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SOME EXPERIMENTAL RESULTS OF HULL FORM RESEARCH

by

Pao C. Pien

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ABSTRACT

A hull form design procedure based on the wavemaking resistance theory is given. To determine its value, this procedure has been used to design a number of experimental hull forms. The experimental resistance results of these forms are given. Conclusions are based on comparisons of these results with those of comparable Taylor's Standard Series or Series 60 forms.

ADMINISTRATIVE INFORMATION

This work was covered by Subproject SR 009 0101 of Task 00103 under the Bureau of Ships In-House Independent Research Program.

INTRODUCTION

Approximately 3 years ago, a research project was initiated at the David Taylor Model Basin for the purpose of deriving hull forms with low total resistance. Existing wavemaking theory has been used in this approach. The limitations of the theory and the manner in which it is applied have been fully discussed in Reference 1.* The large quantities of numerical work involved in application of the theory are handled by high-speed computers e.g., the computation of wavemaking resistance of a given singularity distribution, optimization of singularity distribution in a hull form design problem, and streamline tracing for obtaining hull geometry from a given singularity distribution. Reference 2 gives our scheme for selecting the singularity distribution and location so that the numerical work can be efficiently carried out so as to result in a practical hull form.

A logical hull design procedure has been developed on the basis of the work reported in References 1 and 2. To date, seven hull forms have been designed using this method and tested in model experiments to evaluate the procedure. The resistance results of these forms are given here. Conclusions are based on comparisons of these results with those of comparable Taylor's Standard Series or Series 60 forms. Additional work planned for this project is also outlined.

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*References are listed on page 16.

PROCEDURE FOR HULL FORM DESIGN

Our hull form design procedure is based on the consideration that the forebody of a ship has the most influence on wavemaking resistance and that the afterbody has the most influence on the viscous resistance. Hence, the design procedure for the forebody is different from that for the afterbody. Furthermore, we assume that the effect of the afterbody upon the resistance performance of the forebody of a ship is small and that the forebody can therefore be designed independent of the afterbody.

Before the design of the forebody can be started, we have to consider first the division of length and volume between the forebody and the afterbody. For a given ship speed, the smaller the forebody length, the larger its Froude number when we consider the freewave system of the forebody alone. This Froude number and the displacement volume are important factors influencing the wavemaking resistance.

On the other hand, the afterbody length and its displacement volume have great influence upon the viscous drag. To obtain a design with the least total resistance, optimum divisions of length and volume between the forebody and the afterbody must be found. At the present time, we do not have enough information to determine such optimum divisions. Until more information is available, we must make such divisions on the basis of our past experience.

After the length and the displacement volume of the forebody have been decided upon, we seek the optimum distribution of this volume both along the length and the draft, this being one of the restraint conditions of our optimization. If we have freedom in the choice of beam, the value of block coefficient is to be determined as part of the design problem rather than as a given design condition. If the beam and draft have been chosen for reasons other than resistance considerations, then these values will be included as restraints in the optimization process.

The problem of obtaining the optimum forebody volume distribution both longitudinally and vertically has been divided into two steps as fully described in Reference 2. In the first step, wavemaking resistance theory is used to determine the optimum singularity distribution under the restraints imposed upon the hull shape. In the second step, we assume a symmetrical form fore and aft. The hull geometry is obtained by tracing a number of streamlines on the separating stream surface generated by the singularity distribution, which represents the body of the hull.

If the forebody shape is not exactly as required, the geometrical restraints must be changed or new restraints added. With a new set of restraints, these two steps are repeated. Since the streamline tracing is a numerical procedure for solving a set of simultaneous differential equations, the hull geometry cannot be predicted exactly from the singularity distribution without streamline tracing. Therefore, an iteration process is necessary between Step 1 and Step 2.

The problem of designing the afterbody is far more complex and difficult. Here the validity of wavemaking resistance theory is in question due to large viscosity effects. The wavemaking capacity of the afterbody is greatly reduced because of the viscous wake and yet we cannot ignore it completely. Inasmuch as there is no workable theory on viscous drag, the design of an afterbody is a matter of art rather than science. For the time being we must rely heavily on past experience. Therefore, we tentatively chose the design procedure for the afterbody as follows:

After the forebody has been developed, the singularity of an afterbody is obtained such that the theoretical wavemaking resistance of a resultant ship is optimized. This is done for the reason stated below.

Let us consider two extreme cases. The first is one in which there is no viscosity effect. Then the theory is valid and this approach is correct. The second case is one in which the viscosity effect is very large and the afterbody wavemaking capacity can be neglected. Then whether the afterbody singularity is truly an optimum or not will have no great consequence on wavemaking resistance. The actual situation will lie between these two extremes. The very fact that the forebody alone is optimized first before the combination is optimized greatly reduces the chance of having a stern wave system with large amplitudes. If the whole ship form is optimized without first optimizing the forebody, there is a likelihood of having both bow and stern wave systems with large amplitudes, since the optimum ship wavemaking resistance may be mainly due to the favorable theoretical interference effect between the bows and the stern wave systems. Such favorable interference can easily be destroyed by the viscosity effect. By following the above-mentioned sequence of optimization of singularity distributions, we can keep both the bow and stern wave systems small.

In the optimization of the afterbody singularity distribution, restraints can be added to control the shape of the sectional area curve near the after end for the purpose of improving viscous drag and thrust deduction, etc.

After the singularity distribution of an afterbody has been obtained, the streamline tracing is re-done for the asymmetrical hull form. The body plan is then drawn for both forebody and afterbody. The shape of the sections of the afterbody may be altered later without large changes in section areas.

The essential feature of the hull design procedure described here is to isolate the simpler task of designing a forebody from the more complicated problem of designing a whole ship. The wavemaking resistance theory can then be applied where it is appropriate. We believe that the optimum singularity distribution obtained for a forebody is meaningful since we are not too far from the assumptions made in the development of the theory, namely that the viscosity effect is negligible along the forebody and that wave amplitudes are small compared with their wave lengths. As for the afterbody, we have no choice at the present time other than to compute a sectional area curve and follow the current practice with regard to the shapes of various sections.

In our streamline tracing program, a rigid horizontal plane replaces the free surface and a so-called double model technique is used. This is perhaps one of the weak links in our design procedure. It is very desirable to include the free-surface disturbance velocity components in the streamline tracing process. As discussed in later sections, efforts will be made to include this effect.

EXPERIMENTAL HULL FORMS

The hull form design procedure described in the previous sections is intended to produce "ship-shape" hull forms with better total resistance qualities than those obtained using existing design practice. At this stage of the work it was thought desirable to determine the value of this new design procedure. Obviously the logical way to do this is to use the new procedure to design some experimental hull forms, to test these forms and to compare the results with those of forms which are known to have good resistance qualities. For this purpose, seven hull forms have been designed using the new procedure. Models for these seven forms have been built and tested for resistance.

CHOICE OF DESIGN CONDITIONS

A great deal of thought has been given to the choice of design conditions for the experimental forms. At present, our efforts to reduce the total resistance are mainly concentrated on reducing wavemaking resistance through the application of wavemaking resistance theory. Hence the purpose of model experiments at this stage can be narrowed down to the test of the applicability of the wavemaking resistance theory to the ship design problem. Since the theory is more reliable for ships with small beams and displacement-length ratios, we have deliberately chosen forms with relatively large beams and large displacement-length ratios in the model experiments. The philosophy here is that if we can establish some confidence in the application of the theory to the design of ships with large beams and displacement-length ratios than we have reason to expect that such confidence can be extended to the design of ships with small beams and displacement-length ratios.

HULL CHARACTERISTICS

Figures 1-7 give the hull characteristics of the seven forms. In each case, the speed-length ratio, the displacement-length ratio, and the beam-draft ratio are the main design requirements. From past experience in comparing experimental and theoretical wavemaking resistance curves, we know that the experimental curve is shifted to the right of the theoretical curve. Hence, the theoretical design speed-length ratio, at which the optimization of singularity distributions is carried out, is chosen to be 5 percent less than the actual required value shown in each of these figures.

Models 4996 and 5008 are symmetrical forms. They are built according to the streamlines traced both for the forebody and the afterbody. The design speed-length ratios for these two models are 0.99 and 1.13, respectively. Model 5002 is a modification of Model 4996; it has the same forebody and afterbody sectional area curve but a different shape for the aft sections. Model 5012 incorporates the forebody of Model 5008 and the afterbody of an existing design. A slight modification in the forebody of Model 5008 was required to match the chosen afterbody at midship. For the remaining three forms, the design speed-length ratios are 0.99 for Model 5014, 1.20 for Model 5015, and 0.85, 0.92, and 0.99 for Model 5040. Model 5014 has a much shorter entrance than does Model 4996.

All of the forebodies of the seven models have been designed according to the new design procedure. However the afterbodies of Models 4996, 5008, and 5012 have not been designed by following the design procedure for the afterbody since they were designed before the computing programs were modified to handle asymmetrical forms. The afterbody sectional area curves of these models have not been "optimized".

TEST RESULTS

The test results for these seven models in terms of Ⓒ and Rr/Δ are shown in Figures 8-14. The Ⓒ curves are for 400 foot ships with 0.0004 roughness allowance. The residual resistance is derived from the total resistance by subtracting the frictional resistance based on ATTC friction lines. This is done by following the current Model Basin procedure. Since the principal dimensions, the principal proportions, and the design speed-length ratios of these forms are all different, the resistance result of one cannot be compared with that of the others. Because the Taylor's Standard Series forms have always been used as yardsticks in assessing relative merits of hull forms, the ratios of the test total EHP to that of comparable Taylor's Standard Series forms are also given in Figures 8-14. By "comparable" Taylor's Standard Series form we mean that in each case, the beam-draft ratio, displacement-length ratio, and the prismatic coefficient are the same as those of the actual model.

DISUCSSION OF EXPERIMENTAL RESULTS

Comparisons of these seven forms with their corresponding comparable Taylor Standard Series forms (Figures 8-14) indicate that all the new models show a reduction in total resistance in the vicinity of the designed $V/\sqrt{L}$ value. In most cases, this reduction is in the order of 20 percent. Despite the ever increasing research effort since Taylor's time, no appreciable improvement in hull resistance has been achieved, and it has been generally considered that no significant improvement in total resistance over the Taylor's Standard Series forms can be easily accomplished. In this context, the test results reported here may be viewed with great satisfaction. However, the important thing is not what has been accomplished in these seven cases, but rather, that now we do have a new design procedure to optimize the hull form.

The allocations of the ship length and of the displacement between the forebody and the afterbody in each case are chosen rather arbitrarily. Too much displacement may have been allocated to the forebodies of Models 5012, 5014, and 5015. Based on LWL, the C_{PF} and C_{PA} are respectively .664 and .562 for Model 5012, 0.642 and 0.592 for Model 5014, and 0.656 and 0.606 for Model 5015. The LCB location in each case is very much forward of midships. The designed speed-length ratios are 1.13, 0.99, and 1.20, respectively. For such relatively high design speed-length ratio values, had the past experience been followed by shifting displacement volume aft, it is likely that a further reduction in total resistance could be attained. Therefore when we evaluate the resistance results of these models, this point must be kept in mind.

Also it should be noted that the displacement length ratios for the forms tested in this phase of study are rather large compared with normal practice. A logical question is how much benefit can be derived from the new design procedure when used in the design of ships with "normal" proportions of principal dimensions. To answer this question, we must realize that the "normal" proportions of principal dimensions in current practice are a good compromise in each case between the construction cost and the operating cost, and that the total resistance of each hull form will have a great influence on the determination of its principal dimensions and proportions. Therefore, we must not be bound too rigidly by the current "normal" practice in the choice of ship principal dimensions. To estimate how much benefit can be expected from the new design procedure, it is not quite adequate simply to use this procedure to design a ship with a set of "normal" principal dimensions and proportions and compare its resistance performance with other good designs. For instance, take the case of a slow-speed cargo ship with "normal" proportions of principal dimensions. The wavemaking resistance in such a case is a rather small portion of the total resistance. If the new design procedure is used to redesign the same ship without changing the dimensions, no appreciable gain can be expected. On the other hand, if changes in principal dimensions are allowed, the new design procedure may be able to produce a much shorter ship without increasing the total resistance, and a great benefit may be obtained in construction cost.

To illustrate the above discussion further, a comparison between the resistance results of Model 5040 with those of two Series 60 forms has been shown in Figure 15. The first Series 60 form has the same principal dimensions and block coefficient as those of Model 5040 form. The EHP plot is based on a ship length of 500 feet. At the design speed of Model 5040, 22.15 knots ($V/\sqrt{L}$ = .99), the trial speed of the Series 60 form, 21.48 knots ($\frac{V}{\sqrt{500}}$ = .96) and the service speed of the Series 60 form, 20.14 knots ($\frac{V}{\sqrt{500}}$ = 0.90), the Series 60 form has a total resistance 24.7, 24.3, and 11.5 percent higher than the form of Model 5040.

To conform to more "normal" current practice, a smaller displacement-length ratio of 120 rather than 162.4 would probably be chosen; this would increase the length to 553.6 feet, which is more than 50 feet longer. The EHP curve for this longer Series 60 form is also plotted in the same figure. All the three forms have the same block coefficients and beam-draft ratios. Comparing this curve with the EHP curve for the 500 foot Series 60 ship indicates that a great reduction in total resistance is achieved by increasing the length. Again, comparing the longer Series 60 form with Model 5040 form, we find that at the service speed of 21.17 knots ($\frac{V}{\sqrt{553.6}}$ = .9), the two have the same total resistance, but that at the trial speed of the longer form, 22.58 knots ($\frac{V}{\sqrt{553.6}}$ = 0.96), the longer Series 60 form is 8.6 percent higher.

In the first comparison where the two forms have the same principal dimensions, a significant reduction in total resistance means that the size of the propulsion plant could be reduced, with a consequent reduction in initial cost, decrease in fuel consumption, and increase in cargo-carrying capacity. In the second comparison where one form is more than 50 feet shorter than the other for the same displacement, most of the gain is obviously in construction cost. However at the trial speed, the longer Series 60 form still has 8.6 percent higher total resistance than the form of

Model 5040. When it is considered that the Series 60 forms, especially at 0.60 block (C_B = 0.59 based on LWL), do represent good designs of modern ships, the comparisons given in Figure 15 are rather significant.

Even though a great deal more might be said about the resistance results of the seven forms tested, the prime purpose of this phase of model experiments is to evaluate the new hull form design procedure and particularly the applicability of the wavemaking theory. We can conclude that one of the basic objectives of this research project, namely, the development of a procedure for designing low resistance forms, has been achieved as evidenced by these seven forms.

WORK PLANNED FOR THE IMMEDIATE FUTURE

At this point it may be worthwhile to review briefly some of the research areas in which our efforts will be directed to improve the techniques used in the new design procedure and to utilize it in the design of new ships.

In all the seven cases reported here, the experimental resistance results in the vicinity of the designed speed are much higher than had been hoped. We believe that this situation may have been largely caused by the fact that the streamline tracing procedure involved the double model technique, which does not take the free-surface effect into account.

We still do not know how to estimate the boundary layer around afterbodies because there is no workable method of estimating the growth of boundary-layer thickness along a three-dimensional body under a free surface. This lack of a proper tool has limited our ability to optimize afterbodies where the geometry and the viscous drag are closely related.

Moreover, we can measure the total resistance of a model experimentally, but we are not able to measure wavemaking resistance and viscous resistance separately. This makes it difficult to locate the areas where further improvement in resistance can be made.

Nevertheless, the new design procedure can already serve a useful purpose by producing relatively lower resistance hull forms to meet the immediate needs of the Fleet and our shipping industry. This requires extensive calculations and testing for a range of various design parameters and conditions to produce hull forms which can be used directly or which can serve as a point of departure in the development of a new ship.

Therefore future research work in this project can be logically divided into two parts: (1) the provision of hull forms for a range of design parameters through the immediate application of the new design procedure and (2) a continuing search for more basic knowledge in ship resistance particularly with regard to the design of the afterbody.

IMMEDIATE APPLICATION

To meet the design needs for high-speed ships, low resistance hull forms will be provided for the range of $V/\sqrt{L}$ values of interest. At each chosen design $V/\sqrt{L}$ value, several forms with various B/H and L/B ratios will be designed and tested for resistance. Each of these forms will be designed separately and independently. We note that in a methodical series, forms of L/B and B/H ratio variations are derived from a parent form. Only one set of non-dimensionalized ship lines is involved. This same set of ship lines may not be good for other proportions. For this reason, each form in our project will be especially designed for a particular combination of B/H and L/B ratios. This means that at a given $V/\sqrt{L}$ value, a ship designer will be provided with several sets of shiplines, each appropriate to particular values of principal dimensions. It is realized that in many cases, a designer may wish to modify principal dimensions without changing the non-dimensionalized shiplines. Then he will need to know the extent to which the resistance may change if only the principal dimensions are to be changed. In such case, the Taylor's Standard Series, Series 60 (within certain $V/\sqrt{L}$ ranges covered in this series), and many other methodical series may be used. Hence when this portion of our work is finished, it will be an important complement to all the existing methodical series rather than another addition to them.

CONTINUATION OF BASIC HULL FORM RESEARCH

Basic research in the immediate future will be concentrated on three items: free-surface effect in hull streamline tracing, afterbody influence on ship resistance, and experimental technique of measuring the wavemaking and viscous resistance.

Free-Surface Effect in Hull Streamline Tracing

As mentioned previously, a double model technique has been used to obtain the hull geometry from a given singularity distribution. This technique is simple and, at the present time, is the only practical method that we can use in our complicated scheme of singularity distributions. Because free-surface disturbance velocity components have been neglected in the double model technique, the physical model tests and the theoretical model used in the numerical analysis may not be in good agreement. If the free-surface effect is included in our hull streamline tracing, a better agreement between the theoretical and the actual wavemaking resistances of a forebody can be expected. Another advantage of including free-surface disturbance velocity components in the streamline tracing is that we can obtain a wave profile on the side of a hull as a by-product. A comparison of the theoretical and experimental profiles will provide a great deal of interesting information regarding wavemaking resistance theory. Serious thought has been given to this problem. Actual work will be started very soon.

Influence of Afterbody Upon Ship Resistance

The relationship between the change in afterbody and the change in ship resistance is very complicated, and attempts to establish this relationship will be very difficult. However we will limit ourselves mainly to determining the gross effect of variations in afterbody length and displacement upon ship resistance with a fixed forebody.

Separation of Wavemaking and Viscous Resistance

Several methods of obtaining wavemaking resistance by measuring free wave heights are being investigated at various research institutions. A method of obtaining viscous resistance by wake surveys behind a towed model is also under study at the University of Iowa. We intend to study these matters thoroughly and to find a reliable workable procedure to be used at the Model Basin.

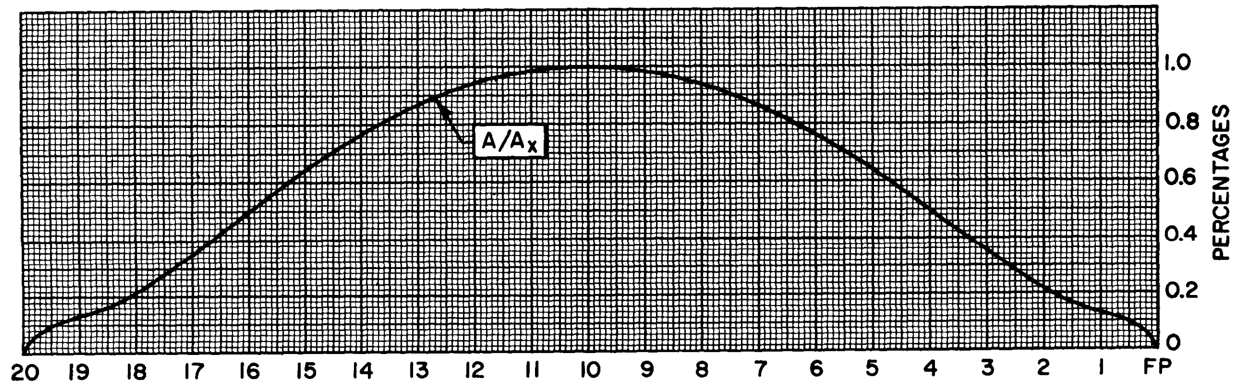
REFERENCES

1. Pien, Pao C., "The Application of Wavemaking Resistance Theory to the Design of Ship Hulls with Low Total Resistance", Fifth Symposium of Naval Hydrodynamics, Bergen, Norway, September 1964
2. Pien, Pao C., and Moore, Wilburn T., "Theoretical and Experimental Study of Wavemaking Resistance of Ships", International Seminar on Theoretical Wave Resistance, University of Michigan, Ann Arbor, Michigan, August 1963

SHIP AND MODEL DATA
FOR
RESEARCH HULL FORM
MODEL 4996

APPENDAGES : NONE

DIMENSIONS			L W L COEFFICIENTS			
	SHIP	MODEL	C_B	0.555	C_{WF}	0.594
LENGTH (LWL), FT.	601.56	20.052	C_P	0.586	C_{WA}	0.594
LENGTH (LBP), FT.	600.00	20.000	C_X	0.948	L_E/L	0.500
BEAM (B_X), FT.	103.14	3.438	C_W	0.594	L_X/L	0.0
DRAFT (H), FT.	39.00	1.300	C_{PF}	0.586	L_R/L	0.500
DISPL. IN TONS (S.W.)	38,460	1.385FW	C_{PA}	0.586	L/B	5.832
WETTED SURF. SQ. FT.	72,675	80.75	C_{PE}	0.586	B_X/H	2.645
DESIGN V, KNOTS	24.28	4.43	C_{PR}	0.586	$\Delta/(.01L)^3$	176.67
LCB_{LWL} = 0.499 AFT OF F.P.			C_{PV}	0.936	$S/\sqrt{\Delta L}$	15.11
LCB_{LBP} = 0.500 AFT OF F.P.			C_{PVA}	0.936	f	
W.L. ENTRANCE HALF ANGLE =			C_{PVF}	0.936	t	
λ = 30.00	$V/\sqrt{L_{LWL}}$ = 0.99		L B P COEFFICIENTS			
Ⓚ=	Ⓟ=		C_B	0.555	L/B	5.817
LINES:			C_P	0.586	$\Delta/(.01L)^3$	178.05



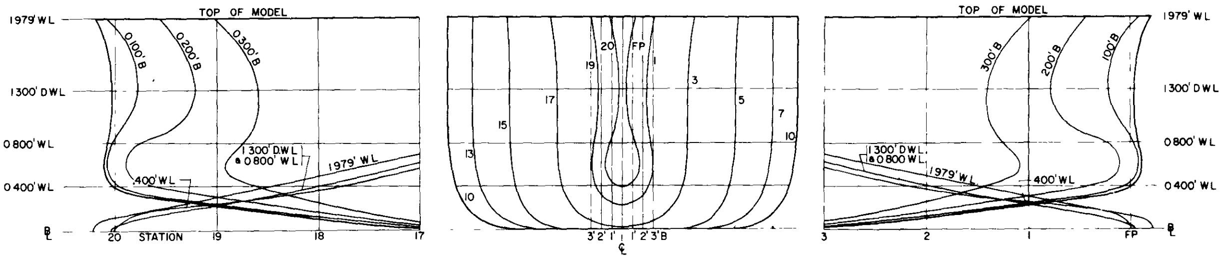
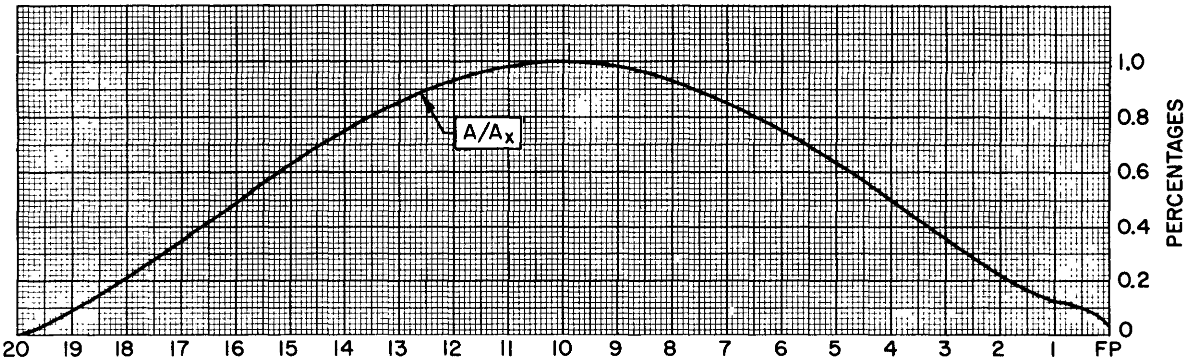


Figure 1 Hull Characteristics of Model 4996

SHIP AND MODEL DATA
FOR
RESEARCH HULL FORM
MODEL 5002

APPENDAGES : NONE

DIMENSIONS			L W L COEFFICIENTS			
	SHIP	MODEL	C_B	0.554	C_{WF}	0.594
LENGTH (LWL), FT.	601.08	20.036	C_P	0.584	C_{WA}	0.713
LENGTH (LBP), FT.	600	20.0	C_X	0.948	L_E/L	0.502
BEAM (B_X), FT.	103.1	3.437	C_W	0.653	L_X/L	0.0
DRAFT (H), FT.	39.0	1.30	C_{PF}	0.586	L_R/L	0.498
DISPL. IN TONS (S.W.)	38,290	1.379FW	C_{PA}	0.582	L/B	5.830
WETTED SURF. SQ. FT.	72,960	81.065	C_{PE}	0.586	B_X/H	2.644
DESIGN V, KNOTS	24.28	4.43	C_{PR}	0.582	$\Delta/(.01L)^3$	176.32
LCB_{LWL} = 0.498 AFT OF F.P.			C_{PV}	0.848	$S/\sqrt{\Delta L}$	15.21
LCB_{LBP} = 0.499 AFT OF F.P.			C_{PVA}	0.774	f	
W.L. ENTRANCE HALF ANGLE =			C_{PVF}	0.936	t	
λ = 30.00	$V/\sqrt{L_{LWL}}$ = 0.99		L B P COEFFICIENTS			
Ⓚ =	Ⓟ =		C_B	0.555	L/B	5.820
LINES:			C_P	0.585	$\Delta/(.01L)^3$	177.27



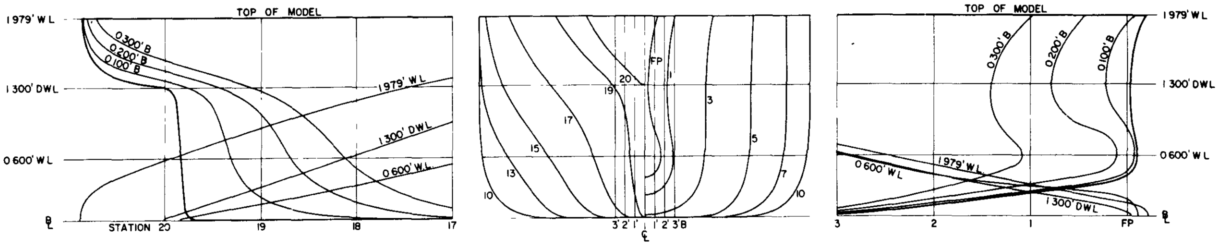
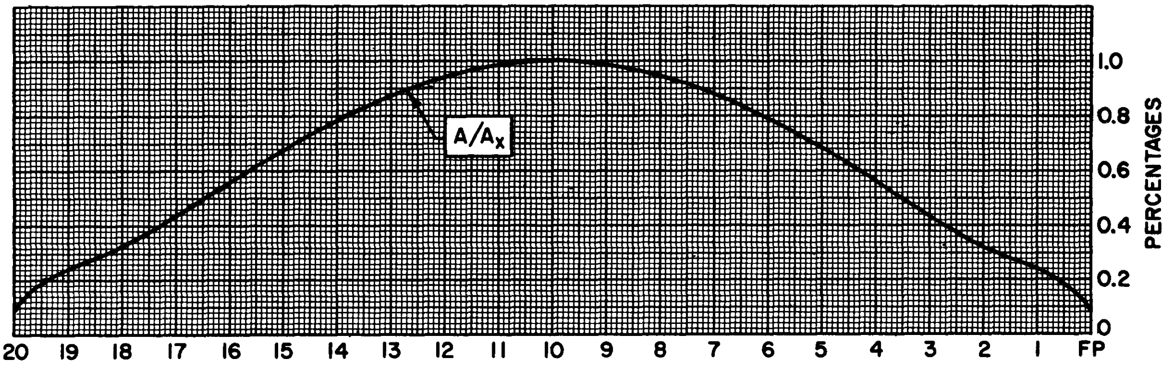


Figure 2 Hull Characteristics of Model 5002

SHIP AND MODEL DATA
FOR
RESEARCH HULL FORM
MODEL 5008

APPENDAGES : NONE

DIMENSIONS			L W L COEFFICIENTS			
	SHIP	MODEL	C_B	0.613	C_{WF}	0.630
LENGTH (LWL), FT.	600.84	20.028	C_P	0.638	C_{WA}	0.630
LENGTH (LBP), FT.	600	20.0	C_X	0.960	L_E/L	0.500
BEAM (B_X), FT.	98.10	3.27	C_W	0.630	L_X/L	0.0
DRAFT (H), FT.	30.00	1.00	C_{PF}	0.638	L_R/L	0.500
DISPL. IN TONS (S.W.)	30,990	1.116FW	C_{PA}	0.638	L/B	6.125
WETTED SURF. SQ. FT.	67,095	74.548	C_{PE}	0.638	B_X/H	3.270
DESIGN V, KNOTS	27.70	5.06	C_{PR}	0.638	$\Delta/(.01L)^3$	142.87
LCB_{LWL} = 0.500 AFT OF F.P.			C_{PV}	0.973	$S/\sqrt{\Delta L}$	15.55
LCB_{LBP} = 0.501 AFT OF F.P.			C_{PVA}	0.973	f	
W.L. ENTRANCE HALF ANGLE =			C_{PVF}	0.973	t	
λ = 30.00	$V/\sqrt{L_{LWL}}$ = 1.13		L B P COEFFICIENTS			
Ⓚ =	Ⓟ =		C_B	0.614	L/B	6.116
LINES :			C_P	0.639	$\Delta/(.01L)^3$	143.47



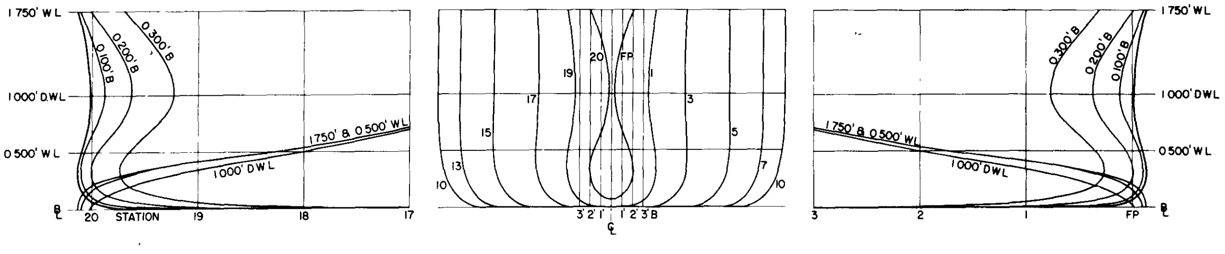
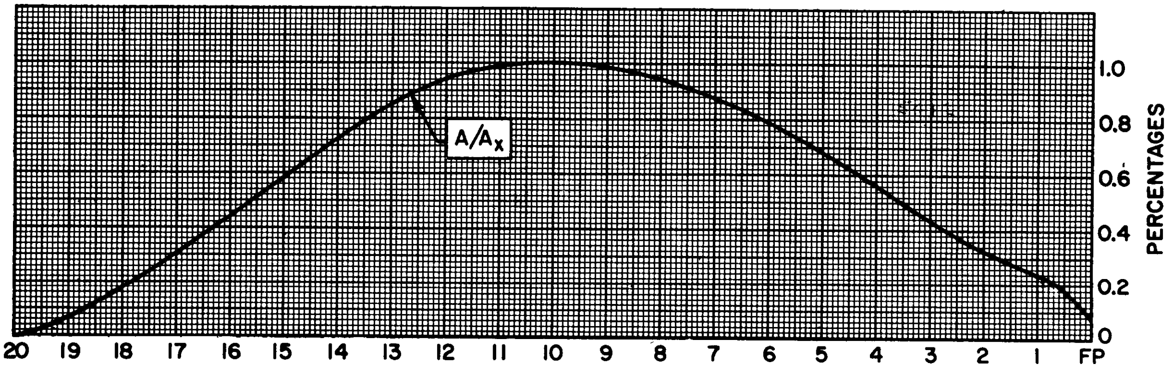


Figure 3 Hull Characteristics of Model 5008

SHIP AND MODEL DATA
FOR
RESEARCH HULL FORM
MODEL 5012

APPENDAGES :

DIMENSIONS			L W L COEFFICIENTS			
	SHIP	MODEL	C_B	0.590	C_{WF}	0.653
LENGTH (LWL)	540	21.00	C_P	0.613	C_{WA}	0.731
LENGTH (LBP)	540	21.00	C_X	0.962	L_E/L	0.465
BEAM (B_X)	85	3.19	C_W	0.692	L_X/L	0.035
DRAFT (H)	28	1.05	C_{PF}	0.664	L_R/L	0.500
DISPL. IN TONS (S.W.)	22,435	1.152FW	C_{PA}	0.562	L/B	6.580
WETTED SURF. SQ. FT.	49,730	70.00	C_{PE}	0.639	B_X/H	3.037
DESIGN V IN KTS.	26.26	5.086	C_{PR}	0.562	$\Delta/(.01L)^3$	127.96
LCB_{LWL} = 0.473 AFT OF F.P.			C_{PV}	0.853	$S/\sqrt{\Delta L}$	15.36
LCB_{LBP} = 0.473 AFT OF F.P.			C_{PVA}	0.739	f	
W.L. ENTRANCE HALF ANGLE =			C_{PVF}	0.977	t	
λ = 26.6535	$V/\sqrt{L_{LWL}}$ = 1.13		L B P COEFFICIENTS			
Ⓚ =	Ⓟ =		C_B	0.590	L/B	6.58
LINES :			C_P	0.613	$\Delta/(.01L)^3$	127.96



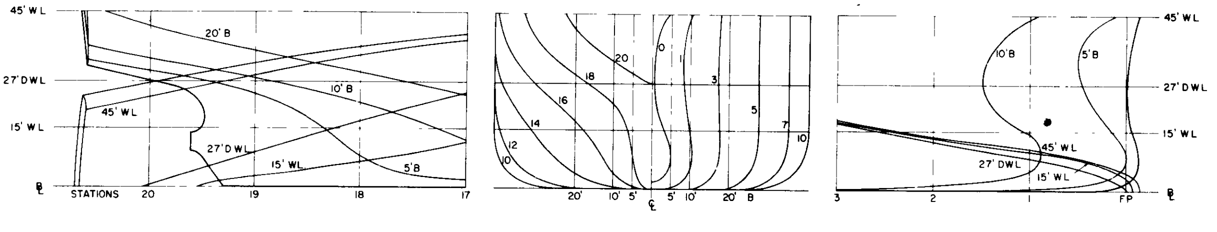


Figure 4 Hull Characteristics of Model 5012

SHIP AND MODEL DATA
FOR
RESEARCH HULL FORM
MODEL 5014

APPENDAGES :

DIMENSIONS			L W L COEFFICIENTS			
	SHIP	MODEL	C_B	0.592	C_{WF}	0.638
LENGTH (LWL)	520	22.50	C_P	0.619	C_{WA}	0.778
LENGTH (LBP)	520	22.50	C_X	0.957	L_E/L	0.455
BEAM (B_X)	79.66	3.447	C_W	0.708	L_X/L	0.0
DRAFT (H)	25.42	1.100	C_{PF}	0.642	L_R/L	0.545
DISPL. IN TONS (S.W.)	17,835	1.405FW	C_{PA}	0.597	L/B	6.528
WETTED SURF. SQ. FT.	47,000	88.00	C_{PE}	0.607	B_X/H	3.133
DESIGN V IN KTS.	22.58	4.70	C_{PR}	0.630	$\Delta/(.01L)^3$	126.77
LCB_{LWL} = 0.491 AFT OF F.P.			C_{PV}	0.836	$S/\sqrt{\Delta L}$	15.44
LCB_{LBP} = 0.491 AFT OF F.P.			C_{PVA}	0.734	f	
W.L. ENTRANCE HALF ANGLE =			C_{PVF}	0.963	t	
λ = 23.11	$V/\sqrt{L_{LWL}}$ = 0.99		L B P COEFFICIENTS			
Ⓚ =	Ⓟ =		C_B	0.592	L/B	6.528
LINES :			C_P	0.619	$\Delta/(.01L)^3$	126.77

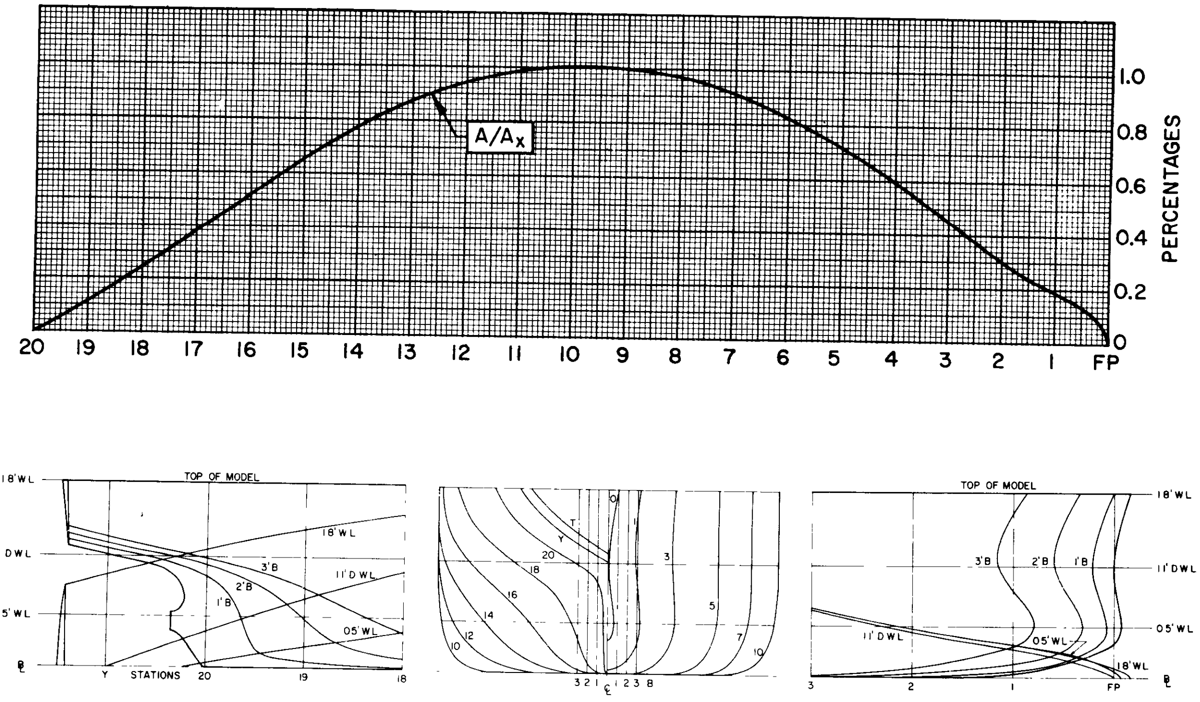
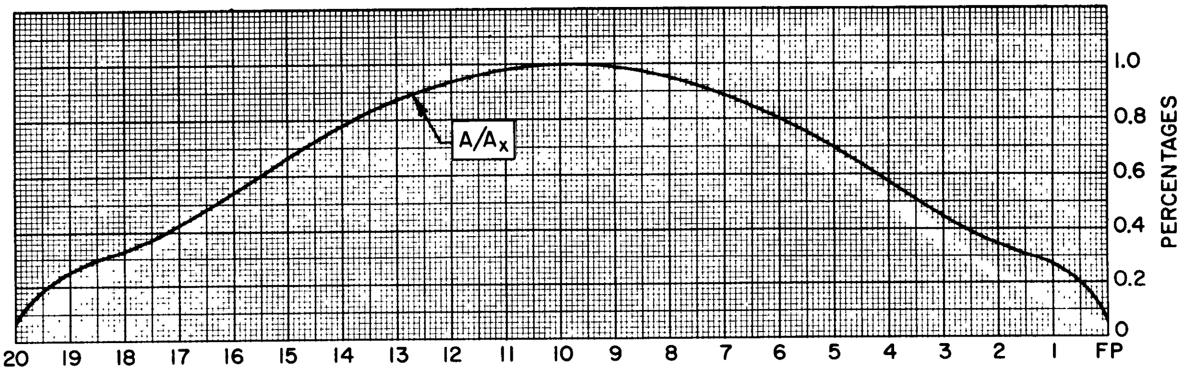


Figure 5 Hull Characteristics of Model 5014

SHIP AND MODEL DATA
FOR
RESEARCH HULL FORM
MODEL 5015

APPENDAGES : **NONE**

DIMENSIONS			L W L COEFFICIENTS			
	SHIP	MODEL	C_B	0.601	C_{WF}	0.655
LENGTH (LWL), FT.	600	20.548	C_P	0.630	C_{WA}	0.789
LENGTH (LBP), FT.	584	20.00	C_X	0.954	L_E/L	0.492
BEAM (B_X), FT.	87.22	2.987	C_W	0.722	L_X/L	0.0
DRAFT (H), FT.	32.12	1.100	C_{PF}	0.656	L_R/L	0.508
DISPL. IN TONS (S.W.)	28,880	1.128FW	C_{PA}	0.606	L/B	6.880
WETTED SURF. SQ. FT.	62,965	73.849	C_{PE}	0.649	B_X/H	2.715
DESIGN V, KNOTS	29.39	5.44	C_{PR}	0.612	$\Delta/(.01L)^3$	133.70
LCB_{LWL} = 0.487 AFT OF F.P.			C_{PV}	0.833	$S/\sqrt{\Delta L}$	15.12
LCB_{LBP} = 0.501 AFT OF F.P.			C_{PVA}	0.732	f	
W.L. ENTRANCE HALF ANGLE =			C_{PVF}	0.954	t	
λ = 29.20	$V/\sqrt{L_{LWL}}$ = 1.20		L B P COEFFICIENTS			
Ⓚ =	Ⓟ =		C_B	0.617	L/B	6.702
LINES:			C_P	0.647	$\Delta/(.01L)^3$	144.67



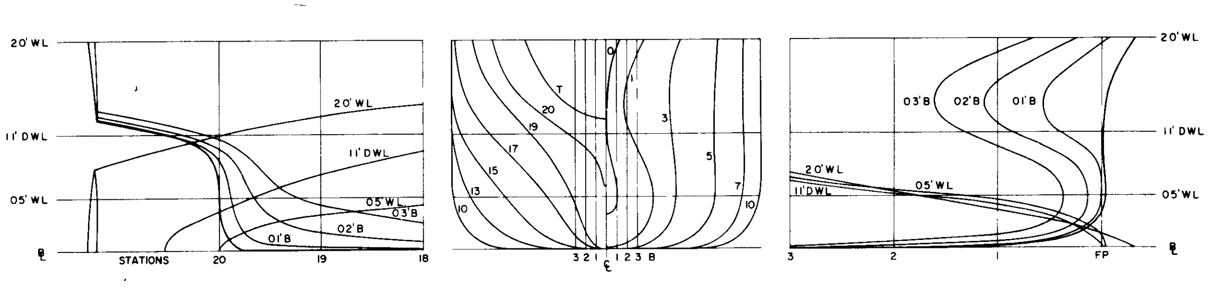


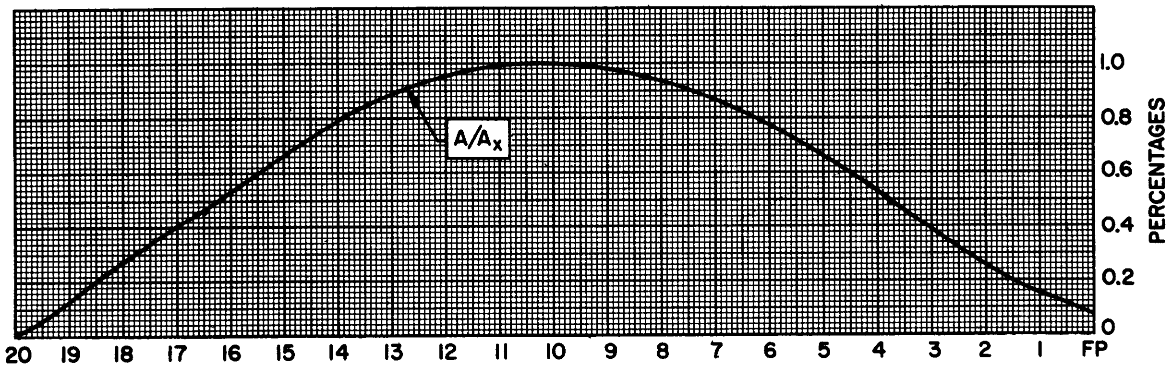
Figure 6 Hull Characteristics of Model 5015

SHIP AND MODEL DATA
FOR
RESEARCH HULL FORM
MODEL 5040

APPENDAGES: NONE

DIMENSIONS			L W L COEFFICIENTS			
	SHIP	MODEL	C_B	0.588	C_{WF}	0.613
LENGTH (LWL), FT.	500	20.00	C_P	0.611	C_{WA}	0.813
LENGTH (LBP), FT.	500	20.00	C_X	0.962	L_E/L	0.510
BEAM (B_X), FT.	80.66	3.227	C_W	0.713	L_X/L	0.0
DRAFT (H), FT.	30.00	0 1.20	C_{PF}	0.611	L_R/L	0.490
DISPL. IN TONS (S.W.)	20,365	1.267FW	C_{PA}	0.612	L/B	6.205
WETTED SURF. SQ. FT.	49,275	78.843	C_{PE}	0.618	B_X/H	2.689
*DESIGN V, KNOTS	19.00	3.80	C_{PR}	0.604	$\Delta/(.01L)^3$	162.9
LCB_{LWL} = 0.499 AFT OF F.P.			C_{PV}	0.824	$S/\sqrt{\Delta L}$	15.44
LCB_{LBP} = 0.499 AFT OF F.P.			C_{PVA}	0.724	f	
W.L. ENTRANCE HALF ANGLE =			C_{PVF}	0.957	t	
λ = 25.0 *$V/\sqrt{L_{LWL}}$ = 0.85, 0.92, 0.99			L B P COEFFICIENTS			
Ⓚ= Ⓟ=			C_B	0.588	L/B	6.205
LINES:			C_P	0.611	$\Delta/(.01L)^3$	162.9
*DESIGN V, KNOTS	20.57	4.114				
*DESIGN V, KNOTS	22.14	4.428				

*This form has been optimized for three speeds.



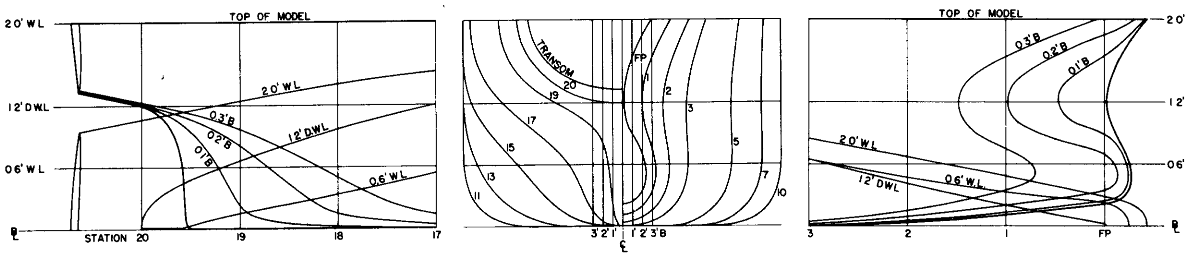
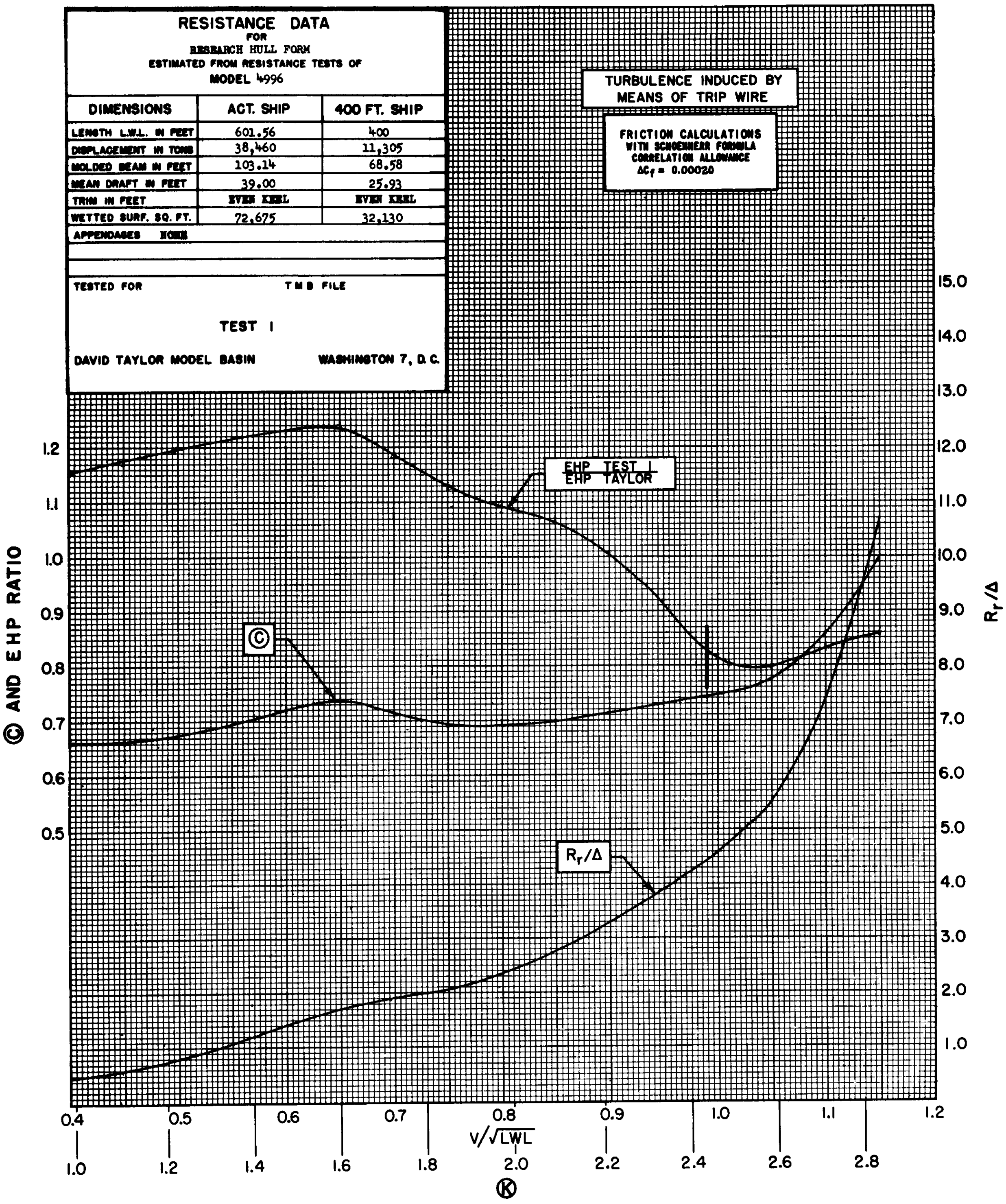


Figure 7 Hull Characteristics of Model 5040



RESISTANCE DATA
FOR
RESEARCH HULL FORM
ESTIMATED FROM RESISTANCE TESTS OF
MODEL 4996

DIMENSIONS	ACT. SHIP	400 FT. SHIP
LENGTH L.W.L. IN FEET	601.56	400
DISPLACEMENT IN TONS	38,460	11,305
MOLDED BEAM IN FEET	103.14	68.58
MEAN DRAFT IN FEET	39.00	25.93
TRIM IN FEET	EVEN KEEL	EVEN KEEL
WETTED SURF. SQ. FT.	72,675	32,130
APPENDAGES NONE		

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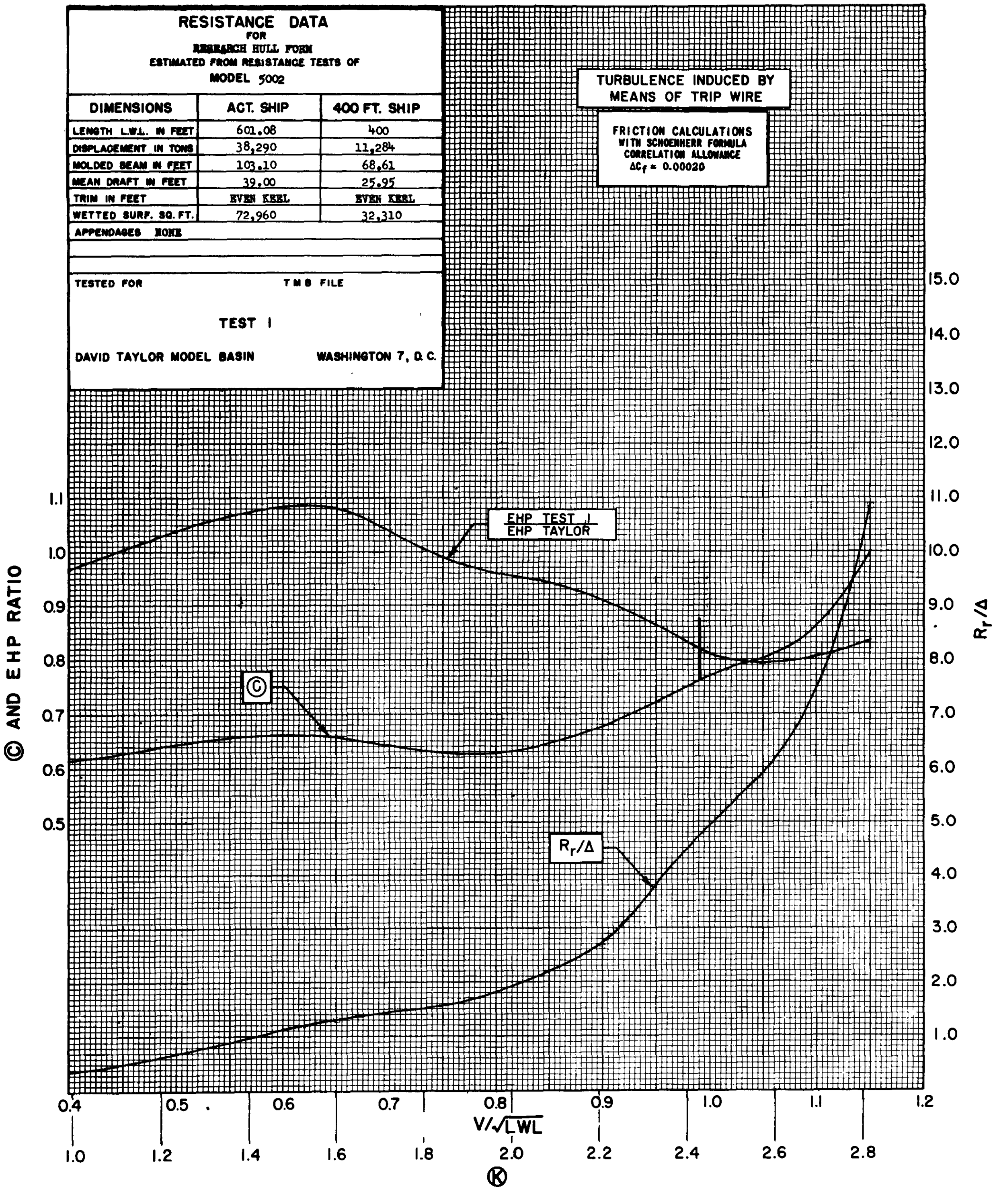
TEST 1

DAVID TAYLOR MODEL BASIN　　　　WASHINGTON 7, D.C.

TURBULENCE INDUCED BY MEANS OF TRIP WIRE

FRICTION CALCULATIONS WITH SCHOENHERR FORMULA CORRELATION ALLOWANCE $\Delta C_f = 0.00020$

Figure 8 Resistance Data of Model 4996



RESISTANCE DATA
FOR
RESEARCH HULL FORM
ESTIMATED FROM RESISTANCE TESTS OF
MODEL 5002

DIMENSIONS	ACT. SHIP	400 FT. SHIP
LENGTH L.W.L. IN FEET	601.08	400
DISPLACEMENT IN TONS	38,290	11,284
MOLDED BEAM IN FEET	103.10	68.61
MEAN DRAFT IN FEET	39.00	25.95
TRIM IN FEET	EVEN KEEL	EVEN KEEL
WETTED SURF. SQ. FT.	72,960	32,310

APPENDAGES NONE

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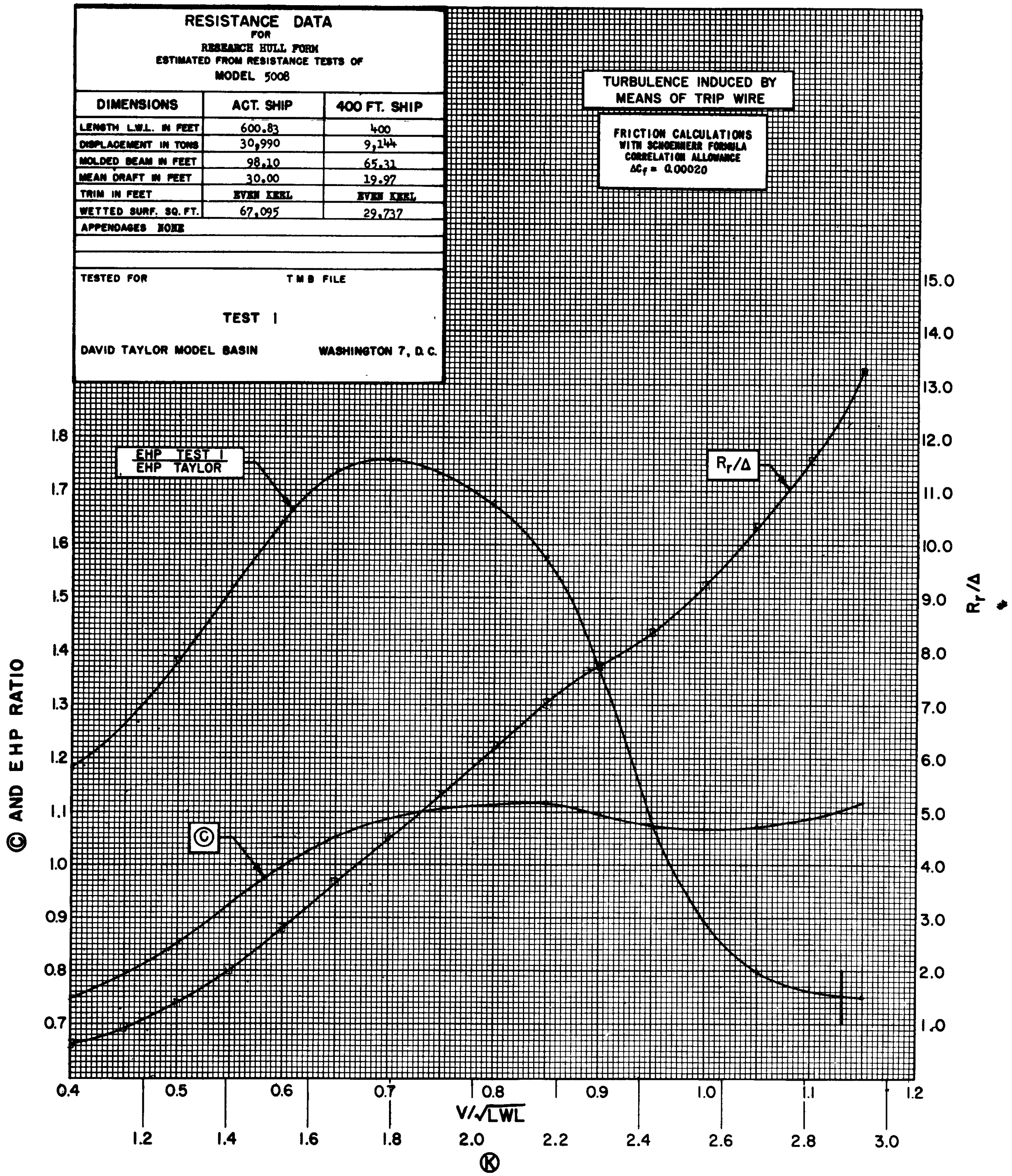
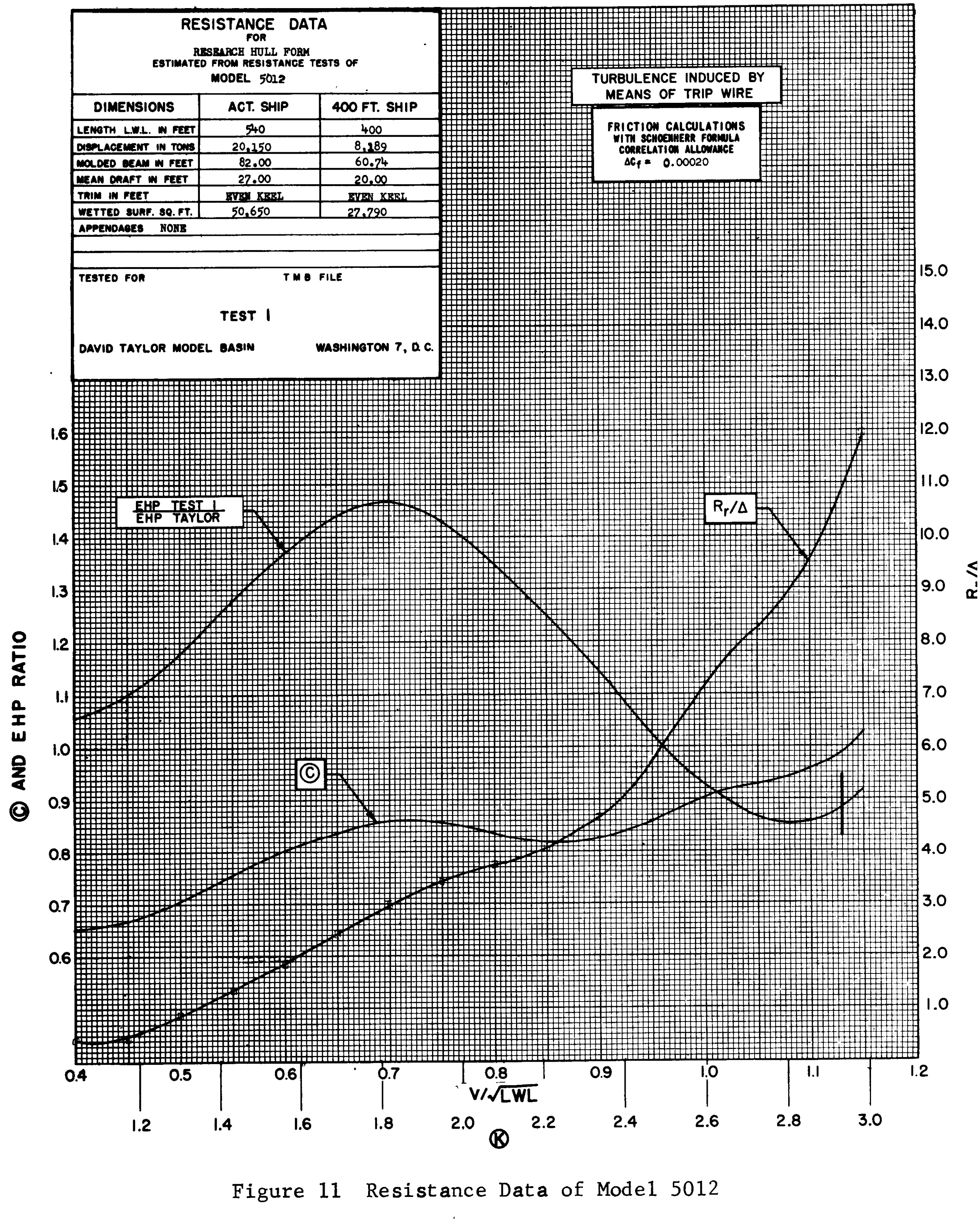
Figure 9 Resistance Data of Model 5002



DIMENSIONS	ACT. SHIP	400 FT. SHIP
LENGTH L.W.L. IN FEET	600.83	400
DISPLACEMENT IN TONS	30,990	9,144
MOLDED BEAM IN FEET	98.10	65.31
MEAN DRAFT IN FEET	30.00	19.97
TRIM IN FEET	EVEN KEEL	EVEN KEEL
WETTED SURF. SQ. FT.	67,095	29,737
APPENDAGES NONE		

Figure 10 Resistance Data of Model 5008



RESISTANCE DATA
FOR
RESEARCH HULL FORM
ESTIMATED FROM RESISTANCE TESTS OF
MODEL 5012

DIMENSIONS	ACT. SHIP	400 FT. SHIP
LENGTH L.W.L. IN FEET	540	400
DISPLACEMENT IN TONS	20,150	8,189
MOLDED BEAM IN FEET	82.00	60.74
MEAN DRAFT IN FEET	27.00	20.00
TRIM IN FEET	EVEN KEEL	EVEN KEEL
WETTED SURF. SQ. FT.	50,650	27,790

APPENDAGES NONE

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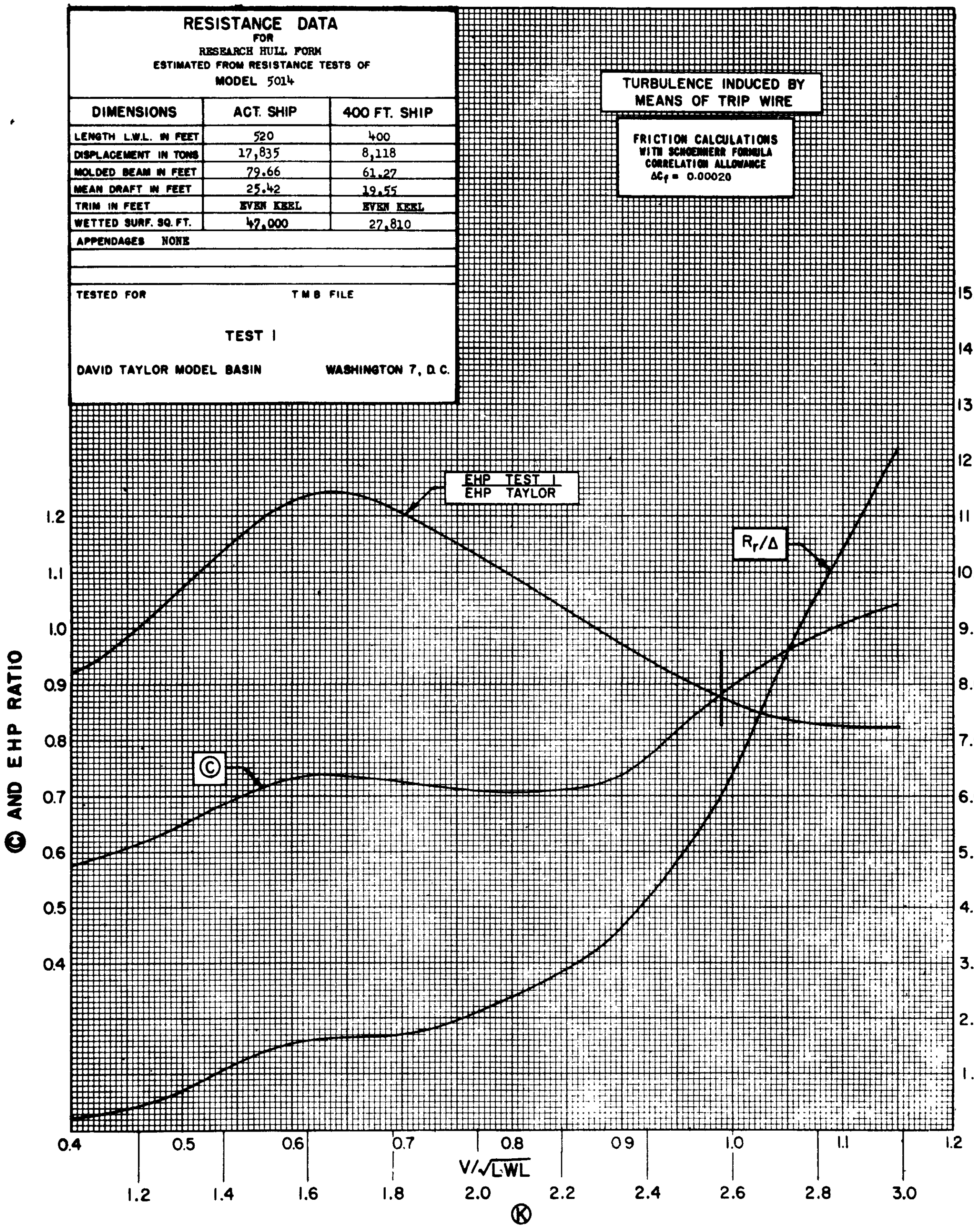
DAVID TAYLOR MODEL BASIN WASHINGTON 7, D. C.

TURBULENCE INDUCED BY MEANS OF TRIP WIRE

FRICTION CALCULATIONS WITH SCHOENHERR FORMULA CORRELATION ALLOWANCE $\Delta C_f = 0.00020$

Figure 11 Resistance Data of Model 5012



RESISTANCE DATA
FOR
RESEARCH HULL FORM
ESTIMATED FROM RESISTANCE TESTS OF
MODEL 5014

DIMENSIONS	ACT. SHIP	400 FT. SHIP
LENGTH L.W.L. IN FEET	520	400
DISPLACEMENT IN TONS	17,835	8,118
MOLDED BEAM IN FEET	79.66	61.27
MEAN DRAFT IN FEET	25.42	19.55
TRIM IN FEET	EVEN KEEL	EVEN KEEL
WETTED SURF. SQ. FT.	47,000	27,810

APPENDAGES NONE

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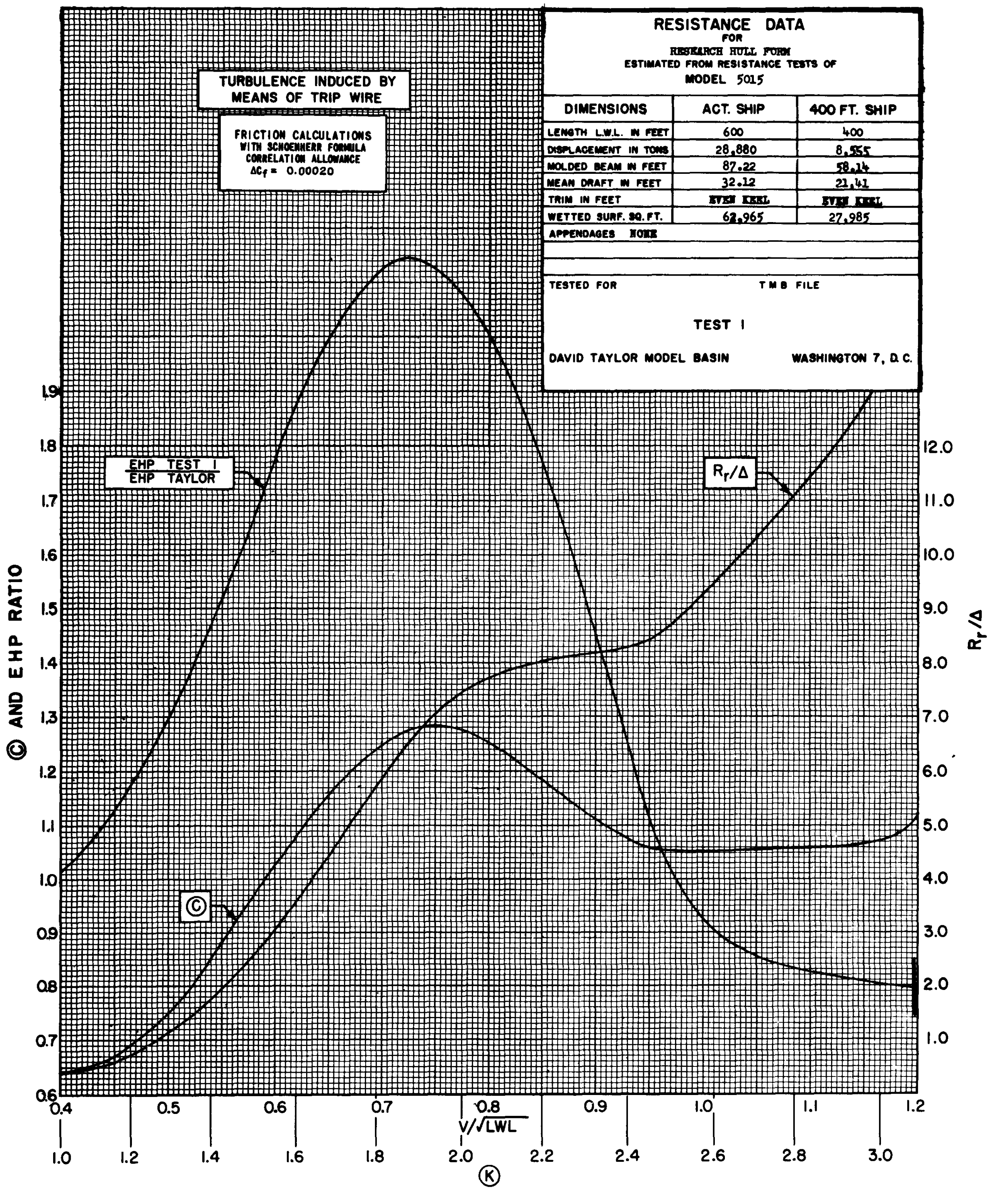
TURBULENCE INDUCED BY MEANS OF TRIP WIRE

FRICTION CALCULATIONS WITH SCHOENHERR FORMULA CORRELATION ALLOWANCE $\Delta C_f = 0.00020$

Figure 12 Resistance Data of Model 5014



TURBULENCE INDUCED BY MEANS OF TRIP WIRE

FRICTION CALCULATIONS
WITH SCHOENHERR FORMULA
CORRELATION ALLOWANCE
$\Delta C_f = 0.00020$

RESISTANCE DATA
FOR
RESEARCH HULL FORM
ESTIMATED FROM RESISTANCE TESTS OF
MODEL 5015

DIMENSIONS	ACT. SHIP	400 FT. SHIP
LENGTH L.W.L. IN FEET	600	400
DISPLACEMENT IN TONS	28,880	8,555
MOLDED BEAM IN FEET	87.22	58.14
MEAN DRAFT IN FEET	32.12	21.41
TRIM IN FEET	EVEN KEEL	EVEN KEEL
WETTED SURF. SQ. FT.	62,965	27,985
APPENDAGES NONE		

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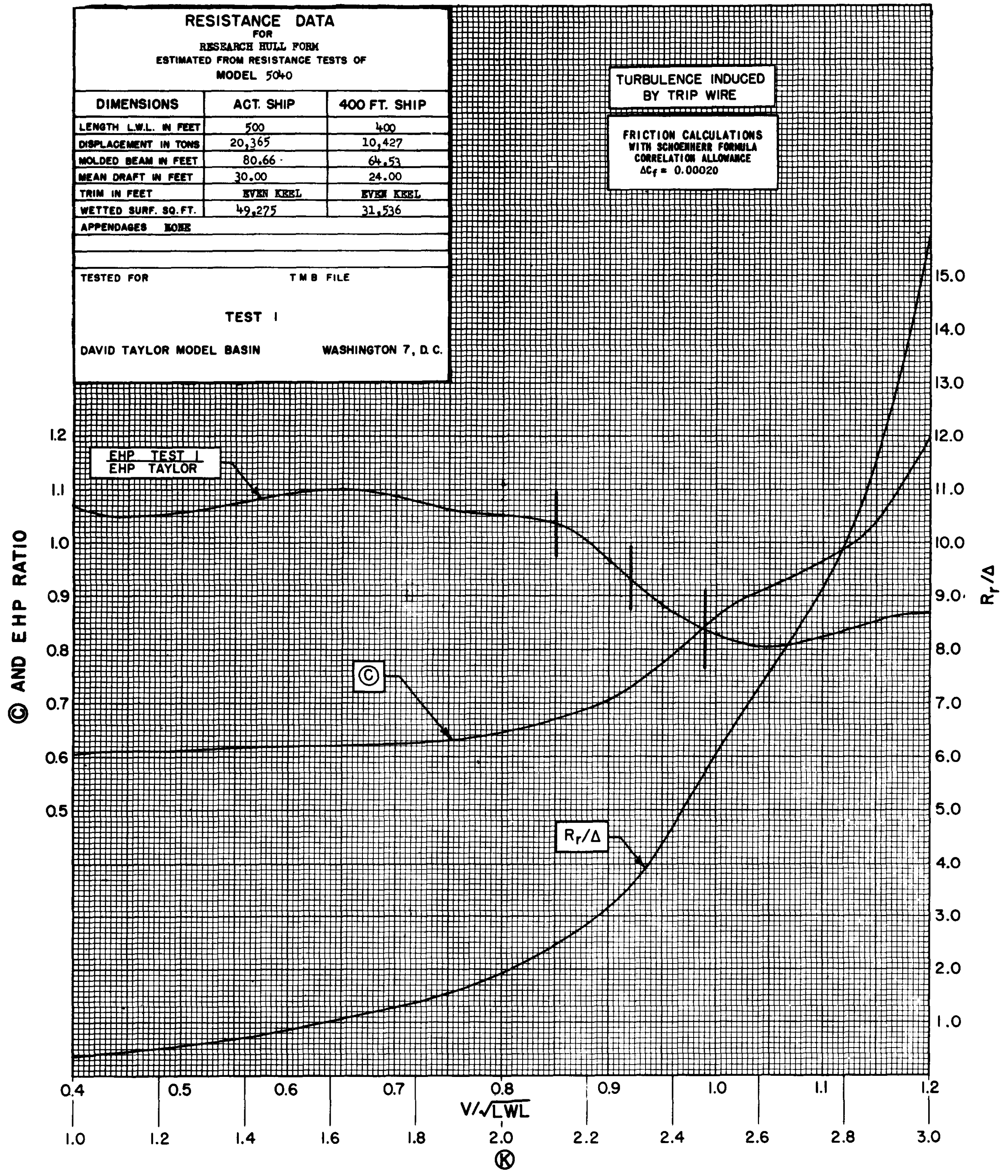
Figure 13 Resistance Data of Model 5015



RESISTANCE DATA
FOR
RESEARCH HULL FORM
ESTIMATED FROM RESISTANCE TESTS OF
MODEL 5040

DIMENSIONS	ACT. SHIP	400 FT. SHIP
LENGTH L.W.L. IN FEET	500	400
DISPLACEMENT IN TONS	20,365	10,427
MOLDED BEAM IN FEET	80.66	64.53
MEAN DRAFT IN FEET	30.00	24.00
TRIM IN FEET	EVEN KEEL	EVEN KEEL
WETTED SURF. SQ.FT.	49,275	31,536
APPENDAGES NONE		

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TEST 1

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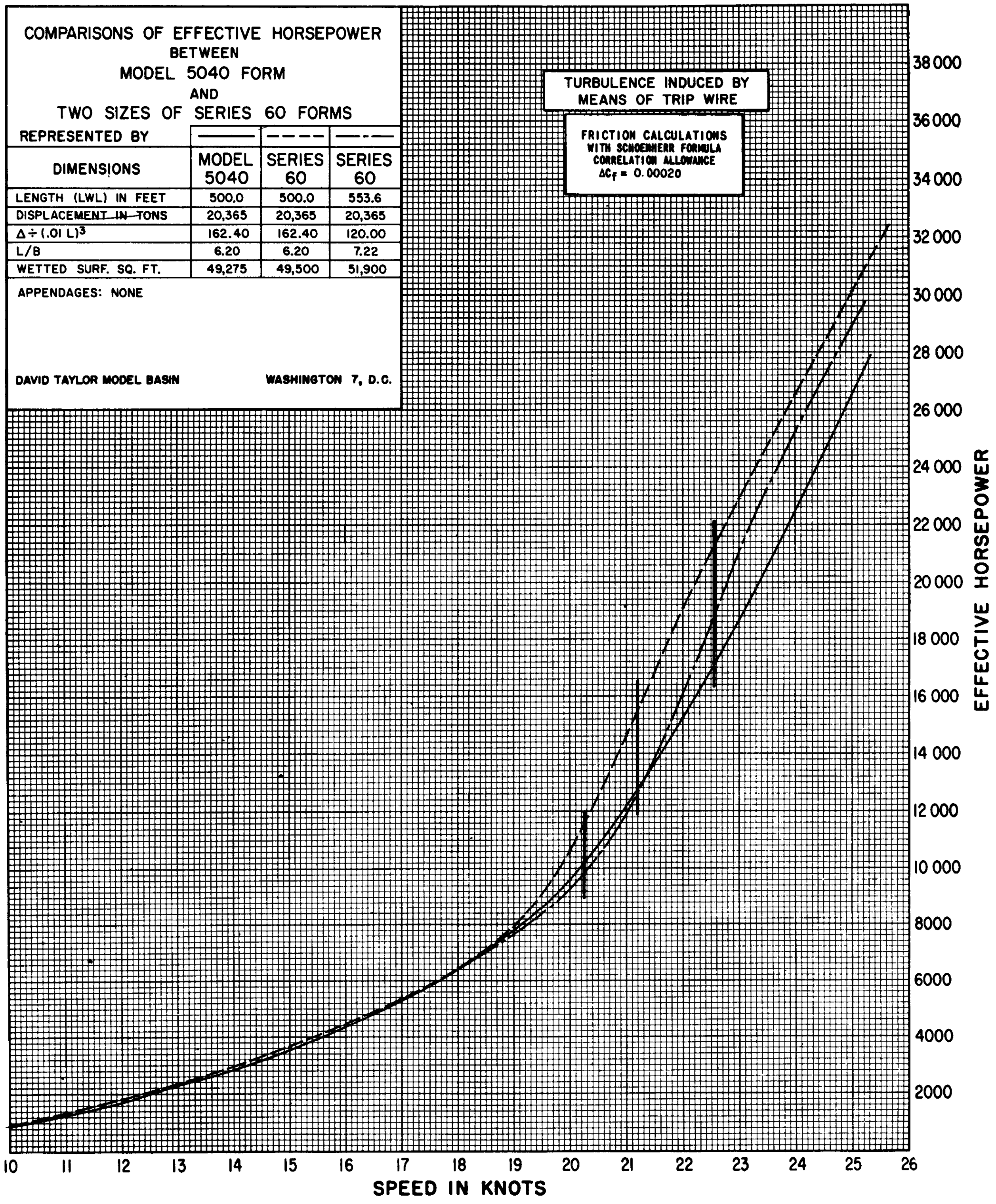
TURBULENCE INDUCED BY TRIP WIRE

FRICTION CALCULATIONS
WITH SCHOENHERR FORMULA
CORRELATION ALLOWANCE
$\Delta C_f = 0.00020$

Figure 14 Resistance Data of Model 5040



REPRESENTED BY	———	– – – –	—·—
DIMENSIONS	MODEL 5040	SERIES 60	SERIES 60
LENGTH (LWL) IN FEET	500.0	500.0	553.6
DISPLACEMENT IN TONS	20,365	20,365	20,365
$\Delta \div (.01\ L)^3$	162.40	162.40	120.00
L/B	6.20	6.20	7.22
WETTED SURF. SQ. FT.	49,275	49,500	51,900

Figure 15 Total Horsepower Comparisons Between
Model 5040 and Two Series 60 Models

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3. REPORT TITLE

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4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

5. AUTHOR(S) *(Last name, first name, initial)*

Pien, Pao C.

6. REPORT DATE November 1965	7a. TOTAL NO. OF PAGES 31	7b. NO. OF REFS 2

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13. ABSTRACT

A hull form design procedure based on the wavemaking resistance theory is given. To determine its value, this procedure has been used to design a number of experimental hull forms. The experimental resistance results of these forms are given. Conclusions are based on comparisons of these results with those of comparable Taylor's Standard Series or Series 60 forms.

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1. Ship hulls--Design--Procedure
2. Experimental ship hulls--Resistance--Model tests
3. Ship models--Model TMB Series 60
I. Pien, Pao C.
II. S-R009 01 01; Task 00103

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