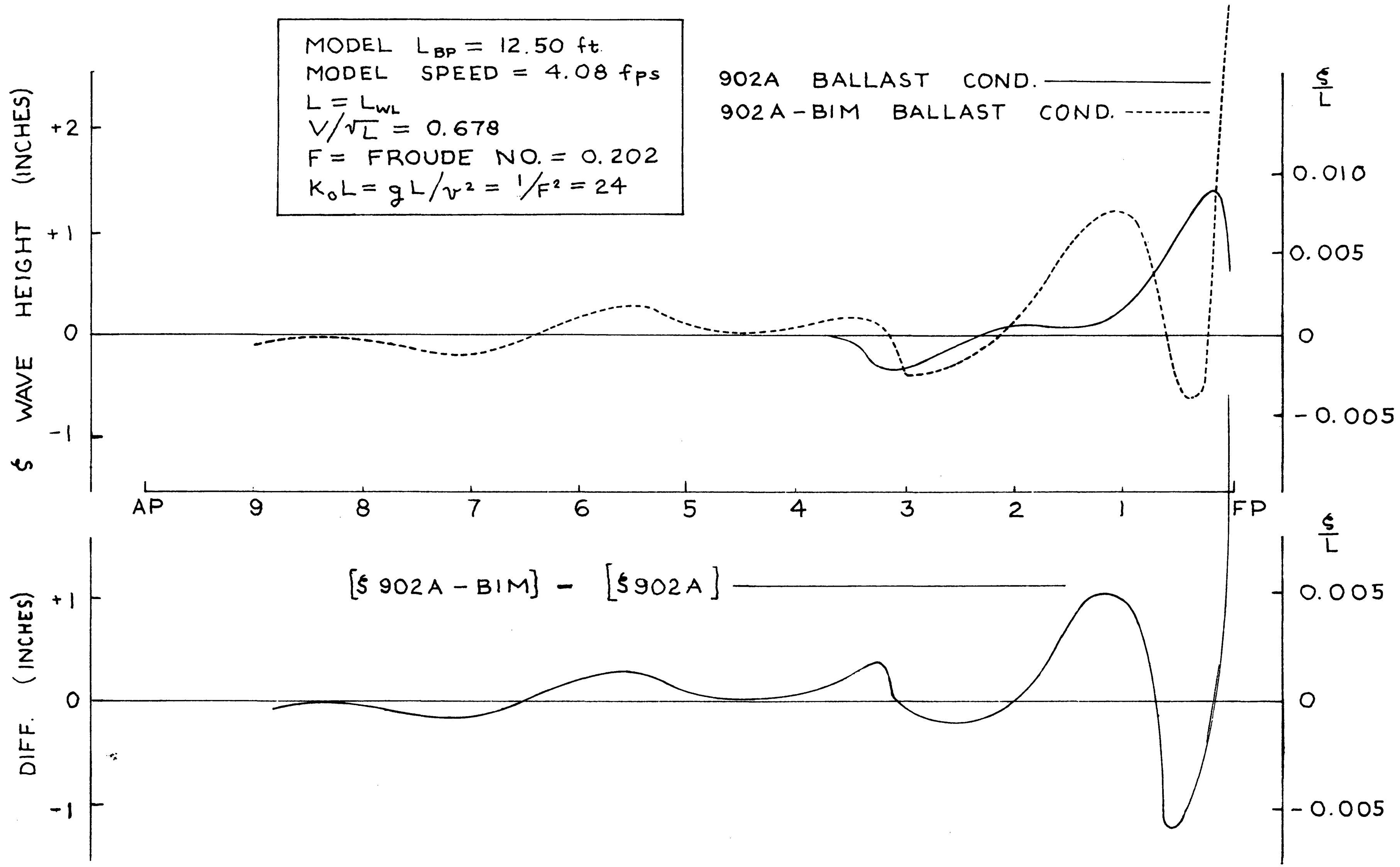


Fig. 25. Wave profile at 4.08 fps, ballast condition.

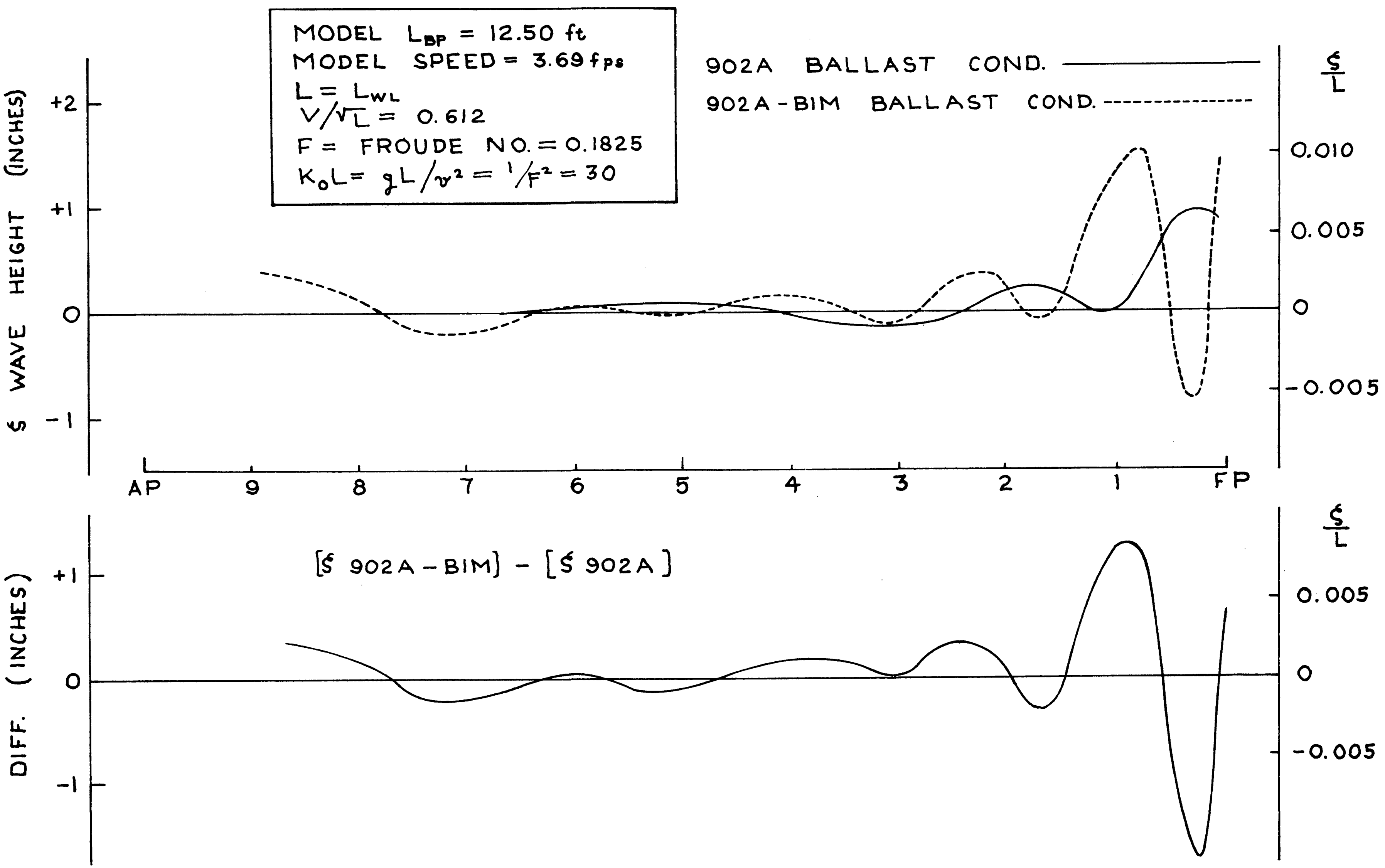


Fig. 26. Wave profile at 3.69 fps, ballast condition.

REFERENCES

1. Finn C. Michelsen, R. B. Couch, and Hun Chol Kim, "Resistance and Propulsion Tests on Two Series 60 Models," University of Michigan Report 03509-1-F, April 1961.
2. Finn C. Michelsen, R. B. Couch, and Hun Chol Kim, "Resistance and Propulsion Test Results on Two Models," University of Michigan Report 04652-1-F, March 1962.
3. Hun Chol Kim, "Resistance Tests on Three Series 60 Bulbuous Bow Models," University of Michigan, College of Engineering, Department of Naval Architecture and Marine Engineering, May 1961.