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# SERIES 60 <br> <br> METHODICAL EXPERIMENTS WITH MODELS <br> <br> METHODICAL EXPERIMENTS WITH MODELS <br> OF SINGLE-SCREW MERCHANT SHIPS 

## by

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## FOREWORD

The research on Series 60 was carried out at the David Taylor Model Basin of the United States Navy. The results were published in the first instance in a number of papers before the Society of Naval Architects and Marine Engineers.

From time to time the wish has been expressed that the results of this research should be assembled in a single volume for easy reference and use. The original papers described a great deal of preliminary work carried out before the final Series 60 was adopted, and because they were read at intervals over a period of nearly 10 years, they also contained a certain amount of duplication and connective matter.

The opportunity has therefore been taken to completely rewrite the text, which is new, eliminating the preliminary work and much of the history, and also, it is hoped, most of the errors which are seemingly inevitable in a research of this magnitude.

In presenting the collected results in this new version, the author wishes to express his indebtedness to all the Staff of the Model Basin who have worked on the project since its inception in 1948 , particularly those who have been coauthors in the original papers-Capt. F.X. Forest, U.S.N., Mr. J.B. Hadler, Mr. G.R. Stuntz, Dr. P.C. Pien W.B. Hinterthan, and N.L. Ficken.

Mr. Hadler and Mr. Stuntz have been most helpful in reviewing the present text, although any opinions expressed are those of the author.

The whole project was carried through under the general guidance of a Panel of the Society of Naval Architects and Marine Engineers, the members of which devoted much time and thought to the choice of parameters and the detail design of the Series. The following people served on this Panel from time to time-Professor L.A. Baier, Mr. J.P. Comstock, Mr. H. de Luce, Capt. F.X. Forest, U.S.N., Mr. J.B. Hadler, Admiral C.O. Kell, U.S.N., Professor G.C. Manning, Mr. V.L. Russo and Dr. F.H. Todd-the successive Chairmen being Admiral Kell, Dr. Todd, and Mr. Hadler.

Thanks are especially due to successive Directors of the Model Basin who have throughout supported the research-Admirals C.O. Kell, G.H. Holderness, A.G. Mumma, W.H. Leahy, E.A. Wright, and Captain J.A. Obermeyerand to the Bureau of Ships which supplied the finance for most of the work under the Fundamental Hydromechanics Research Program, assisted towards the end by the Maritime Administration and the Society of Naval Architects and Marine Engineers.

## SYMBOLS

## Dimensions

$L \quad$ Length in general
$L_{B P} \quad$ Length between perpendiculars ( $L B P$ )
$L_{W L} \quad$ Length on designed waterline
$L_{\hat{S}} \quad$ Length of ship
$L_{M} \quad$ Length of model
$L_{E} \quad$ Length of entrance
$L_{X} \quad$ Length of parallel
$L_{R} \quad$ Length of run
B Beam
H Draft
$\Delta \quad$ Displacersent in tons
$\nabla \quad$ Displacement in cubic feet
$S \quad$ Wetted surface
LCB Longitudinal centre of buoyancy
$1 / 2 \propto_{E} \quad$ Half-angle of entrance on load waterline

## Form Coefficients

$C_{B} \quad$ Block coefficient
$C_{X} \quad$ Midship area coefficient
$C_{P} \quad$ Prismatic coefficient
$C_{P E} \quad$ Prismatic coefficient of entrance
$C_{P X} \quad$ Prismatic coefficient of parallel body
$C_{P R} \quad$ Prismatic coefficient of run

| $\varnothing_{B P}$ | Mid-point of $L B P$ |
| :---: | :---: |
| $\boldsymbol{x}$ | Position of $L C B$ as function of length from forward perpendicular |
| $L$ |  |
| $K_{R}$ | $\text { Coefficient of bilge radius }=\frac{\text { Bilge radius }}{\sqrt{B \times H}}$ |
| $\lambda$ | Scale of model to ship |
| Resistance Coefficients |  |
| R | General symbol for resistance |
| $R_{F}$ | Frictional resistance |
| $R_{R}$ | Residuary resistance |
| $R_{T}$ | Total resistance |
| $V{ }^{\text {, }}$ | Speed in general |
| $V_{S}$ | Speed of ship |
| $V_{M}$ | Speed of model |
| $\rho$ | Mass density of water |
| $g$ | Acceleration due to gravity |
| $\lambda$ | Wave length |
| $\frac{V}{\sqrt{L}}$ | Speed-length ratio |
|  | $R$ |
| $c$ | Resistance coerficient in general $=\frac{1 / 2 \rho S V^{2}}{}$ |
| $C_{F}$ | Frictional resistance coefficient (ATTC) |
| $C^{\prime}{ }_{F}$ | Frictional resistance coefficient (ITTC) |
| $C_{R}$ | Residuary resistance coefficient |
| $C_{T}$ | Total resistance coefficient |
| $C_{A}$ | Ship correlation allowance coefficient |

$0_{m} \quad$ Froude resistance coefficient for model
$O_{s} \quad$ Froude resistance coefficient for ship
EHI, ehp Effective or tow rope horsepower $=\frac{R V}{326}$ with $R$ in pounds and $V$ in knots
(K) Froude speed coefficient $=0.5834 \frac{V}{\Delta^{1 / 6}}$ with $V$ in knots and $\Delta$ in tons
(C) Froude resistance coefficient $=\frac{\text { EHP }}{\Delta^{2 / 3} V^{3}} \times 427.1$ with $V$ in knots and $\Delta$ in tons.

## Propulsion Symbols

| $D$ | Diameter of propeller |
| :--- | :--- |
| $P$ | Pitch of propeller |
| $P . / D$ | Pitch ratio |
| rpm | Revolutions per minute |
| BAR | Blade area ratio |
| BTF | Blade thickness fraction |
| $w^{\prime}$ | Wake fraction (Taylor) |
| $t$ | Thrust deduction fraction |
| $e_{h}$ | Hull efficiency |
| $e_{P}$ | Propeller efficiency (open) |
| $e_{r r}$ | Relative rotative efficiency |

DHP, dhp Delivered horsepower absorbed by propeller
SHP, shp Shaft horsepower measured in shafting
$V_{x} \quad$ Longitudinal velocity of water in wake
$V_{v} \quad$ Vertical velocity of water in wake
$V_{h} \quad$ Horizontal velocity of water in wake
$w_{x} \quad$ Longitudinal wake fraction
$w_{v} \quad$ Vertical wake fraction
$w_{h} \quad$ Horizontal wake fraction
$w_{t r} \quad$ Transverse wake fraction compounded of $w_{\nu}$ and $w_{h}$

## CHAPTER I

## INTRODUCTION

One of the problems which faces the naval architect at an early stage in the design of any new ship is the determination of the necessary horsepower to fulfill the speed requirements and to assess the effect on this power of making different choices for the size, proportions, and fullness of the ship.

To assist him in this problem, he will have recourse to a number of different sources of data. He will have his own experience to draw upon, covering previous designs and ships built to them, and, possibly, results of model tests carried out in this connection. Then there are available many results of specific model tests published in various technical papers and, in particular, the design data sheets published by the Society of Naval Architects and Marine Engineers (SNAME). ${ }^{1}$

Such data, although extremely useful, suffer from the fact that they refer to a large number of models which are unrelated one to the other and in which the variations in design parameters are quite random. Much more valuable are the results of experiments on families of models in which the different design parameters are varied systematically and, so far as is possible in ship design, one at a time. Many such methodical series of model tests have been carried out in the past, perhaps the best known being that due to Admiral D.W. Taylor. ${ }^{2}$ Other such series covering different types of ships have been run by many people, ${ }^{3-43}$ including one by the British Ship Research Association more or less concurrently with the present Series 60 at the David Taylor Model Basin. ${ }^{43}$

The results of such tests can be expressed in design charts from which the naval architect, by interpolation where necessary, can select a number of forms suitable to a particular problem, determine their relative resistance and propulsive qualities, and so make an informed choice of the best combination of parameters to give minimum power within the other limitations of the design conditions.

Many methodical series of the past are not suitable for moderi single-screw merchant ship design for a variety of reasons, and although taken together they cover a large range of values of the usual design parameters, they lack any overall coordinating factor. Also, some doubt exists about the results in a number of the older series because of the absence of any turbulence stimulation on the models.

The need for more systematic information on the design of lines for modern, singlescrew ships has been recognized at the Taylor Model Basin for many years. The subject was revived after the war at the meetings of the American Towing Tank Conference (ATTC) and the Hydromechanics Subcommittee of SNAME held in Ann Arbor in 1948. The Society agreed to spons or the preparation of parent lines suitable for a series of single-screw

[^0]merchant, ship forms, and appointed a Panel to select the pattern and range of parameters to be used in the work.* The methods of deriving the parent lines and presenting the data were developed at the Model Basin, and the experiments were carried out there as part of the Bureau of Ships Fundamental Hydromechanics Research Program during the years 1948-1960.

At the time of the inception of this project, there was beginning a great upsurge in the provision of hydromechanic research facilities all over the world, with the certainty that in consequence many programs of research into hull form, in smooth water and in waves, would be initiated. One of the objects of Series 60 was to provide a parent family which, within the type of ship covered, could serve as a starting point for any such work, so that new series might be elated one to the other by having a common datum line. Considerable s ccess has been achieved in this way, and parents of the series are being used for research into seagoing qualities of ships, both under ATTC and International Towing Tank Conference (ITTC) sponsorship. Other examples include methodical launching calculatic": the effect of bulbous bows on power, the estimation of propeller forces acting on a ship's $h$ and anafting, and the representation of ships' lines by mathematical methods.

The results of the model experiments have been published before the SNAME from time to time to make them available to the profession as soon as possible; this led inevitably to some duplication and the occurrence of a number of minor errors. In the discussions on these papers, a number of requests have been made that the results be brought together in a single publication. In carrying out this suggestion, much of the preliminary work has been omitted since it did not have any bearing on the ultimate results. Readers who are interested in these historical and development phases of the Series can find a full account in the individual papers. For convenier.ce, these are listed separately on page R-5 immediately following the list of specific references.

[^1]
## CHAPTER II

## SELECTION OF THE RANGE OF PROPORTIONS FOR THE SERIES

At the time of the inception of the program, a survey was made of the current practice in shipbuilding to ensure, as far as possible, that the series would cover the normal range of proportions of modern ships. In the course of this, some 40 individuals and organizations were consulted, and after analyzing these comments, the SNAME Panel agreed upon a series of parent forms and variations which would cover the general field of design for singlescrew merchant ships. This was in 1949, and already it is obvious that the Series is no longer adequate for modern single-screw ships, which, on the one hand are being made finer and driven to higher and higher speeds in order to obtain the increased efficiency possible with single-screw as compared with twin-screw propulsion, and on the other hand are being made larger and fuller to achieve the resultant economy in bulk carriers of ore, oil and similar cargoes. At the time of the inception of the program, it appeared that lower and upper limits in block coefficient of 0.60 and 0.80 would be satisfactory, but the intervening years have shown that 0.55 and 0.85 would have been better forecasts. The future extension of the series to such forms would be a very worthwhile project.

The basic parameter chosen for defining the series was block coefficient ( $C_{B}$ ). This was used in preference to the prismatic coefficient ( $C_{p}$ ) because in the preliminary design stages for merchant ships it is a direct measure of the displacement carried on given dimensions, usually a basic consideration. This approach in no way prevents the use of prismatic coefficient in the subsequent presentation of the results if so desired.

The decision to use $C_{B}$ in preference to $C_{P}$ has been a point of comment by numerous contributors to the discussions on the Series 60 papers. In general, the ship designer and operator seem to favor block coefficient. Sir Amos Ayre said that "for the type of ship dealt with, I am pleased to observe that the block coefficient has been chosen as the basic parameter in preference to the prismatic coefficient" (discussion on Reference 44). Mr. Ericson, commenting on the same paper, stated that he "should like . . to put in a few words which will present the viewpoint of the ship operator himself. First, I should like to endorse the use of the block coefficient as a basic parameter. It is fairly useful in making a study, particularly an economic study, where displacement is considered, which is reflected immediately in the carrying capacity of the vessel."

On the other hand, naval architects and hydrodynamicists have emphasized the merits of the prismatic coefficient as being a more meaningful parameter for interpreting resistance results, although even here some doubts have been expressed by Dr. Weinblum: "Other calculations show the now well-known extreme sensibility of the wave resistance to variations of pure form for a given prismatic coefficient. The wave-resistance values corresponding to two such forms can easily reach a ratio of $3: 1$, so that sometimes one even is inclined

TABLE 1
Variation of $\frac{L}{B}, \frac{B}{H}, \frac{\Delta}{\left(\frac{L}{100}\right)^{3}}, \frac{L}{\nabla^{1 / 3}}$, and $L C B$ Position with
$C_{B}$ for the Parent Models

| $C_{B}$ | 0.60 | 0.65 | 0.70 | 0.75 | 0.80 |
| :---: | :---: | :---: | :---: | :---: | :---: |
| $\frac{L}{B}$ | 7.50 | 7.25 | 7.00 | 6.75 | 6.50 |
| $\frac{E}{U}$ | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 |
| $\frac{\Delta}{(L / 100)^{3}}$ | 122.0 | 141.4 | 163.4 | 188.2 | 216.5 |
| $\frac{L / \nabla^{1 / 3}}{}$ | 6.165 | 5.869 | 5.593 | 5.335 | 5.092 |
| $L C B$ as percent <br> of $L_{B P}$ from <br> $Q B P$ | 1.5 aft | 0.5 aft | 0.5 fwd | 1.5 fwd | 2.5 fwd |

to doubt the value of the prismatic coefficient as a standard form parameter' (discussion on Reference 45).

In the present series, the midship area coefficient does not vary very much, and so the resistance qualities can be related either to $C_{B}$ or $C_{P}$ without introducing any conflicting situations. Since the results of such a methodical series will essentially be used by the designer, $C_{B}$ is probably the better choice for presentation of the various curves and contours.

Fivo block coefficients were chosen, each associated in the first instance with given longitudinal center of buoyancy ( $L C B$ ) positions, midship area coefficients, length-beam $\left(\frac{L}{B}\right)$ and beam-draft $\left(\frac{B}{H}\right)$ ratios (Table 1 and Figure 1). $\quad B$ and $H$ are the moulded beam and dratt in feet, respectively, and $L$ is the length between perpendiculars ( $L B P$ ) measured from the centerline of the rudder stock to the forward side of stem at the designed load waterline, as adopted by the SNAME in its Model Resistance Data sheets. It corresponds with that used by the classification societies such as the American Bureau of Shipping.

The variation in $\frac{L}{B}$ with $C_{B}$ was chosen by the panel to take into account the fact that the finer ships were, in general, relatively longer and narrower than the fuller ones.

To cover the general spread of $\frac{L}{B}, \frac{B}{H}$, and $\frac{\Delta}{\left(\frac{L}{100}\right)^{3}}$ for existing designs, and the



Figure 2 - Typical Variation of $\frac{L}{B}$ and $\frac{B}{H}$ Ratios for a Given Value of $C_{B}$

Figure 1 - Variation of Proportions etc., with $C_{B}$
possible variation in $L C B$ position, a grid was adopted as shown by the dotted lines in Figure 1.*

For any one block coefficient and $L C B$ position, a total of nine models was rur in which the $\frac{L}{B}$ and $\frac{B}{H}$ ratios were varied. The pattern for a typical case $\left(C_{B}=0.60\right)$ is shown in Figure 2.
*The values of $\frac{L}{B}, \frac{B}{H}$, and $\frac{\Delta}{\left(\frac{L}{100}\right)^{3}}$ are not independent but are related by the expression

$$
\frac{\Delta}{\left(\frac{L}{100}\right)^{3}}=\frac{C_{B}}{\left(\frac{L}{B}\right)^{2}\left(\frac{B}{H}\right)} \times 28570 \text { with dimensions in feet and displacement }
$$

## CHAPTER III

## CHOICE OF HULL FORM FOR THE PARENT MODELS

In the past, the models of most methodical series have been derived from a single parent form by proportioned geometrical changes. When carried to very different proportions and to fullness coefficients suitable to very different values of speed-length ratio $\left(\frac{V}{\sqrt{L}}\right)$, such changes must inevitably lead to unrealistic forms regardless of how good the parent lines might be for the original design conditions. In planning Series 60, therefore, another approach was tried. A review was made of the resistance results of the single-screw merchant ship models available at the Model Basin, and some 20 were selected which appeared to give good performance as judged by a comparison with Taylor's Standard Series. These models covered a range of fullness, and plots were made of sectional area coefficients and waterline half-breadth coefficients to a base of fore- and aft-body prismatic coefficients. Cross curves were then drawn which, while being fair lines, followed the actual points as closely as possible. In this way it was hoped to obtain, by interpolation at the correct values for the parent forms, a series of models which would retain most of the good resistance qualities of the models on which the coefficient curves were based, while also incorporating the changing characteristics necessary to ensure good performance of each model at its appropriate speed. length ratio. At the same time, these parent forms would be related to one another in accordance with a definite graphical pattern. Once the series was complete and the resultant resistance curves available, a form could be quickly obtained by interpolation of the cross curves to fulfill any desired combination of $C_{B}, L, B, H, \Delta$, and $L C B$ position. Moreover, this design could be immediately associated with a corresponding resistance and effective horsepower.

From these contours, five parent forms were drawn having block coefficients of 0.60 , $0.65,0.70,0.75$ and 0.80 , with $\frac{L}{B}$ ratios, $\frac{B}{H}$ ratios, and $L C B$ positions as shown for the parent models in Figure 1. This group of models was designated Series 57 in succession to earlier TMB Series, and the details of their derivation and the results of the model resistance tests were given in a paper before the SNAME in 1951.44

The resistance results of Series 57 were compared with those for a number of recent successful modern designs of single-screw ships and found to be disappointing. In view of the apparently good qualities of the models on which the contours were based, this was at first sight surprising. Further investigation suggested that although the departures from the actual design lines made when fairing the contours were small, they may have been critical in certain cases, and also that possibly some of the results of the resistance tests on the chosen models were suffering from the effects of laminar flow. Apparently in ship
models, as in human beings, the selection of good parents does not necessarily lead to better - or even as good - offspring!

Although the original conception of the project was to derive a series of related parent forms which would serve as a point of departure for future model programs, and which therefore should have reasonably good but not necessarily optimum resistance qualities (the quest for which might indeed last forever), it was evident from the very lengthy and valuable discussion on the paper that the members of the profession desired something better in quality than Series 57 as a basis for any such systematic program.

The panel thereupon reviewed the original series and agreed that the real merits of the Series 57 models could best be established by comparison with the performance of actual successful ship designs. In this way, differences in proportions and in $L C B$ position could be eliminated and the effects of differences in shape of area curves, waterlines and section shapes evaluated.

Five designs were chosen as being typical of good, modern, single-screw ships, which, of necessity, had to meet many requirements in addition to those of good resistance qualities.

Three of these were Maritime Administration vessels of the MARINER, SCHUYLER OTIS BLAND, and C. 2 classes. The other two were Bethlehem Steel Company designs. One was the tanker PENNSYLVANIA. The other did not represent any built ship but was a design for a 0.70 block coefficient ship given by Mr . H. de Luce in his contribution to the discussion on the Scries 57 paper.

Models of the first four were available at the Model Basin, and a model of the fifth design was made and tested.

For comparison with each of these, an equivalent Series 57 model was made to lines drawn out from the contours. Each pair of models represented a ship of given length, beam, draft, displacement, and position of $L C B$ so that the differences in each case were restricted to the shapes of area, waterline, and section curves.

The results of these model tests are given in full in Reference 45. Briefly, at speeds a ppropriate to the different fullness coefficients, the Series 57 models were in general somewhat worse than those of the actual ships by amounts up to a maximum of 6 percent.

The area and load waterline ( $L W L$ ) curves of any pair of these models were not very different in shape or character, and the chief differences lay in the shape of the cross sections. An analysis of the bow and stern lines indicated that the actual ships had, in every case, more U-shaped sections than the Series 57 models, and the Panel decided that new contours should be drawn using the sectional area and waterline curves for these actual designs as guides, thus giving a more U-shaped character to the transverse sections while paying due attention to stability considerations. This change was also expected to lead to improved propulsive efficiencies.

These new contours formed the basis for Series 60.

## CHAPTER IV

## CHARACTERISTICS OF SERIES 60 LINES

The principal particulars of the Series 60 parent models are set out in Table 2. Attention must be drawn to a number of details which are important in using the contour charts and resistance results.
a. Midship section area coefficient ( $C_{X}$ )

The midship section has no deadrise, in accordance with current practice, and a linear relation between block coefficient and midship area coefficient was adopted. This relation and the corresponding values of the bilge radius are shown in Figure 3.
b. Position of $L C B$

Reference to the published data on the selection of a suitable position of the $L C B$ for different fineness coefficients failed to show any unanimity as to the most desirable location,

TABLE 2
Particulars of Parent Forms, Series 60

| Model Number | 4210W | 4211W | 4212W | 4213W | 4214W-B4 |
| :---: | :---: | :---: | :---: | :---: | :---: |
| $L_{B P}, \mathrm{ft}$. | 400.0 | 400.0 | 400.0 | 400.0 | 400.0 |
| $B, \mathrm{ft}$. | 53.33 | 55.17 | 57.14 | 59.26 | 61.54 |
| $H$, ft. | 21.33 | 22.09 | 22.86 | 23.70 | 24.59 |
| $\Delta$, Tons | 7,807 | 9,051 | 10,456 | 12,048 | 13,859 |
| $L_{E} / L_{B P}$. | 0.5 | 0.472 | 0.410 | 0.350 | 0.290 |
| $L_{1} / L_{B P}$ | 0 | 0.035 | 0.119 | 0.210 | 0.300 |
| $L_{\text {E }} / L_{\text {BP }}$ | 0.5 | 0.493 | 0.471 | 0.440 | 0.410 |
| $C_{B}$ | 0.60 | 0.650 | 0.700 | 0.750 | 0.800 |
| $C_{\text {x }}$ | 0.977 | 0.982 | 0.986 | 0.990 | 0.994 |
| $C_{P}$ | 0.614 | 0.661 | 0.710 | 0.758 | 0.805 |
| $C_{\text {Pr }}$ | 0.581 | 0.651 | 0.721 | 0.792 | 0.861 |
| $C_{\text {PA }}$ | 0.646 | 0.672 | 0.698 | 0.724 | 0.750 |
| $C_{\text {PE }}$ | 0.581 | 0.630 | 0.660 | 0.704 | 0.761 |
| $C_{\text {PR }}$ | 0.646 | 0.667 | 0.680 | 0.686 | 0.695 |
| $C_{P V}$ | 0.850 | 0.871 | 0.891 | 0.907 | 0.920 |
| $C_{\text {PV }}$ | $0: 910$ | 0.927 | 0.944 | 0.961 | 0.971 |
| $C_{P V}$ | 0.802 | 0.823 | 0.842 | 0.856 | 0.867 |
| $C_{\text {w }}$ | 0.706 | 0.746 | 0.785 | 0.827 | 0.871 |
| $C_{\text {wr }}$ | 0.624 | 0.690 | 0.753 | 0.817 | 0.881 |
| $\mathcal{E}_{\text {wa }}$ | 0.788 | 0.802 | 0.818 | 0.838 | 0.860 |
| $C_{1 r}$ | 0.543 | 0.597 | 0.653 | 0.711 | 0.776 |
| $1 / 2 \alpha_{r}$, deg | 7.0 | 9.1 | 14.5 | 22.5 | 43.0 |
| LWL. | 406.7 | 406.7 | 406.7 | 406.7 | 406.7 |
| $L C B \%$ LBP from 8. | 1.5A | 0.5 A | 0.5F | 1.5F | 2.5 F |
| $L / B$. | 7.50 | 7.25 | 7.00 | 6.75 | 6.50 |
| $B / H$. | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 |
| $L / \nabla^{1 / 4}$ | 6.165 | 5.869 | 5.593 | 5.335 | 5.092 |
| $S / \nabla^{1 / 1}$ | 6.481 | 6.332 | 6.200 | 6.091 | 6.028 |
| W.S., sq ft. | 27,280 | 29,410 | 31,705 | 34,232 | 37,200 |
| $K_{R}=R / \sqrt{B H}$ | 0.229 | 0.205 | 0.181 | 0.153 | 0.118 |

IV-1
nor did the information for the selected basis models give any clear guidance. All the data showed a progressive movement aft with reducing block or prismatic coefficient, resulting in finer entrances for the models running at the higher speed-length ratios, as one would expect. A linear variation of position of $L C B$ with fullness was thorefore adopted, as shown in Figure 1. Although arbitrary, this line was in general a mean of the available data. Since the effect of $L C B$ position was the next point to be investigated in the program, this line was considered to be an acceptable point of departure.
c. Load waterline half-angle of entrance ( $1 / 2 \boldsymbol{a}_{E}$ )

This angle varies from 7.0 to 43 deg , as shown in Table 2 and Figure 4.
d. Sectional area and waterline coefficient contours

The length of parallel body and its fore and aft position for the parent models with the selected position of $L C B$ are shown in Figure 4.

The corresponding lengths of entrance and run ( $L_{E}$ and $L_{R}$ ) were determined, each divided into 10 equal intervals, and contours of cross-sectionai area coefficients were plotted to a base of prismatic coefficients of entrance and run respectively ( $C_{P E}$ and $C_{P R}$ ). These contours are shown in Figures 5a and 5b.

The body plans were treated in the same way; contours of waterline half-breadth coefficients to a base of prismatic coefficients of entrance and run are given in Figures 6a to 6 p .

The positions of the centroid of volume of the entrance and run are shown in Figures 7 and 8 for different values of the respective prismatic coefficients. (Text continued on page IV-23)


Figure 3 - Variation of $C_{X}, C_{P}$ and Bilge Radius with $C_{B}$

IV-2


Figure 4 - Variation of Angle of Entrance, Position, and Amount of Parallel Body for Series 60 Parents
Figure 5 - Contours of Cross-Sectional Area Coefficients, Series 60


甘gyy wnwixvw to noilovye sy vait noillogs






| $\stackrel{8}{-}$ |  | $\begin{aligned} & 8 \\ & 0 \\ & 0 \end{aligned}$ |  | $\stackrel{8}{8}$ |  | $\stackrel{8}{\circ}$ |  |  | $\begin{aligned} & 8 \\ & \stackrel{8}{\circ} \end{aligned}$ |  |  | $\begin{aligned} & 0 \\ & 0 \\ & 0 \end{aligned}$ |  | $\stackrel{+}{\square}$ | \% |  | - |  | ¢ |  | $\begin{aligned} & 0 \\ & \hline-1 \end{aligned}$ |  |  |  |
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|  | \# | \# | ¢ |  |  |  |  | - |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | \# | \# |  |  |  |  |  |  |  |  |  | 8 |  |  |  |  |  |  |  |  |  |  |  |  |
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|  |  |  |  | $\# \#$ |  |  | \# |  |  | \# |  | \# | + |  | \# | + | $\pm$ | \# | H |  | 巫 | \# | \# | 8 |



TA SZㅇ LV WVGg WOWIXVW HO NOILOVAy SV WVGe


WVGg WחWIXVW AO NOIL.JVYA SV WVGg




Figure 6k-1.00 W.L. Cross Curves, Entrance

Figure 61 - 1.00 W.L. Cross Curves, Run






Figure 7 - Position of Centroid of Volume of Entrance


Figure 8 … Position of Centroid of Volume of Run


Figure 9 - Ratio of $\frac{L_{E}}{L_{B P}}$ for Different Values of $C_{B}$ and Positions of $L C B$


Figure 10 - Ratio of $\frac{C_{P E}}{C_{P R}}$ for Different
Values of $C_{B}$ and Positions of $L C B$

In order to use the contours to obtain a model having any desired fullness and location of $L C B$, certain auxiliary curves are necessary. These show:

1. the ratio of length of entrance to total length $\frac{L_{E}}{L_{B P}}$ (Figure 9) and
2. the ratio of entrance and run prismatic coefficients $\frac{C_{P E}}{C_{P R}}$ for different blook coefficients and positions of $L C B$ (Figure 10).

In a particular case, the dimensions and displacement of the ship and the desired location of the $L C B$ will be determined first from the general design conditions. A number of different solutions may be tried to explore the effects on horsepower, weights, costs, and so on. In any one case, the block, midship area, and prismatic coefficients can be calculated and the length of parallel body $\left(L_{X}\right)$ can be found from Figure 3. Figures 9 and 10 will then give the length of entrance $\left(L_{E}\right)$ and the ratio of prismatic coefficients of entrance and run $\frac{C_{P E}}{C_{P R}}$. We can then write

$$
C_{P} \times L_{B P}=\left(C_{P E} \times L_{E}\right)+L_{X}+\left(C_{P R} \times L_{R}\right)
$$

from which $C_{P E}$ and $C_{P R}$ can be determined.

These values can be used to enter the area and waterline coefficient contours, and the area curve and lines plan can then be drawn. The stations to which the ordinates refer must be spaced equally along the lengths of entrance and run.
e. Bow and stern contours

These are shown in Figure 11. The stern has an aperture suitable for a single screw with cruiser stern. The bow profile is almost vertical below water, the waterline endings being drawn with a radius. The radius corresponds to 2 in . at 1.1 WL and 24 in . at 1.95 WL for a ship having an $L B P$ of 400 ft . ( 1.00 WL is the designed load waterline.)
f. Although it was realized that the incorporation of a bulb in the bow lines would be of benefit in the finer models of the series, this would have introduced a discontinuity in the graphical representation of the forms. The Panel decided that this was not desirable in a methodical series of this type, and that the effect of bulbs of different shapes and sizes could well be the subject of a future research project of the kind for which Series 60 was designed to be a sterting point.
g. Another future research project which might stem from the Series w.ould be concerned with the behavior of such models in waves, and the effect of changes in fullness and proportions upon their motions anci speed loss. It was therefore important that the above-water forms should be realistic in terms of sheer and flare, and after consultation with the Maritime Administratioun, they were drawn out to represent modern average practice.
NOTE: $\begin{aligned} & 15 \text { INCH BOW RADIUS AT } 1.75 \mathrm{WL} \\ & 24 \text { INCH BOW RAOIUS AT } 1.95 \mathrm{WL}\end{aligned}$

Figure 11 - Bow and Stern Contours

## CHAPTER V

## RESISTANC.E TESTS ON SERIES 60 PARENT MODELS

The five parent models were made to lines drawn out from the new contours and had the numbers and particulars given in Table 2. The lines are shown in Figures 12 through 16; the area curves are given in Figure 17 and the offsets ia Tables 3 through 7.

The models were made of wax, $20 \mathrm{ft} L B P$, and towed in the deep-water basin at the Taylor Model Basin, which has a cross section 51 ft wide and 22 ft deep.

Experiments were made with and without turbulence stimulation. The latter was provided by studs, $1 / 8 \mathrm{in}$. in diameter, $1 / 10 \mathrm{in}$. high, spaced 1 in . apart along a line parallel to the bow contour, the fore and aft position being controlled by the angle of entrance on the LWL as described by Hughes and Allan. 46

When these se:ies experiments were begun in 1949, the question of turbulence stimulation was under intensive study, and its importance, espan "ian full nudulu, had only recently been widely appraciated. At that time, thiere was no agreement as to the bosi method of stimulating turbulent flow, and indeed the subject is not satisfactorily resolved even today. Several methods were being advocated, the principal ones being sand strips, struts, trip wires and studs. The Series 57 models were run with sand strips, buit these were abandoned in favour of studs for the Series 60 parents and $\bar{L} \bar{C} B$ series. The studs were replaced by trip wires for the final series of variaticis in $\frac{L}{B}$ and $\frac{B}{H}$ ratios because experience had shown that trip wires gave slightly higher resistances than studs for the full models. Moreover, it was hoped that other experiment tanks would in the future use Series 60 as a point of departure for series work, and most of them used trip wires. In the final presentation based on the $\frac{L}{B}, \frac{B}{H}$ Series, the contours all apply to tests made with trip wires. An account of the experiments carried out to evaluate the different types of stimulation is given in Appendix A.

The resistance results from the models have been converted to apply to ships of 400 ft $L B P$ and with other dimensions as listed in Table 2. In making this conversion, the ATTC 1947 friction formulation was used together with an addition of +0.0004 for model-ship correlation allowance $C_{A}$. The ship values haye been expressed as values of $C_{T}$ and are plotted to a base of $\frac{V}{\sqrt{L_{W L}}}$ in Figure 18.



Figure 14c - Lody
Figure 14 - Lines of Series 60 Parents. $0.70 C_{B}$ (Model 4212W)


Figure 15 - Lines of Series 60 Parents: $0.75 C_{B}$ (Model 4213W)


Figure 16 - Lines of Series 60 Parents. $0.80 C_{B}$ (Model 4214WB-4)




Table 3 - Table of Offsets-Parent Forms-0.60 Block Coefficient (Half-breadths of waterline given as fraction of maximum beam on each waterline)

Model $=4210 \mathrm{~W}$
W.L. 1.00 is the designed load waterline

Forebody prismatic coefficient $=0.581$ Afterbody prismatic coefficient $=0.648$ Total prismatic coefficient

| Sta. | Tan. | 0.075 | 0.25 | 0.50 | $\begin{aligned} & \text { aterlines } \\ & 0.75 \end{aligned}$ | 1.00 | 1.25 | 1.50 | max. area to 1.00 W.L. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| FP | 0.000 | 0.000 | ' 0.000 | 0.000 | 0.000 | 0.000 | 0.020 | 0.042 | 0.000 |
| 1/2 | 0.009 | 0.032 | 0.042 | 0.041 | 0.043 | 0.051 | 0.076 | 0.120 | 0.042 |
| 1 | 0.013 | 0.064 | 0.082 | 0.087 | 0.090 | 0.102 | 0.133 | 0.198 | 0.085 |
| 11/2 | 0.019 | 0.095 | 0.126 | 0.141 | 0.148 | 0.160 | 0.195 | 0.278 | 0.135 |
| 2 | 0.024 | 0.127 | 0.178 | 0.204 | 0.213 | 0.228 | 0.270 | 0.360 | 0.192 |
| 3 | 0.055 | 0.196 | 0.294 | 0.346 | 0.368 | 0.391 | 0.440 | 0.531 | 0.323 |
| 4 | 0.134 | 0.314 | 0.436 | 0.502 | 0.535 | 0.562 | 0.607 | 0.683 | 0.475 |
| 5 | 0.275 | 0.466 | 0.589 | 0.660 | 0.691 | 0.718 | 0.754 | 0.804 | 0.630 |
| 6 | 0.469 | 0.630 | 0.733 | 0.802 | 0.824 | 0.841 | 0.862 | 0.889 | 0.771 |
| 7 | 0.668 | 0.779 | 0.854 | 0.908 | 0.917 | 0.926 | 0.936 | 0.846 | 0.880 |
| 8 | 0.881 | 0.898 | 0.935 | 0.971 | 0.977 | 0.979 | 0.981 | 0.982 | 0.955 |
| 9 | 0.945 | 0.964 | 0.979 | 0.996 | 1.000 | 1.000 | 1.000 | 1.000 | 0.990 |
| 10 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 11 | 0.965 | 0.982 | 0.990 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 0.996 |
| 12 | 0.882 | 0.922 | 0.958 | 0.994 | 1.000 | 1.000 | 1.000 | 1.000 | 0.977 |
| 13 | 0.767 | 0.826 | 0.892 | 0.962 | 0.987 | 0.994 | 0.997 | 1.000 | 0.938 |
| 14 | 0.622 | 0.701 | 0.781 | 0.884 | 0.943 | 0.975 | 0.990 | 0.999 | 0.863 |
| 15 | 0.463 | 0.560 | 0.639 | 0.754 | 0.857 | 0.937 | 0.977 | 0.994 | 0.750 |
| 16 | 0.309 | 0.413 | 0.483 | 0.592 | 0.728 | 0.857 | 0.933 | 0.975 | 0.609 |
| 17 | 0.168 | 0.267 | 0.330 | 0.413 | 0.541 | 0.725 | 0.844 | 0.924 | 0.445 |
| 18 | 0.065 | 0.152 | 0.193 | 0.236 | 0.321 | 0.536 | 0.709 | 0.834 | 0.268 |
| 181/2 | 0.032 | 0.102 | 0.130 | 0.156 | 0.216 | 0.425 | 0.626 | 0.769 | 0.187 |
| 19 | 0.014 | 0.058 | 0.076 | 0.085 | 0.116 | 0.308 | 0.530 | 0.688 | 0.109 |
| 191/2 | 0.010 | 0.020 | 0.020 | 0.022 | 0.033 | 0.193 | 0.418 | 0.579 | 0.040 |
| AP | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.082 | 0.270 | 0.420 | 0.004 |
| Max. half beam | 0.710 | 0.886 | 0.985 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |  |

Table 4 - Table of Offsets-Parent Forms-0.05 Block Coefficient (Half-breadths of waterlines given as fraction of maximum beam on each waterline)

Model $=4211 \mathrm{~W}$
W.L. 1.00 is the designed load waterline
$\begin{aligned} \text { Forebody prismatic coefficient } & =0.651 \\ \text { Afterbody prismatic coefficient } & =0.672 \\ \text { Total prismatic coefficient } & =0.661\end{aligned}$


Area as fraction of max. area to 1.00 W.L.
0.000
0.055
0.115
0.184
0.261
0.432
0.609
0.765
0.879
0.951
0.987
0.999
1.000
0.998
0.987
0.958
0.898
0.797
0.662
0.492
0.303
0.209
0.121
0.042
0.005

Table 5 - Table of Offsets-Parent Forms-0.70 Block Coefficient
(Half-breadths of waterlines given as fraction of maximum beam on each waterline)
Forebody prismatic coefficient $=0.721$
Afterbody prismatic coefficient $=0.898$
Model $=4212 \mathrm{~W}$
W.L. 1.00 is the designed load waterline

Total prismatic coefficient
Area as
fraction of max. area to 1.00 W.L.
0.000
0.076

0.076
0.165
0.266
0.370
0.579
0.755
0.882
0.958
0.990
0.999
1.000
1.000
1.090
0.999
0.999
0.994
0.977
0.977
0.930
0.844
0.713
0.543
0.543
0.343
0.343
0.239
0.239
0.140
0.047
$\begin{array}{lllllllll}\text { Max. half beam }{ }^{6} & 0.771 & 0.926 & 0.998 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000\end{array}$
0.005

Table 6 - Table of Offsets-Parent Forms-0.75 Block Coefficient (Half-brradths of waterlines given as fraction of maximum beam on each waterline)

Forebody prismatic coefficient $=0.792$
Afterbody prismatic coefficient $=0.724$
Total prismatic coefficient
$=0.758$

Area as fraction of max. area to 1.00 W.L.
0.000
0.120
0.261
0.401
0.535
0.754
0.845
0.969
0.995
1.000
1.000
1.000
1.000
1.000
1.000
0.998
0.987
0.953
0.880
0.780

Model $=4213 \mathrm{~W}$
W.L. 1.00 is the designed load waterline

| Sta. | Tan. |  |  |  | $\begin{aligned} & \text {-Waterlines- } \\ & 0.75 \end{aligned}$ | 1.00 | 1.25 | 1.50 | $\begin{aligned} & \max . \operatorname{area} \\ & \text { to } 1.00 \mathrm{~W} . \mathrm{L} \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | 0.075 | 0.25 | 0.50 |  |  |  |  |  |
| FP | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.025 | 0.062 | 0.000 |
| 1/2 | 0.021 | 0.075 | 0.113 | 0.128 | 0.138 | 0.149 | 0.176 | 0.235 | 0.120 |
| 1 | 0.067 | 0.180 | 0.251 | 0.276 | 0.290 | 0.304 | 0.338 | 0.403 | 0.261 |
| $11 / 2$ | 0.138 | 0.290 | 0.380 | 0.423 | 0.441 | 0.460 | 0.495 | 0.557 | 0.401 |
| 2 | 0.235 | 0.406 | 0.504 | 0.560 | 0.585 | 0.608 | 0.639 | 0.690 | 0.535 |
| 3 | 0.466 | 0.625 | 0.718 | 0.777 | 0.806 | 0.824 | 0.845 | 0.867 | 0.754 |
| 4 | 0.700 | 0.800 | 0.870 | 0.911 | 0.930 | 0.943 | 0.954 . | 0.962 | 0.845 |
| 5 | 0.883 | 0.920 | 0.959 | 0.978 | 0.985 | 0.900 | 0.994 | 0.998 | 0.969 |
| 6 | 0.979 | 0.983 | 0.994 | 0.999 | 0.999 | 1.000 | 1.000 | 1.000 | 0.995 |
| 7 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 8 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
|  | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 10 | 1.000 | 1.000 | 1.000 | 1.000 | 1.300 | 1.000 | 1.000 | 1.000 | 1.000 |
| 11 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 12 | 0.985 | 0.992 | 0.999 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 0.998 |
| 13 | 0.914 | 0.953 | 0.979 | 0.997 | 1.000 | 1.000 | 1.000 | 1.000 | 0.987 |
| 14 | 0.784 | 0.860 | 0.925 | 0.976 | 0.990 | 0.996 | 1.000 | 1.000 | 0.953 |
| 15 | 0.612 | 0.728 | 0.820 | 0.908 | 0.953 | 0.975 | 0.990 | 1.000 | 0.880 |
| 16 | 0.420 | 0.565 | 0.667 | 0.781 | 0.863 | 0.921 | 0.958 | 0.987 | 0.760 |
| 17 | 0.242 | 0.388 | 0.483 | 0.592 | 0.712 | 0.817 | 0.899 | 0.951 | 0.594 |
| 18 | 0.105 | 0.225 | 0.288 | 0.365 | 0.488 | 0.660 | 0.794 | 0.875 | 0.391 |
| 181/2 | 0.058 | 0.151 | 0.197 | 0.249 | 0.354 | 0.554 | 0.715 | 0.812 | 0.282 |
| 19 | 0.028 | 0.084 | 0.109 | 0.135 | 0.211 | 0.427 | 0.614 | 0.726 | 0.172 |
| 191/2 | 0.012 | 0.021 | 0.025 | 0.028 | 0.061 | 0.278 | 0.486 | 0.610 | 0.060 |
| ${ }_{4} \mathbf{P}$ | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.115 | 0.320 | 0.451 | 0.006 |
| Max. half beam ${ }^{\text {a }}$ | 0.807 | 0.947 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |  |

Table 7 - Table of Offsets-Parent Forms-0.80 Block Coefficient
(Half-breadths of waterlines riven as fraction of maximum beam on each waterline)
Forebody prismatic coefficient $=0.861$
Model $=4214 W$-B4
W.I. 1.00 is the designed load waterline

| Sta. | Tan. | 0.075 | 0.25 | 0.50 | aterlines 0.75 | 1.00 | 1.25 | 1.50 | Area as fraction of max, area to 1.00 W.L |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| FP | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.044 | 0.098 | 0.000 |
| $1 / 2$ | 0.053 | 0.162 | 0.235 | 0.258 | 0.267 | 0.288 | 0.318 | 0.378 | 0.243 |
| 1 | 0.160 | 0.324 | 0.435 | 0.486 | 0.505 | 0.522 | 0.554 | 0.613 | 0.458 |
| 11/2 | 0.286 | 0.467 | 0.581 | 0.650 | 0.681 | 0.700 | 0.728 | 0.779 | 0.620 |
| 2 | 0.423 | 0.591 | 0.702 | 0.774 | 0.808 | 0.830 | 0.852 | 0.890 | 0.746 |
| 3 | 0.696 | 0.793 | 0.867 | 0.921 | 0.948 | 0.964 | 0.975 | 0.984 | 0.901 |
| 4 | 0.903 | 0.929 | 0.962 | 0.983 | 0.994 | 0.999 | 1.000 | 1.000 | 0.975 |
| 5 | 0.990 | 0.991 | 0.995 | 0.998 | 1.000 | 1.000 | 1.000 | 1.000 | 0.997 |
| 6 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 7 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 8 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 9 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 10 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 11 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 12 | 0.996 | 0.997 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 0.699 |
| 13 | 0.958 | 0.976 | 0.996 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 0.995 |
| 14 | 0.858 | 0.906 | 0.958 | 0.991 | 1.000 | 1.000 | 1.000 | 1.000 | 0.974 |
| 15 | 0.686 | 0.780 | 0.872 | 0.941 | 0.972 | 0.988 | 0.996 | 1.000 | 0.915 |
| 16 | 0.486 | 0.625 | 0.726 | 0.831 | 0.900 | 0.941 | 0.969 | 0.991 | 0.806 |
| 17 | 0.302 | 0.442 | 0.542 | 0.656 | 0.765 | 0.851 | 0.915 | 0.964 | 0.649 |
| 18 | 0.146 | 0.268 | 0.337 | 0.427 | 0.560 | 0.712 | 0.832 | 0.896 | 0.449 |
| 181/2 | 0.092 | 0.185 | 0.232 | 0.298 | 0.425 | 0.617 | 0.764 | 0.840 | 0.336 |
| 19 | 0.045 | 0.105 | 0.130 | 0.166 | 0.263 | 0.503 | 0.670 | 0.760 | 0.212 |
| 191/2 | 0.013 | 0.026 | 0.032 | 0.035 | 0.071 | 0.353 | 0.546 | 0.644 | 0.079 |
| AP | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.160 | 0.370 | 0.476 | 0.100 |
| Max. half beam | 0.850 | 0.970 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |  |

## R

The symbols are defined as follows: $\quad C_{T}=\frac{1 / 2 \cdot \rho \cdot S \cdot v^{2}}{}$
where $R$ is the ship resistance in pounds,
$\rho \quad$ is the mass density of water in $\frac{\mathrm{lb} / \mathrm{cu} \mathrm{ft}}{g}$,
$S$ is the wetted surface in square feet,
$v$ is the speed of ship in feet per second,
$V$ is the speed of ship in knots, and
$L_{W L}$ is the length of ship on designed load waterline in feet.
The results are also shown in Figure 19 as curves of (C) to a base of $\mathbb{K}$. These two "constants," introduced by Froude, are nondimensional, invclve only speed and displacement (the two factors which usually control the preliminary design of a merchant ship), and are very useful in comparing forms at this stage. They have been used also in the SNAME Model Resistance Data sheets.

In English units they are defined as

$$
(K)=0.5834 \cdot \frac{V}{\Delta^{1 / 6}}
$$


and

$$
(C)=\frac{\operatorname{ehp} \times 427.1}{\Delta^{2 / 3} \cdot V^{3}}
$$

where $V$ is the speed of ship in knots
$\Delta$ is the displacement of shif in tons salt water, (2240 1b), and
ehp is the towrope horsepower for the ship.
The values of ehp used in calculating (C) have been deduced from the model experiments by the use of the ATTC 1947 friction formulation and include the ship correlation allowance of +0.0004 . Therefore both the $C_{T}$ and (C) values are based on the same data and are directly comparable in this respect.
$\frac{V}{\sqrt{L_{W L}}}, \frac{V}{\sqrt{L_{B P}}}$, and $(K)$ are related linearly for any one model. A corresponding set of values is given below, from which any other conversion can be made:

TABLE 8
Relation between $C_{B}, \frac{V}{\sqrt{L}}$, an

| Model <br> Number | $C_{B}$ | $\frac{V}{\sqrt{L_{B P}}}$ | $\frac{V}{\sqrt{L_{W L}}}$ | $\overparen{K}$ |
| :--- | :---: | :---: | :---: | :---: |
| $4210 W$ | 0.60 | 0.96 | 0.952 | 2.515 |
| $4211 W$ | 0.65 | 0.86 | 0.853 | 2.198 |
| $4212 W$ | 0.70 | 0.76 | 0.754 | 1.895 |
| $4213 W$ | 0.75 | 0.66 | 0.655 | 1.609 |
| $4214 W B-4$ | 0.80 | 0.56 | 0.556 | 1.334 |

A vast accumulation of model resistance data based on the Froude skin-friction coefficients is available in the transactions of societies and reports of model basins. Since 1948 this method of extrapolation from model to ship and that based on the ATTC 1947 (Schoenherr') line have both been recognized by the ITTC as acceptable for use in all published data. A quick graphical method of mutually converting the (C) values based on these two formulations was published by Gertler in 1948.47* The ATTC values used therein include the allowance of +0.0004 for ship correlation allowance, so that the application of this chart to the ATTC (C) values given in this present report will yield directly the equivalent (C) values based on the Froude coefficients.

[^2]In 1957 at the Madrid Conference, the ITTC agreed upon a new "model-ship correlation line" for use in all published work, which would give ship results differing somewhat from those based either on Froude or the ATTC line. However, pending agreement on the appropriate correlation allowances to use with the new line, it has not come into common usage as yet. When such agreement is reached, a chari similar to that in Reference 47 can easily be constructed.

In comparing a number of closely allied forms, all suitable to fulfill certain design conditions, this (C) - (K) presentation has the advantage that for a given displacement and speed, (K) is the same for ail models. An ordinate erected at this value of (K) will indicate the relative merits of the forms since (C) also involves only the speed and displacement. The other differences in the various hulls can then be considered to determine which features are responsible for the differences in resistance and power.

Before proceeding with the methodical variations in $L C B$ position and hull proportions, the results of the actual ship models and the Series 60 equivalents were compared. For this purpose, the same five designs as before were used as the control models, and equivalent Series 60 models having the same dimensions, displacement, and LCB position were made and tested. The exception was for the MARINER design where the Series $60,0.60 C_{B}$ parent was used in the comparison.

Such comparisons must be made at speeds appropriate to the individual designs, and for this purpose, service and trial speeds have been chosen based on two suggested relations between fullness and speed-length ratio.

The first of these is an old formula first given by F.H. Alexander, but uising coefficients suggested by Sir Amos Ayre as being more appropriate to modern ships:

$$
\begin{align*}
& \frac{V}{\sqrt{L_{B P}}}=2\left(1.08-C_{B}\right) \text { for trial speed }  \tag{1}\\
& \frac{V}{\sqrt{L_{B P}}}=2\left(1.05-C_{B}\right) \text { for service speed }
\end{align*}
$$

These formulae give reasonable speeds for the fuller ships, but for the fine ships, such as that of $0.60 C_{B}$, they give speeds which are too high from the standpoint of economic performance.

In 1955, Troost proposed a new formula to define the "sustained sea speed.",48 Based on a survey of many single-screw models run in the Netherlands Ship Model Basin (NSMB) over some 20 years, the formula generally gives speeds higher than the Alexander service speed for full ships and lower for fine ships, a result in conformity with modern practice. For all forms, the Troost sea speed lies at that point where the (C) curve first begins rising steeply, and for some range above it the resistance is varying approximately as the cube of the speed, or the power is varying as $V^{4}$. Troost therefore assumed a trial speed $V_{T}$ some 6 percent above the sea speed $V_{s}$, so that the power on trial at speed $V_{T}$ is approximately

25 percent greater than the power on trial at speed $V_{S}$. This is in keeping with the general design practice that the service speed should be attained under trial conditions at 80 percent of the maximum continucus power.

Troost defined thr speeds as follows:

$$
\begin{equation*}
\frac{V_{S}}{\sqrt{L_{B P}}}=1.85-1.6 C_{P} \text { for sustained sea speed } \tag{2}
\end{equation*}
$$

and

$$
V_{T}=1.06 V_{S} \text { for trial speed. }
$$

For the Series 60 models, these two formulae lead to the following speeds for ships 400 ft in length.

TABLE 9
List of Alexander and Troost Speeds

| $C_{B}$ | $C_{P}$ | ALEXANDER SPEEDS (Equation (1)) |  |  |  |  |  | TROOST SPE EDS (Equation (2)) |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | SERVICE |  |  | TRIAL |  |  | SEA |  |  | TRIAL |  |  |
|  |  | $\frac{V}{\sqrt{L_{B P}}}$ | (K) | $\begin{gathered} V \\ \text { knots } \end{gathered}$ | $\frac{V}{\sqrt{L_{B} P}}$ | (K) | $\begin{gathered} V \\ \text { knots } \end{gathered}$ | $\frac{V}{\sqrt{L_{B P}}}$ | (K) | $\begin{gathered} V \\ \text { knots } \end{gathered}$ | $\frac{V}{\sqrt{L_{B P}}}$ | (K) | $\begin{gathered} V \\ \text { knots } \end{gathered}$ |
| 0.60 | 0.614 | 0.90 | 2.358 | 18.0 | 0.96 | 2.515 | 19.20 | 0.869 | 2.274 | 17.38 | 0.921 | 2.410 | 18.42 |
| 0.65 | 0.661 | 0.80 | 2.045 | 16.0 | 0.86 | 2.198 | 17.20 | 0.792 | 2.022 | 15.84 | 0.839 | 2.142 | 16.78 |
| 0.70 | 0.710 | 0.70 | 1.746 | 14.0 | 0.76 | 1.895 | 15.20 | 0.714 | 1.781 | 14.28 | 0.757 | 1.889 | 15.14 |
| 0.75 | 0.758 | 0.60 | 1.462 | 12.0 | 0.66 | 1.609 | 13.20 | 0.637 | 1.552 | 12.74 | 0.675 | 1.645 | 13.50 |
| 0.80 | 0.805 | 0.50 | 1.190 | 10.0 | 0.56 | 1.334 | 11.20 | 0.562 | 1.338 | 11.24 | 0.596 | 1.419 | 11.92 |

A comparison of these speeds with modern American practice was made by Mr. H. de Luce in his discussion on the first series paper. ${ }^{44}$ He examined the (C) curves for a number of ships and plotted the value of the speed-length ratio $\frac{V^{*}}{\sqrt{L}}$ against prismatic coefficient for the point on the (C) curve where there was a sharp "upturn" (Figure 20). He drew a mean curve through these points, designated as the mean "upturn", $\frac{V}{\sqrt{L}}$ on Figure 20. This figure also shows the Alexander and Troost lines, and it is clear that the latter conform much more with the general trend of the points and the de Luce line. An examination of the $C_{T}$ curves for the Series 60 parent models, as given in Figure 18, shows that the values of $\frac{V}{\sqrt{L}}$ for the "upturn" points for these designs also lie very nearly on the Troost "sustained sea speed" line, and the latter would therefore seem to be a close guide to modern design trends (Figure 20 ).
*Mr. de Luce used $L_{B P}$ for single-screw ships and $L_{W L}$ for twin-screw ships.


Figure 20 - Comparison of Alexander and Troost Speeds with Modern American Data

Mr. de Luce emphasised the need to relate the "upturn" speed to the speed insidered in preparing an actual design. In Figure 21, prismatic coefficients are plotted against the speed-length ratio $\frac{V}{\sqrt{L}}$ corresponding to the speed on trial at designed draft with the machinery developing maximum rated continuous shaft horsepower, mostly taken from actual ship data. The "uptum" carve reproduced from Figure 20 is again a reasonable mean through the trial points, indicating that "many designers over the years have believed it desirable to select dimensions and proportions leading to a flat (C) curve up to the point corresponding to trial speed" (de Luce, discussion on Reference 44).

Designs I, II, and III in Figure 21 represented three modern (1951) designs of good performance. The "uptum" speeds for these three ships are close to the mean line in Figure 20, but the design speeds are higher than the average line in Figure 21 by about 0.05 in terms of $\frac{V}{\sqrt{L}}$. Mr. de Luce stated that all three designs were being "pushed," I because of the economics of transporting petroleum, and II and III for military considerations; he concluded that for the purpose of evaluating hull form parameters and performance, the "upturn" speed was satisfactory and independent of economic and other considerations. Since 1951, when these comparisons were made, high speed has become more and more a


Figure 21 - Relation between Design Speed and Upturn Speed
characteristic of the modern dry-cargo ship, and this has led to the use of block ccefficients lower than the range covered by Series 60 . Before leaving the discussion of these data for modern American ships, as given by Mr. de Luce, it is interesting to compare the coverage of Series 60 with actual ship proportions. This has been done in Figures 22, 23, and 24 which show the same points as given by de Luce with the addition of the corresponding ones for the Series 60 parents and the limits covered by the whole series.

In general, the coverage for single-screw ships appears to be adequate, with the exception that some models having a $\frac{B}{H}$ value of 2.0 would have been a valuable addition to the program. In regard to the $L C B$ variation, the "upturn'' speeds for Series 60 occur in general with the $L C B$ somewhat further aft than in the case of the actual designs, but the latter are covered by the limiting models.

Comparisons between the (C) values for the actual ship models and Series 60 equivalents are shown in Figures 25a through $25 e$.

The MARINER-Class ships (Figure 25a) differed somewhat in coefficients and proportions from the Series 60 parert of 0.60 block coefficient; also, the latter had no bulb at the forefoot. However, the differences were not considered sufficient to justify making an entirely new Series 60 equivalent model.


Figure 22 - Comparison of Series 60 with
U. S. Data, $\frac{L}{B}$ and $\frac{B}{H}$


Figure 23 - Comparison of Series 60 with U. S. Data,

$$
\frac{\hat{V}}{\sqrt{L}} \text { and } \frac{\Delta}{(L / 100)^{3}}
$$



Figure 24 - Comparison of Series 60 with U. S. Data, $\frac{V}{\sqrt{L}}$ and $L C B$

Figure 25 - Comparison between the (C) Values for Models of Actual Ships and Series 60 Equivalents


Figure 25a - Comparison, Series 60 and MARINER Class

(
Figure 25b - Comparison, Series 60 and SCHUYLER OTIS BLAND


Figure 25c - Comparison, Series 60 and C. 2


Figure 25d - Comparison, Series 60 and Bethlehem. 0.70 Design


Figure 25 - Comparison, Series 60 and PENNSYLVANIA

The Series 60 parent gave a lower resistance than the MARINER model over the useful speed range, but above this the (C) curve turned up more rapidly, at least partly because of the absence of the bulb. However, the Series 60 model was finer than the MARINER ( $C_{B}$ being 0.60 instead of 0.61 ), and to obtain a better comparison the MARINER model was changed by removing the bulb, and the Series 60 parent resistance was corrected for the difference in fullness and proportions by using Taylor Standard Series data. There was then no appreciable difference in performance over the service and designed speed range.

There was no essential difference in results in the case of SCHUYLER OTIS BLAND, (Figure 25b), the slightly better (C) value of the SCHUYLER OTIS BLAND at the trial speeds probably being due to the 2 percent bulb.

The C. 2 ship model (Figure 25c) was somewhat better than the equivalent Series 60 model by some 1 percent and 4.5 percent at the service and trial speeds respectively, probably again partly due to a small bulb on the C.2.

The Series 60 equivalent was some 1 to 2 percent better than the $0.70 C_{B}$ design, (Figure 25 d ) in the neighborhood of the service and trial speeds.

Several models of the PENNSYLVANIA (Figure 25e) were made at different times, some in wax and some in wood. There was a certain amount of scatter in the results, influenced to some extent by questions of turbulence stimulation. Over the useful speed range, this difference amounted to some 2 to 4 percent, and the highest results for the PENNSYLVANIA model were the same as those for the equivalent Series 60 model.

No modern cargo vessel design of about 0.80 block coefficient and of approved merit was available for comparison with Series 60. A number of models with a variety of bow and stern shapes were therefore made and run. The sterns were usually U-type, similar to those of Series 60, and the bows ranged from U - to V -forms. In general, the models with the V-shaped bows showed to some advantage, but they did not fit well into the cross-sectional area and waterline contours since the other model lines were predominantly of U-type. The Panel was of the opinion that seagoing merchant ships were unlikely to be built with such fullness coefficients. The somewhat fuller lake steamers would have much greater $\frac{L}{E}$ ratios than those covered by the present series, and in fact were considered to be another problem. The 0.80 $C_{B}$ model of the series could therefore be considered as really only an end point to which the contours could be anchored. However, subsequent evidence suggests that the form as finally adopted had some intrinsic merits of its own as well as being an "end point" to the series. In the discussion on one Series 60 paper (Reference 45), Professor Baier said that since block coefficients of 0.80 to 0.87 were of particular interest to the Great Lakes region, he had carried out a series of tests with models in this range in the tank at the University of Michigan. He reported that "seven models were designed with rather extreme variations in sections at blocks of 0.857 and 0.872 . At each of these block coefficients one form was derived from the contours of Series 60, with some adjustments in the forebody for lake-traffic requirements. It is gratifying to report that these two models were definitely superior to the
other five designs, both in t.r.h.p.* and propulsive coefficients when self-propelled.' In Professor Baier's opinion, "the parent form finally adopted by the panel for the 0.80 block was a suitable and wise decision."

As in the case of the lower limit of the series being taken as 0.60 block coefficient, this idea that the 0.80 block model could be treated as an end point seemed a good one at the time, but events have already overtaken the program in this respect also. Just as singlescrew ships are now being built with block coefficients well below 0.60 , so in the range of supertankers and bulk carriers, designs in the neighborhood of 0.80 to 0.85 block coefficient have become of great importance. There is therefore a good practical case for extending the series at both ends.

In the light of the above survey, the members of the Panel came to the conclusion that the new contours of Series 60 formed a suitable basis for use in defining parent models for a systematic investigation of resistance and propulsive qualities, and it was then possible to proceed to the next phases.

[^3]
## CHAPTER VI

## EFFECT ON RESISTANCE OF VARIATION IN LCB POSITION

In planning the Series 60 parents, a decision had to be made as to the longitudinal distribution of displacement for each model. This distribution is conveniently described, - other things being equai, by the position of the $L C B$.

This is an important parameter in ship design for more than one reason. So far as resistance is concerned, the optimum position of the $L C B$ depends very much on the speedlength ratio at which the ship is to run. Ai high values of $\frac{V}{\sqrt{L}}$, it is essential to keep the bow fine to delay the onset of wavemaking resistance; at the same time, the stern cannot be made too full or eddymaking resistance will increase. The result is a ship of overall low block coefficient with the $L C B$ aft of midships. For low $\frac{V}{\sqrt{L}}$ values, the stern must still be kept reasor ably fine to avoid excessive resistance, but the bow can be made much fuller, since at such speed-length ratios the wavemaking resistance is only a small percentage of the total. The result is a ship with a fine run and full entrance, with the $L C B$ forward of amidships. This trend is well illustrated in the Series 60 parents. The prismatic coefficients of the afterbody range only from 0.646 to 0.750 in going from the 0.60 to the 0.80 block coefficient designs, whereas the forebody prismatics go from 0.581 to 0.861 . If the efficiency is measured by the resistance per ton of displacement, the fuller ship is the more efficient at low speed-length ratios, and the advantage passes to finer and finer ships as $\frac{V}{\sqrt{L}}$ is increased.

The position of the $L C B$ also affects propulsive efficiency for, in general, as it moves forward for a given overall coefficient, wake and thrust deduction both decrease, but the effect of the former usually predominates. Thus it is not unknown for a forward shift of $L C B$ to reduce both resistance and propulsive efficiency in such a way that the final shaft horsepower* is increased. Insofar as hydrodynamic efficiency is concerned, the location of $L C B$ therefore rests finally on the delivered horsepower* required and not on the resistance, although the latter is an important component of the former.

There is also another feature in ship performance which depends on the $L C B$ position, and that is the behaviour in waves, both as regards ship motions and loss of speed. There is little doubt that in the past ships have been built with too full bows, which may have given excellent smooth-water results but have militated greatly against good seagoing qualities. This question is one which should have an early priority in future methodical series testing.

[^4]In the design of a ship, the LCB position is also dependent to some extent on considerations other than low power and good sea behavior. Chief of these is the problem of achieving correct trim under a variety of loading conditions, particularly in tankers and other bulk carriers. The tendency to place machinery aft in dry-cargo ships and passenger ships also gives rise to trim problems and in such cases the size of machinery may restrict the hull shape aft and, by requiring additional volume there, also influence the LCB position.

In the discussion on one of the Series 60 papers (Reference 63), Professar Manning set out very clearly the importance of $L C B$ position in designing the single-screw merchant ship, and one cannot do better than quote his remarks. "Taylor states very clearly that his use of the prismatic coefficient as a major parameter was based on the fact that it is an excellent measure of the longitudinal distribution of the volume of displacement . . . In the case of the Taylor Standard Series, the prismatic coefficient was sufficient in itself as a measure of the longitudinal distribution of displacement by reason of the process used in determining the offsets of all the models of this family and the fact that none of the models had parallel middle body. Whenever a ship has parallel middle body, a substantial change in the longitudinal distribution of the displacement may be made without any change in the prismatic coefficient. For example, if the lengths of entrance, parallel middle body and run are held constant, and the prismatic coefficient of entrance is given to the run, and that for the run to the entrance, the prismatic coefficient of the entire hull has not been altered, but the longitudinal distribution of the displacement certainly has. The wave-making resistance and viscous form-drag have therefore also been changed in substantial magnitude. The difference between the longitudinal distribution of the displacement of vessels which have the same value of prismatic coefficient may be related to differences in the longitudinal position of the centre of buoyancy. This paper (Reference 63) is essentially a study of the effect of changes in the longitudinal position of the centre of buoyancy on the resistance and power required for parallel middle body ships at speeds which reflect current practice. . . From this paper, the ship designer can not only estimate with good precision the position of the centre of buoyancy which gives the least resistance or shaft horsepower, but how much he must pay in terms of these if other conditions favor a different location for this point. The latter is just as important as the former."

For all the above reasons, it was agreed by the Panel that before proceeding to the last phase of this project-the effect upon resistance and propulsion of variations in $\frac{L}{B}$ and $\frac{B}{H}$ ratios-the effect of change in $L C B$ position should be investigated for each of the Series 60 parents in order, if possible, to determine the optimum location.

The positions of the LCB chosen for the five parent models are shown in Figure 1, together with the variation in these positions for the other 17 models making up the complete set. The positions of $L C B$ are shown in Table 10, and the principal particulars of the models are given in Tables 11 through 15.

Table 10 - Pattern of $L C B$ Series Models

| $C_{B}$ | $\text { —Position of } \mathrm{LCB} \text { as } \% \mathrm{LBP}^{\text {Model }}$ |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 0.60 . |  | 4215 | 4210 | 4216 | 4217 |
|  |  | 2.48 A | 1.50A | 0.51 A | $0.52 F$ |
| 0.65. | 4231 | 4218 | 4211 | 4219 | 4220 |
|  | 2.46 A | 1.54A | 0.50A | 0.38 F | 1.37 F |
| 0.70. | 4230 | 4221 | 4212 | 4222 | 4223 |
|  | 2.05A | 0.55A | 0.50 F | $1.54 F$ | $2.55 F$ |
| 0.75... |  | 4224 | 4213 | 4225 | 4226 |
|  |  | 0.48 F | 1.50 F | 2.57 F | 3.46F |
| 0.80 | 4227 | 4228 | 4214 | 4229 |  |
|  | $0.76 F$ | 1.45 F | 2.50 F | $3.51 F$ |  |

Nots: Column 3 of model numbers applies to Series 60 Parents.

The lines for each model were drawn out by using the contours of sectional area and waterline coefficients already described. The models are therefore related to one a nother by the graphical charts, and for a giyen set of design conditions a unique hull form is determined.

The models were made and the tests carried out in exactly the same manner as described for the parent models. The model results have been converted to apply to ships with $400-\mathrm{ft} L B P$ by using the ATTC line for the friction extrapolation with an addition of +0.0004 for ship correlation allowance, as before.

The ship figures are given in Tables 18 through 20 as values of $C_{T}$ to a base of $\frac{V}{\sqrt{L_{W} L}}$ and in Tables 21 through 25 as values of $(C)$ to a base of $(K)$, all for a standard temperature of $59^{\circ} \mathrm{F}\left(15^{\circ} \mathrm{C}\right)$.

To obtain a visual picture of the resistance results, the $(C$ values can be plotted as cross curves to a base of $L C B$ location, using $(K)$ as a parameter. When this is done, it is found that for the speeds within the range of economic performance for these models a locus of $L C B$ position to give minimum resistance is usually well defined. At high speeds, beyond the useful range, the minimum lies in general in a region where the $L C B$ is much further aft than was used in any of these experiments.

As might be expected, there is in general no unique relation between block coefficient and optimum $L C B$ location-it depends on what speed is chosen as the criterion for comparison. Figures 26 through 30 show cross-curves of (C) to a base of $L C B$ position for

Table 12 - Principal Particulars of 0.65 Block Coefficient Fornis

| Model No.. | . 4281 | 4218 | 4211 | 4218 | 42.20 |
| :---: | :---: | :---: | :---: | :---: | :---: |
| $L_{\text {BP }}$, ft. | 400.0 | 400.0 | 400.0 | 400.0 | 400.0 |
| $B$, ft. . | 55.17 | 55.17 | 55.17 | 55.17 | 55.17 |
| $H$, ft. | 22.09 | 22.09 | 22.09 | 22.09 | 22.09 |
| $D$, tons. | 8092 | 9051 | 9051 | 9051 | 9065 |
| $L_{E} / L_{\text {BP }}$ | 0:477 | 0.475 | 0.472 | 0.470 | 0.469 |
| $L_{x} / L_{\text {BP }}$ | 0.035 | 0.035 | 0.035 | 0.035 | 0.035 |
| $L_{R} / L_{\text {BP }}$ | 0.488 | 0.490 | 0.493 | 0.495 | 0.496 |
| $C_{B} \ldots \ldots$ | 0.652 | 0.650 | 0.650 | 0.650 | 0.650 |
| $C^{\text {I }}$ | 0.982 | 0.982 | 0.982 | 0.982 | 0.982 |
| $C_{P}$ | 0.664 | 0.661 | 0.681 | 0.661 | 0.862 |
| $C_{\text {Pr }}$ | 0.612 | 0.628 | .0.651 | 0.670 | 0.692 |
| $\mathrm{C}_{\text {PA }}$ | 0.715 | 0.694 | 0.672 | 0.652 | 0.632 |
| $C_{\text {Pr }}$ | 0.594 | 0.609 | 0.630 | 0.649 | 0.672 |
| $C_{\text {PR }}$ | 0.709 | 0.688 | 0.667 | 0.648 | 0.630 |
| $C_{\text {PV }}$ | 0.871 | 0.874 | 0.871 | 0.865 | 0.862 |
| $C_{\text {PVF }}$ | 0.920 | 0.924 | 0. 927 | 0.929 | 0.934 |
| $C_{\text {PVA }}$ | 0.833 | 0.832 | 0.823 | 0.808 | 0.794 |
| $C_{\text {w }}$ | 0.749 | 0.744 | ). 746 | 0.750 | 0.754 |
| $C_{\text {wr }}$ | 0.654 | 0.668 | 1.690 | 0.708 | 0.728 . |
| Cwa | 0.843 | 0.819 | 0.802 | 0.792 | 0.781 |
| $C_{\text {IT }}$. | 0.594 | 0.593 | 0.597 | 0.601 | 0.619 |
| 1/2aE, deg | 7.7 | 8.3 | 9.1 | 11.2 | 13.8 |
| $L_{\text {wL }} \mathrm{ft}$. | 406.7 | 406.7 | 408.7 | 406.7 | 406.7 |
| LCB \% $L_{\text {BP }}$ from | 2.46A | 1.54A | 0.54 | $0.38 F$ | 1.37 F |
| L/B.......... | 7.25 | 7.25 | 7.25 | 7.25 | 7.25 |
| B/H. | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 |
| L/ $\mathbf{F}^{1 / 2}$ | 5.860 | 5.869 | 5.869 | 5.869 | 5.866 |
| $\Delta /(L / 100)^{4}$. | 142.0 | 141.4 | 141.4 | 141.4 | 141.5 |
| $S / \nabla^{3} \ldots$ | 6.320 | 6.326 | 6.328 | 6.328 | 6.347 |
| WS, sq ft. | 29380 | 29380 | 29390 | 29390 | 29480 |
| $K_{R}=R / \sqrt{B H}$. | 0.205 | 0.205 | 0.205 | 0.205 | 0.205 |
| $\mathrm{C}_{\mathrm{PE} / \mathrm{C}^{\text {PR }}}$. | 0.838 | 0.885 | 0.945 | 1.001 | 1.067 |

Table 13 - Principal Particulars of 0.70 Block Coefficient Forms

| Model No. | 4230 | 4221 | 4212 | 4222 | 4223 |
| :---: | :---: | :---: | :---: | :---: | :---: |
| $L_{\text {Br }} \mathrm{ft}$. | 400.0 | 400.0 | 400.0 | 400.0 | 400.0 |
| $B$, ft. . | 57.14 | 57.14 | 57.14 | 57.14 | 57.14 |
| $H$, ft. | 22.86 | 22.86 | 22.86 | 22.86 | 22.86 |
| $D$, tons. | 10441 | 10456 | 10456 | 10456 | 10456 |
|  | 0.434 | 0.420 | 0.410 | 0.400 | 0.390 |
| $L_{1} / L_{\text {BP }}$ | 0.119 | 0.119 | 0.119 | 0.119 | 0.119 |
| $L_{R} / L_{\text {BP }}$ | 0.447 | 0.461 | 0.471 | 0.481 | 0.491 |
| $C_{B}$. | 0.699 | 0.700 | 0.700 | 0.700 | 0.700 |
| $C_{\text {x }}$ | 0.986 | 0.986 | 0.986 | 0.986 | 0.986 |
| $C_{\text {P }}$ | 0.709 | 0.710 | 0.710 | 0.710 | 0.710 |
| $C_{\text {Pr }}$ | 0.667. | 0.700 | 0.721 | 0.744 | 0.766 |
| $C_{\text {PA }}$ | 0.752 | 0.721 | 0.698 | 0.675 | 0.654 |
| $C_{\text {PE }}$ | 0.616 | 0.642 | 0.660 | 0.680 | 0.700 |
| ${ }^{\text {CPR }}$ | 0.722 | 0.698 | 0.680 | 0.662 | 0.647 |
| $C_{\text {PV }}$ | 0.887 | 0.890 | 0.891 | 0.886 | 0.880 |
| $C_{\text {PVI }}$ | 0.932 | 0.940 | 0.944 | 0.948 | 0.950 |
| $C_{\text {PVA }}$ | 0.852 | 0.846 | 0.842 | 0.827 | 0.811 |
| $C^{W}$ | 0.788 | 0.787 | 0.785 | 0.790 | 0.795 |
| $C_{\text {wr }}$ | 0.706 | 0.734 | 0.753 | 0.774 | 0.795 |
| $C_{\text {wa }}$ | 0.871 | 0.841 | 0.818 | 0.805 | 0.795 |
| $C_{17}$. | 0.650 | 0.651 | 0.653 | 0.658 | 0.663 |
| 1/2as. | 9.3 | 11.6 | 14.5 | 17.1 | 20.0 |
| $L_{\text {WL }}$ | 406.7 | 406.7 | 406.7 | 406.7 | 406.7 |
| LCB \% $L_{\text {BP }}$ from | 2.05 A | 0.55 A | $0.5 F$ | $1.54 F$ | 2.55F |
| $L / B, \ldots . . . .$. | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 |
| $B / H$. | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 |
| $L / \nabla^{1 / 1}$ | 5.593 | 5.593 | 5.593 | 5.593 | 5.593 |
| $\Delta /(L / 100)^{\prime}$. | 163.4 | 163.4 | 163.4 | 163.4 | 163.4 |
| S/733 | 6.220 | 6.230 | 6.200 | 6.224 | 6.224 |
| WS, sq ft. | 31777 | 31859 | 31705 | 31830 | 31828 |
| $K$ R $=R / \sqrt{B H}$. | 0.181 | 0.181 | 0.181 | 0.181 | 0.181 |
| $\mathbf{C}_{\mathbf{P E}} / \mathbf{C}_{\mathbf{P R}}$. | 0.853 | 0.920 | 0.971 | 1.027 | 1.082 |

Table 14: - Principal Particulars of 0.75 Block Coefficient Forms

| Model No.. | 4224 | 4213 | 4225 | 4226 |
| :---: | :---: | :---: | :---: | :---: |
| $L_{\text {ar }} \mathrm{ft}$. | 400.0 | 400.0 | 400.0 | 400.0 |
| B, ft. | 59.26 | 59.26 | 59.26 | 59.26 |
| H, ft. | 23.70 | 23.70 | 23.70 | 23.70 |
| $D$, tons | 12048 | 12048 | 12048 | 12038 |
| $L_{E} / L_{\text {gr }}$ | 0.360 | 0.350 | 0.340 | 0.332 |
| $L_{\text {I }} / L_{\text {gr }}$. | 0.210 | 0.210 | 0.210 | 0.210 |
| $L_{B} / L_{B P}$. | 0.430 | 0.440 | 0.450 | 0.458 |
| Cs. | 0.750 | 0.750 | 0.750 | 0.749 |
| $C^{2}$ | 0.980 | 0.890 | 0.900 | 0.890 |
| $C^{\text {P }}$ | 0.758 | 0.758 | 0.758 | 0.757 |
| $C_{\text {Pr }}$ | 0.770 | 0.792 | 0.813 | 0.833 |
| $C_{\text {PA }}$ | 0.745 | 0.724 | 0.702 | 0.681 |
| $\mathrm{CPE}_{\text {PR }}$ | 0.680 | 0.704 | 0.725 | 0.748 |
| $C_{\text {PR }}$ | 0.704 | 0.686 | 0.668 | 0.652 |
| $C_{\text {PV }}$ | 0.905 | 0.807 | 0.903 | 0.898 |
| $C_{\text {PVF }}$ | 0.956 | 0.981 | 0.959 | 0.959 |
| Crya | 0.858 | 0.856 | 0.846 | 0.833 |
| ${ }_{C}{ }^{\text {w }}$. | 0.828 | 0.827 | 0.830 | 0.834 |
| $C_{\text {wr }}$. | 0.797 | 0.817 | 0.839 | 0.860 |
| $C_{\text {WA, }}$ | 0.860 | 0.838 | 0.821 | 0.808 |
| $C_{\text {IT }}$ | 0.708 | 0.711 | 0.717 | 0.722 |
| $1 / 2 \alpha_{5}$ | $18.8^{\text {a }}$ | $22.5{ }^{\circ}$ | $27.4{ }^{\text {a }}$ | $33.8{ }^{\text {® }}$ |
| $L_{\text {WLi }} \mathrm{ft}$ | 406.7 | 406.7 | 406.7 | 406.7 |
| LCB \% $L_{\text {BP }}$ from | $0.48 F$ | 1.5F | $2.57 F$ | 3.46F |
| L/B... | 6.75 | 6.75 | 6.75 | 6.75 |
| $B / H$. | 2.50 | 2.50 | 2.50 | 2.50 |
| L/ $\boldsymbol{\nabla}^{3}$ | 5.335 | 5.335 | 5.335 | 5.337 |
| $\Delta /(L / 100)^{2}$. | 188.2 | 188.2 | 188.2 | 188.1 |
| $S / \nabla^{3 / 5}$ | 6.104 | 6.091 | 6.094 | 6.098 |
| WS, sq ft. | 34308 | 34232 | 34252 | 34281 |
| $K_{R}=R / \sqrt{B H}$ | 0.153 | 0.153 | 0.153 | 0.153 |
| $\mathrm{C}_{\mathbf{P E}} / \mathrm{C}_{\mathbf{P R}} \cdots \cdots$ | 0.966 | 1.026 | 1.0853 | 1.147 |

Table 15 - Principal Particulars of 0.80 Block Coefficient Forms

| Model No.. | 4227 | 4228 | 4214 | 4229 |
| :---: | :---: | :---: | :---: | :---: |
| $L_{\text {BP, }} \mathrm{ft}$. | 400.0 | 400.0 | 400.0 | 400.0 |
| $B$, ft. | 61.54 | 61.54 | 61.54 | 61.54 |
| $\boldsymbol{H}, \mathrm{ft}$. | 24.59 | 24.59 | 24.59 | 24.59 |
| $D$, tons. | 13859 | 13859 | 13859 | 13859 |
| $L_{B} / L_{\text {BP }}$. | 0.307 | 0.299 | 0.290 | 0.280 |
| $L_{\mathrm{z}} / L_{\mathrm{BP}}$ | 0.300 | 0.300 | 0.300 | 0.300 |
| $L_{R} / L_{\text {BP }}$. | 0.383 | 0.401 | 0.410 | 0.420 |
| $C_{\text {E }} \ldots .$. | 0.800 | 0.800 | 0.800 | 0.800 |
| $C_{1}$ | 0.894 | 0.994 | 0.994 | 0.994 |
| $C_{P}$ | 0.805 | 0.805 | 0.805 | 0.805 |
| $C_{\text {Pr }}$ | 0.822 | 0.838 | 0.861 | 0.881 |
| $C_{\text {Pa }}$ | 0.787 | 0.772 | 0.750 | 0.729 |
| $C_{\text {Pe }}$ | 0.710 | 0.728 | 0.761 | 0.787 |
| $C_{\text {PR }}$ | 0.730 | 0.716 | 0.695 | 0.678 |
| $C_{\text {PV }}$ | 0.921 | 0.920 | 0.920 | 0.922 |
| $C_{\text {PVI }}$ | 0.966 | 0.967 | 0.971 | 0.976 |
| $\mathrm{CPVAA}^{\text {Pre }}$ | 0.878 | 0.874 | 0.867 | 0.885 |
| $C_{\text {W }}$. | 0.869 | 0.870 | 0.871 | 0.867 |
| $C_{\text {wr }}$ | 0.845 | 0.861 | 0.881 | 0.897 |
| $C_{\text {wh }}$ | 0.892 | 0.878 | 0.860 | 0.838 |
| $C_{\text {IT }}$ | 0.769 | 0.767 | 0.776 | 0.778 |
| 1/20E. | $26.6{ }^{\circ}$ | $32.5{ }^{\circ}$ | $43.0{ }^{\circ}$ | $52.0^{\circ}$ |
| $L_{\text {wh }}, \mathrm{ft}$. | 406.7 | 406.7 | 406.7 | 406.7 |
| LCB \% Lap from $¢$ | 0.76 F | 1.45F | $2.5 F$ | 3.51 F |
| L/B...... | 6.50 | 6.50 | 6.50 | 6.50 |
| $B / H$. | 2.50 | 2.50 | 2.50 | 2.50 |
| $L / \nabla^{1 / 2}$ | 5.092 | 5.092 | 5.092 | 5.002 |
| $\Delta /(L / 100)^{1}$. | 216.5 | 216.5 | 216.5 | 216.5 |
|  | 6.011 | 6.020 | 6.028 | 6.025 |
| WS, sq ft. | 37098 | 37148 | 37200 | 37183 |
| $K_{R}=R / \sqrt{B H}$. | 0.118 | 0.118 | 0.118 | 0.118 |
| $\mathrm{C}_{\mathbf{P E}} \mathrm{C}_{\mathbf{P R}}$ | 0.973 | 1.017 | 1.095 | 1.161 |

Table 16 - Resistance Data as Values of $C_{T}$ to a Base of $\frac{V}{\sqrt{L_{W L}}}$, LCB Series 0.60 Block Coefficient Models
(Ship dimensions-400.0 $\mathrm{ft} \times 53.33 \mathrm{ft} \times 21.33 \mathrm{ft} \times 7807$ tons. Turbulence $\mathbf{s t i m u l a t e d}$ by atuds )

| Model No. <br> LCB as $\% L_{a p}$ from $\%$ |  | 4215 | 4210 | 4216 | 4217 |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | 2.48A | 1.50A | 0.51A | 0.52 F |
| $V \sqrt{L_{W L}}$ |  | $\sim C_{1} \times 10^{2}$ for $400-\mathrm{ft} L_{\mathrm{gr}}$ |  |  |  |
| 0.35 | 0.925 | 2.641 | 2.654 | 2.620 | 2.589 |
| 0.40 | 1.057 | 2.611 | 2.624 | 2.604 | 2.577 |
| 0.45 | 1.189 | 2.596 | 2.618 | 2.597 | 2.564 |
| 0.50 | 1.321 | 2.618 | 2.618 | 2.602 | 2.563 |
| 0.65 | 1.453 | 2,629 | 2.628 | 2.613 | 2.573 |
| 0.60 | 1.585 | 2.641 | 2.639 | 2.627 | 2.589 |
| 0.625 | 1.651 | 2.650 | 2.640 | 2.632 | 2.612 |
| 0.65 | 1.717 | 2.666 | 2.648 | 2.653 | 2.647 |
| 0.675 | 1.783 | 2.685 | 2.671 | 2.681 | 2.676 |
| 0.70 | 1.849 | 2.697 | 2.689 | 2.706 | 2.694 |
| 0.725 | 1.915 | 2.715 | 2.701 | 2.712 | 2.705 |
| 0.75 | 1.881 | 2.736 | 2.699 | 2.718 | 2.713 |
| 0.775 | 2.047 | 2.765 | 2.713 | 2.711 | 2.729 |
| 0.80 | 2.113 | 2.783 | 2.727 | 2.727 | 2.755 |
| 0.825 | 2.179 | 2.814 | 2.744 | 2.794 | 2.814 |
| 0.85 | 2.245 | 2.861 | 2.792 | 2.873 | 2.953 |
| 0.875 | 2.312 | 3.008 | 2.933 | 3.003 | 3.120 |
| 0.90 | 2.378 | 3.236 | 3.197 | 3.252 | 3.392 |
| 0.925 | 2.444 | 3.511 | 3.497 | 3.627 | 3.677 |
| 0.95 | 2.610 | 3.811 | 3.787 | 3.952 | 3.887 |
| 0.975 | 2.576 | 4.046 | 4.037 | 4.157 | 4.217 |
| 1.00 | 2.642 | 4.173 | 4.197 | 4.292 | 4.407 |
| 1.025 | 2.708 | 4:225 | 4.288 | 4.382 | 4.608 |
| 1.05 | 2.774 | 4.236 | 4.272 | 4.412 | 4.497 |
| 1.075 | 2.840 | 4.228 | 4.258 | 4.408 | 4.450 |
| 1.10 | 2.906 | 4.223 | 4.273 | 4.413 | 4.484 |
| 1.15 | 2.038 | 4.471 | 4.534 | 4.656 | 4.778 |
| 1.20 | 3.170 | 5.198 | 5.223 | 5.188 | 5.373 |

Table 17 - Resistance Data as Values of $C_{T}$ to a Base of $\frac{V}{\sqrt{L_{W L}}}$
$L C B$ Series 0.65 Block Coefficient Models
(Ship dimensions $-400.0 \mathrm{ft} \times 55.17 \mathrm{ft} \times 22.09 \mathrm{ft} \times 9051$ tons. Turbulence stimulated by studs)

| Model No. <br> LCB as $\% L_{\mathrm{BP}}$ from |  |
| :---: | :---: |
| $\mathrm{V} / \sqrt{\mathrm{L}_{\text {WL }}}$ | (1) |
| 0.25 | 0.644 |
| 0.30 | 0.773 |
| 0.35 | 0.802 |
| 0.40 | 1.031 |
| 0.45 | 1.160 |
| 0.50 | 1.289 |
| 0.55 | 1.418 |
| 0.60 | 1.546 |
| 0.65 | 1.675 |
| 0.675 | 1.740 |
| 0.70 | 1.804 |
| 0.725 | 1.869 |
| 0.75 | 1.933 |
| 0.775 | 1.997 |
| 0.80 | 2.062 |
| 0.825 | 2.126 |
| 0.85 | 2.191 |
| 0.875 | 2.255 |
| 0.90 | 2.320 |
| 0.95 | 2.448 |
| 1.00 | 2.577 |
| 1.05 | 2.706 |
| 1.10 | 2.835 |
| 1.15 | 2.964 |
| 1.20 | 3.093 |


| 4231 | 4218 | 42 |
| :---: | :---: | :---: |
| 2.46A | 1.54A | 0. |
|  | C | $10^{2}$ fo |
| 2.883 | 2.745 | 2 |
| 2,840 | 2.707 | 2 |
| 2.805 | 2.677 | 2 |
| 2.777 | 2.649 | 2 |
| 2.760 | 2.648 | 2 |
| 2.749 | 2.681 | 2. |
| 2.746 | 2.676 | 2 |
| 2.746 | 2.686 | 2. |
| 2.785 | 2.743 | 2. |
| 2.837 | 2.777 | 2. |
| 2.888 | 2.810 | 2. |
| 2.803 | 2.825 | 2. |
| 2.808 | 2.841 | 2. |
| 2.899 | 2.864 | 2. |
| 2.902 | 2.883 | 2. |
| 2.928 | 2.913 | 2. |
| 3.012 | 3.027 | 3. |
| 3.210 | 3.287 | 3. |
| 3.508 | 3.780 | 3 |
| 4.721 | 4.971 | 5 |
| 5.771 | 5.941 | 6 |
| 6.163 | 6.313 | 6 |
| 6. 104 | 3.224 | 6 |
| 6.055 | 3.161 | 6. |


| 211 | 0 |
| :--- | :--- |
| for 400 -ft | $L_{\mathrm{B}}$ |

Table 18 - Resistance Data as Values of $C_{T}$ to a Base of $\frac{V}{\sqrt{L_{W L}}}$
LCB Series 0.70 Block C'oefficient Models
(Ship dimensions $-400.0 \mathrm{ft} \times 57.14 \mathrm{ft} \times 22.86 \mathrm{ft} \times 10456$ tons. Turbulence $\mathbf{~ s t i m u l a t e d ~ b y ~ s t u d s ) ~}$

| Model No. <br> LCB as \% $L_{\mathrm{Br}}$ from $\varnothing$ |  |
| :---: | :---: |
| $V, \sqrt{L_{\text {L }}}$ | (1) |
| 0.25 | 0.629 |
| 0.30 | 0.755 |
| 0.35 | 0.881 |
| 0.40 | 1.006 |
| 0.45 | 1.132 |
| 0.50 | 1.258 |
| 0.55 | 1.384 |
| 0.60 | 1.510 |
| 0.65 | 1.636 |
| 0.675 | 1.698 |
| 0.70 | 1.761 |
| 0.725 | 1.824 |
| 0.75 | 1.887 |
| 0.775 | 1.950 |
| 0.80 | 2.013 |
| 0.85 | 2.139 |
| 0.90 | 2.264 |
| 0.95 | 2.390 |
| 1.00 | 2.516 |
| 1.05 | 2.642 |
| 1.10 | 2.768 |
| 1.15 | 2.894 |
| 1.20 | 3.019 |


| 4230 | 4221 | 4212 | 4222 | 4223 |
| :---: | :---: | :---: | :---: | :---: |
| 2.05A | 0.55A | 0.50 F | $1.54 F$ | 2.55 F |
|  | ( $\times 10^{2}$ for 400-ft $L_{B P}$ |  |  |  |
| 2.960 | 2.829 | 2.894 | 2.824 | 2.752 |
| 2.932 | 2.786 | 2.851 | 2.776 | 2.713 |
| 2.915 | 2.750 | 2.815 | 2.738 | 2.688 |
| 2.903 | 2.729 | 2.794 | 2.716 | 2.681 |
| 2.800 | 2.738 | 2.793 | 2.742 | 2.695 |
| 2.904 | 2.762 | 2.796 | 2.754 | 2.719 |
| 2.937 | 2.793 | 2.803 | 2.758 | 2.760 |
| 2.971 | 2.811 | 2.866 | 2.836 | 2.826 |
| 3.001 | 2.867 | 2.915 | 2.908 | 2.945 |
| 3.033 | 2.896 | 2.923 | 2.943 | 3.041 |
| 3.054 | 2.931 | 2.956 | 3.003 | 3.151 |
| 3.083 | 2.976 | 3.039 | 3.092 | 3.274 |
| 3.117 | 3.050 | 3.155 | 3.238 | 3.448 |
| 3.171 | 3.148 | 3.311 | 3.451 | 3.708 |
| 3.235 | 3.255 | 3.445 | 3.650 | 4.005 |
| 3.436 | 3.495 | 3.711 | 4.023 | 4.675 |
| 4.220 | 4.457 | 4.652 | 5.152 | 5.650 |
| 5.882 | 6.172 | 6.602 | 6.965 | 7.502 |
| 7.647 | 8.002 | 8.662 | 8.887 | 9.627 |
| 8.693 | 9.180 | 9.918 | 10.330 | 11.143 |
| 8.884 | 9.312 | 10.049 | 10.554 | 11.409 |
| 8.516 | 9.126 | 9.596 0.292 | 10.151 | 11.006 |

Table 19 - Resistance Data as Values of $C_{T}$ to a Base of $\frac{V}{\sqrt{L_{W L}}}$
$L C B$ Series 0.75 Block Coefficient Models
(Ship dimensions-400.0 $\mathrm{ft} \times 59.26 \mathrm{ft} \times 23.70 \mathrm{ft} \times 12048$ tons. Turbulence stimulated by studs)

| Model No. <br> LCB as $\% L_{\mathrm{BP}}$ from $\varnothing$ |  | $\begin{aligned} & 4224 \\ & 0.48 F \end{aligned}$ | $\begin{aligned} & 4213 \\ & 1.50 F \end{aligned}$ | $\begin{aligned} & 4225 \\ & 2.57 F \end{aligned}$ | $\begin{aligned} & 4226 \\ & 3.46 F \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  |
| $\mathrm{V} / \sqrt{\mathrm{L}}$ WL (B) |  |  | C) $\times 10$ | -ft $L_{\text {BP }}$ |  |
| 0.35 | 0.860 | 2.947 | 2.917 | 2.892 | 2.897 |
| 0.40 | 0.983 | 2.947 | 2.887 | 2.875 | 2.867 |
| 0.45 | 1.106 | 2.943 | 2.882 | 2.877 | 2.841 |
| 0.50 | 1.229 | 2.971 | 2.907 | 2.887 | 2.824 |
| 0.55 | 1.352 | 3.014 | 2.939 | 2.878 | 2.877 |
| 0.60 | 1.474 | 3.101 | 2.982 | 2.899 | 2.981 |
| 0.65 | 1.597 | 3.185 | 3.140 | 3.151 | 3.210 |
| 0.675 | 1.659 | 3.237 | 3.227 | 3.314 | 3.452 |
| 0.70 | 1.720 | 3.320 | 3.362 | 3.525 | 3.748 |
| 0.725 | 1.782 | 3.463 | 3.568 | 3.803 | 4.053 |
| 0.75 | 1.843 | 3.711 | 3.876 | 4.156 | 4.423 |
| 0.775 | 1.904 | 4.110 | 4.235 | 4.630 | 4.830 |
| 0.80 | 1.966 | 4.473 | 4.628 | 5.093 | 5.253 |
| 0.825 | 2.027 | 4.758 | 4.988 | 5.403 | 5.693 |
| 0.85 | 2.089 | 4.942 | 5.277 | 5.662 | 6.142 |
| 0.875 | 2.150 | 5.217 | 5.567 | 5.977 | 6.529 |
| 0.90 | 2.212 | 5.746 | 6.026 | 6.481 | 6.988 |

Table 20 - Resistance Data as Values of $C_{T}$ to a Pase of $\frac{V}{\sqrt{L_{W L}}}$ LCB Series 0.80 Block Coefficient Models
(Ship dimensions $-400.0 \mathrm{ft} \times 61.54 \mathrm{ft} \times 24.59 \mathrm{ft} \times 13859$ tons. Turbulence stimulated by studs)

| Model No. <br> LCB as $\%$ | $L_{\text {BP }}$ |
| :--- | :---: |
| from $\varnothing 0$ |  |
| $V \sqrt{L_{W L}}$ | $\bigotimes$ |
| 0.25 | 0.600 |
| 0.30 | 0.720 |
| 0.35 | 0.840 |
| 0.40 | 0.960 |
| 0.45 | 1.080 |
| 0.50 | 1.200 |
| 0.55 | 1.320 |
| 0.575 | 1.380 |
| 0.60 | 1.440 |
| 0.625 | 1.500 |
| 0.65 | 1.561 |
| 0.675 | 1.621 |
| 0.70 | 1.681 |
| 0.725 | 1.741 |
| 0.75 | 1.801 |
| 0.775 | 1.861 |
| 0.80 | 1.921 |
| 0.85 | 2.041 |


| 4227 | 4228 | 4214 | 4229 |
| :--- | :---: | :---: | :---: |
| $0.76 F$ | $1.45 F$ | $2.50 F$ | $3.51 F$ |
| 3.472 | $C: \times 10^{2}$ | for | $400 . f \mathrm{ft} L_{\mathrm{BP}}-$ |
| 3.452 | 3.194 | 3.075 | 3.090 |
| 3.434 | 3.172 | 3.040 | 3.055 |
| 3.432 | 3.147 | 3.012 | 3.017 |
| 3.444 | 3.134 | 2.997 | 2.992 |
| 3.476 | 3.128 | 2.998 | 3.016 |
| 3.528 | 3.144 | 3.014 | 3.059 |
| 3.564 | 3.196 | 3.061 | 3.146 |
| 3.616 | 3.238 | 3.121 | 3.256 |
| 3.682 | 3.306 | 3.241 | 3.441 |
| 3.785 | 3.407 | 3.392 | 3.690 |
| 3.945 | 3.565 | 3.590 | 3.987 |
| 4.175 | 3.772 | 3.862 | 4.297 |
| 4.463 | 4.015 | 4.215 | 4.622 |
| 4.843 | 4.323 | 4.583 | 5.038 |
| 5.475 | 4.778 | 5.008 | 5.718 |
| 6.393 | 5.390 | 5.660 | 6.580 |
| 7.222 | 6.088 | 6.543 | 7.378 |
|  | 7.487 | 7.732 | 8.737 |

Table 21 - Resistance Data as Values of (C) to a Base of (K) $L C B$ Series, 0.60 Block Coefficient Models
(Ship dimensions $-400.0 \mathrm{ft} \times 53.33 \mathrm{ft} \times 21.33 \mathrm{ft} \times 7807$ tons. Turbulence stimulated by studs)

| Model No. <br> LCB as $\% L_{\mathrm{BP}}$ from $\varnothing$ |  | 4215 | 4210 | 4216 | 4217 |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | 2.48 A | 1.50 A | 0.51 A | $0.52 F$ |
| $V / \sqrt{L_{\text {wL }}}$ | (1) |  | -(c) fo | $L_{\text {BP }}$ |  |
| $0.35{ }^{\text {² }}$ | 0.925 | 0.681 | 0.685 | 0.679 | 0.676 |
| 0.40 | 1.057 | 0.674 | 0.677 | 0.675 | 0.670 |
| 0.45 | 1.189 | 0.670 | 0.676 | 0.673 | 0.666 |
| 0.50 | 1.321 | 0.675 | 0.676 | 0.674 | 0.661 |
| 0.55 | 1.453 | 0.678 | 0.678 | 0.677 | 0.669 |
| 0.60 | 1.585 | 0.681 | 0.681 | 0.680 | 0.673 |
| 0.625 | 1.651 | 0.684 | 0.681 | 0.682 | 0.679 |
| 0.65 | 1.717 | 0.688 | 0.684 | 0.687 | 0.689 |
| 0.675 | 1.783 | 0.693 | 0.689 | 0.694 | 0.696 |
| 0.70 | 1.849 | 0.696 | 0.694 | 0.701 | 0.700 |
| 0.725 | 1.915 | 0.700 | 0.697 | 0.702 | 0.703 |
| 0.75 | 1.981 | 0.706 | 0.697 | 0.704 | 0.705 |
| 0.775 | 2.047 | 0.713 | 0.700 | 0.702 | 0.709 |
| 0.80 | 2.113 | 0.718 | 0.704 | 0.706 | 0.716 |
| 0.825 | 2.179 | 0.726 | 0.708 | 0.724 | 0.731 |
| 0.85 | 2.245 | 0.738 | 0.721 | 0.744 | 0.768 |
| 0.875 | 2.312 | 0.776 | 0.757 | 0.778 | 0.811 |
| 0.90 | 2.378 | 0.835 | 0.825 | 0.842 | 0.882 |
| 0.925 | 2.444 | 0.906 | 0.904 | 0.940 | 0.956 |
| 0.95 | 2.510 | 0.983 | 0.978 | 1.024 | 1.031 |
| 0.975 | 2.576 | 1.044 | 1.042 | 1.077 | 1.096 |
| 1.00 | 2.642 | 1.077 | 1.083 | 1.118 | 1.145 |
| 1.025 | 2.708 | 1.090 | 1.102 | 1.135 | 1.172 |
| 1.05 | 2.774 | 1.093 | 1.103 | 1.143 | 1.169 |
| 1.075 | 2.840 | 1.090 | 1.099 | 1.142 | 1.159 |
| 1.10 | 2.906 | 1.089 | 1.103 | 1.143 | 1.165 |
| 1.15 | 3.038 | 1.153 | 1.170 | 1.206 | 1.241 |
| 1.20 | 3.170 | 1.341 | 1.348 | 1.344 | 1.397 |

Table 22 - Resistance Data as Values of (C) to a Base of ( $K$ )
$L C P$ Series, 0.65 Block Coefficient Models
(Ship dimensions-400.0 $\mathrm{ft} \times 55.17 \mathrm{ft} \times 2209 \mathrm{ft} \times 9051$ tons. Turbulence stimulated by studs)


Table 23 - Resistance Data as Values of (C) to a Base of ( $B$ ) $L C B$ Series, 0.70 Block Coefficient Models
(Ship dimensions-400.0 $\mathrm{ft} \times 5714 \mathrm{ft} \times 2286 \mathrm{ft} \times 10456$ tons. Turbulence stimulated by studs)

| Model No. <br> LCB as \% $L_{\mathrm{BP}}$ from $\mathbb{C}$ |  | 4230 | 4221 | 4212 | 4222 | 4223 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | 2.05A | 0.55A | 0.50F | $1.54 F$ | $2.55 F$ |
| $V / \sqrt{L_{\text {wL }}}$ |  |  | (c) for $400-\mathrm{ft} L_{\text {BP }}$ |  |  |  |
| $0.25{ }^{\text {mL }}$ | 0.629 | 0.732 | 0.702 | 0.715 | 0.700 | 0.682 |
| 0.30 | 0.755 | 0.726 | 0.691 | 0.704 | 0.688 | 0.672 |
| 0.35 | 0.881 | 0.721 | 0.682 | 0.695 | 0.678 | 0.666 |
| 0.40 | 1.006 | 0.718 | 0.677 | 0.690 | 0.673 | 0.664 |
| 0.45 | 1.132 | 0.718 | 0.679 | 0.690 | 0.680 | 0.668 |
| 0.50 | 1.258 | 0.7185 | 0.685 | 0.690 | 0.682 | 0.674 |
| 0.65 | 1.384 | 0.727 | 0.693 | 0.690 | 0.683 | 0.684 |
| 0.60 | 1.510 | 0.735 | 0.697 | 0.708 | 0.703 | 0.700 |
| 0.65 | 1.638 | 0.742 | 0.711 | 0.718 | 0.721 | 0.730 |
| 0.675 | 1.698 | 0.750 | 0.718 | 0.722 | 0.729 | 0.754 |
| 0.70 | 1.761 | 0.756 | 0.727 | 0.730 | 0.744 | 0.781 |
| 0.725 | 1.824 | 0.763 | 0.738 | 0.750 | 0.766 | 0.811 |
| 0.75 | 1.887 | 0.771 | 0.756 | 0.779 | 0.802 | 0.854 |
| 0.775 | 1.950 | 0.785 | 0.781 | 0.818 | 0.855 | 0.918 |
| 0.80 | 2.013 | 0.800 | 0.807 | 0.851 | 0.904 | 0.893 |
| 0.85 | 2.139 | 0.850 | 0.867 | 0.916 | 0.997 | 1.159 |
| 0.90 | 2.264 | 1.044 | 1.106 | 1.149 | 1.277 | 1.400 |
| 0.95 | 2.390 | 1.455 | 1:531 | 1.630 | 1.726 | 1.859 |
| 1.00 | 2.516 | 1.892 | 1.985 | 2. 139 | 2.202 | 2.388 |
| 1.05 | 2.642 | 2.151 | 2.277 | 2.449 | 2.533 | 2.762 |
| 1.10 | 2.768 | 2.198 | 2.310 | 2.481 | 2.616 | 2.828 |
| 1.15 | 2.894 | 2.107 | 2.204 | 2.369 | 2.516 | 2.728 |
| 1.20 | 3.019 |  |  | 2.302 |  |  |

Table 24 - Resistance Data as Values of (C) to a Base of (H) $L C B$ Series, 0.75 Block Coefficient Models (Ship dimensions-400.0 ft $\times 59.26 \mathrm{ft} \times 23.70 \mathrm{ft} \times 12048$ tons. Turbulence stimulated by studs)

| Model No. <br> LCB as \% $L_{\text {BP }}$ from $\%$ |  | 4224 | 4213 | 4225 | 4226 |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | 0.48 F | $1.50 F$ | 2.57 F | $3.46 F$ |
| $V / \sqrt{L_{W L}}$ | (1) |  | (c) for 400-ft $L_{\text {BP }}$ |  |  |
|  | 0.860 | 0.716 | 0.707 | 0.702 | 0.704 |
| 0.40 | 0.983 | 0.716 | 0.700 | 0.698 | 0.696 |
| 0.45 | 1.106 | 0.715 | 0.699 | 0.698 | 0.690 |
| 0.50 | 1.229 | 0.722 | 0.705 | 0.701 | 0.686 |
| 0.55 | 1.352 | 0.732 | 0.713 | 0.698 | 0.699 |
| 0.60 | 1.474 | 0.753 | 0.723 | 0.704 | 0.724 |
| 0.65 | 1.597 | 0.774 | 0.761 | 0.765 | 0.780 |
| 0.675 | 1.659 | 0.786 | 0.782 | 0.804 | 0.838 |
| 0.70 | 1.720 | 0.806 | 0.815 | 0.855 | 0.910 |
| 0.725 | 1.78. | 0.841 | 0.865 | 0.923 | 0.984 |
| 0.75 | 1.843 | 0.902 | 0.940 | 1.008 | 1.074 |
| 0.775 | 1.904 | 0.998 | 1.027 | 1.124 | 1.173 |
| 0.80 | 1.966 | 1.087 | 1.122 | 1.236 | 1.276 |
| 0.825 | 2.027 | 1.156 | 1.210 | 1.311 | 1.383 |
| 0.85 | 2.089 | 1.201 | 1.279 | 1.374 | 1.492 |
| 0.875 | 2.150 | 1.267 | 1.350 | 1.450 | 1.586 |
| 0.90 | 2.212 | 1.396 | 1.461 | 1.573 | 1.697 |

Table 25 - Resistance Data as Values of (C) to a Base of (K) $L C B$ Series, 0.80 Block Coefficient Models (Ship dimensions- $400.0 \mathrm{ft} \times 61.54 \mathrm{ft} \times 24.59 \mathrm{ft} \times 13859$ tons. Turbulence stimulated by studs)

| Model No. |  |
| :--- | ---: |
| LCB as \% | $L_{\text {BP }}$ from $\varnothing$ |
| $V / \sqrt{L_{W L}}$ | 0 |
| 0.25 | 0.600 |
| 0.30 | 0.720 |
| 0.35 | 0.840 |
| 0.40 | 0.960 |
| 0.45 | 1.080 |
| 0.50 | 1.200 |
| 0.55 | 1.320 |
| 0.575 | 1.380 |
| 0.60 | 1.440 |
| 0.625 | 1.500 |
| 0.65 | 1.561 |
| 0.675 | 1.621 |
| 0.70 | 1.681 |
| 0.725 | 1.741 |
| 0.75 | 1.801 |
| 0.775 | -1.861 |
| 0.80 | 1.921 |
| 0.85 | 2.041 |


| 4227 | 4228 | 4214 | 4229 |
| :---: | :---: | :---: | :---: |
| $0.76 F$ | $1.45 F$ | $2.50 F$ | 3.51 F |
| (C) for 400 -ft $L_{\mathrm{BP}}$ |  |  |  |
| 0.831 | 0.766 | 0.739 | 0.743 |
| 0.826 | 0.760 | 0.730 | 0.734 |
| 0.822 | 0.754 | 0.724 | 0.725 |
| 0.822 | 0.751 | 0.720 | 0.719 |
| 0.824 | 0.750 | 0.720 | 0.725 |
| 0.832 | 0.754 | 0.724 | 0.735 |
| 0.845 | 0.766 | 0.736 | 0.756 |
| 0.853 | 0.776 | 0.750 | 0.783 |
| 0.866 | 0.792 | 0.779 | 0.827 |
| 0.881 | 0.817 | 0.815 | 0.887 |
| $0.90 t$ | 0.855 | 0.863 | 0.958 |
| 0.944 | 0.904 | 0.928 | 1.033 |
| 1.000 | 0.962 | 1.013 | 1.111 |
| 1.068 | 1.036 | 1.101 | 1.211 |
| 1.158 | 1.145 | 1.203 | 1.374 |
| 1.311 | 1.292 | 1.360 | 1.582 |
| 1.530 | 1.459 | 1.572 | 1.774 |
| 1.729 | 1.795 | 1.858 | 2.100 |



Figure 26 - Cross Curves of (C) on $L C B . C_{B}=0.60$


Figure 27 - Cross Curves of (C) on $L C B . C_{B}=0.65$


Figure 28 - Cross Curves of (C) on $L C B . C_{B}=0.70$


Figure 29 - Cross Curves of (C) on LCB. $C_{B}=0.75$


Figure 30 - Cross Curves of (C) on $L C B . C_{B}=0.80$
values of $\mathbb{K}$ corresponding to the Alexander and Troost speeds set out in Table 9. The locus of the LCB position for minimum resistance is indicated on each figure. Table 26 summarizes the data from all five figures.

The optimum $L C B$ locations and the coresponding minimum (C) values are given in Figure 31. This shows how, for a given block coefficient, the optimum LCB location moves aft as the desired speed is increased. When the block coefficient and speed are known, this figure will give the optimum $L C B$ position and the corresponding minimum (C) value which will result if the lines of the ship conform with those of the Series 60 contours. Thus for a block coefficient of 0.65 and a speed corresponding to $\mathbb{K}=2.1$, entering Figure 31 on the (K) scale, we find the best position of $L C B$ is 1.45 percent $L B P$ aft of $\varnothing$, the corresponding minimum (C) $400-\mathrm{ft}$ value being 0.73 and $\frac{V}{\sqrt{L_{B P}}}=0.82$. This chart, in fact, summarizes the conclusions to be drawn from the resistance data and should be of considerable use to designers in all cases where the lines and proportions are not too different from those of the series.

One point of considerable interest which arises from these data is the remarkable constancy of the minimum (C) value at the sustained sea speed as defined by Troost. These speeds are shown in Figure 31; for block coefficients varying from 0.60 to 0.80 , the minimum (C) 400 - ft values at 0.05 intervals in coefficient are respectively, $0.735,0.720,0.730,0.740$, and 0.740 .

Table 26 - Comparison of Resistance Results for LCB Series


The optimum locations of $L C B$ for Series 60 at the sustained sea speed and trial speed, as defined by Troost, are plotted in Figure 32. If desired, the effect of speed can be brought out by treating it as a parameter for a series of curves such as the two shown. From the cross curves of Figures 26-30, the permissible movement of the $L C B$ forward or aft of the optimum position has been determined in order that the minimum (C) value shall not be exceeded by more than 1 percent. The resultant limits are shown as dotted curves in Figure 32 for both sea and trial speeds.

It should be noted that all the Series 60 forms have a vertical stem line but no bulb at the forefoot, and that the recommended $L C B$ locations refer to such designs. In the finer forms, it is probable that in many cases a bulb would be fitted which would result in some variation in $L C B$ position, depending upon how much the bulb was treated as an addition or how far the extra displacement was used to fine down the load waterline and forebody generally.


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were calculated using the resistance of the model as measured during the self-propulsion tests, in association with the corresponding values of torque and rpm. This is a correct meas ure of propulsive efficiency since all the quantities apply to the model in the actual condition of test. However, for a variety of reasons, the actual resistance of the model at that time may not agree exactly with that measured during the original resistance tests, and on which the ehp values are based. The model has a keel piece, rudder, and propeller hub installed, and the surface and shape of the wax model may have changed slightly. The dhp values deduced straight from the torque and rpm will therefore correspond to a different resistance from that used to calculate the ehp values. For this reason, the dhp values have been calculated from the ehp values, using the propulsive efficiencies measured during the propulsion experiments but ignoring the actual torque and rpm values, i.e.,

$$
\mathrm{dhp}=\frac{\text { ehp }}{\text { Propulsive efficiency }}
$$

In this way there is no inconsistency between the dhp values and the ehp values previously given from the resistance experiments and made when the models were new and in the barehull condition with no appendages and a new, clean surface.

The choice of a 600 -ft ship to illustrate the propulsion tests was made principally because it was considered more representative of modern ships than the 400 ft chosen for the resistance presentation. This latter is made in coefficient form and may be corrected quite easily to any other desired ship length; most of the resistance data published elsewhere are on the $400-\mathrm{ft}$ basis. The propulsion data, on the other hand, cannot be so corrected, and must be completely recalculated for any other length. Moreover, unless the model has been run at a number of loadings, it is possible to make such correction only for a small change in length.

The results are presented in detail in Tables 27 through 31. The change in wake fraction with moverent in $L C B$ affects the optimum pitch ratio for the highest propulsive efficiency, but series chart calculations show that this effect does not amount to more than 1 or 2 percent. Cross curves of dhp similar to those of $C$ have been drawn for the same four chosen speeds. The data are tabulated in Table 32 and the cross curves are shown in Figure 38. On these have been drawn the loci of optimum $L C B$ location to give minimum dhp. Those already derived from the resistance data to give minimum ehp are also shown for purposes of comparis n .

In general, the minimum dhp is not so well defined as the minimum ehp, but, within practical limits, the dhp and ehp results agree in defining the same optimum $L C B$ loci for each set of models except the fullest - that with $C_{B}=0.80$. For this set, the dhp results indicate reducing power the further forward the $L C B$, even beyond the extreme position of 3.51 percent used in the experiments. The ehp results indicate an optimum location at about 2.50 percent of the length forward of midships, and this is a more practical answer - any

Table 27 - Results of Self-Propulsion Experiments, 0.60 Block Coefficient
(All figures are for ship of $600-\mathrm{ft} I, B P$ )

| Model No. |  | 4210 |  | 4215 |  |  | 4216 |  |  | 4217 |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| LC: | EHP | $\operatorname{per}_{N}$ | SHP | EHP | $\stackrel{\text { per }}{N}$ | SHP | HHP | $N$ | SHP | EHP |  | SHP |
| 12 | 2304 | 52.4 | 2931 | 2296 | 51.2 | 2789 | 2299 | 520 | 2796 | 2273 | 52.8 | 298 |
| 13 | 2940 | 56.9 | 3712 | 2943 | 55.6 | 3585 | 2933 | 56.7 | 3608 | 2896 | 87.1 | 3685 |
| 14 | 3085 | 60.9 | 4607 | 3687 | 60.0 | 4501 | 3675 | 61.3 | 4560 | 3631 | 61.8 | 4697 |
| 16 | 4549 | 65.7 | 6893 | 4549 | 64.7 | 5644 | 4540 | 65.9 | 5689 | 4499 | 66.3 | 5695 |
| 16 | 5545 | 70.4 | 7091 | 5577 | 69.6 | 6998 | 5565 | 70.7 | 7053 | 5575 | 71.2 | 7057 |
| 17 | 6730 | 75.6 | 8740 | 6764 | 74.7 | 8501 | 6796 | 76.1 | 8713 | 6796 | 76.2 | 8624 |
| 18 | 8063 | 80.6 | 10445 | 8113 | 79.2 | 10231 | 8162 | 80.9 | 10518 | 8145 | 81.2 | 10561 |
| 19 | 9531 | 85.1 | 12203 | 9677 | 83.6 | 11977 | 9555 | 85.9 | 12360 | 9835 | 86.8 | 12728 |
| 20 | 11219 | 00.4 | 14383 | 11484 | 88.5 | 14355 | 11316 | 91.1 | 14696 | 11445 | 82.6 | 15119 |
| 20.5 | 12142 | 93.0 | 15867 | 12454 | 91.1 | 16888 | 18422 | 93.9 | 16132 | 12571 | 94.6 | 16606 |
| 21 | 13880 | 95.5 | 17292 | 13031 | 94.5 | 17725 | 13726 | 96.9 | 17990 | 13973 | 97.7 | 18458 |
| 21.5 | 14778 | 98.8 | 19470 | 15202 | 98.1 | 19976 | 15253 | 99.8 | 20044 | 15873 | 101.0 | 21051 |
| 22 | 16961 | 102.9 | 22615 | 17273 | 101.6 | 22727 | 17297 | 103.1 | 22971 | 18217 | 104.9 | 24551 |
| 22.5 | 19533 | 107.3 | 26468 | 19726 | 105.9 | 26093 | 20247 | 108.3 | 27324 | 20887 | 1098 | 28730 |
| 23 | 22468 | 112.2 | 30903 | 22587 | 110.1 | 30309 | 23541 | 113.6 | 32248 | 28818 | 114.8 | 33210 |
| 23.5 | 25894 | 117.4 | 36165 | 25772 | 115.6 | 35794 | 28880 | 119.0 | 37566 | 27084 | 119.7 | 38140 |
| 24 | 28773 | 121.9 | 40755 | 28864 | 120.7 | 41059 | 29850 | 123.2 | 42281 | 30392 | 124.6 | 43170 |
| 25 | 34202 | 129.8 | 49354 | 34363 | 128.1 | 49301 | 35157 | 130.6 | 50011 | 36288 | 131.9 | 51839 |
| 26 | 39112 | 135.5 | 56196 | 38795 | 133.2 | 55739 | 40595 | 137.0 | 57663 | 41496 | 137.6 | 59443 |

Table 28 - Results of Self-Propulsion Experiments, 0.65 Block Coefficient
(All figures are for ship of 600 -ft $L B P$ )

| Mo LC1 |  | $4211$ <br> per ce |  |  | 42 |  |  | 42 |  |  | 42 |  |  | 4231 |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | EHP | N | SHP | EHP | $N$ | SHP | $\mathbf{E H P}$ | per | SHP | EHP | $\stackrel{N}{N}$ | SHP | $\mathbf{E H P}^{2 .}$ | per | $\mathbf{A}$ |
| 10 | 1475 | 41.4 | 1993 | 1453 | 41.0 | 1856 | 1428 | 41.8 | 1833 | 1427 | 41.0 | 1695 | 1526 | 41.8 | 2221 |
| 11 | 1949 | 45.4 | 2547 | 1933 | 45.3 | 2453 | 1898 | 46.0 | 2446 | 1908 | 45.3 | 2288 | 2022 | 45.8 | 2905 |
| 12 | 2516 | 49.6 | 3238 | 2526 | 49.4 | 3169 | 2485 | 50.5 | 3203 | 2505 | 50.0 | 3051 | 2613 | 49.8 | 3706 |
| 13 | 3200 | 64.1 | 4098 | 3225 | 53.6 | 4017 | 3204 | 54.9 | 4134 | 3226 | 54.6 | 3997 | 3322 | 53.8 | 4652 |
| 14 | 4011 | 58.7 | 5243 | 4040 | 57.9 | 5031 | 4046 | 59.3 | 5214 | 4067 | 59.4 | 5122 | 4147 | 57.9 | 5728 |
| 15 | 5010 | 68.1 | 6472 | 4992 | 62.3 | 6311 | 5018 | 63.6 | 6458 | 5064 | 64.4 | 6501 | 5116 | 62.1 | 6989 |
| 16 | 6172 | 67.7 | 7985 | 6172 | 67.4 | 7963 | 6197 | 68.3 | 7965 | 6267 | 60.3 | 8128 | 6214 | 68.4 | 8486 |
| 17 | 7505 | 72.4 | 0536 | 7581 | 72.5 | 9858 | 7627 | 73.1 | 9753 | 7724 | 74.2 | 10045 | 7782 | 72.3 | 10763 |
| 18 | 9044 | 77.0 | 11594 | 9113 | 77.3 | 11835 | 9235 | 78.0 | 11750 | 9500 | 79.2 | 12337 | 9369 | 77.3 | 12976 |
| 19 | 10818 | 81.8 | 13941 | 10852 | 82.1 | 14094 | 11051 | 83.3 | 14371 | 11641 | 84.8 | 15118 | 11010 | 81.6 | 15208 |
| 19.5 | 11789 | 84.2 | 15291 | 11779 | 82.5 | 15317 | 12118 | 86.1 | 15903 | 12910 | 87.6 | 16788 | 11903 | 83.7 | 16417 |
| 20 | 12881 | 87.0 | 16882 | 12777 | 86.8 | 16881 | 13319 | 88.7 | 17501 | 14322 | 90.6 | 18673 | 12879 | 86.0 | 17788 |
| 20.6 | 14145 | 90.1 | 18834 | 13944 | 89.2 | 18347 | 14800 | 91.9 | 19473 | 16026 | 94.1 | 21031 | 14013 | 8 C .5 | 19436 |
| 21 | 15771 | 93.8 | 21458 | 15565 | 92.8 | 20809 | 16753 | 95.5 | 22043 | 18191 | 98.0 | 24062 | 15439 | 91.6 | 21605 |
| 21.5 | 18129 | 99.0 | 25534 | 17803 | 97.0 | 24288 | 19353 | 99.7 | 25565 | 20815 | 102.4 | 27865 | 17477 | 95.5 | 24860 |
| 22 | 21855 | 104.4 | 31014 | 21338 | 102.6 | 29719 | 22705 | 104.4 | 30559 | 24031 | 107.5 | 32830 | 20326 | 100.5 | 29935 |
| 22.5 | 25884 | 109.2 | 37539 | 25648 | 108.5 | 36484 | 27138 | 111.0 | 37797 | 28204 | 113.0 | 39612 | 24428 | 108.5 | 36459 |
| 28 | 31221 | 115.7 | 45913 | 30621 | 115.0 | 44703 | 32800 | 118.1 | 46974 | 33510 | 119.4 | 48848 | 29254 | 112.4 | 43991 |
| 23.6 | 37337 | 121.7 | 86061 | 36588 | 121.9 | 54527 | 38626 | 125.2 | 57308 | 40546 | 127.0 | 61063 | 34704 | 118.9 | 53064 |
| 24 | 43782 | 128.8 | 67048 | 42542 | 128.6 | 65248 | 44889 | 132.1 | 68638 | 47386 | 133.7 | 73353 | 40734 | 125.6 | 64047 |

Table 29 - Results of Self-Propulsion Experiments, 0.70 Block Coefficient (All figures are for ship of $600-\mathrm{ft} L B P$ )

| Model No. |  | 4212 |  | 4221 |  |  | 4222 |  |  | 4223 |  |  | 4230 |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| ${ }^{\mathrm{LCB}}$ | , | per | SHP | $\underset{\mathrm{EHP}}{\mathrm{OH}}$ | per | SHP | EHP ${ }^{1}$ | per | SHP | EHP |  | SHP | EHP | per | SHP |
|  | EH | $N$ |  |  |  | SHP |  | $N$ | SHP | EHP | $N$ | SHP | EHP | $N$ | SHP |
| 10 | 1660 | 41.1 | 2065 | 1625 | 40.0 | 1972 | 1618 | 40.2 | 1951 | 1596 | 40.3 | 1977 | 1729 | 40.2 | 2145 |
| 11 | 2207 | 45.3 | 2762 | 2172 | 44.0 | 2627 | 2173 | 4. 5 | 2809 | 2131 | 44.2 | 2635 | 2305 | 44.4 | 2859 |
| 12 | 2867 | 49.6 | 3643 | 2842 | 48.5 | 3474 | 2835 | 48.9 | 3375 | 2780 | 48.8 | 3419 | 2995 | 48.6 | 3725 |
| 13 | 3652 | 54.0 | 4700 | 36.52 | 52.8 | 4536 | 3607 | 53.1 | 4336 | 3593 | 53.1 | 4393 | 3821 | 52.7 | 4746 |
| 14 | 4597 | 58.4 | 5970 | 4594 | 67.0 | 5742 | 4542 | 57.5 | 5566 | 4553 | 57.5 | 5573 | 4814 | 57.1 | 6018 |
| 15 | 5788 | 63.2 | 7517 | 5690 | 61.5 | 7139 | 5754 | 62.4 | 7257 | 5729 | 62.2 | 7073 | 6010 | 61.7 | 7607 |
| 15.5 | 6454 | 65.4 | 8393 | 0322 | 63.5 | 7943 | 6428 | 64.8 | 8137 | 6419 | 64.7 | 8033 | 6673 | 64.1 | 8501 |
| 16 | 7117 | 67.5 | 9267 | 7026 | 66.1 | 8860 | 7127 | 67.1 | 9033 | 7208 | 67.4 | 9138 | 7378 | 68.5 | 2471 |
| 16.5 | 7827 | 69.7 | 10205 | 7770 | 68.5 | 9835 | 7895 | 69.5 | 10019 | 8113 | 70.3 | 10428 | 8145 | 69.0 | 10564 |
| 17 | 8603 | 71.8 | 11246 | 8581 | 70.8 | 10903 | 8754 | 72.0 | 11109 | 9137 | 72.9 | 11882 | 8954 | 71.3 | 11735 |
| 17.5 | 9545 | 74.4 | 12510 | 9488 | 73.4 | 12122 | 9733 | 74.7 | 12352 | 10275 | 76.1 | 13555 | 9831 | 73.7 | 12987 |
| 18 | 10834 | 77.2 | 13991 | 10452 | 76.1 | 13489 | 10894 | 77.2 | 13860 | 11567 | 79.1 | 15443 | 10781 | 76.3 | 14436 |
| 15.5 | 11934 | 80.0 | 15724 | 11597 | 78.9 | 15080 | 12306 | 80.3 | 15919 | 13127 | 82.4 | 17763 | 11827 | 79.0 | 15897 |
| 19 | 13470 | 83.1 | 17770 | 12892 | 81.5 | 16809 | 14067 | 83.7 | 18412 | 15038 | 86.3 | 20488 | 12983 | 81.6 | 17545 |
| 19.5 | 15097 | 88.4 | 20048 | 14317 | 84.5 | 18838 | 15980 | 87.2 | 21222 | 17400 | 90.5 | 23803 | 14285 | 84.5 | 19515 |
| 20 | 16775 | 89.3 | 22367 | 15912 | 87.3 | 21047 | 17985 | 90.8 | 24206 | 20027 | 94.9 | 27738 | 15697 | 87.2 | 21621 |
| 21 | 20756 | 95.3 | 28086 | 19583 | 93.1 | 26216 | 22619 | 98.3 | 31328 | 26381 | 103.9 | 37741 | 19187 | 93.3 | 26988 |
| 22 | 29724 | 107.5 | 41631 | 26948 | 102.7 | 37016 | 31477 | 109.9 | 45685 | 35065 | 114.2 | 52180 | 25803 | 103.8 | 37780 |

Table 30 - Results of Self-Propulsion Experiments, 0.75 Block Coefficient
(All figures are for ship of $600-\mathrm{ft} L \mathcal{L}$ )

| Model No. |  | 4213 |  |
| :---: | :---: | :---: | :---: |
| LCB |  |  |  |
| $V$ | EHP | $N$ | SHP |
| 10 | 1851 | 40.0 | 2103 |
| 11 | 2485 | 44.6 | 3002 |
| 12 | 3216 | 48.9 | 3981 |
| 13 | 4142 | 63.3 | 5126 |
| 14 | 5210 | 57.7 | 6480 |
| 14.6 | 5824 | 59.0 | 7279 |
| 15 | 6526 | 62.1 | 8178 |
| 15.5 | 7348 | 64.8 | 9278 |
| 16 | 8278 | 67.8 | 10505 |
| 16.5 | 0311 | 70.2 | 11937 |
| 17 | 10483 | 73.0 | 13527 |
| 17.5 | 11871 | 76.4 | 15.538 |
| 18 | 13654 | 80.1 | 18006 |
| 19 | 18592 | 89.0 | 26888 |
| 20 | 25004 | 97.8 | 35009 |
| 21 | 32135 | 107.6 | 47749 |
| 22 | 40815 | 116.3 | 62504 |

EHP
1012
2554
3332
4276
6435
6111
6850
7649
8508
9465
10535
11805
13341
18125
24328
30356
38029

| 4224 |  |
| :---: | :---: |
| .48 per cent $F$ |  |
| $N$ | SHP |
| 40.3 | 2192 |
| 44.4 | 2902 |
| 48.8 | 3875 |
| 53.1 | 5072 |
| 57.6 | 6548 |
| 59.9 | 7425 |
| 62.5 | 8374 |
| 64.9 | 9431 |
| 67.1 | 10542 |
| 69.6 | 11757 |
| 72.1 | 13136 |
| 74.9 | 14798 |
| 78.0 | 16857 |
| 86.5 | 23880 |
| 96.0 | 34120 |
| 103.5 | 43804 |
| 112.3 | 57396 |


| 4225 |  |  |
| :---: | :---: | :---: |
| STP 2.57 per cent $F$ |  |  |
| SHP | $\boldsymbol{N}$ | SHP |
| 1846 | 40.8 | 2222 |
| 2459 | 45.0 | 2991 |
| 3203 | 49.1 | 3864 |
| 4102 | 63.3 | 4030 |
| 5184 | 87.5 | 6238 |
| 5831 | 60.0 | 7051 |
| 6584 | 62.7 | 8015 |
| 7368 | 65.8 | 9096 |
| 8313 | 68.1 | 10430 |
| 9491 | 71.4 | 12215 |
| 10905 | 74.8 | 14330 |
| 12577 | 78.3 | 16880 |
| 14830 | 82.0 | 19455 |
| 20275 | 0.8 | 27399 |
| 27518 | 101.2 | 30367 |
| 33361 | 108.8 | 50318 |
| 42478 | 118.1 | 65250 |


| 4226 |  |  |
| :---: | :---: | :---: |
| $\xrightarrow{3} \mathbf{3} 46$ per cent F |  |  |
| EHP | $\boldsymbol{N}$ | SHP |
| 1837 | 40.7 | 2159 |
| 2427 | 44.9 | 2939 |
| 3135 | 49.0 | 3883 |
| 4020 | 63.5 | 4044 |
| 5126 | 58.8 | 6390 |
| 5777 | 60.8 | 724 |
| 6529 | 63.8 | 8233 |
| 7404 | 65.9 | 0360 |
| 8446 | 68.6 | 10691 |
| 9821 | 72.1 | 12479 |
| 11526 | 75.8 | 14834 |
| 13412 | 79.7 | 17601 |
| 15593 | 83.7 | 20791 |
| 21254 | 92.8 | 29235 |
| 28474 | 102.1 | 40620 |
| 37471 | 113.2 | 55505 |
| 47694 | 123.2 | 72705 |

Table 31 - Results of Self-Propulsion Experiments, 0.80 Block Coefficient
(All figures are for ship of $\mathbf{6 0 0 - f t} L B P$ )

| Model No.LCB | 4214 |  |  | 4227 |  |  | 4228 |  |  | 4229 |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | per |  |  | per |  | EHP | ${ }^{\prime}$ |  | EHP ${ }^{3}$ | N |  |
| $V$ | EHP | $N$ | SHP | EHP | $\boldsymbol{N}$ | SHP | EHP | $N$ | SHP | EHP | $N$ | SHP |
| 9 | 1531 | 37.8 | 1858 | 1751 | 42.2 | 2678 | 1599 | 38.9 | 1955 | 1630 | 37.5 | 1620 |
| 10 | 2096 | 42.2 | 2552 | 2403 | 47.0 | 8698 | 2187 | 48.2 | 2697 | 2089 | 42.1 | 2336 |
| 11 | 2791 | 46.6 | 3433 | 3212 | 51.8 | 4004 | 2914 | 47.7 | 3620 | 2800 | 46.6 | 3203 |
| 12 | 3639 | 51.2 | 4531 | 4197 | 58.6 | 6507 | 3786 | 52.0 | 4744 | 3680 | 61.1 | 4230 |
| 12.6 | 4127 | 53.3 | 5172 | 4772 | 59.0 | 7309 | 4305 | 64.3 | 6422 | 4187 | 84.2 | 4812 |
| 13 | 4666 | 55.6 | 5892 | 8405 | 61.7 | 8367 | 4878 | 56.9 | 6182 | 4756 | 55.7 | 6478 |
| 13.5 | 5274 | 58.2 | 6893 | 6006 | 04.1 | 0482 | 5605 | 54.5 | 7031 | 5405 | 88.0 | 6203 |
| 14 | 5970 | 60.6 | 7625 | 0855 | 66.7 | 10594 | 6208 | 62.1 | 7990 | 6190 | 60.7 | 7248 |
| 14.5 | 6796 | 63.3 | 8713 | 7603 | 69.8 | 11927 | 6893 | 64.9 | 8093 | 7162 | 63.7 | 8486 |
| 15 | 7792 | 66.2 | 10028 | 8035 | 72.1 | 13470 | 7896 | 67.7 | 10363 | 8327 | 67.5 | 9997 |
| 16 | 10315 | 72.9 | 13519 | 10876 | 78.2 | 17345 | 10222 | 78.9 | 13084 | 11468 | 74.4 | 14231 |
| 17 | 14099 | 81.0 | 18975 | 14117 | 85.5 | 22955 | 13546 | 81.3 | 18668 | 15580 | 82.4 | 20286 |
| 18 | 19249 | 90.5 | 27381 | 18042 | 03.4 | 30763 | 18102 | 00.0 | 26278 | 21280 | 92.0 | 29271 |
| 10 | 26847 | 101.3 | 40432 | 25823 | 103.1 | 42642 | 25708 | 101.2 | $3882{ }^{\circ}$ | 81410 | 104.0 | 46822 |

Table 32 - Comparis on of DHP Results for $L C B$ Series
(Speed and dhp are given for ship. 600 ft long, between perpendiculars)

| $C_{B}$ | $C_{P}$ | Position of LCB as Percent $L_{B P}$ from | SERVICE SPEED (a) |  |  | TRIAL SPEED (8) |  |  | SEA SPEED (b) |  |  | TRIAL SPEED (b) |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | $\frac{V}{\sqrt{L_{B P}}}$ | $\left\{\begin{array}{c} V \\ \text { knots } \end{array}\right.$ | DHP | $\frac{V}{\sqrt{L_{B P}}}$ | $\begin{gathered} V \\ \text { knots } \end{gathered}$ | DHP | $\frac{V}{\sqrt{L_{B P}}}$ | $\begin{gathered} V \\ \text { knots } \end{gathered}$ | DHP | $\frac{V}{\sqrt{L_{B P}}}$ | $\underset{\text { knots }}{V}$ | DHP |
| 0.60 | 0.614 | 2.48 A | 0.90 | 22.04 | 22954 | 0.96 | 23.52 | 36197 | 0.869 | 21.26 | 18853 | 0.921 | 22.54 | 26372 |
|  |  | 1.50A |  |  | 22954 |  |  | 36353 |  |  | 18334 |  |  | 26712 |
|  |  | 0.51 A |  |  | 23328 |  |  | 37836 |  |  | 19026 |  |  | 27688 |
|  |  | 0.52 F |  |  | 24870 |  |  | 38382 |  |  | 19698 |  |  | 29085 |
| 0.65 | 0,661 | 2.46 A | 0.80 | 19.60 | 16664 | 0.86 | 21.06 | 21950 | 0.792 | 19.40 | 16150 | 0.839 | 20.56 | 19676 |
|  |  | 1.54A |  |  | 15572 |  |  | 21204 |  |  | 15047 |  |  | 18642 |
|  |  | 0.50A |  |  | 15602 |  |  | 21933 |  |  | 15018 |  |  | 19120 |
|  |  | 0.38 F |  |  | 16197 |  |  | 22390 |  |  | 15566 |  |  | 19729 |
|  |  | 1.37F |  |  | 17123 |  |  | 24473 |  |  | 16427 |  |  | 21319 |
| 0.70 | 0.710 | 2.05A | 0.70 | 17.15 | 12106 | 0.76 | 18.62 | 16282 | 0.714 | 17.49 | 12958 | 0.757 | 18.54 | 16028 |
|  |  | 0.55A |  |  | 11263 |  |  | 15462 |  |  | 12096 |  |  | 15180 |
|  |  | 0.50 F |  |  | 11600 |  |  | 16205 |  |  | 12465 |  |  | 15901 |
|  |  | 1.54F |  |  | 11475 |  |  | 16482 |  |  | 12326 |  |  | 16111 |
|  |  | 2.55 F |  |  | 12358 |  |  | 18400 |  |  | 13519 |  |  | 17972 |
| 0.75 | 0.758 | 0.48 F | 0.60 | 14.70 | 7807 | 0.66 | 16.17 | 10934 | 0.637 | 15.60 | 9650 | 0.675 | 16.54 | 11855 |
|  |  | 1.50 F |  |  | 1616 |  |  | 10993 |  |  | 9509 |  |  | 12064 |
|  |  | 2.57 F |  |  | 7422 |  |  | 11000 |  |  | 9350 |  |  | 12390 |
|  |  | 3.46 F |  |  | 7622 |  |  | 11242 |  |  | 9604 |  |  | 12634 |
| 0.80 | 0.805 | 0.76 F | 0.50 | 12.25 | 6948 | 0.56 | 13.72 | 9926 | 0.562 | 13.77 | 10050 | 0.596 | 14.60 | 12230 |
|  |  | 1.45 F |  |  | 5073 |  |  | 7447 |  |  | 7546 |  |  | 9333 |
|  |  | 2.50 F |  |  | 4843 |  |  | 7098 |  |  | 7185 |  |  | 8972 |
|  |  | 3.51F |  |  | 4514 |  |  | 6672 |  |  | 6770 |  |  | 8776 |

(a) From Equation 1
(b) From Equation 2

Figure 38 - Cross-Curves of DHP for $L C B$ Series
(Speeds and dhp given for ship 600 ft long, between perpendiculars)


Figure $38 a-C_{B}=0.60$.


Figure $38 \mathrm{~b}-C_{B}=0.65$


Figure 38c $-C_{B}=0.70$


Figure 38d $-C_{B}=0.75$


Figure 38e $-C_{B}=0.80$
further movement forward would result in excessively full entrance waterlines and probably poor behavior and heavy speed loss in a seaway.

It can be concluded that if the $L C B$ location is chosen to give minimum (C) values and so minimum ehp, the dhp also will be practically a minimum except for the very fullest models of the series. The charts given in Figures 31 and 32 can thus be used by the designer with the knowledge that, within practical limits, they will.lead to ship forms having both minimum ehp and dhp in smooth water.

The detailed results of the self-propelled experiments are given in Tables 27 to 31 . Cross plots of these data show a general waviness of character, associated with changes in wake fraction $\underline{w}$ consequent upon changes in wave formation with speed, but for a given fullness, both wake fraction and thrust deduction fraction tend to decrease as the $L C B$ moves forward, due to the progressive fining of the afterbody. As a result, the hull efficiency remains fairly constant, although showing considerable variation due to the interplay of the changes in $w$ and $t$. The one exception to this pattern is the set of models of $0.80 C_{B}$, where the value of $w$ remains fairly constant with $L C B$ movement, but $t$ decreases rapidly as the $L C B$ moves forward. As a result, the hull efficiency increases continually, and the resultant increase in propulsive efficiency and decrease in dhp is the reason why this set shows no optimum $L C B$ location for minimum dhp within the range tested.

## CHAPTER VIII

## EFFECT ON RESISTANCE AND DHP OF VARIATION in SHIP PROPORTIONS

The experiments described in the last section showed that the original choice of $L C B$ positions had not been too far from the optimum, although improvement could be obtained in certain areas. For the final series of experiments, in which the effect of variation in $C_{B}$, $\frac{L}{B}, \frac{B}{H}$, and $\frac{\Delta}{\left(\frac{L}{100}\right)^{3}}$ upon resistance and propulsive efficiency were determined, the five models chosen as parents were those of the $L C B$ series having the $L C B$ in the position nearest to the optimum.

| $C_{B}$ | 0.60 | 0.65 | 0.70 | 0.75 | 0.80 |
| :--- | :--- | :--- | :--- | :--- | :--- |
| Model Number | 4210 | 4218 | 4221 | 4213 | 4214 |
| $L C B$ as Percent $L_{B} P$ <br> from $\mathcal{X X}_{B} P$ | 1.5 aft | 1.54 aft | 0.55 aft | 1.5 fwd | 2.5 fwd |
| $L C B$ in Original <br> Series 60 Parents | 1.5 aft | 0.5 aft | 0.5 fwd | 1.5 fwd | 2.5 fwd |

It will be seen that the change involves a movement of the $L C B$ aft in the 0.65 and $0.70 C_{B}$ models. The models chosen for the final phase are also indicated in Figure 1. In developing this geometrical series, the assumption has been made that the optimum location of $L C B$ for the model having the $\frac{L}{B}$ and $\frac{B}{H}$ ratios of any one parent will remain near-optimum with changes of $\frac{L}{B}$ and $\frac{B^{B}}{H}$ for the same block coefficient. This assumption has not been tested in the present research, but any other would have led to a great extension of the test program.

Having chosen the new parents, eight additional models were made for each block coefficient, making a total of 45 models in all, including the original parents.

| $C_{B}$ | VARIATION OF $\frac{L}{B}$ AND $\frac{B}{H}$ RATIOS |  |  |
| :--- | :--- | :---: | :---: |
|  | Range of Variation in |  |  |
|  | $\frac{L}{B}$ | $\frac{B}{H}$ | $\frac{\Delta}{(L / 100)^{3}}$ |
| 0.60 | $6.5-8.5$ | $2.5-3.5$ | $67.8-162.4$ |
| 0.65 | $6.25-8.25$ | $2.5-3.5$ | $78.0-190.3$ |
| 0.70 | $6.0-8.0$ | $2.5-3.5$ | $89.3-222.4$ |
| 0.75 | $5.75-7.75$ | $2.5-3.5$ | $102.0-259.3$ |
| 0.80 | $5.5-7.5$ | $2.5-3.5$ | $116.2-302.4$ |

A typical pattern of the variation (for $C_{B}=0.60$ ) is shown in Figure 2.

The eight new models of any one set were derived from the parents by a straightforward geonetrical variation of beam and draft to give the required combinations of $\frac{L}{B}$ and $\frac{B}{H}$ values. The lines of the parents for $C_{B}$ values of $0.60,0.75$, and 0.80 are shown in Figures 12,15 , and 16 and those for the aew parents of 0.65 and $0.70 C_{B}$ are shown in Figures 39 and 40. Particulars of all 45 models are given in Tables 33 through 37.

The models were made in wax, $20 \mathrm{ft} L B P$, as before, but the turbulence stimulation was provided by a trip wire instead of studs; the 0.036 -in. diameter wire was placed around a station 5 percent of the length from the forward perpendicular. This change was made for the reasons set out in Appendix A. The model results have been converted to apply to a ship $400 \mathrm{ft} L B P$, using the ATTC 1947 model-ship correlation line with an addition of +0.0004 for ship correlation allowance. The ship figures are given in Appendix B as values of $C_{T}$ and (C) for a standard temperature of $59^{\circ} \mathrm{F}\left(15^{\circ} \mathrm{C}\right)$.

For the propulsion experiments, the models were fitted with a rudder and keelpiece and the experiments carried out as described in Chapter VII. The propeller diameter was in every case 0.7 of the draft. The propellers for the parent models were specially made for the Series 60 tests, and, as already described, were of the Troost B-type with four blades. As the draft was varied in this geometrical series, so also the propeller diameter had to be changed. To avoid making large numbers of new propellers, and since the principal objective of the propulsion tests was to obtain systematic data on the components of propulsive efficiency, such as wake and thrust-deduction fractions, stock model propellers were used whenever possible. These were chosen to have rake, blade-area ratio, sections, and other features as near to the Troost standard design as possible. Table 38 shows the propeller particulars.

The propulsion tests were run without bilge keels, and trip wires were used for turbulence stimulation. They were carried out at a propeller loading corresponding to the 600 -ft ship self-propulsion point with a ship correlation allowance of +0.0004 . The data extrapolated to apply to a ship $600 \mathrm{ft} L B P$ are presented in detail in Appendix B.





Figure 40 - Lines of $0.70 C_{B}$ Parent for $\frac{L}{B} \frac{B}{H}$ Series (Model 4221)

Table 33 - Principal Particulars of 0.60 Block Coefficient Models

| Model Number | 4210 | 4255 | 4253 | 4240 | 4252 | 4241 | 4243 | 4254 | 4242 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $L / B$ | 7.50 | 7.5 | 7.5 | 6.5 | 6.5 | 6.5 | 8.5 | 8.5 | 8.5 |
| $B / H$ | 2.50 | 3.0 | 3.5 | 2.5 | 3.0 | 3.5 | 2.5 | 3.0 | 3.5 |
| B, ft | 53.33 | 53.33 | 53.33 | 61.54 | 61.54 | 61.54 | 47.06 | 47.06 | 47.06 |
| H, ft | 21.33 | 17.78 | 15.24 | 24.62 | 20.51 | 17.58 | 18.82 | 15.69 | 13.44 |
| $\Delta$, tons | 7807 | 6506 | 5577 | 10394 | 8661 | 7423 | 6077 | 5066 | 4340 |
| $1 / 2{ }^{\text {a }}$ E , deg | 7.0 | 7.0 | 7.0 | 8.7 | 8.7 | 8.7 | 6.2 | 6.2 | 6.2 |
| $L / \nabla^{1 / 3}$ | 6.165 | 6.552 | 6.897 | 5.604 | 5.956 | 6.270 | 6.702 | 7.122 | 7.498 |
| $\Delta(L / 100)^{3}$ | 122.0 | 101.6 | 87.14 | 1624 | 135.3 | 116.0 | 94.95 | 79.16 | 67.81 |
| WS, sq ft | 27280 | 24906 | 23207 | 31590 | 28659 | 26893 | 24082 | 21941 | 20502 |
| $S / \nabla^{2 / 3}$ | 6.481 | 6,682 | 6.900 | 6.202 | 6.354 | 6.608 | 6.762 | 6.955 | 7:205 |
| $L_{W L}, \mathrm{ft}$ |  |  |  |  | 406.7 |  |  |  |  |
| $L_{\text {BP }}, \mathrm{ft}$ |  |  |  |  | 400.0 |  |  |  |  |
| $L_{E} / L_{B P}$ |  |  |  |  | 0.5 |  |  |  |  |
| $L_{X} / L_{B P}$ |  |  |  |  | 0 |  |  |  |  |
| $L_{R} / L_{B P}$ |  |  |  |  | 0.5 |  |  |  |  |
| $C_{B}$ |  |  |  |  | 0.60 |  |  |  |  |
| $C_{X}$ |  |  |  |  | 0.977 |  |  |  |  |
| $C_{P}$ |  |  |  |  | 0.614 |  |  |  |  |
| $C_{P F}$ |  |  |  |  | 0.581 |  |  |  |  |
| $C_{P A}$ |  |  |  |  | 0.646 |  |  |  |  |
| $C_{P E}$ |  |  |  |  | 0.581 |  |  |  |  |
| $C_{P R}$ |  |  |  |  | 0.646 |  |  |  |  |
| $C_{P V}$ |  |  |  |  | 0.850 |  |  |  |  |
| $C_{P V F}$ |  |  |  |  | 0.910 |  |  |  |  |
| $C_{\text {PVA }}$ |  |  |  |  | 0.802 |  |  |  |  |
| $C_{W}$ |  |  |  |  | 0.706 |  |  |  |  |
| $C_{W F}$ |  |  |  |  | 0.624 |  |  |  |  |
| $C_{\text {W }}$ |  |  |  |  | 0.788 |  |  |  |  |
| $C_{I T}$ |  |  |  |  | 0.543 |  |  |  |  |
| LCB, \% LBP from 》 |  |  |  | -- | . 1.5 A . |  |  |  |  |

VIII-5

Table 34 - Principal Particulars of 0.65 Block Coefficient Models

| Model Number | 4218 | 1275 | 1273 | 4264 | 1272 | 1265 | 4267 | 1274 | 1266 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $L / B$ | 7.25 | 7.25 | 7.25 | 6.25 | 6.25 | 6.25 | 8.25 | 8.25 | 8.25 |
| B/H | 2.50 | 3.0 | 3.5 | - 2.5 | 3.0 | 3.5 | 2.5 | 3.0 | 3.5 |
| B, ft | 55.17 | 55.17 | 55.17 | 64.00 | 64.00 | 64.00 | 48.48 | 48.48 | 48.48 |
| $\mathrm{H}, \mathrm{ft}$ | 22.09 | 18.39 | 15.76 | 25.60 | 21.33 | 18.28 | 19.39 | 16.16 | 13.85 |
| $\Delta_{1}$ tons | 9051 | 7542 | 6463 | 12179 | 10148 | 8696 | 6988 | 5824 | 4991 |
| $1 / 2 \alpha_{E^{\prime}}$ deg | 8.3 | 8.3 | 8.3 | 9.6 | 9.6 | 9.6 | 7.3 | 7.3 | 7.3 |
| $L / \nabla^{1 / 3}$ | 5.869 | 6.236 | 6.566 | 5.316 | 5.649 | 5.948 | 6.398 | 6.798 | 7.157 |
| $\Delta /(L / 100)^{3}$ | 141.4 | 117.8 | 101.0 | 190.3 | 158.6 | 135.9 | 109.2 | 91.00 | 77.98 |
| WS, sq ft | 29380 | 26789 | 25042 | 34116 | 31082 | 29045 | 25822 | 23532 | 21989 |
| $5 / \nabla^{2 / 3}$ | 6.324 | 6.512 | 6.748 | 6.026 | 6.200 | 6.422 | 6.606 | 6.997 | 7.039 |
| $L_{\text {WL } L}$, ft |  |  |  |  | 406.7 |  |  |  |  |
| $L_{B P}, \mathrm{ft}$ |  |  |  |  | 400.0 |  |  |  |  |
| $L_{E} / L_{B P}$ |  |  |  |  | 0.175 |  |  |  |  |
| $L_{X} / L_{B P}$ |  |  |  |  | 0.035 |  |  |  |  |
| $L_{R} L^{\prime} L_{B P}$ |  |  |  |  | 0.190 |  |  |  |  |
| $C_{B}$ |  |  |  |  | 0.650 |  |  |  |  |
| ${ }^{c_{X}}$ |  |  |  |  | 0.982 |  |  |  |  |
| $C_{P}$ |  |  |  |  | 0.661 |  |  |  |  |
| $C_{P F}$ |  |  |  |  | 0.628 |  |  |  |  |
| $C_{P A}$ |  |  |  |  | 0.694 |  |  |  |  |
| $C_{P E}$ |  |  |  |  | 0.609 |  |  |  |  |
| $C_{P R}$ |  |  |  |  | 0.688 |  |  |  |  |
| $C_{P V}$ |  |  |  |  | 0.874 |  |  |  |  |
| $C_{\text {PVF }}$ |  |  |  |  | 0.924 |  |  |  |  |
| $C_{\text {PVA }}$ |  |  |  |  | 0.832 |  |  |  |  |
| $C_{\text {w }}$ |  |  |  |  | 0.744 |  |  |  |  |
| $C_{\text {wF }}$ |  |  |  |  | 0.668 |  |  |  |  |
| $C_{\text {WA }}$ |  |  |  |  | 0.819 |  |  |  |  |
| $C_{\text {IT }}$ |  |  |  |  | 0.593 |  |  |  |  |
| $L C B, \% L B P$ from |  |  |  |  | 1.54A |  |  |  |  |

Table 35 - Principal Particulars of 0.70 Block Coefficient Models

| Model Mumber | 4221 | 4259 | 4257 | 4244 | 4256 | 4245 | 4247 | 4258 | 4246 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $L / B$ | 7.00 | 7.0 | 7.0 | 6.0 | 6.0 | 6.0 | 8.0 | 8.0 | 8.0 |
| $B / H$ | 2.50 | 3.0 | 3.5 | 2.5 | 3.0 | 3.5 | 25 | 3.0 | 3.5 |
| B, ft | 57.14 | 57.14 | 57.14 | 66.67 | 66.67 | 66.67 | 50.00 | 50.00 | 50.00 |
| H, ft | $2 ? .86$ | 19.05 | 16.32 | 26.67 | 22.22 | 19.05 | 20.00 | 16.67 | 14.28 |
| $\Delta$ tons | 10456 | 8714 | 7465 | 14234 | 11859 | 10167 | 8005 | 6672 | 5716 |
| $1 / 2{ }^{\text {c }}{ }_{E}$, deg | 11.6 | 11.6 | 116 | 12.9 | 12.9 | 12.9 | 9.7 | 9.7 | 9.7 |
| $L / \nabla^{1 / 3}$ | 5.593 | 5.944 | 6.258 | 5.047 | 5.364 | 5.646 | 6.114 | 6.497 | 6.841 |
| $\Delta(L / 100)^{3}$ | 163.4 | 136.2 | 116.6 | 222.4 | 185.3 | 158.8 | 125. 1 | 104.2 | 89.31 |
| WS, sq ft | 31859 | 29183 | 27189 | 37070 | 33913 | 31882 | 27864 | 25436 | 23870 |
| $S / \nabla^{2 / 3}$ | 6.230 | 6.444 | 6.656 | 5.901 | 6.097 | 6.352 | 6.510 | 6.710 | 6.981 |
| $L_{W L}, \mathrm{ft}$ |  |  |  |  | 406.7 |  |  |  |  |
| $L_{B P}, \mathrm{ft}$ |  |  |  |  | 400.0 |  |  |  |  |
| $L_{B} / L_{B P}$ |  |  |  |  | 0.420 |  |  |  |  |
| $L_{X} L^{\prime}{ }_{B P}$ |  |  |  |  | 0.119 |  |  |  |  |
| $L_{R} L_{B P}$ |  |  |  |  | 0.461 |  |  |  |  |
| $C_{B}$ |  |  |  |  | 0.700 |  |  |  |  |
| $c_{X}$ |  |  |  |  | 0.986 |  |  |  |  |
| $C_{P}$ |  |  |  |  | 0.710 |  |  |  |  |
| $C_{P F}$ |  |  |  |  | 0.700 |  |  |  |  |
| $C_{P A}$ |  |  |  |  | 0.721 |  |  |  |  |
| $C_{\text {PE }}$ |  |  |  |  | 0.642 |  |  |  |  |
| $C_{P R}$ |  |  |  |  | 0.698 |  |  |  |  |
| $c_{P V}$ |  |  |  |  | 0.890 |  |  |  |  |
| $C_{P V F}$ |  |  |  |  | 0.940 |  |  |  |  |
| $C_{P V A}$ |  |  |  |  | 0.846 |  |  |  |  |
| $C_{\text {w }}$ |  |  |  |  | 0.787 |  |  |  |  |
| $C_{\text {WF }}$ |  |  |  |  | 0.734 |  |  |  |  |
| $C_{\text {WA }}$ |  |  |  |  | 0.841 |  |  |  |  |
| $C_{I T}$ |  |  |  |  | 0.651 |  |  |  |  |
| $L C B, \$ L B P$ from $\mathbf{Q}$ |  |  |  |  | 0.55 A |  |  |  |  |

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Table 36 - Principal Particulars of 0.75 Block Coefficient Models

| Model Number | 4213 | 4279 | 4271 | 4268 | 4276 | 4269 | 4271 | 4278 | 4270 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $L / B$ | 6.75 | 6.75 | 6.75 | 5.75 | 5.75 | 5.75 | 7.75 | 7.75 | 7.75 |
| $B / H$ | 2.50 | 3.0 | 3.5 | 2.5 | 3.0 | 3.5 | 2.5 | 3.0 | 3.5 |
| $B, \mathrm{ft}$ | 59.26 | 59.26 | 59.26 | 69.56 | 69.56 | 69.56 | 51.61 | 51.61 | 54.61 |
| H, ft | 23.70 | 19.75 | 16.93 | 27.82 | 23. 19 | 19.87 | 20.64 | 17.20 | 14.74 |
| $\triangle$ tons | 12048 | 10038 | 8606 | 16598 | 13836 | 11855 | 9136 | 7614 | 6525 |
| $1 / 2 \alpha_{E}$, deg | 22.5 | 22.5 | 22.5 | 25.9 | 25.9 | 25.9 | 19.8 | 19.8 | 19.8 |
| $L / \nabla^{1 / 3}$ | 5.335 | 5.670 | 5.968 | 4.795 | 5.095 | 5. 364 | 5.851 | 6.217 | 6.546 |
| $\Delta /(L / 100)^{3}$ | 188.2 | 156.8 | 134.4 | 259.3 | 216.2 | 185.2 | 142.8 | 119.0 | 102.0 |
| WS, sq it | 34232 | 31459 | 29502 | 40252 | 36964 | 34659 | 29802 | 27400 | 25693 |
| $S / \nabla^{2 / 3}$ | 6.090 | 6.322 | 6.569 | 5.784 | 5.997 | 6.233 | 6.376 | 6.620 | 6.880 |
| $L_{W L}, \mathrm{ft}$ |  |  |  |  | 406.7 |  |  |  |  |
| $L_{B P}, \mathrm{ft}$ |  |  |  |  | 400.0 |  |  |  |  |
| $L_{E} / L_{B P}$ |  |  |  |  | 0.350 |  |  |  |  |
| $L_{X} L_{B P}$ |  |  |  |  | 0.210 |  |  |  |  |
| $L_{R} / L_{B P}$ |  |  |  |  | 0.440 |  |  |  |  |
| $C_{B}$ |  |  |  |  | 0.750 |  |  |  |  |
| $C_{X}$ |  |  |  |  | 0.990 |  |  |  |  |
| $C_{P}$ |  |  |  |  | 0.758 |  |  |  |  |
| $C_{\text {PF }}$ |  |  |  |  | 0.792 |  |  |  |  |
| $C_{P A}$ |  |  |  |  | 0.724 |  |  |  |  |
| $C_{P E}$ |  |  |  |  | 0.704 |  |  |  |  |
| $C_{P R}$ |  |  |  |  | 0.686 |  |  |  |  |
| $C_{P V}$ |  |  |  |  | 0.907 |  |  |  |  |
| $C_{P V F}$ |  |  |  |  | 0.961 |  |  |  |  |
| $C_{P V A}$ |  |  |  |  | 0.856 |  |  |  |  |
| $C_{W}$ |  |  |  |  | 0.827 |  |  |  |  |
| $C_{W F}$ |  |  |  |  | 0.817 |  |  |  |  |
| $C_{\text {W/A }}$ |  |  |  |  | 0.838 |  |  |  |  |
| $C_{I T}$ |  |  |  |  | 0.711 |  |  |  |  |
| $L C B, \% L B P$ from $\varnothing$ |  |  |  |  | 1.5F |  |  |  |  |

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Table 37 - Principal Particulars of 0.80 Block Coefficient Models

| Model Number | 4214 | 4263 | 4261 | 4248 | 4260 | 4249 | 4251 | 4262 | 4250 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $L / B$ | 6.50 | 6.5 | 6.5 | 5.5 | 5.5 | 5.5 | 7.5 | 7.5 | 7.5 |
| $B / H$ | 2.50 | 3.0 | 3.5 | 2.5 | 3.0 | 3.5 | 2.5 | 3.0 | 3.5 |
| $B_{1}, \mathrm{ft}$ | 61.54 | 61.54 | 61.54 | 72.73 | 72.73 | 72.73 | 53.33 | 53.33 | 53.33 |
| $H_{0} \mathrm{ft}$ | 24.59 | 20.51 | 17.58 | 29.09 | 24.24 | 20.78 | 21.33 | 17.78 | 15.24 |
| $\triangle$ tons | 13859 | 11547 | 9898 | 19356 | 16129 | 13827 | 10407 | 8675 | 7436 |
| $1 / 2 \alpha_{E}$, deg | 43,0 | 43.0 | 43.0 | 47.8 | 47.8 | 47.8 | 38.9 | 38.9 | 38.9 |
| $L / \nabla^{1 / 3}$ | 5.092 | 5.411 | 5.696 | 4.555 | 4.841 | 5.096 | 5.602 | 5.9542 | 6.266 |
| $\Delta /(L / 100)^{3}$ | 216.5 | 180.4 | 154.6 | 302.4 | 252.0 | 216.0 | 162.6 | 135.5 | 116.2 |
| WS, sq ft | 37200 | 34316 | 32149 | 44010 | 40512 | 38103 | 32230 | 29617 | 27868 |
| $S / \nabla^{2 / 3}$ | 6.028 | 6.280 | 6.521 | 5.706 | 5.934 | 6.184 | 6.322 | 6.559 | 6.839 |
| $L_{\text {WL }}, \mathrm{ft}$ |  | $\cdots$ | , | - | 406.7 |  |  |  |  |
| $L_{B P}, \mathrm{ft}$ |  |  |  |  | 400.0 |  |  |  |  |
| $L_{E} / L_{B P}$ |  |  |  |  | 0.290 |  |  |  |  |
| $L_{X} L_{3 P}$ |  |  |  |  | 0.300 |  |  |  |  |
| $L_{R} / L_{B P}$ |  |  |  |  | 0.410 |  |  |  |  |
| $C_{B}$ |  |  |  |  | 0.800 |  |  |  |  |
| $C_{X}$ |  |  |  |  | 0.994 |  |  |  |  |
| $C_{P}$ |  |  |  |  | 0.805 |  |  |  |  |
| $C_{P F}$ |  |  |  |  | 0.861 |  |  |  |  |
| $C_{P A}$ |  |  |  |  | 0.750 |  |  |  |  |
| $C_{P E}$ |  |  |  |  | 0.761 |  |  |  |  |
| $C_{P R}$ |  |  |  |  | 0.695 |  |  |  |  |
| $C_{P V}$ |  |  |  |  | 0.920 |  |  |  |  |
| $C_{P V F}$ |  |  | $\therefore$ |  |  |  |  |  |  |
| $C_{\text {PVA }}$ |  |  |  |  | 0.867 |  |  |  |  |
| $C_{\text {W }}$ |  |  |  |  | 0.871 |  |  |  |  |
| $C_{W F}$ |  |  |  |  | 0.881 |  |  |  |  |
| $C_{\text {WA }}$ |  |  |  |  | 0.860 |  |  |  |  |
| $C_{I T}$ |  |  |  |  | 0.776 |  |  |  |  |
| LCB, \% LBP from $\square^{\text {d }}$ |  |  |  |  | 2.57 |  |  |  |  |

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Table 38 - Propel lers U'sed on Series 60 Models

| Propeller <br> Number | D <br> $(f t)$ | P <br> $(f t)$ | P/D | MWR | EA/DA | BTF | Rake <br> (deg) | Number of <br> Blades |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 2452 | 27.66 | 30.88 | 1.116 | 0.237 | 0.503 | 0.047 | 8.78 | 4 |
| 2501 | 18.88 | 15.50 | 0.822 | 0.225 | 0.458 | 0.055 | 6.10 | 4 |
| 2502 | 20.00 | 23.81 | 1.190 | 0.203 | 0.415 | 0.042 | 15.00 | 4 |
| 2765 | 16.10 | 17.80 | 1.105 | 0.290 | 0.576 | 0.056 | 9.46 | 4 |
| 2813 | 16.90 | 19.65 | 1.162 | 0.280 | 0.582 | 0.056 | 9.46 | 4 |
| 2815 | 17.50 | 19.35 | 1.106 | 0.270 | 0.550 | 0.049 | 4.00 | 4 |
| 2828 | 26.82 | 27.08 | 1.010 | 0.220 | 0.456 | 0.042 | 5.014 | 4 |
| 2837 | 14.13 | 10.60 | 0.750 | 0.245 | 0.513 | 0.042 | 7.67 | 4 |
| 2944 | 22.00 | 18.70 | 0.850 | 0.279 | 0.588 | 0.047 | 4.761 | 4 |
| 3156 | 29.14 | 29.58 | 1.015 | 0.250 | 0.531 | 0.050 | 7.765 | 4 |
| 3375 | 21.36 | 20.30 | 0.950 | 0.255 | 0.536 | 0.045 | 6.00 | 4 |
| 3376 | 24.00 | 26.40 | 1.100 | 0.237 | 0.500 | 0.045 | 6.00 | 4 |
| 3377 | 25.82 | 23.75 | 0.920 | 0.213 | 0.450 | 0.045 | 6.00 | 4 |
| 3378 | 22.40 | 24.08 | 1.075 | 0.261 | 0.550 | 0.045 | 6.00 | 4 |
| 3379 | 24.89 | 25.51 | 1.025 | 0.225 | 0.475 | 0.045 | 6.00 | 4 |
| 3380 | 23.20 | 25.52 | 1.100 | 0.235 | 0.525 | 0.045 | 6.00 | 4 |
| 3446 | 24.60 | 25.07 | 1.019 | 0.204 | 0.428 | 0.048 | 4.35 | 4 |
| 3471 | 26.06 | 29.94 | 1.149 | 0.250 | 0.512 | 0.052 | 7.50 | 4 |
| 3488 | 17.52 | 18.33 | 1.046 | 0.229 | 0.477 | 0.048 | 6.33 | 4 |
| 3563 | 30.55 | 29.02 | 0.050 | 0.210 | 0.446 | 0.045 | 6.00 | 4 |
| 3564 | 15.00 | 14.25 | 0.950 | 0.261 | 0.554 | 0.045 | 6.00 | 4 |
| 3565 | 21.00 | 21.00 | 1.000 | 0.239 | 0.506 | 0.046 | 6.00 | 4 |
| 3645 | 19.25 | 19.25 | 1.000 | 0.259 | 0.549 | 0.045 | 6.00 | 4 |
| 3646 | 14.54 | 14.54 | 1.000 | 0.259 | 0.550 | 0.045 | 6.00 | 4 |
| 3647 | 15.48 | 12.77 | 0.825 | 0.258 | 0.548 | 0.045 | 6.00 | 4 |
| 3648 | 18.06 | 14.90 | 0.825 | 0.258 | 0.548 | 0.045 | 6.00 | 4 |

## CHAPTERIX

## DESIGN CHARTS

The resistance and propulsion results for ships exactly similar to each of the 45 models of the geometrical series have been given in Chapter VIII. This form of presentation is not very useful to the designer, however, since he will almost always have to do some interpolation to fit his particular problem of the moment. A great deal of thought was given to the most desirable method of plotting these data so as to make them of the greatest value and yet simple to use. It was finaily decided to present the resistance information in the form of contour charts similar to those made so familiar by Taylor.

To reduce the data to this form presented a formidable proposition in fairing since there were 45 models in all and contours had to be drawn for a number of values of $\frac{V}{\sqrt{L_{W L}}}$ and (1). To expedite this phase of the work, the fairing was done on the UNIVAC computer in the Applied Mathematics Laboratory at Taylor Model Basin. The process is described in detail in Appendix C. The contours are given in Appendix B.

The first set shows contours of residuary resistance in pounds per ton of displacement $\left(\frac{\boldsymbol{R}_{\boldsymbol{R}}}{\Delta}\right)$, each individual chart showing, for given values of $\frac{B}{H}$ and $\frac{V}{\sqrt{L_{W L}}}$, the variation of $\frac{R_{R}}{\Delta}$ with block coefficient and $\frac{L}{B}$ ratio.

The second set is of the same kind but shows contours of (C) for a ship with $L B P$ of 400 ft against $C_{B}$ and $\frac{L}{B}$ for chosen values of $\mathbb{K}$ and $\frac{B}{H}$.

The third set gives contours of wake and thrust deduction fractions plotted against $C_{B}$ and $\frac{L}{B}$ for chosen values of $\frac{V}{\sqrt{L_{W}}}$ and $\frac{B}{H}$.

Both the $\frac{R_{R}}{\Delta}$ and the (C) values have been derived on the basis of the Froude assumption that the total resistance can be divided into two parts, the skin friction of an "equivalent plank', and the residuary resistance, the latter obeying Froude's Law of Comparison. In the present work, the skin friction resistance for both model and ship has been calculated in accordance with the ATTC 1947 line, the appropriate values of $C_{F}$ and Reynolds number being taken from previous Model Basin reports. ${ }^{59,60}$

In using the first set of contours, the value of $\frac{R_{R}}{\Delta}$ is first determined for the desired speed-length ratio. To it must be added the frictional resistance, which can be expressed in the form $\frac{R_{F}}{S}$, where $S$ is the wetted surface. The total resistance is then

$$
R=\frac{R_{R}}{\Delta} \cdot \Delta+\frac{R_{F}}{S} \cdot S
$$

To simplify the use of the contours, a nomograph is given in Appendix B from which the frictional resistance per square foot of wetted surface $\frac{R_{F}}{S}$ can be determined. Contours are also given for estimating the wetted surface for any combination of design parameters.

The (C) - (K) contours are for the total resistance, residuary plus frictional, and the (C) values are those appropriate to a ship of $400 \mathrm{ft} L B P$. For any other length, a correction must be made which depends upon the actual length and the wetted surface coefficient $\frac{S}{\nabla^{2 / 3}}$.

For those who wish to compare the Series 60 (C) values with those of other models in which the Froude values of $O_{m}$ and $O_{s}$ have been used in the analysis, a rapid method of making the conversion has been given by Gertler. ${ }^{47}$ See also Appendix D.

In the (C) charts and the nomograph for determining $\frac{R_{F}}{S}$, an allowance for ship correlation amounting to +0.0004 has been made in accordance with the ATTC 1947 recommendation. Calculation forms for finding the (C) 400 ft and ehp values for any single-screw merchant ship having lines derived from the Series 60 contours and proportions within the range covered by the Series are also given in Appendix B. Methods are also described there for calculsting (C) for a ship of other than $400-\mathrm{ft}$ length and for including a ship correlation allowance $C_{A}$ having some value different from +0.0004 . Although the calculation forms are largely self-explanatory, a numerical example is worked out in Appendix $D$ to clear up any difficulties still remaining after reading the text.

As stated on page V-14 the ITTC agreed in 1957 to the use of a new "model-ship correlation line" in future published work. However, pending some agreement on a standard ship correlation allowance to be associated with the new line, it has not yet come into general use. The ITTC and ATTC lines differ both over the model and ship ranges of Reynolds number, and so affect the division of the model resistance into its "frictional" and "residuary" components, as well as the yalues of the corresponding ones for the ship. It is thus not merely a question of using different values of $R_{F}$; all the values of residuary resistance $\frac{\mid R_{R}}{\Delta}$ will be different also. Some notes and an additional nomograph are given in Appendices D and E for readers who may wish to make estimates using the ITTC line.

## CHAPTER X

## EFFECT OF VARIATIONS IN PROPELLER DIAMETER AND SHIP DRAFT AND TRIM

A propeller diameter equal to 0.70 of the designed load draft was adopted as a standard in the $L C B$ and geometrical variation series. Although this is fairly representative of average practice, there will be many occasions on which a different diameter will be necessary because of the design of machinery used or for other reasons. In order to give some guidance on this matter, each of the five parent models of Series 60 was run with additional propellers having diameters smaller and larger than the standard.

Also, the main test program covered the models only at the full load draft and level trim. To get some information on the performance at other displacements and trims, additional experiments were made on three of the parent models, those with $C_{B}$ of $0.60,0.70$, and 0.80 .

The stern arrangement was identical with that already described in Chapter VII and shown in Figure 36. The vertical dimensions are given there as functions of the designed draft or propeller diameter, and all longitudinal dimensions are given as functions of $L B P$. The propeller position is so defined that the generating line at 0.70 radius is 0.94 percent of the $L B P$ forward of the after perpendicular. The stern details are therefore defined completely regardless of the selection of design draft or propeller diameter, so that Figure 36 defines the arrangement for all the models. The clearances were rather larger than normal practice at the time, but this was considered desirable in view of the ever-increasing horsepower of singlescrew ships, and their use has been justified by later developments.

One method of achieving larger clearances cr, alternatively, of using a larger diameter propeller without sacrificing clearance is to fit a semi-balanced rudder and no rudder sthoe. This arrangement was fitted to the MARINER ships, and has become known as a "clearwater stern," which is now used on many seagoing ships. In the course of the propulsion tests, the opportunity was taken to run the $0.60 C_{B}$ model with such a stern arrangement for comparison with the normal streamlined rudder results.

The standard propellers for the parent models had a diameter equal to 0.7 of the draft and have already been described in Chapter VII. For the experiments with larger and smaller diameters, propellers as similar as possible to the Troost type were selected from stock. The selection was made on a basis of general similarity, and the actual diameters of the propellers departed somewhat from the desired values.

The selection of propeller characteristics was based on the assumption that diameter was fixed and revolutions could be chosen to obtain maximum efficiency. The values of expanded-area ratio were selected on the basis of current design practice and checked for suitability as to cavitation by Lerb's data. ${ }^{49}$

Table 39 - Particulars of $600-$ Ft Ships Corresponding to Series 60 Models

| $\begin{aligned} & C_{B} \\ & L B P, \mathrm{ft} \\ & B, \mathrm{tt} \end{aligned}$ | $\begin{gathered} 0.60 \\ 600.0 \\ 80.0 \end{gathered}$ |  |  | $\begin{gathered} 0.65 \\ 600.0 \\ 82.76 \end{gathered}$ |  |  | $\begin{gathered} 0.70 \\ 600,0 \\ 85.71 \end{gathered}$ |  |  | $\begin{gathered} 0.75 \\ 600.0 \\ 88.89 \end{gathered}$ |  |  |  | $\begin{gathered} 0.80 \\ 600.0 \\ 92.31 \end{gathered}$ |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $H, \mathrm{ft}$ $\Delta$, tons | 32.0 26349 | $\begin{aligned} & 26.5^{\circ *} \\ & 21080 \end{aligned}$ | $\begin{array}{l\|l} 20.6 \\ 15810 \end{array}$ | $\begin{array}{\|c} 33.14 \\ 30547 \end{array}$ | $\cdots$ | $\cdots$ | $\begin{array}{\|c\|c} 34.29 \\ 35289 \end{array}$ | $\begin{gathered} 28,000 \\ 28230 \end{gathered}$ | $\begin{gathered} 21.6^{\dagger} \\ 21170 \end{gathered}$ | $\begin{aligned} & 35.55 \\ & 40662 \end{aligned}$ | $\cdots$ |  | $\ldots$ | $\begin{array}{\|l\|} \hline 36.93 \\ \hline 46774 \end{array}$ | $\begin{aligned} & 30.0^{\circ *} \\ & 37420 \end{aligned}$ | $22.8{ }^{\dagger}$ 28060 |  |
| $\frac{-}{B}$ | 7.5 |  |  | 1.25 |  |  | 7.0 |  |  | 6.75 |  |  |  | 6.50 |  |  |  |
| $\frac{B}{H}$ | 2.50 | 3.02 | 3.88 | 2.50 | $\cdots$ | $\cdots$ | 2.50 | 3.06 | 3.97 | 2.50 | $\cdots$ | $\cdots$ | $\ldots$ | 2.50 | 3.08 | 4.05 |  |
| $L$ | 0.515 | -..- | $\cdots$ | 0.505 | $\cdots$ | .... | 0.495 | $\cdots$ | $\cdots$ | 0.485 | $\cdots$ | -... | $\cdots$ | 0.475 | $\cdots$ | .... |  |
| Propeller Number | 2422 | 3378 | 3375 | 2852 | 3380 | 3375 | 2852 | 3376 | 2966 | 2828 | 3379 | 3066 | $3648^{4}$ | 1356 | 3371 | 2944 | $3645^{\text {A }}$ |
| D, ft | 25.62 | 22.40 | 21.37 | 26.40 | 23.20 | 21.37 | 26.40 | 24.00 | 22.00 | 26.83 | 24.89 | 23.00 | 18.06 | 27.00 | 25.82 | 22.00 | 19.25 |
| $P$, ft | 25.62 | 24.08 | 20.30 | 26.61 | 25.52 | 20.30 | 26.61 | 26.40 | 20.75 | 28.23 | 25.51 | 22.24 | 14.90 | 24.52 | 23.75 | 18.70 | 19.25 |
| P/D | 1.00 | 1.075 | 0.95 | 1.008 | 1.100 | 0.95 | 1.008 | 1.100 | 0.943 | 1.052 | 1.025 | 0.967 | 0.825 | 0.908 | 0.929 | 0.850 | 1.000 |
| bar | 0.456 | 0.550 | 0.536 | 0.454 | 0.525 | 0.537 | 0.454 | 0.500 | 0.519 | 0.456 | 0.475 | 0.515 | 0.548 | 0.448 | 0.450 | 0.583 | 0.549 |
| BTF | 0.04 | 0.045 | 0.045 | 0.047 | 0.045 | 0.045 | 0.047 | 0.045 | 0.056 | 0.042 | 0.045 | 0.055 | 0.045 | 0.044 | 0.045 | 0.047 | 0.045 |
| Rake, deg | 6.5 | 6.0 | 6.0 | 4.76 | 6.0 | 6.0 | 4.76 | 6.0 | 7.71 | 5.0 | 6.0 | 5.38 | 6.00 | 3.75 | 6.95 | 4.76 | 6.00 |
| Number of Blades | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Blade ares saft | 235 | 216 | 192 | 248 | 222 | 192 | 248. | 226 | 197 | 258 | 231 | 214 | 140 | 257 | 238 | 222 | 160 |
|  |  | rod from $\begin{aligned} \operatorname{ter} n & =1 p \\ \operatorname{ten} n & =2 . \end{aligned}$ | forward p reent LB percent | rpendia <br> EP |  | $\begin{aligned} & \text { \& Prev } \\ & \Delta \text { Prev } \end{aligned}$ | ously u <br> ously us | $\begin{aligned} & \text { don Mode } \\ & \text { d on Mode } \end{aligned}$ | $\begin{gathered} 4278 \\ \leq 4265, \end{gathered}$ |  |  |  |  |  |  |  |  |

The details of the propellers and hulls referred to a ship length of $600 \mathrm{ft} L B P$ are shown in Table 39. In fitting the different diameter propellers, the shaft centerline was altered vertically to maincain the same vertical position of the blade tips at their lowest point in the disk, and so also the same minimum clearance between blade tips and the rudder shoe. This was considered to be the more practical approach rather than fitting all propellers to the same shaft elevation. In the latter case, the hull lines would have to te adapted to the largest propeller, with excessive clearances for the smaller ones, and with these any advantage in resistance which might result from a lower and longer cruiser stern would be lost. The end lines from Station 18 aft were modified to suit the different apertures, and the rudder area was kept constant by narrowing the rudders associated with the larger diameter propellers.

The stern lines and aperture arrangements are shown in Figures 41 through 45, and the čurves of power, wake, thrust deduction and other data in Figures 46 through 50. These figures all apply to ships of $600 \mathrm{ft} L B P$, as in the case of Chapters VII and VIII. The extrapolation used was the ATTC 1947 line, with a ship correlation allowance of +0.0004 . During these tests, which chronologically were run before the $L C B$ and geometrical variation series, turbulence was stimulated by studs and no bilge keels were fitted. The propulsion
(Text continued on page $X-11$.)


Figure 41 - Stern Lines for Propeller Diameter.Variations, 0.60 Block Parent (Model 4210)


Figure 42 - Stern Lines for Propeller Diameter Variations, 0.65 Block Parent (Model 4211)


Figure 43 - Stern Lines for Propeller Diameter Variations, 0.70 Block Parent (Model 4212)


Figure 44 - Stern Lines for Propeller Diameter Variations, 0.75 Block Parent (Model 4213)


Figure 45 - Stern Lines for Propeller Diameter Variations, 0.80 Block Parent (Model 4214)


Figure 46 - Power, RPM, and Coefficient Curves for 0.60 Block Parent, at Even Keel and Designed Displacement-Model 4210


Figure 47 - Power, RPM, and Coefficient Curves for 0.65 Block Parent, at Even Keel and Designed Displacement-Model 4211


Figure 48 - Power, RPM, and Coefficient Curves for 0.70 Block Parent, at Even Keel and Designed Displacement-Model 4212


Figure 49 - Power, RPM, and Coefficient Curves for 0.75 Block Parent, at Even Keel and Designed Displacement-Model 4213


Figure 50 - Power, RPM, and Coefficient Curves for 0.80 Block Parent, at Even Keel and Designed Displacement-Model 4214
tests on the parent models with the propellers of standard diameter ( $\Rightarrow 0.7 \mathrm{H}$ ) were run over a complete speed range, and those with the larger and smaller diameters were made only from speeds 10 percent below the service speed to 10 percent above the trial speed.

The three parent models of $0.60,0.70$, and $0.80 C_{B}$ were run at two lighter conditions, with the standard propellers of diameter equal to 0.7 H only. The conditions chosen were 60 and 80 percent of the load displacement. With the models in the lighter of these conditions, the propellers were just submerged at a speed about 10 percent below the service speed; this was considered essential if reliable wake data were to be obtained. In addition to tests on even keel, the models were also run at 80 percent of load displacement with a trim of 1 percent of the $L B P$ by the stern and at 60 percent of load displacement with a trim of 2.5 percent by the stern. These were chosen after reference to much data in the records of the Maritime Administration. The results of the propulsion tests in these conditions are shown in Figures 51 through 53.

Figure 54 shows the variation with diameter in the values of the propulsive coefficient and its various components for the five parent models. The trial and service speeds used throughout the presentation of these propulsion experiments are those derived on the Alexander basis given in Equation (1), page V-14. The wake fraction shown is the Taylor wake fraction calculated on the basis of thrust identity in open and behind the model. Having obtained actual wake fractions from these model experiments, estimates were made from the Troost design charts for Troost-type propellers for all the different conditions in which stock propellers had been used. These showed that any increase in propeller efficiency which would result from such a change was quite small-on the average less that 0.5 percent, the maximum being 1.1 percent.

Figure 55 shows the propulsive efficiency factors plotted against block coefficient. Figure 55b for the standard propellers represents actual test data. The results given in Figures 55a and 55c are for the smaller and larger diameter propellers, respectively, modified to suit the variation of diameter with block coefficient shown in Figure 56 .

Similar curves for the 80 - and 60 -percent displacement conditions are shown in Figure 57 . In the 60 -percent condition for the $0.60 C_{B}$ model, even keel, there was some indication that air was being drawn into the propeller, and it is significant that the wake curve for this model appears to be inconsistent with the other data.

The principal reasons for running the experiments described in this section were to compare the propulsive performance of the parents with existing modern designs of ships and to give the practicing naval architect guidance on the general effects on propulsive efficiency of changes in propeller diameter, in ship displacement, and in trim.

As to the first of these, comparisons were made between models of the SCHUYLER OTIS BLAND and PENNSYLVANIA and their Series 60 counterparts. The corresponding pairs of models were run under as nearly similar conditions as possible. Thus the Series 60 sterns were modified to give the same aperture and rudder arrangements as in the actual


Figure 51 - Power, RPM, and Coefficient Curves for 0.00 Block Parent at
Light Displacement Conditions

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Figure 52 - Power, RPM, and Coefficient Curves for 0.70 Block Parent at Light Displacement Conditions


Figure 53 - Power, RPM, and Coefficient Curves for 0.80 Block Parent at Light Dis placement Conditions


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Figure 55a-For Small Diameter Figure 55b-For Normal Diameter Figure 55c - For Large Diameter
Figure 55 - Propulsive Efficiency Factors versus Block Coefficient

TABLE 40
Comparison of Series 60 Propulsion Results with Actual Ships

| Model | $4468-3$ | 4057 | $4484-1$ | $4133-2$ |
| :--- | :---: | :---: | :---: | :---: |
| Representing | Series 60 <br> Equivalent of <br> PENNSYLVANIA | PENNSYLVANIA <br> as Built | Series 60 <br> Equivalent of <br> SCHUYLER 0TIS BLAND | SCHUYLER <br> OTIS BLAND <br> as Built |
| $V$, knots | 15.37 | 15.37 | 18.20 | 18.20 |
| shp | 9200 | 8850 | 8750 | 8900 |
| ehp/shp | 0.739 | 0.750 | 0.784 | 0.760 |
| $e_{h}$ | 1.231 | 1.199 | 1.092 | 1.076 |
| $e_{p}$ | 0.603 | 0.616 | 0.690 | 0.696 |
| $e_{r r}$ | 0.995 | 1.016 | 1.040 | 1.015 |



Figure 56 - Variation of Diameter with $C_{B}$
ships, and the model propellers used were made to the designs fitted to the ships. The results given in Table 40 show that the performance of the Series 60 designs was very comparable with that of the two ships.

The designer can find the wake and thrust deduction fractions for any ship within the limits of the series and fitted with the standard diameter of propeller from the contours in Appendix B. The results given in this chapter will enable him to make estimates of the probable change in these and other factors when it is necessary or desirable to use larger or smaller propellers, and also for conditions of lighter displacement with or without trim. It is not intended here to attempt to draw any overall conclusions regarding the variation of the propulsive factors. The data given can be applied to individual designs or used by the naval architect for his own research purposes to set up his own methods of estimating such coefficients for future use. Much additional information is included in Reference 61 for those who wish to study this part of the work in more detail.


Figure 57 - Propulsive Efficiency Factors at Light Dis placements

One other comparison made in the course of these tests is of general interest. A number of modern single-screw ships, including the MARINER class, have been fitted with a semi-balanced rudder and no rudder shoe. This arrangement enables a larger diameter propeller to be fitted without sacrifice of clearances or, conversely, larger clearances on the same diameter, both very desirable features in view of the large powers now being transmitted through a single shaft and the accompanying risk of propeller-excited vibration. In the endeavor to obtain such clearances with the normal single-screw aperture and rudder, the rudder shoe has become longer and more vulnerable, and a number of fractures have occurred, so that on this score also the new artangement, generally known as a "clearwater stern," has something to offer.

The stern arrangements of the Series 60 parent of $0.60 C_{B}$ with the normal and clearwater sterns are shown in Figure 58, and the results of the model propulsion tests in Figure 59 and Table 41.

At a service speed of 22 knots, there is no noticeable difference in propeller performance.
The shp is higher for the conventional stern only because of its higher ehp, and this persists throughout the speed range.

TABLE 41
Comparison of Clearwater and Conventional Sterns
on $0.60 C_{B}$ Model 4210 of Series 60
(Principal dimensions: $600 \mathrm{ft} \times 80 \mathrm{ft} \times 32 \mathrm{ft} \times 26,349$ tons)

| Stern Arrangement | Normal | Clearwater |
| :--- | :--- | :--- |
| Propeller Number | 2422 | 1967 |
| $D, \mathrm{ft}$ | 25.62 | 25.33 |
| $P, \mathrm{ft}$ | 25.62 | 26.67 |
| BAR | 0.456 | 0.464 |
| Rake, deg | 6.5 | 6.0 |
| Number of blades | 4 | 4 |
| $V$, knots | 22.04 | 22.04 |
| shp | 23,250 | 22,530 |
| ehp $/$ shp | 0.77 | 0.77 |
| $e_{h}$ | 1.073 | 1.089 |
| $e_{p}$ | 0.709 | 0.709 |
| $e_{r r}$ | 1.012 | 0.997 |


Figure 58 - Stern Arrangements for 0.60 Block Parent (Model 4210)


Figure 59 - Power, RPM, and Coefficient Curves of Clearwater and Conventional Sterns for 0.60 Block Parent-Model 4210

## CHAPTER XI

## EFFECT OF VARIATION IN AFTERBODY SHAPE UPON WAKE DISTRIBUTION AND POWER

The original conception of Series 60 was a'set of related basic hull forms which, in terms of fullness and proportions, would cover the general field of single-screw merchant ships. The principal purpose was to indicate the trends which might be expected in resistance and power by changes in these basic parameters, but it was also realized that the results were likely to be used for making power estimates for new designs. It was therefore necessary that the resistance and power characteristics of the series models should be of reasonably good standard, and an effort was made to ensure this by the preliminary work with Series 57 and the later comparisons with models of existing ships of accepted good performance. ${ }^{62,63}$

On the other hand, any effort to explore all the possible changes of shape in waterlines and sections before embarking on the series proper would have been prohibitive both in time and money. One of the objectives in setting up the Series $\mathbf{6} 0$ design contours has always been the hope that they would be used as a point of departure in future research so that there would always be a link with new work, and this hope has been in a large meas ure fulfilled.

The variation of hull shape as exemplified by changes in waterline and section shape is one such research which could well begin from Series 60 as a basis, and a start on this phase has been made at Taylor Model Basin. Since a great deal of interest has been generated in recent years in the effects of afterbody shape upon the wake distribution, propellerexcited forces on the hull, and horsepower, the first experiments covered the measurement of wake pattern behind the five parent models, together with the effect upon wake pattern and power of two additional models of 0.70 block coefficient having, respectively, more $U$ - and more $V$-shaped afterbody sections than the parent. This work was sponsored by the Bureau of Ships, the Maritime Administration and SNAME, and carried out at the Taylor Model Basin. The results have been given in detail in Reference 64.

The parent 0.70 block coefficient model was No. 4280 , made in wood, and identical as regards lines with the parent wax model No. 4221. Two additional wooden models, No. 4281 and No. 4282 , were made with the same forebody, identical with that of No. 4280 , but with more U - and more V -Type stern sections, respectively. The section area curve, load waterline (WL No. 1.00), deck waterline (WL No. 1.50), and stern profile remained unchanged. As a result, all coefficients of form and dimensions except those related to wetted surface and section shape are the same for all three models (Table 42). A comparison between the after end sections is shown in Figure 60. Table 42 also includes values of a coefficient $r$ to describe the slope of Station 18 at the level of the propeller shaft. This coefficient was first proposed by Harvald ${ }^{65}$ and is measured as shown in Figure 61. Average values of $\boldsymbol{T}$

Table 42 - Principal Particulars of Models

|  | 400 -ft ship | 600-ft ship |
| :---: | :---: | :---: |
| L wL, ft | 406.7 | 610.0 |
| $L_{\text {Br }}$, ft | 400.0 | 600.0 |
| $B, \mathrm{ft}$ | 57.14 | 85.71 |
| H, ft | 22.86 | 34.29 |
| $\Delta$, tons. | 10456 | 35289 |
| 1/3OE, deg | 11.6 | 11.6 |
| *WS, sq ft (Model 4280) | 31859 | 71683 |
| *WS, sq ft, (Model 4281) | 32008 | 72018 |
| *WS, sq ft, (Model 4282) | 31759 | 71458 |


|  |  | Hull Coofflcionts |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| L/B............... 7.00 |  |  |  |  |  |
| $B / H$ | 2.50 |  |  |  |  |
| L/ ${ }^{1 / 3}$ | 5.593 | $C_{\text {B }}$ | 0.700 | $C_{\text {Pv }}$. | 0.890 |
| $\Delta /(L / 100)^{2}$ | 163.4 | $C^{\text {x }}$ | 0.986 | $C_{\text {PV }}$ | 0.950 |
| $S / \nabla^{2 / 3}(4280)$. | 6.230 | $C_{P}$ | 0.710 | $C_{\text {PVA }}$ | 0.846 |
| $S / \nabla^{2 / 3}$ (4281) | 6.260 |  | 0.700 | Cw | 0.787 |
| $S / \nabla^{2 / 3}$ (4282) | 6.210 | $C_{\text {P }}$ | 0.721 | Cwr. | 0.734 |
| $L_{\text {b }} / L_{\text {br }}$ | 0.420 | $C_{\text {F }}$ | 0.642 | $C_{\text {wa }}$ | 0.841 |
| $L_{x} / L_{B P}$ | 0.119 |  | 0.698 |  | 0.651 |
| $L_{\mathrm{R}} / L_{\mathrm{BP}} \ldots$ | 0.461 |  | LBP fro | Q 0.55 A |  |

Section Coeffecient $\tau$
Series 60-Forms

| Parent form . . . . . . . . Model 4280: | $T=0.359$ |
| :---: | :---: |
| U-shaped form . . . . . . Model 4281: | $\tau=0.179$ |
| V-shaped form . . . . . . Model 4282: | $\tau=0.543$ |
| Average Values |  |
| Moderate stern sections. | $=0.500$ |
| Extreme U-shaped stern sections. | $=0.20$ |
| Extreme V-shaped stern sections. | $\tau=0.75$ |



Figure 60 - Comparison of Afterbody Lines of 0.70 Block Parent Stern Variations


Figure 61 - Definition of Section Shape Coefficient
from a number of existing designs are also given in Table 42, and these show that the Series 60 parent of $0.70 C_{B}$ is somewhat $U$ in character to start with, and the $V$-shaped variation is rather moderate in this respect. The models were fitted with rudder and propeller as previously described, the propeller used being TMB 3376 which was that fitted to the original $0.70 C_{B}$ parent, Model 4221. It represented a $24-\mathrm{ft}$ diameter propeller on a $600-\mathrm{ft}$ ship (or 16 ft on a $400-\mathrm{ft}$ ship).

Models 4280,4281 , and 4282 were all made in wood, had an $L B P$ of 20 ft , and a smooth enamel finish. They were fitted with a trip wire and run in the deep-water basin which is 51 ft wide and 22 ft deep. Experiments were made at the designed displacement, level trim, and at 60 percent of this displacement and a trim of 2.5 percent of $L B P$ by the stern.

The results of the resistance and propulsion tests are given in Tables 43 through 48 and in Figures 62 through 70.

The change in resistance, as shown in Figures 62 to 65 , is relatively small, the $U$ form being about 2 percent worse and the $V$-form 3 percent better than the parent at the Troost service speed. On the other hand, the $U$-form favors the propulsive efficiency, but this is insufficient to offset the superior resistance qualities of the V-stern, with the result that the latter has the lower dhp at all speeds in the full-load condition and over most of the speed range at 60 -percent displacement. These changes in resistance and propulsive efficiency are of the kind to be expected as a result of such stern changes. In general, the increase in propulsive efficiency with the U-stern is usually sufficient to more than offset the increase in resistance, although not in this particular case.

Velocity surveys were also made in the plane of the propeller for all five of the Series 60 parents and for the two stern variations of the $0.70 C_{B}$ model. This plane was normal to the propeller shaft (and to the baseline) and 0.94 percent of the $L B P$ forward of the after perpendicular. In accordance with the stern arrangement shown in Figure 36, it passed through the 0.7 radius point on the propeller generating line. The velocities were measured at 59 points over a rectangular grid extending from the baseline to a waterline at 0.85 of the load draft and on the port side from the center line out to a vertical line distant 0.425 of the load draft. They were all made at the full-load displacement and at the Troost, service speed, using a 5 -hole spherical pitot tube, which determines the velocity vector at each point (for details, see Reference 64).

Tiese velocities have been analysed into longitudinal (fore and aft), vertical and horizontal components $V_{\underline{x}}, V_{\underline{v}}$, and $\boldsymbol{V}_{\underline{h}}$, defined as shown in Figure 71. These can be converted to Taylor wake fractions
and

$$
\begin{aligned}
& w_{x}=1-\frac{V_{x}}{V} 100 \\
& w_{v}=1-\frac{V_{v}}{V} 100 \\
& w_{h}=1-\frac{V_{h}}{V} 100
\end{aligned}
$$

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Table 43 - Results of Resistance and Self-Propulsion Experiments for Parent Form-
Model 4280, 100-Percent Displacement

| $V / \sqrt{\text { Lit }}$ | $\mathrm{C}_{1} \times 10^{8}$ | (1) | (C) | $v / \sqrt{L_{V L}}$ | V | N | Eip | ${ }_{*}$ | $t$ | ${ }^{\text {cm }}$ | - | ${ }^{*}$ | EHP/SHP |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0.60 | 9.038 | 0.76 | 0.704 | 0.884 | 8.0 | 83.7 | 1917 | $0.80{ }^{\text {a }}$ | 0.907 | 1.180 | 0.618 | 0.07 | 0.702 |
| 0.85 | 8.781 | 0.818 | 0.688 | 0.884 | . 0 | 0.1 | 109 | 0.880 | 0.804 | 1.104 | 0.681 | 0.078 | 0.788 |
| 0.40 | 9.748 | 1.008 | 0.080 | 0.408 | 10.0 | 40.5 | 2188 | 0.828 | 0.1 e | 1.188 | 0.658 | 0.008 | 0.778 |
| 0.65 | 8.78 | 1.188 | 0.080 | 0.448 | 11.0 | 44.6 | 9788 | 0.880 | 0.197 | 1.181 | 0.657 | 1.004 | 0.778 |
| 0.50 | 9.718 | 1.958 | 0.574 | 0.484 | 18.0 | 48.4 | 300 | 0.818 | 0.14 | 1.177 | 0.080 | 1.004 | 0.760 |
| 0.85 | 8.784 | 1.384 | 0.681 | 0.894 | 18.0 | 58.7 | 4485 | 0.818 | 0.102 | 1.174 | 0.689 | 0.018 | 0.777 |
| 0.80 | 9.787 | 1.610 | 0.607 | 0.584 | 14.0 | 57.8 | 6908 | 0.810 | 0.120 | 1.174 | 0.488 | 0.018 | 0.778 |
| 0.85 | 8.840 | 1.888 | 0.710 | 0.607 | 18.0 | 01.5 | 7888 | 0.807 | 0.188 | 1.165 | 0.648 | 0.098 | 0.787 |
| 0.70 | 9.850 | 1.781 | 0.789 | 0.685 | 15.5 | 88.7 | 8913 | 0.808 | 0.105 | 1.160 | 0.681 | 0.688 | 0.788 |
| 0.75 | 8.000 | 1.887 | 0.747 | 0.648 | 16.0 | 66.1 | 9088 | 0.805 | 0.108 | 1.154 | 0.850 | 1.008 | 0.768 |
| 0.800 | 8.816 | 8.018 | 0.804 | 0.668 | 16.8 | 68.5 | 10100 | 0.805 | 0.109 | 1.151 | 0.68 | 1.004 | 0.761 |
| 0.896 | 8.808 | 2.076 | 0.898 | 0.688 | 17.9 | 70.7 | 11180 | 0.808 | 0.800 | 1.148 | 0.057 | 1.000 | 0.789 |
| 0.85 | 8.412 | 9.189 | 0.088 | 0.708 | 17.8 | 78.9 | 18890 | 0.808 | 0.200 | 1.148 | 0.658 | 1.000 | 0.758 |
| 0.875 | 8.889 | 8.208 | 0.920 | 0.788 | 18.0 | 75.8 | 13740 | 0.801 | 0.200 | 1.144 | 0.658 | 1.010 | 0.758 |
| 0.00 | 4.807 | 9.985 | 1.008 | 0.740 | 18.3 | 78.8 | 15850 | 0.800 | 0.900 | 1.148 | 0.058 | 1.011 | 0.788 |
| 6.088 | 6.111 | 2.387 | 1.277 | 0.788 | 10.0 | 81.2 | 17150 | 0.200 | 0.201 | 1.141 | 0.649 | 1.01\% | 0.750 |
| 0.050 | 6.028 | 9.890 | 1.500 | 0.700 | 10.5 | 84.0 | 19800 | 0.290 | 0.908 | 1.188 | 0.645 | 1.018 | 0.746 |
| 0.975 | 6.997 | 9.458 | 1.740 | 0.810 | 20.0 | 87.1 | 81380 | 0.298 | 0.208 | 1.185 | 0.849 | 1.016 | 0.740 |
| 1.000 | 7.857 | 2.618 | 1.884 | 0.880 | 20.5 | 90.4 | 23840 | 0.997 | 0.805 | 1.181 | 0.085 | 1.018 | 0.788 |
| 1.025 | 8.588 | 2.570 | 8.147 | 0.851 | 21.0 | 98.8 | 28800 | 0.996 | 0.207 | 1.188 | 0.628 | 1.018 | 0.780 |
| 1.050 | 0.088 | 8.648 | 8.87i | 0.871 | 81.5 | 98.0 | 31180 | 0.294 | 0.800 | 1.198 | 0.618 | 1.018 | 0.708 |
| 1.078 | 0.882 | 8.705 | 8.820 | 0.801 | 22.0 | 108.1 | 37530 | 0.898 | 0.208 | 1.120 | 0.602 | 1.084 | 0.681 |
| 1.10 | 9.814 | 2.768 | 8.389 | (All numbers are for ship of 600-ft LBP) |  |  |  |  |  |  |  |  |  |
| 1.125 | 0.200 | 2.881 | 8.999 |  |  |  |  |  |  |  |  |  |  |
| 1.150 | 8.891 | 2.894 | 2.247 |  |  |  |  |  |  |  |  |  |  |
| 1.178 | 8.78 | 8.957 | 8.187 |  |  |  |  |  |  |  |  |  |  |
| 1.80 | 8.794 | 8.010 | 8.180 |  |  |  |  |  |  |  |  |  |  |
| 1.895 | 8.788 | 8.088 | 8.197 |  |  |  |  |  |  |  |  |  |  |
| (All numbers are for shlp of 400-ft LBP) |  |  |  |  |  |  |  |  |  |  |  |  |  |

Table 44 - Results of Resistance and Self-Propulsion Experiments for U-Shaped FormModel 4281, 100-Percent Displacement

| $\mathrm{V} / \sqrt{L_{\text {wi }}}$ | $\mathrm{C}_{2} \times 10^{3}$ | (K) | (C) | $\mathrm{V} / \sqrt{L_{\text {wi }}}$ | V | N | SHP | ${ }^{\omega_{T}}$ | 4 | ${ }^{1}$ | ${ }^{\circ}$ | $\bullet$ | EHP/SEP |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0.80 | 8.888 | 0.755 | 0.780 | 0.884 | 8.0 | 82.1 | 1178 | 0.858 | 0.188 | 1.857 | 0.835 | 0.988 | 0.744 |
| 0.35 | 9.881 | 0.881 | 0.708 | 0.864 | 0.0 | 88.0 | 1578 | 0.367 | 0.190 | 1.280 | 0.631 | 0.987 | 0.797 |
| 0.40 | 2.788 | 1.008 | 0.690 | 0.405 | 10.0 | 80.8 | 2078 | 0.860 | 0.188 | 1.281 | 0.688 | 1.000 | 0.818 |
| 0.45 | 2.757 | 1.188 | 0.098 | 0.445 | 11.0 | 48.8 | 2608 | 0.351 | 0.185 | 1.258 | 0.845 | 1.015 | 0.888 |
| 0.50 | 8.734 | 1.958 | 0.688 | 0.488 | 18.0 | 47.8 | 8487 | 0.848 | 0.181 | 1.947 | 0.650 | 1.014 | 0.888 |
| 0.55 | 2.764 | 1.884 | 0.608 | 0.588 | 13.0 | 51.8 | 4488 | 0.848 | 0.178 | 1.851 | 0.649 | 1.011 | 0.881 |
| 0.60 | 8.885 | 1.510 | 0.718 | 0.586 | 14.0 | 58.0 | 5811 | 0.348 | 0.178 | 1.850 | 0.648 | 1.018 | 0.880 |
| 0.65 | 8.890 | 1.886 | 0.788 | 0.607 | 15.0 | 00.4 | 7078 | 0.848 | 0.181 | 1.847 | 0.644 | 1.019 | 0.810 |
| 0.70 | 8.955 | 1.761 | 0.748 | 0.088 | 15.5 | 03.8 | 7918 | 0.848 | 0.184 | 1.248 | 0.643 | 1.028 | 0.817 |
| 0.75 | 8.088 | 1.887 | 0.774 | 0.648 | 16.0 | 85.0 | 8809 | 0.848 | 0.187 | 1.887 | 0.648 | 1.088 | 0.815 |
| 0.80 | 8.281 | 8.018 | 0.894 | 0.668 | 18.5 | 07.4 | 0744 | 0.841 | 0.188 | 1.882 | 0.641 | 1.029 | 0.818 |
| 0.885 | 8.371 | 9.076 | 0.848 | 0.688 | 17.0 | 69.7 | 10700 | 0.841 | 0.188 | 1.230 | 0.640 | 1.030 | 0.811 |
| 0.850 | 8.478 | 9.189 | 0.878 | 0.708 | 17.6 | 78.1 | 11880 | 0.839 | 0.188 | 1.228 | 0.688 | 1.087 | 0.810 |
| 0.878 | 8.780 | 9.908 | 0.949 | 0.789 | 18.0 | 74.5 | 13220 | 0.888 | 0.188 | 1.227 | 0.685 | 1.086 | 0.807 |
| 0.800 | 4.887 | 8.286 | 1.097 | 0.749 | 18.5 | 77.1 | 14810 | 0.887 | 0.189 | 1.228 | 0.688 | 1.038 | 0.804 |
| 0.885 | 5.281 | 9.887 | 1.881 | 0.769 | 19.0 | 70.8 | 16540 | 0.886 | 0.180 | 1.281 | 0.628 | 1.048 | 0.800 |
| 0.950 | 6.158 | 8.890 | 1.548 | 0.790 | 19.5 | 82.5 | 18480 | 0.395 | 0.190 | 1.218 | 0.625 | 1.044 | 0.793 |
| 0.875 | 7.181 | 9.488 | 1.806 | 0.810 | 20.0 | 85.6 | 20880 | 0.884 | 0.191 | 1.215 | 0.620 | 1.048 | 0.788 |
| 1.000 | 8.017 | 9.616 | 2.018 | 0.880 | 20.5 | 88.7 | 22740 | 0.888 | 0.198 | 1.208 | 0.618 | 1.041 | 0.775 |
| 1.085 | 8.788 | 2.578 | 8.900 | 0.851 | 81.0 | 02.4 | 85010 | 0.880 | 0.195 | 1.201 | 0.600 | 1.046 | 0.765 |
| 1.080 | 2.148 | 9.048 | 9.801 | 0.871 | 21.5 | 08.8 | 80450 | 0.828 | 0.195 | 1.189 | 0.600 | 1.051 | 0.750 |
| 1.075 | 0.888 | 8.705 | 8.841 | 0.891 | 88.0 | 108.1 | 86700 | 0.826 | 0.185 | 1.184 | 0.588 | 1.045 | 0.784 |
| 1.100 | 1.887 | 9.788 | 9.844 | (All numbers are for shlp of 600-ft LBP) |  |  |  |  |  |  |  |  |  |
| 1.125 | 0.200 | 9.881 | 2.810 |  |  |  |  |  |  |  |  |  |  |
| 1.150 | 8.001 | 9.894 | 2.858 |  |  |  |  |  |  |  |  |  |  |
| 1.175 | 8.708 | 9.987 | 2.200 |  |  |  |  |  |  |  |  |  |  |
| 1.200 | 8.784 | 8.017 | 2.180 |  |  |  |  |  |  |  |  |  |  |
| 1.985 | 8.785 | 8.082 | 4.807 |  |  |  |  |  |  |  |  |  |  |
| (All numbers are for ship of 400 -1t LBP) |  |  |  |  |  |  |  |  |  |  |  |  |  |

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Table 45 - Results of Resistance and Self-Propulsion Experiments for V-Shaped FormModel 4282, 100-Percent Displacement

| $v / \sqrt{2 / 2}$ | $\mathrm{C}_{2} \times 10^{8}$ | (1) | (C) |
| :---: | :---: | :---: | :---: |
| 0.80 | 8.744 | 0.758 | 0.684 |
| 0.85 | 8.79 | 0.081 | 0.678 |
| 0.40 | 9.697 | 1.008 | 0.678 |
| 0.45 | 8.657 | 1.188 | 0.688 |
| 0.10 | 8.614 | 1.858 | 0.051 |
| 0.55 | 8.685 | 1.884 | 0.657 |
| 0.10 | 8.708 | 1.510 | 0.678 |
| 0.65 | 8.758 | 1.688 | 0.087 |
| 0.70 | 9.786 | 1.781 | 0.695 |
| 0.75 | 8.874 | 1.887 | 0.716 |
| 0.80 | . 8.118 | 8.018 | 0.777 |
| 0.885 | 8.208 | 9.078 | 0.798 |
| 0.850 | 8.818 | 8.188 | 0.685 |
| 0.875 | 8.508 | 8.808 | 0.895 |
| 0.600 | 4.187 | 2.265 | 1.088 |
| 0.085 | 4.049 | 2.887 | 1.888 |
| 0.050 | 5.878 | 2.800 | 1.404 |
| 0.075 | 0.851 | 8.458 | 1.707 |
| 1.000 | 7.087 | 9.616 | 1.918 |
| 1.035 | 8.478 | 8.579 | 2.111 |
| 1.050 | 0.00\% | 2.848 | 2.244 |
| 1.075 | . 2.808 | 9.705 | 2.298 |
| 1.100 | 0.181 | 2.768 | 9.888 |
| 1.185 | 1.04: | 8.881 | 8.858 |
| 1.150 | 6.831 | 2.894 | 8.800 |
| 1.175 | 6.647 | 9.887 | 8.154 |
| 1.800 | \$.558 | 8.014 | 2.181 |
| 1.995 | 0.578 | 8.009 | 2.188 |
| (All numbers are for ship of 400-ft LBP) |  |  |  |


| $V / \sqrt{1 / 2}$ | $V$ | N | SRP | $\boldsymbol{\omega}_{T}$ | $t$ | ${ }^{6}$ | $\bullet$ | ${ }^{*}$ | CHP/SHP |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0.884 | 8.0 | 88.7 | 1184 | 0.828 | 0.229 | 1.180 | 0.652 | 0.045 | 0.708 |
| 0.884 | 9.0 | 86.7 | 1500 | 0.884 | 0.228 | 1.150 | 0.648 | 1.001 | 0.752 |
| 0.408 | 10.0 | 40.5 | 2098 | 0.884 | 0.228 | 1.168 | 0.049 | 1.025 | 0.778 |
| 0.445 | 11.0 | 44.6 | 2691 | 0.820 | 0.222 | 1.144 | 0.660 | 1.082 | 0.778 |
| 0.488 | 12.0 | 48.6 | 3480 | 0.814 | 0.220 | 1.187 | 0.668 | 1.085 | 0.780 |
| 0.588 | 18.0 | 68.8 | 4475 | 0.815 | 0.219 | 1.140 | 0.602 | 1.029 | 0.717 |
| 0.680 | 14.0 | 67.1 | 5717 | 0.814 | 0.210 | 1.188 | 0.860 | 1.020 | 0.778 |
| 0.607 | 15.0 | 61.5 | 7175 | 0.811 | 0.220 | 1.182 | 0.660 | 1.025 | 0.768 |
| 0.628 | 15.8 | 88.7 | 7978 | 0.308 | 0.220 | 1.127 | 0.660 | 1.027 | 0.764 |
| 0.648 | 16.0 | 68.1 | 8871 | 0.308 | 0.221 | 1.122 | 0.680 | 1.028 | 0.760 |
| 0.688 | 16.5 | 68.5 | 8797 | 0.804 | 0.224 | 1.114 | 0.659 | 1.081 | 0.757 |
| 0.888 | 17.0 | 70.6 | 10800 | 0.804 | 0.227 | 1.111 | 0.858 | 1.083 | 0.755 |
| 0.708 | 17.5 | 78.2 | 12000 | 0.808 | 0.229 | 1.108 | 0.657 | 1.033 | 0.751 |
| 0.729 | 18.0 | 75.8 | 18800 | 0.301 | 0.282 | 1.090 | 0.058 | 1.040 | 0.747 |
| 0.749 | 18.8 | 78.8 | 14800 | 0.801 | 0.284 | 1.098 | 0.651 | 1.048 | 0.744 |
| 0.740 | 10.0 | 81.2 | 16820 | 0.802 | 0.251 | 1.093 | 0.648 | 1.044 | 0.739 |
| 0.780 | 19.5 | 84.0 | 18800 | 0.808 | 0.288 | 1.098 | 0.842 | 1.047 | 1.735 |
| 0.810 | 80.0 | 87.1 | 80900 | 0.804 | 0.280 | 1.008 | 0.685 | 1.050 | 0.729 |
| 0.880 | 80.5 | 00.4 | 28450 | 0.804 | 0.240 | 1.092 | 0.828 | 1.051 | 0.721 |
| 0.851 | 81.0 | 98.6 | 28580 | 0.804 | 0.240 | 1.092 | 0.620 | 1.050 | 0.711 |
| 0.871 | 81.5 | 18.0 | 80880 | 0.805 | 0.241 | 1.002 | 0.610 | 1.046 | 0.607 |
| 0.001 | 09.0 | 108.0 | 87040 | 0.805 | 0.241 | 1.092 | 0.597 | 1.048 | 0.680 |

Table 46 - Results of Resistance and Self-Propulsion Experiments for Parent FormModel 4280, 60-Percent Displacement, Trim $21 / 2$ Percent $L_{B P}$ by Stern

| $v / \sqrt{V_{1}}$ | $C_{8} \times 10^{3}$ | (K) | (C) |
| :---: | :---: | :---: | :---: |
| p. 30 | 2.880 | 0.829 | 0.794 |
| 0.35 | 2.837 | 0.959 | 0.781 |
| 0.40 | 2.810 | 1.08 | 0.774 |
| 0.45 | 2.795 | 1.238 | 0.768 |
| 0.50 | 2.774 | 1.370 | 0.764 |
| 0.55 | 2.809 | 1.507 | 0.773 |
| 0.60 | 2.857 | 1.044 | 0.780 |
| 0.65 | 2.902 | 1.781 | 0.798 |
| 0.70 | 2.967 | 1.818 | 0.817 |
| 0.75 | 3.029 | 2.055 | 0.834 |
| 0.80 | 8.089 | 2.192 | 0.850 |
| 0.825 | 3.158 | 2.890 | 0.888 |
| 0.850 | 8.272 | 8.889 | 0.001 |
| 0.875 | 8.492 | 2.397 | 0.981 |
| 0.000 | 8.847 | 8.468 | 1.059 |
| 0.925 | 4.201 | 2.584 | 1.178 |
| 0.050 | 4.681 | 9.608 | 1.889 |
| 0.075 | 5.121 | 8.078 | 1.410 |
| 1.060 | 5.588 | 9.740 | 1.585 |
| 1.025 | 5.858 | 9.808 | 1.611 |
| 1.080 | 5.685 | 9.877 | 1.648 |
| 1.075 | 6.088 | 2.045 | 1.669 |
| 1.100 | 6.100 | 8.014 | 1.679 |
| 1.185 | 6.157 | 8.082 | 1.605 |
| 1.150 | 6.910 | 8.151 | 1.710 |
| 1.175 | 6.800 | 8.210 | 1.784 |
| 1.200 | 6.450 | 8.288 | 1.77 |
| 1.895 | 6.668 | 8.858 | 1.88 |


| $V / \sqrt{V_{1}}$ | $V$ | $N$ | SHP | ${ }^{\mathbf{W}}$ T | $t$ | ${ }^{6}$ | ${ }^{\circ}$ | ${ }^{6}$ | EHP/SHP |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0.384 | 8.0 | 29.2 | 851 | 0.893 | 0.210 | 1.302 | 0.654 | 0.975 | 0.830 |
| 0.364 | 0.0 | 32.9 | 1201 | 0.393 | 0.207 | 1.808 | 0.653 | 0.970 | 0.835 |
| 0.405 | 10.0 | 38.6 | 1605 | 0.390 | 0.205 | 1.803 | 0.854 | 0.984 | 0.889 |
| 0.445 | 11.0 | 40.2 | 2061 | 0.384 | 0.204 | 1.292 | 0.681 | 0.984 | 0.840 |
| 0.488 | 12.0 | 44.2 | 2703 | 0.876 | 0.202 | 1.278 | 0.683 | 0.995 | 0.843 |
| 0.526 | 13.0 | 48.0 | 3438 | 0.366 | 0.200 | 1.262 | 0.669 | 0.998 | 0.843 |
| 0.586 | 14.0 | 52.2 | 4338 | 0.358 | 0.200 | 1.242 | 0.671 | 1.008 | 0.840 |
| 0.607 | 15.0 | 50.6 | 5462 | 0.347 | 0.201 | 1.224 | 0.672 | 1.011 | 0.832 |
| 0.628 | 15.5 | 58.8 | 6121 | 0.348 | 0.203 | 1.213 | 0.672 | 1.014 | 0.827 |
| 0.648 | 18.0 | 61.0 | 6839 | 0.339 | 0.204 | 1.204 | 0.672 | 1.014 | 0.821 |
| 0.668 | 18.5 | 63.2 | 7845 | 0.387 | 0.207 | 1.188 | 0.672 | 1.016 | $0: 817$ |
| 0.688 | 17.0 | 65.4 | 8478 | 0.384 | 0.210 | 1.188 | 0.672 | 1.017 | 0.811 |
| 0.708 | 17.5 | 67.6 | 9838 | 0.331 | 0.212 | 1.178 | 0.672 | 1.019 | 0.807 |
| 0.729 | 18.0 | 69.8 | 10250 | 0.828 | 0.218 | 1.171 | 0.672 | 1.023 | 0.805 |
| 0.749 | 18.5 | 72.1 | 11880 | 0.320 | 0.215 | 1.165 | 0.672 | 1.022 | 0.800 |
| 0.76\% | 18.0 | 74.5 | 18470 | 0.823 | 0.217 | 1.156 | 0.671 | 1.028 | 0.708 |
| 0.790 | 18.5 | 78.9 | 18880 | 0.821 | 0.220 | 1.149 | 0.669 | 1.029 | 0.791 |
| 0.810 | 80.0 | 79.2 | 15080 | 0.321 | 0.222 | 1.146 | 0.668 | 1.028 | 0.787 |
| 0.880 | 20.5 | 01.8 | 16850 | 0.820 | 0.228 | 1.148 | 0.667 | 1.027 | 0.788 |
| 0.851 | 81.0 | 84.7 | 18680 | 0.819 | 0.228 | 1.141 | 0.662 | 1.028 | 0.776 |
| 0.671 | 21.5 | 88.0 | 21890 | 0.318 | 0.222 | 1.141 | 0.654 | 1.029 | 0.768 |
| 0.801 | 92.0 | 02.2 | 94980 | 0.317 | 0.220 | 1.148 | 0.648 | 1.026 | 0.734 |
| 0.811 | 88.5 | 07.0 | 99740 | 0.814 | 0.216 | 1.148 | 0.688 | 1.080 | 0.737 |
| 0.088 | 88.0 | 102.4 | 35880 | 0.810 | 0.212 | 1.142 | 0.619 | 1.017 | 0.715 |

(All numbers are for ehip of 400-ft LBP)

Table 47 - Results of Resistance and Self-Propulsion Experiments for U-Shaped FormModel 4281, 60-Percent Dis placement, Trim $21 / 2$ Percent $L_{B P}$ by Stern

| $V / \sqrt{L_{V L}}$ | $C_{1} \times 10^{3}$ | (3) | (C) | $V / \sqrt{\text { VL }}$ | V | N | 848 | ${ }^{\boldsymbol{W}} \mathbf{T}$ | $t$ | - | $\bullet$ | ${ }^{60}$ | 2P/1迷 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0.80 | 8.889 | 0.888 | 0.898 | 0.884 | 1.0 | 84.1 | 088 | 0.884 | 0.150 | 1.407 | 0.088 | 0.058 | 0,000 |
| 0.85 | 8.088 | 0.858 | 0.607 | 0.84 | 0.0 | 31.7 | 1185 | 0.818 | 0.185 | 1.404 | 0.058 | 0.048 | 0.048 |
| 0.40 | 8.988 | 1.004 | 0.605 | 0.405 | 10.0 | 84.8 | 584 | 0.34 | 0.150 | 1.887 | 0.05 | 0.870 | 0.035 |
| 0.45 | 8.817 | 1.988 | 0.508 | 0.448 | 11.0 | 40.0 | 2048 | 0.884 | 0.104 | 1.875 | 0.035 | 0.088 | 0.098 |
| 0.50 | 9.804 | 1.870 | 0.707 | 0.484 | 18.0 | 48.4 | 2978 | 0.800 | 0.168 | 1.84 | 0.85 | 0.008 | 0.801 |
| 0.55 | 8.018 | 1.507 | 0.608 | 0.684 | 18.0 | 47.6 | 248 | 0.88 | 0.178 | 1.247 | 0.857 | 1.004 | 0.800 |
| 0.60 | 2.862 | 1.644 | 0.818 | 0.884 | 14.0 | 51.7 | 4895 | 0.888 | 0.177 | 1.818 | 0.088 | 1.017 | 0.880 |
| 0.65 | 8.008 | 1.781 | 0.69 | 0.607 | 18.0 | E.t | 5480 | 0.877 | 0.181 | 1.815 | 0.657 | 1.031 | 0.05 |
| 0.70 | 8.070 | 1.018 | 0.845 | 0.68 | 18.5 | 58.1 | cose | 0.874 | 0.184 | 1.206 | 0.457 | 1.088 | 0.878 |
| 0.75 | 8.148 | 8.085 | 0.85 | 0.848 | 14.0 | 00.8 | 678 | 0.870 | 0.187 | 1.980 | 0.856 | 1.080 | 0.878 |
| 0.80 | 8.818 | 8.188 | 0.884 | 0.48 | 18.5 | 68.4 | 7485 | 0.817 | 0.180 | 1.881 | 0.658 | 1.088 | 0.807 |
| 0.885 | 8.858 | 9.960 | 0.597 | 0.68 | 17.0 | 04.6 | 0878 | 0.864 | 0.108 | 1.870 | 0.0.58 | 1.088 | 0.688 |
| 0.850 | 3.305 | 8.889 | 0.084 | $0.70{ }^{\circ}$ | 17.5 | 6.8 | 0189 | 0.860 | 0.105 | 1.94* | 0.657 | 1.058 | 0.850 |
| 0.875 | 8.838 | 8.807 | 1.000 | 0.798 | 18.0 | 68.0 | 10040 | 0.387 | 0.17 | 1.848 | 0.658 | 1.040 | 0.085 |
| 0.900 | 4.017 | 9.466 | 1.108 | 0.748 | 18.8 | 71.8 | 11040 | 0.854 | $0.10{ }^{0}$ | 1.940 | 0.458 | 1.044 | 0.853 |
| 0.825 | 4.451 | 8.584 | 1.225 | 0.740 | 19.0 | 78.8 | 18110 | 0,851 | 0.808 | 1.880 | 0.487 | 1.088 | 0.800 |
| 0.030 | 4.004 | 8.608 | 1.380 | 0.780 | 18.5 | 78.0 | 13380 | 0.848 | 0.205 | 1.821 | 0.687 | 1.054 | 0.84 |
| 0.075 | 5.856 | 8.678 | 1.474 | 0.810 | 90.0 | 78.6 | 14680 | 0.847 | 0.908 | 1.918 | 0.653 | 1.080 | 0.840 |
| 1.000 | 5.758 | 8.740 | 1.585 | 0.830 | 90.5 | 81.0 | 18900 | 0.844 | 0.210 | 1.900 | 0.458 | 1.058 | 0.83 |
| 1.025 | 6.025 | 9.808 | 1.858 | 0.851 | 91.0 | 84.0 | 18910 | 0.846 | 0.910 | 1.808 | 0.647 | 1.05 | 0.85 |
| 1.050 | 6.158 | 2.877 | 1.885 | 0.871 | 81.5 | 87.4 | 80870 | 0.847 | 0.911 | 1.908 | 0.688 | 1.05 | 0.818 |
| 1.075 | 0.848 | 8.045 | 1.718 | 0.881 | 8.0 | 01.5 | 94510 | 0.347 | 0.210 | 1.810 | 0.487 | 1.054 | 0.800 |
| 1.100 | 6.887 | 3.014 | 1.730 | 0.011 | 8.5 | 4.9 | 89810 | 0.846 | 0.807 | 1.818 | 0.410 | 1.058 | 0.7E |
| 1.185 | 0.817 | 8.008 | 1.730 | 0.038 | 88.0 | 101.8 | 35050 | 0.348 | 0.908 | 1.218 | 0.504 | 1.044 | 0.738 |
| 1.150 | 6.371 | 3.151 | 1.754 | (A11 numbers are for ship of 600-ft LBP) |  |  |  |  |  |  |  |  |  |
| 1.175 | 6.477 | 3.818 | 1.78 |  |  |  |  |  |  |  |  |  |  |
| 1.200 | 6.648 | 3.288 | 1.030 |  |  |  |  |  |  |  |  |  |  |
| 1.225 | 6.892 | 1856 | Lent |  |  |  |  |  |  |  |  |  |  |

Table 48 - Results of Resistance and Self-Propulsion Experiments for V-Shaped FormModel 4282, 60-Percent Displacement, Trim $21 / 2$ Percent $L_{B P}$ by Stern

| $\mathrm{V} / \sqrt{\text { L-L }}$ | $C_{4} \times 10^{3}$ | (3) | (C) |
| :---: | :---: | :---: | :---: |
| 0.80 | 2.754 | 0.688 | 0.750 |
| 0.85 | 2.711 | 0.950 | 0.747 |
| 0.40 | 2.668 | 2.093 | 0.735 |
| 0.45 | 2.648 | 1.988 | 0.788 |
| 0.50 | 2.651 | 1.370 | 0.780 |
| 0.55 | 9.675 | 1.507 | 0.787 |
| 0.60 | 8.717 | 1.644 | 0.748 |
| 0.85 | 2.768 | 1.781 | 0.781 |
| 0.70 | 8.887 | 1.018 | 0.778 |
| 0.75 | 8.806 | 8.058 | 0.798 |
| 0.80 | y.068 | 2.108 | 0.817 |
| 0.825 | 8.089 | 2.960 | 0.887 |
| 0.880 | 8.187 | 9.329 | 0.884 |
| 0.875 | 3.820 | 2.889 | 0.915 |
| 0.900 | 8.088 | 2.486 | 1.000 |
| 0.885 | 4.041 | 2.584 | 1.118 |
| 0.950 | 4.444 | 8.608 | 1.294 |
| 0.157 | 4.851 | 8.878 | 1.884 |
| 1.000 | 5.227 | 8.740 | 1.440 |
| 1.095 | 5.838 | 2.808 | 1.584 |
| 1.050 | 5.718 | 2.877 | 1.575 |
| 1.075 | 5.801 | 2.945 | 1.598 |
| 1.100 | 5.834 | 8.014 | 1.607 |
| 1.185 | 5.878 | 8.088 | 1.818 |
| 1.150 | 5.921 | 8.181 | 1.881 |
| 1.175 | 5.900 | 8.819 | 1.688 |
| 1.800 | 6.188 | 8.888 | 1.681 |
| 1.895 | 6.838 | 8.858 | 1.746 |


| $V / \sqrt{L_{\text {WL }}}$ | V | N | SHP | $W_{T}$ | $t$ | . | - | ${ }^{6}$ | EEF/EXP |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0.384 | 8.0 | 89.8 | 818 | 0.847 | 0.948 | 1.185 | 0.678 | 1.018 | 0.788 |
| 0.884 | 0.0 | 84.0 | 1188 | 0.848 | 0.848 | 1.158 | 0.678 | 1.088 | 0.800 |
| 0.408 | 10.0 | 87.6 | 1580 | 0.848 | 0.94 | 1.188 | 0.672 | 1.088 | 0.804 |
| 0.445 | 11.0 | 41.6 | 2080 | 0.388 | 0.948 | 1:180 | 0.678 | 1.044 | 0.804 |
| 0.486 | 18.0 | 45.8 | 9678 | 0.834 | 0.948 | 1.188 | 0.681 | 1.047 | 0.807 |
| '0.588 | 18.0 | 48.8 | 8484 | 0.889 | 0.844 | 1.114 | 0.688 | 1.089 | 0.807 |
| 0.586 | 14.0 | 53.8 | 4305 | 0.885 | 0.94 | 1.117 | 0.688 | 1.085 | 0.604 |
| 0.607 | 15.0 | 57.8 | 5458 | 0.880 | 0.948 | 1.110 | 0.488 | 1.044 | 0.784 |
| 0.628 | 15.5 | 59.5 | 611\% | 0.817 | 0.944 | 1.107 | 0.688 | 1.085 | 0.785 |
| 0.448 | 16.0 | 61.7 | 6851 | 0.815 | 0.948 | 1.108 | 0.68 | 1.081 | 0.778 |
| 0.668 | 16.5 | 68.8 | 7430 | 0.818 | 0.848 | 1.100 | 0.084 | 1.097 | 0.778 |
| 0.688 | 17.0 | 66.8 | 0508 | 0.808 | 0.948 | 1.094 | 0.688 | 1.09 | 0.70 |
| 0.708 | 17.5 | 68.8 | 9410 | 0.801 | 0.944 | 1.001 | 0.681 | 1.081 | 0.74 |
| 0.720 | 18.0 | 70.7 | 10870 | 0.808 | 0.845 | 1.088 | 0.680 | 1.041 | 0.78 |
| 0.749 | 18.5 | 75.0 | 11460 | 0.308 | 0.944 | 1.085 | 0.678 | 1.048 | 0.700 |
| 0.769 | 19.0 | 75.8 | 19590 | 0.304 | 0.848 | 1.000 | 0.678 | 1.088 | 0.75 |
| 0.790 | 10.5 | 77.6 | 18880 | 0.805 | 0.240 | 1.078 | 0.678 | 1.097 | 0.751 |
| 0.810 | 90.0 | 80.0 | 15880 | 0.808 | 0.858 | 1.076 | 0.675 | 1.087 | 0.746 |
| 0.830 | 20.5 | 88.5 | 16810 | 0.308 | 0.884 | 1.075 | 0.671 | 1.081 | 0.744 |
| 0.881 | 81.0 | 88.8 | 18780 | 0.807 | 0.884 | 1.07 | 0.688 | 1.088 | 0.78 |
| 0.871 | 81.5 | 81.6 | 81840 | 0.807 | 0.854 | 1.076 | 0.658 | 1.088 | 0.788 |
| 0.881 | 88.0 | 18.4 | 9400 | 0.808 | 0.988 | 1.076 | 0.880 | 1.031 | 0.793 |
| 0.811 | 88.5 | 87.0 | 23880 | 0.605 | 0.980 | 1.078 | 0.640 | 1.061 | 0.710 |
| 0.988 | 93.0 | 108.0 | 24410 | 0.302 | 0.245 | 1.089 | 0.085 | 1.044 | $0.70 \%$ |

(All numbers are for ahip of
$400-\mathrm{ft} \mathrm{LBP}$ )


Figure 62 - Curves of Resistance Coefficient $C_{T}$ to a Base of $\frac{V}{\sqrt{L_{W L}}}$ for Series $60,0.70 C_{B}$ Models





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Figure 66 - Comparison of Power, RPM, and Efficiency Curves


Figure 67 - Comparison of Coefficient Curves


Figure 68 - Comparison of Power, RPM, and Efficiency Curves


Figure 69 - Comparison of Coefficient Curves


Figure 70 - Comparis on of Coeffitient Curves


Figure 71 - Velocity-Component Vectors in Propeller Plane

Contours of constant values of $w_{x}, w_{v}$, and $w_{h}$ are shown in Figures 72 through 77 for the five parent models and the two stern variations of the $0.70 C_{B}$ design.

In designing a propeller for a ship, we are interested in the fore and aft and transverse components of the wake. The total transverse wake $w_{t r}$, compounded of the values of $w_{v}$ and $w_{h}$, is shown for the seven models in Figures 78 through 84.

Figure 75 shows that the wake in the fore and aft direction has the same general pattern for all block coefficients; there is a steady increase in the wake values with increase in block coefficient, and the same is generally true for the transverse wakes in Figures 81 through 84.

One rather important feature of the transverse wake pattern for the three different stern designs for the $0.70 C_{B}$ model should be noted in Figures 78, 79, and 80. In the V-stern model, there is a strong upward component over most of the disk except for an inward and downward component near the centerline immediately above the propeller. For the parent form, intermediate between V and U , there is an indication of a definite rotation in the wake below the propeller centerline (Figure 78) and with the more pronounced U-stern, this rotation seems to be definitely established (Figure 79). Flow tests carried out in the circulating water channel at the Taylor Model Basin have shown that when a model has excessively $U$ stern sections, a definite vortex may leave the bilge line some distance ahead of the nropeller and extend aft right through the disk. In such cases, this downward flow ahead of and into the propeller may cause cavitation with consequent noise and vibration. It is therefore wise to avoid a very hard bilge radius aft when using $U$ sections, and it would be good practice to carry out flow tests before deciding on the final shape of the aft end sections of fuller ships.

The principal uses of the wake data are in the design of the propeller and the calculation of the variation in thrust and torque on the blades.

The average circumferential wake around a circle of any particular radius within the propeller disk can be found from such diagrams, and from this the appropriate pitch and blade section can be determined. However, in actual operation, the propeller section at that radius will meet constantly changing velocity conditions in the course of a revolution and so experience constantly changing thrust and torque forces. Integrating such forces over the blade will give the variation of thrust and torque on that blade during a complete revolution, and summing these forces for all blades will give the variation in total thrust and torque on the whole propeller. While the forces on a single blade will vary over 360 deg , the pattern for the whole propeller will repeat itself as the blades successively reach the same position. Thus for a 4 -bladed propeller, the pattern of thrust and torque variation will repeat every 90 deg; in other words, at blade frequency. The importance of these variations in thrust and torque is that they are one of the causes of hull and machinery vibration; the varying pressures around the blades cause varying pressures on the neighboring hull structure, and the varying force and torque are also transmitted through the shaft and stern bearings to the hull and


Figure 72b - U-Shaped Stern, Model 4281
Figure 72c - V-Shaped Stern, Model 4282

Figure 72a - Parent Form, Model 4280
$\%$

XI-18
 Figure 73c - V-Shaped Stern, Model $4282^{\text {E }}$

Figure 73a - Parent Form, Model 4280
Figure 73 - Lines of Equal Vertical Wake Components $\quad v_{v}=\left(V_{v} / V\right) .100$


 Figure 74b - U-Shaped Stern, Model 4281

Figure 74 - Lines of Equal Horizontal Wake Components $w_{h}=\left(V_{h} / V\right) .100$
 Figure 75d - Model 4214 $C_{B}=0.80$

 $C_{B}=0.75$
 Figure $75 \mathrm{~b}-$ Mode1 4218
$C_{B .}=0.65$

Figure 75a - Model 4210 $C_{B}=0.60$

Figure 76 - Lines of Equal Vertical Wake Components $w_{v}=\left[\left(V_{v} / V\right)\right] 100$

Figure 77d - Model 4214 Figure 77 - Lines of Equal Horizontal Wake Components $w_{h}=\left[\left(V_{h} / V\right)\right] 100$

Figure 77a - Model 4210
$C_{B}=0.60$

Figure 77b - Model 4218
$C_{B}=0.65$

Figure 77c - Model 4213 $C_{B}=0.75$



Figure 78 - Wake Diagram for Parent Form, Model 4280, $C_{B}=0.70$


Figure 79 - Wake Diagram for U-Shaped Form, Model 4281, $C_{B}=0.70$


Figure 80 - Wake Diagram for V-Shaped Form, Model 4282, $C_{B}=0.70$


Figure 81 - Wake Diagram for Model $4210-C_{B}=0.60$


Figure 82 - Wake Diagram for Model 4218- $C_{B}=0.65$


Figure 83 - Wake Diagram for Model 4213- $C_{B}=0.75$


Figure 84 - Wake Diagram for Model 4214- $C_{B}=0.80$
thrust block. Any smoothing of the wake will therefore not only improve the hydrodynamic performance of the propeller but also reduce one of the causes of hull vibration.

Knowing the wake components at any point, it is possible to calculate the forces on the section of the propeller blade at that point on the assumption that they will be the same as those it would encounter in a steady flow of the same pattern and, by summation, the total force and moment on the whole propeller. This method of analysis is called the "quasisteady" method, and Figure 85 shows the variation in total thrust for a 4 -bladed propeller behind the three $0.70 C_{B}$ models calculated in this way. Much theoretical work is in progress directed towards taking into account the dynamic effects of variations in wake velocitythe so-called "unsteady" method-but in the meantime the "quasi-steady" method is commonly used for comparative qualitative calculations when considering the effects of possible changes in propeller design. Wake diagrams of the type given will be useful in this respect. The longitudinal and tangential velocity components around any circumferential line in the propeller disk can be analysed into harmonic components, and the relative magnitudes of these will have an important influence on the vibratory thrust and torque forces. The wake pattern should therefore be considered as one factor whenever any decision is to be made in the choice of number of propeller blades.


Figure 85 - Thrust Fluctuation

## CHAPTER XII

## REVIEW OF SERIES 60 PROJECT

In the design of any given ship the naval architect has always to meet a number of conflicting demands which, to a greater or lesser extent, limit his choice of dimensions, proportions, fullness, and other features. An increase in length is generally favorable from the points of view of low resistance in smooth water and maintenance of speed in rough weather, but it is expensive structurally, carries penalties in crew numbers, and, in specific cases, may be limited by dimensions of locks, piers, drydocks, etc, which may also restrict beam and draft. The depth of water in the world's harbors today is also a definite limitation on draft, particularly for large tankers and other bulk carriers. On the other hand, beam is limited on the minimum side by the need for adequate stability, and questions of trim and weight distribution, especially in bulk carriers, may exercise some control over the necessary longitudinal distribution of displacement and so on the $L C B$ position.

In practice, therefore, the naval architect has usually to design a ship within dimensions already defined to a large extent by such considerations, but there is generally some latitude available for adjustment to suit the demands of good resistance and propulsion qualities.

The results of the Series 60 experiments can be of material help to the designer in any single-screw ship design which in its proportions and other features falls within the area of variables covered. If the designer adopts the lines of Series 60 , the position of $L C B$ as used in the parent forms, and a propeller having the standard ratio of diameter to draft of 0.7 , he can make a very accurate estimate of both the ehp and shp of a ship for any particular selection of length, beam, draft, and displacement:

If for trim or other reasons, the $L C B$ has to be placed in some other position, allowance for this can be made using the data given in Chapter VII or in Tables 49 through 53, and for departures from the standard propeller diameter the values of $w$, $t$, and relative rotative efficiency $\left(e_{r r}\right)$ from the contours can be corrected by using the results of the experiments with different diameter propellers detailed in Chapter $X$. The $w$ and $t$ data can also be used for assessing the propulsive efficiency to be expected for power plant conditions different from those assumed in the propeller designs used with the series models.

In addition to estimating the required power for a particular ship design having agreed characteristics, the data are also useful in assessing the penalties which must be paid or the advantages to be gained by changing such characteristics. This is a problem which occurs at some time or other in almost every design study, and this use of the data may well be as important as estimates of actual power.

Table 49 - Effect of Change in $L C B$ Position - $0.60 C_{B}$
Figures show increase or decrease in resistance for movement of $L C B$ from position in patent model, in percentage of (C)

| $\frac{V}{\sqrt{L_{W} L}}$ | (b) | $\frac{V}{\sqrt{L_{B P}}}$ | $L C B$ Position |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | 2.48A | $\begin{aligned} & 1.50 \mathrm{~A} \\ & \text { Parent } \end{aligned}$ | 0.51A | 0.52F |
| 0.40 | 1.057 | 0.403 | -0.4 |  | -0.3 | -1.0 |
| 0.45 | 1.189 | 0.454 | -0.9 |  | -0.3 | -2.2 |
| 0.50 | 1.321 | 0.504 | -0.2 |  | -0.3 | -2.2 |
| 0.55 | 1.453 | 0.555 | --- |  | -0.3 | -1.3 |
| 0.60 | 1.585 | 0.605 | --- |  | -0.2 | -1.2 |
| 0.65 | 1.717 | 0.655 | + 0.6 |  | +0.4 | +0.7 |
| 0.70 | 1.849 | 0.706 | $+0.3$ |  | $\therefore 1.0$ | +0.9 |
| 0.75 | 1.981 | 0.756 | +1.3 |  | +1.0 | +1.2 |
| 0.80 | 2.113 | 0.807 | $+2.0$ |  | +0.3 | +1.7 |
| 0.85 | 2.245 | 0.857 | +2.4 |  | +3.2 | +6.5 |
| 0.90 | 2.378 | 0.908 | +1.2 |  | $+2.0$ | $+6.9$ |
| 0.95 | 2.510 | 0.958 | +0.5 |  | $+4.7$ | +5.4 |
| 1.00 | 2.642 | 1.008 | -0.6 |  | +3.2 | +5.7 |
| 1.05 | 2.774 | 1.059 | -0.9 |  | +3.6 | +6.0 |
| 1.10 | 2.906 | 1.109 | -1.3 |  | +3.6 | +5.6 |
| 1.15 | 3.038 | 1.160 | -1.5 |  | +3.1 | +6.1 |
| 1.20 | 3.170 | 1.210 | -0.5 | ---- | -0.3 | +3.6 |

Table 50 - Effect of Change in $L C B$ Position - $0.65 C_{B}$
Figures show increase or decrease in resistance for movement of LCB from position in parent model, in percentage of (C)

|  | (K) | $\frac{V}{\sqrt{L_{B} P}}$ | LCB Position |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\frac{V}{\sqrt{L_{W} L}}$ |  |  | 2.46A | $\begin{aligned} & 1.54 \mathrm{~A} \\ & \text { Parent } \end{aligned}$ | 0.50A | 0.38 F | 1.37F |
| 0.40 | 1.031 | 0.403 | +4.8 | ---- | +1.7 | -1.5 | - 1.6 |
| 0.45 | 1.160 | 0.454 | +4.2 | ---- | +0.6 | -1.8 | - 1.2 |
| 0.50 | 1.289 | 0.504 | +3.3 | ---- | -0.3 | -1.1 | - 0.5 |
| 0.55 | 1.418 | 0.555 | +2.7 | ---- | -0.7 | -0.3 | + 0.3 |
| 0.60 | 1.546 | 0.605 | +2.4 | ---- | $+0.3$ | +0.4 | + 1.2 |
| 0.65 | 1.675 | 0.655 | +1.4 | ---- | -0.5 | --- | + 1.1 |
| 0.70 | 1.804 | 0.706 | +2.7 |  | -1.4 | +0.7 | + 2.2 |
| 0.75 | 1.933 | 0.756 | +2.4 | ---- | -0.4 | +1.7 | + 5.6 |
| 0.80 | 2.062 | 0.807 | +0.7 | ---- | +0.2 | +3.3 | +10.4 |
| 0.85 | 2.191 | 0.857 | -0.4 | ---- | +1.3 | + 7.2 | +16.2 |
| 0.90 | 2.320 | 0.908 | -5.3 | ---- | +0.4 | +5.2 | +10.2 |
| 0.95 | 2.448 | 0.958 | -5.0 |  | +2.0 | +5.5 | + 10.6 |
| 1.00 | 2.577 | 1.008 | -2.9 | ---- | +4.5 | +6.0 | + 9.8 |
| 1.05 | 2.706 | 1.059 | -2.4 | ---- | +3.6 | +4.1 | + 8.6 |
| 1.10 | 2.835 | 1.109 | -1.9 | ---- | +3.6 | + 6.2 | + 8.6 |
| 1.15 | 2.964 | 1.160 | -1.7 | ---- | +2.6 | +4.6 | + 9.1 |

Table 51 - Effect. of Change in $L C B$ Position - $0.70 C_{B}$
Figures show increase or decrease in resistance for movement of $L C B$ from position in parent model, in percentage of (C)

| $\frac{V}{\sqrt{L_{W} L}}$ | (K) | $\frac{V}{\sqrt{L_{B P}}}$ | LCB Position |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | 2.05A | $\begin{aligned} & \hline 0.55 \mathrm{~A} \\ & \text { Parent } \end{aligned}$ | 0.50F | 1.54 F | 2.55 F |
| 0.40 | 1.006 | 0.403 | +6.0 | ---- | +1.9 | - 0.6 | -1.9 |
| 0.45 | 1.132 | 0.454 | +5.8 | ---- | +1.6 | + 0.2 | - 1.6 |
| 0.50 | 1.258 | 0.504 | +4.8 | ---- | +0.7 | - 0.4 | -1.6 |
| 0.55 | 1.384 | 0.555 | +4.9 | ---- | -0.4 | - 1.4 | -1.3 |
| 0.60 | 1.510 | 0.605 | +5.5 | ---- | +1.6 | + 0.9 | + 0.4 |
| 0.65 | 1.636 | 0.655 | +4.3 | ---- | +0.9 | + 1.4 | + 2.6 |
| 0.70 | 1.761 | 0.706 | +4.0 | ---- | +0.4 | + 2.3 | + 7.4 |
| 0.75 | 1.887 | 0.756 | +2.0 | ---- | +3.1 | + 6.1 | +13.0 |
| 0.80 | 2.013 | 0.807 | -0.9 | ---- | +5.4 | + 12.0 | +23.0 |
| 0.85 | 2.139 | 0.857 | -2.0 | ---- | +5.6 | +15.0 | +33.6 |
| 0.90 | 2.264 | 0.908 | -5.6 | ---- | +3.9 | +15.5 | +26.6 |
| 0.95 | 2.390 | 0.958 | -5.0 | ---- | +6.5 | +12.7 | +21.4 |
| 1.00 | 2.516 | 1.008 | -4.7 | ---- | +7.8 | +10.9 | +20.2 |
| 1.05 | 2.642 | 1.059 | -5.5 | ---- | +7.6 | +11.2 | +21.3 |
| 1.10 | 2.768 | 1.109 | -4.8 | ---- | +7.4 | +13.2 | +22.4 |
| 1.15 | 2.894 | 1.160 | -6.9 | ---- | +4.6 | +11.1 | +20.5 |

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Table 52 - Effect of Change in $L C B$ Position - $0.75 C_{B}$
Figures show increase or decrease in resistance for movement of $L C B$ from position in parent model, in percentage of (C)

|  | (K) | $\frac{V}{\sqrt{L_{B P}}}$ | $L C B$ Position |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\overline{\sqrt{L_{W L}}}$ |  |  | 0.48F | $\begin{aligned} & 1.50 \mathrm{~F} \\ & \text { Parent } \end{aligned}$ | 2.57F | 3.46F |
| 0.40 | 0.983 | 0.403 | +2.2 | ---- | -0.3 | - 0.6 |
| 0.45 | 1.106 | 0.454 | +2.3 | ---- | - 0.1 | - 1.3 |
| 0.50 | 1.229 | 0.504 | +2.4 |  | - 0.6 | - 2.7 |
| 0.55 | 1.352 | 0.555 | +2.7 | ---- | - 2.1 | - 1.9 |
| 0.60 | 1.474 | 0.605 | +4.1 | ---- | - 2.6 | + 0.1 |
| 0.65 | 1.597 | $0.655^{\circ}$ | +1.7 | ----- | + 0.5 | + 2.5 |
| 0.70 | 1.720 | 0.706 | -1.1 | ---- | + 4.9 | +11.7 |
| 0.75 | 1.843 | 0.756 | -4.0 | ---- | + 7.2 | +14.3 |
| 0.80 | 1.966 | 0.807 | -3.1 | ---- | +10.2 | +13.7 |
| 0.85 | 2.089 | 0.857 | -6.1 | ---- | + 7.4 | +16.6 |
| 0.90 | 2.212 | 0.908 | -4.5 | ---- | + 7.7 | +16.2 |

Table 53 - Effect of Change in $L C B$ Position - $0.80 C_{B}$
Figures show increase or decrease in resistance for movement of $L C B$ from position in parent model, in percentage of $C$

|  | (K) | $\frac{V}{\sqrt{L_{B P}}}$ | $L C B$ Position |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\frac{V}{\sqrt{L_{W L}}}$ |  |  | 0.76F | 1.45 F | $\begin{aligned} & 2.50 \mathrm{~F} \\ & \text { Parent } \end{aligned}$ | 3.51 F |
| 0.40 | 0.960 | 0.403 | +14.2 | +4.3 | ---- | - 0.1 |
| 0.45 | 1.080 | 0.454 | +14.4 | +4.2 | ---- | + 0.7 |
| 0.50 | 1.200 | 0.504 | +14.9 | +4.1 | ---- | + 1.5 |
| 0.55 | 1.320 | 0.555 | +14.8 | +4.1 | ---- | + 2.7 |
| 0.60 | 1.440 | 0.605 | +11.2 | +1.7 |  | + 6.2 |
| 0.65 | 1.561 | 0.655 | + 5.0 | -0.9 | --- | +11.0 |
| 0.70 | 1.681 | 0.706 | - 1.3 | -5.0 | ---- | + 9.7 |
| 0.75 | 1.801 | 0.756 | - 3.7 | $-4.8$ | --- | +14.2 |
| 0.80 | 1.921 | 0.807 | - 2.7 | -7.2 | --- | +12.8 |
| 0.85 | 2.041 | 0.857 | - 7.0 | -3.4 | ---- | +13.0 |

The number of models run had to be limited both on the score of time and expense. In view of the wide field covered, the question may be asked as to how well the contours of residuary resistance, (C), wake fraction, thrust deduction fraction, and relative rotative efficiency represent the probable values of these quantities at points not directly supported by test results-in other words, how reliable would be estimates made of these quantities from the interpolated contours? One such comparison is given in Appendix C (see Figure C-3) where it is shown that the particular set of contours chosen represents extremely well the results of the nine models on which they were based.

A more general method of answering this question is available, however. In the process of assessing the merits of the Series 60 parents, actual models of Series 60 equivalents of the SCHUYLER OTIS BLAND, C.2., and PENNSYLVANIA were made and tested. These models had the corresponding dimensions, displacement, and $L C B$ position of the actual ship but Series $60^{\circ}$ lines. It is now possible to estimate the ehp for these three forms from the contours and to compare the results with the ehp actually meas ured on the models. Such comparisons are shown in Figures 86, 87, and 88. Two estimated curves are shown in each


Figure 86 - Comparison of EHP obtained by testing a Model having Series 60 Lines and Proportions of SCHUYLER OTIS BLAND with Corresponding Estimate from Series 60 Contours


Figure 87 - Comparison of EHP obtained by testing a Model having Series 60 Lines and Proportions of C.2. Class with Corresponding Estimate from Series 60 Contours
case, one for a ship having the $L C B$ in the position used in the Series 60 models on which the contours are based, the other for a ship having the $L C B$ in the same position as the actual ship in question. The change in ehp for the shift in $L C B$ was estimated from the data in Chapter VII and Tables 49 to 53.

For the SCHUYLER OTIS BLAND and PENNSYLVANIA, the actual LCB positions were within 0.5 percent $L B P$ of those used in the Series 60 models from which the contours were developed, and the effects on ehp were extremely small (Figures 86 and 88 ). In the case of the C.2. design, the actual ship had the LCB 1.4 percent forward of midships, and the position corresponding to the Series 60 contours was 1 percent aft. The actual and estimated ehp did not differ materially below 15 knots, but above this speed, the estimated ehp from the Series 60 contours was lower than that of the C.2. Series 60 equivalent, the reduction at 18 knots being some 12 percent (Figure 87). This illustrates the advantage of the finer entrance at these higher speeds. The estimated curve for the Series 60 equivalent with the $L C B$ in the actual ship position (1.4 percent forward), corrected by the data in


Figure 88 - Comparison of EHP obtained by testing a Model having Series 60 Lines and Proportions of SS PENNSYLVANIA with Corresponding Estimate from Series 60 Contours

Chapter VII, shows excellent agreement with the ehp measured on the model. Thus when allowance is made for differences in $L C B$ position, the ehp estimated from the contours is in very good agreement with that measured on these three models. This fact should give confidence in the use of the contours throughout the range, for of course the results of the tests on these three Series 60 equivalent models were not used in any way in the process of deriving contours.

Self-propulsion tests were also carried out on the Series 60 equivalents of the SCHUYLER OTIS BLAND and the PENNSYLVANIA. The values of $w, t$, and $e_{r r}$ measured in the tests are compared in Figures 89 and 90 with the corresponding values estimated from the appropriate contours, and the agreement is again very satisfactory.

Although estimates of power made from the contours apply strictly only to ships having lines derived from the Series 60 charts, they can, with proper exercise of caution, be used as guides over a somewhat wider field. For example, in developing the original Series 60 lines, Bethlehem Steel Company provided a set of lines equivalent to the MARINER class of fast


Figure 90 - Comparison of $w, t$, and $e_{r r}$ for Series 60 PENNSYLVANIA from Contours and Test Results
cargo ships but without a bulbous bow (Model 4440). A comparison of this model with the Series 60, $0.60 C_{B}$ parent (Model 4210) showed the latter to have appreciably lower (C) values at the service and trial speeds (Figure 6 of Reference 45). Although the lines were rather similar, the hull form coefficients were different-for example, the block coefficient of Model 4440 was 0.611 -and a comparison of the ehp for Model 4440 with that derived from the contours for a Series 60 equivalent form of $C_{B} 0.611$ (Figure 91) indicates that again the agreement is good.

The contours can also be used for comparative purposes in much the same way as is done with the Taylor Standard Series. If a new design has secondary characteristics which differ from those of its Series 60 equivalent but model results are available for some other ship which more closely resembles it in these respects, the latter may be used as a "basic" ship. Calculations of ehp can be made from the contours for the "Series 60 equivalents" of both the new design and the basic ship. Then the approximate ehp for the new ship will be

$$
\text { ehp of Series } 60 \text { equivalent } \times \frac{\text { ehp for basic ship }}{\text { ehp of Series } 60 \text { equivalent of basic ship }}
$$

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Figure 91 - Comparison of EHP obtained by testing a Model having Proportions of MARINER Class, but without Bulbous Bow, with Corresponding Estimate from Series 60 Contours

Figure 92 shows the predicted ehp for an ocean-going ore carrier of $0.78 C_{B}$ compared with actual model test results; the estimate was made as outlined above, using the PENNSYLVANIA as the "basic" ship.

Even more extreme uses can be made of the Series with some success, as shown by Professor Baier's adoption of the series bow and stern lines with parallel body in the design of lake ships (page V-22). The demonstration of the qualitative uses of Series 60 is easy, but the establishment of their absolute quantitative value is more difficult. In discussing the very first paper in the series (Reference 44), Mr. V. L. Russo made the following observations: "The real value of the contours proposed in the paper could be established best by determining what results these contours would give by comparison with acceptable results exemplified not by the standard of a phantom form but by actual successful ship designs . . . This way of comparison . . . would have the advantage of being conclusive as it would furnish a true comparison under practical conditions and be devoid of imponderable


Figure 92 - Comparison of EHP obtained by testing a Model of an Ocean-going Ore Carrier with Corresponding Estimate from Series 60 Contours using SS PENNSYLVANIA as Basic Ship
discrepancies." This suggestion was taken up by the SNAME Panel (of which Mr. Russo was a member), and the subsequent Series 60 parents were developed using just this method, as described earlier in this report. It is believed that these parents now compare very well in performance with the successful ship designs on which they were based.

Comparisons with results of similar work at the Netherlands tank have already been mentioned in Chapter VI, and in this connection, it is of interest to quote the remarks of Professor L. Troost, one-time Director of that establishment, with a vast experience in the model testing field: "The writer has applied the computations as presented in the paper to the results of some high-quality hulls and propellers of foreign (European) design. $\mu_{e}$ is satisfied that the optimum Series 60 data are indicative of very high performance and that it will require great skill and experience to improve on them for an amount of 2 percent in total ehp and shp in regular designs. He also found that an extrapolation to 0.82 block, which will often be necessary in the field of super-tankers and comparable ships, not too hazardous.". (Discussion on Reference 64).

Although no claim can possibly le made that Series 60 -or indeed any other Seriesrepresents optimum resistance qualities, the above remarks and other evidence do suggest that the contours will be of help in preliminary design work and can be used with some confidence in the estimation of ship performance, both in the absolute sense and also in the investigation of various alternative choices which may face the naval architect.

In using the Series 60 results, it is worth recalling that the hull forms are all related to one another in a clear and unambiguous way by means of graphical methods. As has been pointed out before, this has the advantage over geometrical variation of one parent form in that the characteristics can be varied with fullness to suit the corresponding changes in speed-length ratio. The alternative use of a single parent form to cover such a wide range of variables as used in Series 60 would have led inevitably to unrealistic designs towards the limits of the area covered. Another point to remember is that all models were of the same length and run in the same tank with the same instrumentation, thus eliminating other possible sources of difference.

In the course of the discussions on the many Series 60 papers, much has been said about various methods of presenting the data. The two most commonly used are to give values of residuary resistance per ton of displacement $\frac{R_{R}}{\Delta}$, in terms of speed-length ratio $\frac{V}{\sqrt{L_{\mathbb{Z}^{\prime}} L}}$, almost universally used in the United States, or values of © C $_{400 \mathrm{ft}}$ in terms of (K) , as used in Great Britain. Both systems have merits and demerits, as one might expect, but they are well-entrenched in their respective homes. The Series 60 results have therefore been given in both ways as contours of $\frac{R_{R}}{\Delta}$ and of (C) to their respective bases. There is a vast amount of model data expressed in one or other of these forms, with which the Series 60 results can be compared directly. The SNAME Model Resistance Data sheets also give the information in both these forms.

The presentation of $\frac{R_{R}}{\Delta}$ in terms of $\frac{V}{\sqrt{L_{W / L}}}$ has the advantage of simplicity but suffers from two drawbacks. In the first place, a true merit comparison has to be made on the basis of total resistance per ton of displacement, and comparisons on the basis of $\frac{R_{R}}{\Delta}$ can be quite misleading. Skin friction resistance is the major component of total resistance in most if not all single-screw merchant ships, and this depends on wetted surface, not directly on displacement. To make a merit comparison from data presented in this way, it is therefore necessary to estimate the frictional resistance in each case and so obtain total resistance or ehp.

The true merit comparison of interest to the naval architect and ship owner is the total resistance per ton of displacement $\frac{R_{T}}{\Delta}$. To present this properly in curve form it is
necessary to have the abscissa and ordinate values compatible. For abscissa, the speedlength ratio $\frac{V}{\sqrt{L}}$ is preferred by many naval architects for its simplicity. In order to keep the values of $\frac{R_{T}}{\Delta}$ within a reasonable numerical range, it is usual to divide them by some function of (speed) ${ }^{2}$ since this makes the ordinates almost constant over the lower speed range. If it is desired to use $\frac{V}{\sqrt{L}}$ as the speed parameter, then the ordinates should be

$$
\frac{\frac{R_{T}}{\Delta}}{\left(\frac{V}{\sqrt{L}}\right)^{2}} \quad \text { or } \frac{R_{T} \cdot L}{\Delta \cdot V^{2}}
$$

If the comparison is to be made on a power basis, then the ordinate becomes $\frac{R_{T} \cdot L \cdot V}{\Delta \cdot V^{3}}$ or $\frac{\text { EHP } \cdot L}{\Delta \cdot V^{3}}$ or $\frac{\text { SHP } \cdot L}{\Delta \cdot V^{3}}$

Dr. Telfer has made this point very clearly in discussing the Series 60 papers. ". . . the designer's problem is usually to find the model having the lowest resistance per ton displacement on a given length, length being usually approximately fixed by conditions other than resistance" (discussion on Reference 44). And again, "Figure 16 gives us an incompatible presentation of a power-displacement function $\frac{\text { SHP }}{\Delta^{2 / 3} V^{3}}$ presented in terms of a speed-length function $\frac{V}{\sqrt{L}}$. From this diagram a designer is led to infer that the finest ships are always the most economical. Such a conclusion from the basic data would be completely erroneous. To review the data correctly they must be presented in a compatible form. As the speed-length ratio $\frac{V}{\sqrt{L}}$ is preferred by most practical ship designers it must by retained and the requisite change for compatibility made in the power-displacement function. This must be converted to a power-length basis, still using, however, power per ton dis placement. The conversion produces the function $\frac{\text { SHP } \cdot L}{\Delta \cdot V^{3}}$ which correctly grades the power per ton of all vessels having the same length and speed'' (discussion of Reference 61).

The basic resistance and dhp data for the Series 60 parents are presented in this form in Figures 93 and 94. To again quote Dr. Telfer: "A designer now sees that if his speed is low t... most economical ships have the fuller and not the finer forms. Certainly as the speed is increased the finer form becomes the more economical, and by drawing a tentative envelope to the individual curves a mean scale of optimum block coefficient and optimum power constant for given speed-length ratio is at once available." 61

Dr. Telfer has recently converted the results of the resistance experiments on the Series 60 models to this method of presentation, and compared them with other available data. ('"The Design Presentation of Ship Model Resistance Data。" E.V. Telfer, Trans NECI, Vol. 79 (1962-63).)


Figure $93-\frac{R L}{\Delta V^{2}}$ on $\frac{V}{\sqrt{L}}$ for Series 60 Parents
The (C) and (B) constants were introduced by R.E. Froude. At corresponding speeds for model and ship, $\frac{V}{\sqrt{L}}$ is the same, $\boldsymbol{\nabla}$ (volume of displacement) is proportional to $L^{3}$, and so $\frac{V}{\nabla^{1 / 6}}$ is the same. This ratio has different values in different systems of units, and


Wave speed $=\sqrt{\frac{g \lambda}{2 \pi}}=\sqrt{\frac{g}{2 \pi} \cdot \frac{\nabla^{1 / 3}}{2}}=\nabla^{1 / 6} \sqrt{\frac{g}{4 \pi}}$.
Hence (K) $=\frac{\text { ship speed }}{\text { wave speed }}=\frac{V}{\nabla^{1 / 6}} \cdot \sqrt{\frac{4 \pi}{g}}$, which is nondimensional. The resistance is expressed in terms of $\frac{R_{T}}{\Delta}$ which is also nondimensional in a consistent system of units. If this is to be presented to a base of $(\mathbb{K})$, we must divide by $\not \measuredangle^{2}{ }^{2}$, and Froude added 1000


Figure $94-\frac{\text { SHP } \cdot L}{\Delta V^{3}}$ on $\frac{V}{\sqrt{L}}$ for Series 60 Parents
to the numerator to avoid unnecessarily small numerical quantities. Thus he defined his resistance constant (C) as

$$
(C)=\frac{R_{T}}{\Delta \cdot(B)^{2}} \times 1000
$$

and speed constant

$$
(B)=\frac{V}{\nabla_{1 / 6}} \cdot \sqrt{\frac{4 \pi}{g}}
$$

both being nondimensional.
For use in usual ship units of $V$ in knots and displacement $\Delta$ in tons, these assume the well-known forms

$$
(R)=0.5834 \cdot \frac{V}{\Delta^{1 / 6}}
$$

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$$
\text { (C) }=\frac{R_{T}}{\Delta} \cdot \frac{\Delta^{1 / 3}}{(0.5834 \cdot V)^{2}} \times 1000=\frac{R_{T}}{\Delta^{2 / 3} \cdot V^{2}} \times 2938
$$

where $R$ and $\Lambda$ are both in tons or, in terms of horsepow $\lrcorner r$,

$$
C=\frac{E H P}{\Delta^{2 / 3} V^{3}} \times 427.1
$$

A presentation of resistance data in the (C)-(K) system is therefore compatible and places models or ships in a correct merit order. In the design of a merchant ship, the two principal basic design factors are the speed and displacement--how much displacement (and therefore deadweight) has the ship to carry at a given speed? The (C)- $(B)$ system involves only $V$ and $\Lambda$ and leaves length along with other dimensions and coefficients among the variables which are at the designer's disposal in attempting to find that combination which will result in the most economical overall design.

From the various charts and tables presented in this report, the designer can extract the data he desires in either form, according to his needs and in keeping with the method with which he is most familiar or in which his own data are recorded. The conversion of the (C) data using the ATTC line, as given in this paper, to the equivalent (C) data using Froude, or vice versa, can also be quickly made by the use of the chart given in Appendix D (Figure D-4), thus giving a connecting link with the large quantity of (C) data in existence in this form.

## CHAPTER XIII

## POSSIBLE EXTENSION OF SERIES 60 AND FUTURE RESEARCH

Although at the time the original series was planned, the numerical ranges adopted for the variables seemed adequate for future designs of single-screw ships, developments over the last 15 years have already overtaken the choice made in 1948.

The single-screw arrangement is preferred by most ship owners because it results in higher propulsive coefficients, cheaper machinery installations and lower running costs than equivalent twin-screw machinery, and in recent years single-screw ships have been built of greater and greater size, with more and more power, higher speeds, and larger propellers. For the dry-cargo or refrigerated ship there has been a demand for increasing speed which, with these other factors, has resulted in many single-screw ships having block coefficients less than the smallest one of 0.60 used in Series 60 . Coefficients of 0.55 have been used, and to take care of the future and have adequate design information, it would be useful to extend the series down to a block coefficient of at least 0.55 and perhaps 0.50 .

At the other end of the scale, the economics of carrying bulk cargoes, whether oil, ore or grain, have resulted in the mammoth supertankers of today with block coefficients in the neighborhood of 0.825 to 0.85 . An extension of Series 60 to 0.85 block coefficient would therefore be of great interest to designers in this field.

The range of $\frac{B}{H}$ for the Series is from 2.5 to 3.5. The former figure is rather too high (many cargo ships have ratios around 2.25), and an extension to a value of $\frac{B}{H}$ equal to 2.0 would be of interest. The upper limit of 3.5 is probably adequate for most ships in fully loaded condition, but with draft restrictions in many ports and canals, it is reasonable to suppose that supertankers and similar ships may well spend appreciable time in a partially loaded condition when $\frac{B}{H}$ may quite likely exceed 3.5. As a first step, a few models having $\frac{B}{H}$ values of 2.0 and 4.0 could be run to see how reliable an'extrapolation outside the present limits might prove to be before embarking on an extensive program.

- Studies of seakeeping characteristics have shown the advantages of longer ships in maintaining sea speed, and an extension of the series at the finer block coefficients to higher values of $\frac{L}{B}$ would be of interest in this respect; at the full end, a similar increase in $\frac{L}{B}$ would cover ships designed for the Great Lakes trade.

The extension of Series 60 to cover any or all of these areas would be a worthwhile research project. In addition, there remain the planning and running of additional series to cover twin-screw ships, trawlers, tugs, and high displacement-length craft of all kinds. In
the latter types, the effect of shallow water on performance would also be a matter of secial interest. The availability of such systematic information would provide the naval architect with much basic and background information and greatly reduce the need for routine model testing.

The results prosented in this report are for models tested for resistance and propulsion in smooth water only. They cover the major features of single-screw merchant ships such as proportions, fullness, $L C B$ position, and variation in propeller diameter. They enable a designer to obta in very quickly from contours a lines plan having the correct dimensions, displacement and $L C B$. Moreover, because of the graphical relationship between the models, he can also associate with these lines a close estimate of resistance and shaft horsepower. As pointed out earlier, although no claim can be made that such a design is an optimum one, the comparisons made between Series 60 and new successful ships indicates that it will be of a reasonably high standard.

When the series was begun, the hope was expressed that it would provide an acceptable starting point for additional series planned to investigate many other facets of the hull design problem. This hope has been realized to a very considerable extent-models of Scries 60 have been used for a number of comparisons of models in waves, sponsored by the ATTC and the ITTC, for a methodical investigation into launching, and for calculations of the forces on ships in a seaway and their responses to such forces. They have also been used in studies of wavemaking resistance and of the effects of adding different sizes of bulb at the bow upon resistance and ship motions. As described in this report, the Series 60 parent models have also been used for the measurement of wake patterns and the resultant propeller forces, and for the median model of $0.70 C_{B}$, the effects on these and upon resistance and propulsion of changes in shape of stern sections from $U$ to $V$ have also been evaluated.

Probably the most urgent need for extension of this methodical series work lies in the realm of seagoing qualities. It by no means follows that the hull form chosen for good performance in smooth water will be equally successful in waves, either as regards maintenance of speed or minimum ship motions. This applies particularly to the fuller, slower ships, where the absence of any significant wavemaking calls forfull bows and slender sterns to achieve good smooth-water performance. A methodical program should be carried out first, to test key models of the series in waves, and this should include experiments to find the effect of $L C B$ position upon maintenance of sea speed. The next step would be to evaluate the effects of changes in section and waterline shapes, both below and above water. These would include, for example, an examination of the relative merits of $U$ - and $V$-sections, and the best type of above-water form at the bow to ensure a clean, dry ship by the provision of adequate freeboard and flare. An extensive program of experiments of this kind, based on Series 60 models as parents, has been designed at the NSMB. The results of some tests have already been published, but much yet remains to be done.

XIII-2

In order to keep the original program at the Taylor Model Basin within reasonable bounds, a graphical method of delineating the models was adopted, and except for the fact that comparisons were made with existing "good" ships, no attempt was made at that time to explore the vast field of possible changes in the shapes of area curves, sections or waterlines. At the time of publication of the earlier papers, this adoption of certain area curte and section shapes was subject to some criticism as having been done too arbitrarily and accepted too casily. But the fact that it has taken 15 years to reach the present position is sufficient indication of how long it might have taken had we been led astray in the early days by the temptation to explore all the delectable byways, opening up vistas of attractive changes in area curves, waterline and section shapes. Now that the main framework has been finished, such exploration is undoubtedly necessary; it could well form the subject of a number of research projects in different tanks.

There are a number of possible approaches to this type of research. One would be the trial and error method of trying different shapes of area curves, waterlines and sections, being guided in successive choices by the results of each step in turn. A second would be to apply statistical methods to the results of previous model tests-both Series 60 and othersto determine the influence of the different design parameters, and so approach closer to an optimum combination to suit any given design conditions. Considerable success has been achieved in this way in the particular field of trawler design. ${ }^{66}$

Thirdly, one may seek guidance from the mathematical work being carried out in the field of wavemaking resistance. As a matter of history, it is perhaps worth recording that much thought was given to this aspect of ship resistance research when the original series was being planned. At that time, Dr. Weinblum was a consultant at the Taylor Model Basin, and he took an active part in the planning and in the early phases of the project. The question of using mathematically defined lines was seriously considered, and it is perhaps of interest to record some of Dr. Weinblum's views as set out in his discussion on the first series paper (discussion on Reference 44, pp 722-4).
"For a considerable time attempts have been made to establish a rational theory of ship resistance as the function of its form by using analytical methods and pertinent basic experiments. Although this approach is developing successfully, if slowly, the choice of proper ship forms for practice has still to rely widely upon experimental data, obtained by testing methodical series or single models. Clearly, the latter procedure is the most wasteful way of getting results which are capable of appropriate generalization. Therefore, from a practical point of view, the need for Series work cannot be denied at present. On the contrary, the substitution of methodical experimenting for single testing promises within plausible limits decisive advantages in various respects . . . when the present series was being planned the authors received proposals to base the work on algebraically defined lines . . There is no magic in mathematical lines. Their use in research work is desirable essentially

1. to obtain well-defined expressions for the ship forms, which admit especially of clearly defined variations in these forms . .
2. to enable us to perform resistance, seaworthiness and similar calculations in a simple and systematical manner.
. . . in the writer's opinion a reasonable evaluation of the existing theories (of wave resista nce and sea-going qualities) could be reached by using graphically-defined parent hulls, by approximating these forms mathematically and using the latter for the calculations involved.. . . . This reasoning together with some difficulties . . . in representing full sections justifies the use of empirical lines at present . . . The idea of the proposed wave resistance calculations is essentially two-fold: we intend to make a contribution to the analysis of the experi-mentally-obtained resistance curves and to indicate what improvements in the parent forms are suggested by theory. Especially the latter purpose can become rather interesting. On the other hand, since we are dealing with a first order theory, valuable checks of its validity may be obtained from systematic experiments.
. . . Finally, the series work may make use of other procedures applied in hydrodynamics and thus stimulate the whole field of model research. It does not give credit to theoretical naval architecture and to general hydrodynamics that in text books on the latter subject the ship has nearly disappeared."

In view of such opinions, the basic lines of Series 60 were developed empirically and defined graphically, and Dr. Weinblum showed in his discussion how the waterlines and sections could be closely represented by polynomial expressions.

Today much effort is being applied to the problem of representing a ship form mathematically, either by means of sections and waterlines or as a three-dimensional surface, for use on a digital computer. ${ }^{67,68,69}$ Such an a pproach would enable calculations of wavemaking resistance, velocity distribution, and motions in waves to be made very quickly and permit examination of many alternative ideas. In the particular case of calculations of wavemaking resistance, these will still suffer in the absolute sense from limitations in the theory, particularly as regards the inclusion of viscosity effects, but they should furnish a guide to the experimenter in the choice of hull changes likely to reduce wavemaking resistance. It must be remembered, however, that in the type of ship with which this research is concerned, the wavemaking resistance is, in general, only a small part of the total. By fining the entrance, for example, it may well be that the reduction in wavemaking resistance will be equalled or even exceeded by an increase in viscous form drag.and eddymaking occasioned by the correspondingly fuller stern. On the other hand, the wavemaking resistance is the part over which we have most control since it depends essentially on the hull shape, and every use should be made of any guidance that mathematical work can provide as to the type and character of changes likely to reduce it. This approach will be most fruitful in high-speed ships, but at present it seems that for low-speed cargo ships we must in the final analysis still have resort to experiments.

XIII-4

Finally, it is be lieved that much of the value of ship model research in the past has not been realized because of the lack of a common point of departure: Indeed, as a result of this lack, there has been much duplication of effort. It is suggested that Series $\mathbf{6 0}$ provides such a common starting point. Used in this way, it would have the effect, in its own limited field, of unifying research everywhere. Much more research, both fundamental and applied, remains to be done; there are staff shoriages in most places, but with such a link these problems could be shared among towing tanks everywhere and the rate of progress much enhanced.

## APPENDIX A

## EFFECTS OF TURBULENCE STIMULATORS

The need for artificial stimulation of turbulence on ship models in order to avoid the spurious results obtained in ship predictions based upon model experiments in which some laminar flow persisted was recognised in some tanks, including Hamburg and Wageningen, before 1930. Its importance was not generally appreciated, however, until around 1948 when it was realised that on some hull forms, notably those with a full forebody and raked stem, laminar flow could persist to an alarming extent. Thus experiments with LIBERTY ship models showed that the effect of stimulation over the lower speed range could amount to 15 or even 20 percent.

A number of methods of stimulating turbulence have been devised from time to time. Kempf early proposed a "comb" which made a pattern of grooves in the wax hull around a station about 5 percent of the length aft of the stem, while a "trip-wire" placed around the hull at the same place was adopted very early in the work and has maintained its place as one accepted method to the present time. Sand strips down the stem and along the LWL for a short distance from the fore end are aiso used. All these devices add some parasitic drag to the hull, and to avoid this use has been made of struts ahead of the model attached to the towing carriage. Some experiments of this kind made with fine models in which no laminar flow effects could be detected suggested that the wake from the strut could actually reduce the measured resistance of the hull. In order to avoid some of these effects, studs similar to those developed on a ircraft models were tried; they have the stimulating effect of trip wires or sand strips but a very low parasitic drag. These were described by Hughes and Allan in $1951 .{ }^{46}$

The original Series 57 models were run with and without turbulence stimulation. The standard method used on all models was a sand strip $1 / 2 \mathrm{in}$. wide down each side of stem and along the LWL for a distance of 4 ft or one-fifth of the length of the model. In addition, ${ }_{L}$ some models were run with a trip wire, 0.04 in . in diameter placed around a station at $\frac{L}{20}$ from the stem. Others were fitted with studs, as described in Reference 46; these have a diameter of $1 / 8 \mathrm{in}$., were $1 / 10 \mathrm{in}$. high and spaced 1 in . apart along a line parallel to the stem profile. The distance of the line from the stem depends on the half angle of entrance on the LWL $\left(1 / 2 \alpha_{E}\right)$. For the three Series 57 models of $0.70,0.75$, and $0.80 C_{B}$, the $1 / 2 \boldsymbol{\alpha}_{E}$ values were $13.3,27.1$, and 44.0 deg , the distance of the studs from the stem being, respectively, $2.13,2.70$, and 3.25 in .

The effects upon resistance were somewhat erratic but never very serious.

| Model | Sand Strips | Trip Wire | Studs |
| :---: | :--- | :---: | :---: |
| $4200\left(0.60 C_{B}\right)$ | Slight increase over lower <br> speeds | No change | - |
| $4201\left(0.65 C_{B}\right)$ | No change except at very <br> lowest speed, $C_{T}$ rising <br> slightly with decreasing <br> speed | No change except at <br> very lowest speed, <br> $C_{T}$ level with de- <br> creasing speed | - |
| $4202\left(0.70 C_{B}\right)$ | No change | - | No change |
| $4203\left(0.75 C_{B}\right)$ | Below $\frac{V}{\sqrt{L}} \times 0.4$, <br> large increase in resis- <br> tance-some 60 percent <br> on $C_{R}, ~ A t ~ s e r v i c e ~ s p e e d, ~$ <br> increase in $C_{R}$ was 4 per- <br> cent and in $C_{T}$ about $11 / 2$ <br> percent | - | Same as sand strips |
| $4204\left(0.80 C_{B}\right)$ | Slight increase at all <br> speeds- $C_{T}$ up $11 / 2$ per- <br> cent at service speed | - | Somewhat larger in- <br> crease- $C_{T}$ up 3 per- <br> cent at service speed |

(The percentage increase are for a 400 -ft ship)

In view of the small effects of stimulation, it was decided to use results with sand strips without deduction for any parasitic drag.

The first step in developing the new Series 60 was a comparison between the results of certain good ships and the Series 57 equivalents. Studs were used for these tests because they were easy to fit, were positive in location, had some theoretical backing as a means of stimulation, and had very small parasitic drag. The only peculiar results found were with the models of the PENNSYLVANIA series. The PENNSYLVANIA was a tanker of $0.76 C_{B}$ and a number of variations were tested. The models are listed in the order in which the tests were carried out. For the first five, the increases in resistance were quite substantial, averaging 10 and 7.5 percent at the service and trial speeds respectively. For the last four, the corresponding figures were 0.8 and 1.2 percent. It should be noted that Models 4435 W and 4435 W.A are built to identical lines, both of wax, and yet they fall into the two groups as regards stimulation effects. The (C) 400 ft values listed are those derived from the model results with stimulation; they show no serious change in the resistance picture, indicating that the differences occurred in the tests in the unstimulated conditions. The only division one can make is a chronological one, and no explanation has been found for this peculiar behaviour.

| Model | Details | Percentage Increase in (C) with Studs |  | (C) 400 ft with Stimulation |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Service Speed | Trial Speed | Service Speed | Trial Speed |
| 4435) | PENNSYLVANIA (as built) | 11.8 | 9.0 | 0.715 | 0.735 |
| +42013 | Series 57 equivalent | 10.4 | 8.2 | 0.735 | 0.765 |
| 4200N-1 | PENSSYLNANIA forebody-Series 57 aft body | 10.7 | 7.0 | 0.710 | 0.730 |
| 4.468 W | Series 60 equivalent | 9.0 | 7.0 | 0.727 | 0.760 |
| 4468 NT - 1 | PENNSYLVANIA forebody with Series 60 stem profile-Series 60 stern aft body | 9.0 | 6.6 | 0.736 | 0.763 |
| 4435M. 1 | PENNSYLVANIA with Series 60 stem and stern contours | 0.3 | 2.0 | 0.735 | 0.760 |
| 4435W. 2 | PENNSYLVANIA with Series 60 stern and PENNSYLVANIA bow contours | 2.0 | 0 | 0.730 | 0.753 |
| 4435W.A. | PENNSYLVA:IA (new casting of 44351:) | 0.0 | 2.8 | 0.725 | 0.772 |
| +466\% ${ }^{\text {d }}$ - | Series 60 equivalent with PENNSYL VANIA stem contour | 0.8 | , 0 | 0.747 | 0.772 |

For the actual Series 60 parent models, studs were used throughout and the following effects were measured:

$$
\begin{array}{ll}
C_{B}=0.60 \text { and } 0.65 & \text { Resistance unaffected } \\
C_{B}=0.70 & \text { (C) }_{400 \mathrm{ft}} \text { values increased } 0 \text { to } 3 \text { percent } \\
C_{B}=0.75 \text { and } 0.80 & \text { © }_{400 \mathrm{ft}} \text { values increased } 0 \text { to } 12 \text { percent }
\end{array}
$$

The propulsion tests on the Series 60 parents were all carried out with models fitted with studs.

The $L C B$ series were all run in the first place with studs. For comparison, 14 of the 22 models were also run with trip wires.

The results for the models without stimulation and with studs were as follows:

| $C_{B}$ | LCP from 8 | $\text { Effect of Studs }=\frac{C_{T} \text { Studs }}{C_{T} \text { Bare }}$ |  |
| :---: | :---: | :---: | :---: |
| $\begin{aligned} & 0.60 \\ & 0.65 \\ & 0.70 \end{aligned}$ | All Models | No measurable effect |  |
| 0.75 | $\begin{aligned} & 0.18 \mathrm{~F} \\ & 1.50 \mathrm{~F} \\ & 2.57 \mathrm{~F} \\ & 3.46 \mathrm{~F} \end{aligned}$ | Sea speed  <br> 1.037  <br> 1.030 Nean <br> 1.090 1.050 <br> 1.068  | Trial Speed  <br> 1.029  <br> 1.028 Mean <br> 1.098 1.050 <br> 1.075  |
| 0.80 | $\begin{aligned} & 0.76 \mathrm{~F} \\ & 1.45 \mathrm{~F} \\ & 2.50 \mathrm{~F} \\ & 3.51 \mathrm{~F} \end{aligned}$ | $\begin{array}{ll} 1.050 & \\ 1.079 & \text { Mean } \\ 1.035 & 1.055 \\ 1.074 & \end{array}$ | 1.054  <br> 1.081 Mean <br> 1.037 1.060 <br> 1.070  |

The average increase with the two fuller block coefficients is 5 to 6 percent. For the 0.75 $C_{B}$, there appears to be some tendency for the increase in resistance with stimulation to be higher the further forward the $L C B$, and therefore the fuller the forebody and entrance. The $0.80 C_{B}$ does not show such a definite trend, however, and no generalization can be made on this point.

When trip wires were used in place of studs, there was no difference in the results except for two of the $0.80 C_{B}$ models, when the service and trial speed (C) values were about 2 percent higher with wires than with studs.

For the models used in the main series to explore the effects of changes in $\frac{L}{B}$ and $\frac{B}{H}$ ratios, turbulence was stimulated by trip wires, 0.036 in . in diameter, placed around a section of the model 5 percent of the length from the stem. This choice was made basically on two grounds. Although in general there was no difference in the results using studs or trip wires, the latter did give the higher results on some fuller models, as described above, and, secondly, a review of practices in other model basins indicated a more general acceptance of the trip-wire technique rather than studs.

The results of the main series of models, from which all the contours of $C_{R}$ and (C) have been derived, were therefore consistent in that they were all measured on models fitted with trip wires.

## APPENDIX B

## USE OF CONTOURS AND CHARTS

In order to make the data derived from the very extensive Series 60 research project readily available and useful to naval architects, they have been presented wherever possible as design charts and contours. From these the designer can very quickly make an estimate of performance for any normal single-screw merchant ship whose proportions fall within the area covered by the series.

The essential data are shown in the following figures and tables:
Figure 3
Variation of $C_{X}, C_{P}$, and Bilge Radius with $C_{B}$
Figure $4 \quad$ Variation of Angle of Entrance, Position, and Amount of Parallel Body for Series 60 Parents
Figure 5
Figure 6
Contours of Cross-Sectional Area Coefficients
Contours of Waterline Half-Breadth Coefficients
Figure 9
Ratio of $\frac{L_{E}}{L_{B P}}$ for Different Values of $C_{B}$ and Positions of $L C B$
Figure 10
Ratio of $\frac{C_{P E}}{C_{P R}}$ for Different Values of $C_{B}$ and Positions of $L C B$
Figure 11
Figures 26-30
Figure 31
Figure 38
F igures 54-57
Figures B1-B39
Figures B40-B78
Bow and Stern Contours
Cross Curves of (C) to Base of $L C B$ Position
Minimum Values of (C) and Corresponding Optimum LCB Locations
Cross Curves of DHP on $L C B$ Position
Variation of Propulsive Factors with Propeller Diameter and Draft Contours of Residuary Resistance in Pounds per Ton of Displacement Contours of (C) for Ship with 40 C - Ft LBP
Figures B79-B120 Contours of Wake Fraction and Thrust Deduction
Figures B121-B123 Contours of Relative Rotative Efficiency $e_{r r}$
Figures B124-B126 Contours of Wetted Surface Coefficient
Figure B127

Figure D4
Tables 16-26
Tables 27-32
Tables 49-53
Tables B1-B45


To assist in the use of the data, calculation forms for the prediction of ehp and $\mathbb{C O}_{400} \mathrm{ft}$ are given in Tables B46 and B47. The tables are largely self-explanatory, but a few points call for a little comment.

The contours give $\frac{R_{R}}{.1}$ and (C) for three values of $\frac{B}{I I}-2.5,3.0$, and 3.5 . For any particular ship, therefore, it is necessary to interpolate between these to obtain the correct value for the actual $\frac{B}{H}$ of the ship in question. This could be done by plotting the three values and lifting off the ordinate at the correct $\frac{B}{H}$ value. In Table B 46 , it is suggested that this interpolation be done by assuming a parabola to pass through the three points. This, in effect, means that all users will obtain the same value of $\frac{R_{R}}{.}$ or (C) for the desired $\frac{B}{H}$, i.e., it removes personal interpretation of the data; moreover, experience has shown that the data can thereby be extended to $\frac{B}{H}$ values of 2.0 and 4.0 .

For comparison purposes, it is sometimes desirable to compute (C) and ( 4 ) for the actual ship under consideration, and this can be done by completing columns $\mathrm{O}, \mathrm{P}$, and Q in Table B46. This value of (C) will be different from that for the equivalent $400-\mathrm{ft}$ ship, of course, since frictional resistance is a function of length. The value of (C) for lengths other than 400 ft can be estimated approximately from the differences shown in Table B48, due to Professor L.A. Baier (discussion on Reference 63, page 571). Nuch of the resistance data published elsewhere refer to a standard ship length of 400 ft and the (C) contours given in this report are for such a standard length, and for $\frac{B}{H}$ values of $2.5,3.0$, and 3.5 . Table B47 will enable the value of $C_{400 \mathrm{ft}}$ to be interpolated for any other desired value of $\frac{B}{H}$.

The $\frac{R_{F}}{S}$ nomograph in Figure B127 gives a rapid graphical method of finding the frictional resistance per square foot of wetted surface for ships of different lengths operating at various speeds. The results apply to a ship in sea water at a temperature of $59^{\circ} \mathrm{F}\left(15^{\circ} \mathrm{C}\right)$, which has been adopted as a standard figure by the ITTC. A standard ship correlation allowance of +0.0004 has been included. $\frac{R_{F}}{S}$ is obtained by passing a straight line through appropriate values of $V L$ and $V$ and reading the answer at the intersection of this line with the $\frac{R_{F}}{S}$ scale which is connected to the $V$-scale used. Estimates for other than standard correlation allowance of +0.0004 can be made by taking the above $\frac{R_{F}}{S}$ values and increasing them in the ratio of the total $C_{F}$ values for the desired allowance and +0.0004 , respectively. In computing the frictional resistance for estimating power for a proposed vessel, it is recommended that the wetted surface for the proposed vessel be used. If this figure is not known, the wetted surface for the equivalent Series 60 hull can be obtained from the contours in Figures B124 to B126.

The models used in the $\frac{L}{B}, \frac{B}{I}$ series had, for any given block cocfficient, a fixed position of $L C B$, determined from the carlier series of models in which the $L C B$ position was varied. In making ar. estimate of power for a new ship using the Series 60 resistance contours, the result will apply to a ship having the $L C B$ in the position chosen for the parent serics. If for one reason or another, the new design must have the $L C B$ in some other fore and aft position, then a correction must be made for this difference. If it is assumed that the effect of movement of $L C B$ on the parent model of given $C_{B}$ and values of $\frac{L}{B}$ and $\frac{B}{H}$ applies also to a model of the same $C_{B}$ but different values of $\frac{L}{B}$ and $\frac{B}{H}$, appropriate to the design in question, then the correction can be made from the data given in Chapter VI of this report; see Tables 49-53.

In applying results of the kind given in this report, there are often a number of points which at first are somewhat obscure tothe now user and may create difficulties or even errors in making estimates. For this reason, a numerical example has been worked in some detail in Appendix D in the hope that it will obviate any such problems arising in the present work.

Figures B1 through B39
Contours of Residuary Resistance in Pounds per Ton of Displacement


Figure B1


Figure B2


Figure B3


Figure B4


Figure B5


Figure B6


Figure B7


Figure B8


Figure B9


Figure B10
Figure B11


Figure B12

Figure B13


Figure B14


Figure B15


Figure B16


Figure B17


Figure B18

B-11


Figure B19


Figure B20


Figure B21


Figure B22

B-13


Figure B23


Figure B25

Figure B26


Figure B27


Figure B28

B-15


Figure B29


Figure B30


Figure B31


Figure B32


Figure B33


Figure B34


Figure B35


Figure B36
Figure B37



Figure B38


Figure B39

Figures B40 through B78 Contours of © 400 Ft Ship LBP


Figure B40


Figure B41


Figure B42


Figure B43


Figure B44


Figure B45


Figure B46


Figure B47


Figure B48

Figure B49


Figure B50



Figure B53


Figure B54


Figure B55


Figure B56


Figure B57


Figure B58


Figure B59


Figure B60


Figure B61

Figure B62


Figure B63


Figure B64
Figure B65


Figure B66


Figure B67


Figure B68


Figure B69


Figure B70


Figure B71


Figure B72


Figure B73


CONTOURS of ©, 400 Ft . SHIP LBP
Figure B74
Figure B75

B-37


Figure B76


Figures B79 through B120
Contours of Wake Fraction and Thrust Deduction


Figure B79


Figure B80


Figure B81


Figure B82

B-41


Figure B83


Figure B84


Figure B85


Figure B86


Figure B87


Figure B88
Figure B89


Figure B90


Figure B91


Figure B92


Figure B93


Figure B94


Figure B95


Figure B96


Figure B97

## B-47



Figure B98


Figure B99


Figure B100


Figure B101


Figure B102
Figure B103


Figure B104
Figure B105
Figure B106


Figure B107


Figure B108

B-51


Figure B109


Figure B110
B. 52


Figure B111


Figure B112


Figure B113


Figure B114


Figure B115


Figure B116
Figure B117



Figure B120

Figures B121 through B123

Contours of Relative Rotative Efficiency, $e_{r r}$


Figure B121


Figure B122


Figure 123

Figures B124 through B126

## Contours of Wetted Surface Coefficient



Figure B124


Figure B125


Figure B126


Figure B127 - Nomograph for Calculating Frictional Component of Resistance $R_{F}$ on Basis of ATTC Line

TABLES B-1 through B-45

Results of Resistance and Self-Propulsion Experiment for 45 Models of Series 60
TABLE B-1



TABLE B-2
Results of Resistance and Sel f-Propulsion Experiments Model Number 4210, $C_{B}=0.60, L / B=7.5, B / H=2.5$, Propeller Number 3378


 All Figures are for Ship of 400 Ft Length BP



TABLE B-3




| $\mathrm{V} / \mathrm{m}_{\text {vI }}$ | All pigures are for ship of 600 pt Length gp |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $v$ | N | s sp | $\mathrm{w}_{\mathrm{T}}$ | t | ${ }^{0}$ | ${ }^{\text {P }}$ |
| 0.405 | 10.0 | 37.6 | 2412 | 0.295 | 0.195 | 1.241 | 0.674 |
| 0.445 | 12.0 | 41. | 307 | 0.300 | 0.192 | 1.154 | 0.675 |
| 0.486 | 12.0 | 44.5 | 3882 | 0.306 | 0.190 | 1.166 | 0.673 |
| . 526 | 23.0 | 48.3 | 4905 | 0.306 | 0.186 | 1.173 | 0.672 |
| 0.566 | 14.0 | 52.0 | 6120 | 0.309 | 0.184 | 1.182 | 0.670 |
| 0.587 | 14.5 | 54.0 | 6859 | 0.30 | 0.185 | 1.177 | . 670 |
| . 607 | 15. | 56.0 | 2646 | 0.307 | 0.188 | 1.172 | 0.669 |
| 0.628 | 15.5 | 58.0 | 8534 | 0.306 | 0.192 | 1.164 | 0.667 |
| 0.648 | 16.0 | 60.3 | 9540 | 0.302 | 0.199 | 1.147 | 0.669 |
| 0.668 | 16.5 | 62.5 | 610 | 0.296 | 0.205 | 1.129 | 0.670 |
| 0.688 | 17.0 | 64.7 | 11760 | 0.291 | 0.206 | 1.120 | 0.671 |
| . 708 | 17.5 | 67.0 | 130 | 0.283 | 0.206 | 1.107 | 0.6 |
| 0.729 | 18.0 | 69.1 | 14290 | 0.279 | 0.204 | 1.104 | 0.675 |
| 0.749 | 18.5 | 71.2 | 15610 | 0.275 | 0.199 | 1.104 | 0.676 |
| 0.769 | 19.0 | 73.3 | 16900 | 0.270 | 0.19 | 1.1 | 0.6 |
| 0.790 | 19.5 | 75.5 | 18290 | 0.267 | 0,195 | 1.098 | 0.678 |
| 810 | 20.0 | 77.7 | 20000 | 0.268 | 0.197 | 1.0 | 0.676 |
| 0.830 | 20.5 | 80.0 | 22080 | 0.269 | 0.199 | 1.08 | 0.673 |
| 0.851 | 21.0 | 83.0 | 25240 | 0.271 | 0.203 | 1.094 | , 666 |
| 0.871 | 21. | 87.0 | 29910 | 0.268 | 0.201 | 1.091 | 0.659 |
| 0.891 | 22. | 92.0 | 36500 | 0.265 | 0.1 | 1.092 | 0.649 |
| 0.911 | 22.5 | 97.5 | 45140 | 0.262 | 0.1 | 1.10 | 32 |
| 0.932 | 23. | 103.5 | 56250 | 0.250 | 0.175 | 1.100 | 0.622 |
| 0.952 | 23.5 | . 0 | 20160 | 0.236 | 0.161 | 1.099 | 0.613 |
| 0.972 | 24.0 | 127.0 | 86350 | . 216 | 0.152 | 1.081 | 0.6 |
| 0.992 | 24.5 | 124 | 103800 | 0.189 | 0.152 | 1.047 | 0.604 |
| 1.013 | 25.0 | 131.0 | 123000 | 0.164 | 0.159 | 1.005 | 0.603 |
| . 033 | 25.5 | 137.6 | 142000 | 0.132 | 0.173 | 0.952 | 0.607 |

All pigures are for Ship of 400 Ft Length BP
TABLE B-5 Results of Resistance and Self-Propuision Experiments Model Number 4218, $C_{B}=0.65, L / B=7.25, B / H=2.5$, Propeller Number 3380

TABLE B－6

| Results of Resistance and Selif．Propuls ion Experime |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Tel | $c_{1} \times 10^{8}$ | ${ }_{( }$ | © | V／4IM |  |  | stp | ${ }^{\text {T }}$ ， | O | － | ${ }^{\circ}$ |  |
| 0.45 | 2535 |  |  | 0.886 |  |  |  | 0.2720 .147 | 1.12 |  |  |  |
| $\xrightarrow{0.35}$ |  |  |  |  |  |  |  | ${ }_{\substack{0.278 \\ 0.30}}^{0.158}$ | 1．175 | 近 | 1028 |  |
|  | ${ }_{2}^{2.548}$ |  |  | 0．eer |  | ${ }^{\text {ni．}}$ | \％89 |  | 1．188 | ${ }^{\text {a }}$ 0，638 | 1．209 | ， |
| ${ }_{\substack{0}}^{0.085}$ | $\underbrace{2.265}_{208}$ | ${ }_{1}^{12,98}$ | ce．ef | 0 | ${ }^{188} 18$ | 7e， | ¢sis | ${ }^{\text {a }}$ | 1，1989 | ${ }^{\text {a }}$ | 1027 | ， |
| 0.80 | $c20432000$ | $c2006205$ | ${ }_{\text {a }}^{\substack{\text { aroz } \\ 0.007}}$ | O， | ${ }_{\text {lites }}^{12.5}$ |  |  | $\underbrace{\substack{0.158 \\ 0.152}}_{\text {0．2，868 }}$ |  | \％ 0.084 | 退 | ．36 |
|  | ${ }_{2}^{2631}$ | ${ }_{2}^{2294}$ | 20，76 | 0，089 | ${ }_{\text {l2，}}^{12}$ | ${ }_{8}^{8,8}$ | 坔s | ${ }^{\text {0．282 }} 0$ | ， 11.18 | 迷 ${ }^{\text {aess }}$ | a |  |
|  | ceini | 2，4 |  |  |  |  |  |  |  |  |  |  |
|  | ${ }_{\text {3，}}$ |  | （1023 | 0.78 | 19.0 | ${ }_{02,5}^{32,5}$ | veso | ${ }^{0.238} 00.140$ | ${ }^{1.159}$ | o．ess | 1.08 | ， 19 |
|  | ciser |  |  | （0．720 |  | ${ }^{8.1}$ |  | ${ }^{\text {0．2．35 }} 0$ | （1．48 | ${ }^{\text {a }}$ | （1020 |  |
| 0.0 | ${ }^{\text {a，} 200}$ |  |  | 0，800 |  | mo， 8 | 1385 | 0.238 | 1．40 | ${ }_{0}^{1086}$ | ${ }_{\text {1，027 }}$ | ， |
|  |  |  |  |  |  | 10．9 |  | 0.2470 |  |  |  |  |
|  | ${ }^{2.858}$ |  |  | 0.981 |  | 1120 |  | 0.344 | 1.24 | \％e93 | 1.02 |  |
| ${ }^{1.078}$ | ${ }_{3}^{3.808}$ |  |  | 0.911 |  |  |  |  | ${ }^{1.144}$ |  | 108 |  |
|  |  |  |  |  |  |  |  | coill |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  | coill |  |  |  |  |
|  |  |  |  |  | 22.5 |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |

TABLE B-7

| Results of Resistance and Self-Propulsion Experiments Model Number 4244, $C_{B}=0.70, L / B=6.0, B / H=2.5$, Propeller Number 2452 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| All Figures are for Ship of 400 Ft Length BP |  |  |  |  | All Figures are for Ship of 600 Ft Length BP |  |  |  |  |  |  |  |  |
| $V^{\prime} \sqrt{L_{\text {WI }}}$ | $\mathrm{C}_{\mathrm{t}} \times 10^{3}$ | (K) |  | $V / \sqrt{L_{W L}}$ | V | N | SHP | ${ }^{W}$ T | $t$ | ${ }^{\text {e }} \mathrm{h}$ | ${ }^{\text {e }}$ p | ${ }^{0} \mathrm{rr}$ | EHP/SHP |
| 0.40 | 3.068 | 0.957 | 0.720 | 0.364 | 9.0 | 31.1 | 1895 | 0.324 | 0.214 | 1.164 | 0.657 | 1.081 | 0.827 |
| 0.45 | 3.048 | 1.076 | 0.715 | 0.405 | 10.0 | 34.5 | 2541 | 0.316 | 0.218 | 1.144 | 0.664 | 1.084 | 0.824 |
| 0.50 | 3.052 | 1.196 | 0.716 | 0.445 | 11.0 | 37.8 | 3339 | 0.324 | 0.218 | 1.156 | 0.661 | 1.088 | 0.931 |
| 0.55 | 3.081 | 1.315 | 0.723 | 0.486 | 12.0 | 41.2 | 4354 | 0.330 | 0.218 | 1.168 | 0.657 | 1.085 | 0.833 |
| 0.60 | 3.128 | 1.435 | 0.734 | 0.526 | 13.0 | 44.9 | 5635 | 0.325 | 0.221 | 1.154 | 0.658 | 1.087 | 0.825 |
| 0.625 | 3.150 | 1.495 | 0.739 | 0.566 | 14.0 | 48.9 | 7254 | 0.313 | 0.225 | 1.129 | 0.661 | 1.084 | 0.809 |
| 0.65 | 3.173 | 1.555 | 0.744 | 0.607 | 15.0 | 52.8 | 9166 | 0.304 | 0.222 | 1.117 | 0.663 | 1.078 | 0.799 |
| 0.675 | 3.191 | 1.614 | 0.748 | 0.628 | 15.5 | 54.6 | 10220 | 0.305 | 0.218 | 1.125 | 0.662 | 1.072 | 0.798 |
| 0.70 | 3.217 | 1.674 | 0.754 | 0.648 | 16.0 | 56.4 | 11280 | 0.307 | 0.216 | 1.130 | 0.661 | 1.070 | 0.800 |
| 0.725 | 3.266 | 1.734 | 0.766 | 0.668 | 16.5 | 58.1 | 12370 | 0.310 | 0.213 | 1.141 | 0.659 | 1.072 | 0.806 |
| 0.75 | 3.332 | 1.794 | 0.781 | 0.688 | 17.0 | 60.0 | 13560 | 0.309 | 0.213 | 1.140 | 0.659 | 1.076 | 0.808 |
| 0.775 | 3.395 | 1.854 | 0.796 | 0.708 | 17.5 | 62.0 | 14940 | 0.308 | 0.214 | 1.135 | 0.658 | 1.077 | 0.806 |
| 0.80 | 3.477 | 1.913 | 0.815 | 0.729 | 18.0 | 64.0 | 16480 | 0.305 | 0.214 | 1.131 | 0.658 | 1.077 | 0.801 |
| 0.825 | 3.589 | 1.973 | 0.842 | 0.749 | 18.5 | 66.3 | 18270 | 0.297 | 0.214 | 1.118 | 0.660 | 1.076 | 0.794 |
| 0.85 | 3.777 | 2.033 | 0.886 | 0.769 | 19.0 | 68.8 | 20330 | 0.288 | 0.214 | 1.105 | 0.661 | 1.076 | 0.785 |
| 0.875 | 4.249 | 2.093 | 0.996 | 0.790 | 19.5 | 71.2 | 22740 | 0.284 | 0.212 | 1.100 | 0.660 | 1.071 | 0.777 |
| 0.90 | 5.076 | 2.153 | 1.190 | 0.810 | 20.0 | 73.9 | 25520 | 0.275 | 0.202 | 1.093 | 0.660 | 1.087 | 0.770 |
|  |  |  |  | 0.830 | 20.5 | 76.6 | 28810 | 0.270 | 0.198 | 1.099 | 0.657 | 1.060 | 0.768 |
|  |  |  |  | 0.851 | 21.0 | 79.5 | 32760 | 0.271 | 0.187 | 1.115 | 0.651 | 1.054 | 0.765 |
|  |  |  |  | 0.891 | 22.0 | 87.8 | 47450 | 0.272 | 0.139 | 1.181 | 0.624 | 1.037 | 0.765 |




|  | All Figures are for Stip of 600 Ft Length BP |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\mathrm{V} / \sqrt{L_{W L}}$ | v | N | SHP | ${ }_{\text {W }}^{\text {T }}$ | $t$ | $0_{\text {h }}$ | ${ }^{\circ} \mathrm{p}$ |
| 0.364 | 9.0 | 36.4 | 1520 | 0.314 | 0.146 | 1.245 | 0.661 |
| 0.405 | 10.0 | 40.4 | 2039 | 0.297 | 0.128 | 1.24 | . 873 |
| 0.445 | 11.0 | 44.5 | 2717 | 0.299 | 0.180 | 1.241 | 0.671 |
| 0.486 | 12.0 | 48.7 | 51 | 0.291 | 0.138 | 1.21 | 0.675 |
| 0.526 | 13.0 | 52.9 | 4558 | 0.294 | 0.148 | 1.20 | 0.672 |
| 0.568 | 14.0 | 57.3 | 8842 | 0.298 | 0.15 | 1.20 | 0.668 |
| 0.807 | 15.0 | 61.9 | 7807 | 0.291 | 0.156 | 1.191 | 0.667 |
| 0.628 | 15.5 | 64.2 | 8206 | 0.294 | 0.15 | 1.18 | 8.863 |
| 0.648 | 16.0 | 66.5 | 9036 | 0.287 | 0.158 | 1.18 | 0.660 |
| 0.668 | 16.5 | 69.0 | 10050 | 0.283 | 0.160 | 1:17 | . 660 |
| 0.688 | 17.0 | 71.2 | 11100 | 0.284 | 0.160 | 1.17 | 0.665 |
| 0.708 | 17 | 73.8 | 12320 | 0.277 | 0.161 | 1.180 | 0.666 |
| 0.729 | 18.0 | 78.4 | 13630 | 0.272 | 0.164 | 1.148 | 0.660 |
| . 49 | 18 | 79.2 | 15250 | 0.277 | 0.171 | 1.146 | . 659 |
| 0.769 | 19.0 | 81.9 | 17030 | 0.279 | 0.176 | 1.148 | 0.654 |
| 0.790 | 19.5 | 84.8 | 19010 | 0.276 | 0.177 | 1.13 | 0.652 |
| 0.810 | 20.0 | 87.8 | 21390 | 0.279 | 0.176 | 1.143 | 0.6 |
| 0.830 | 20.5 | 90.6 | 23900 | 0.281 | 0.176 | 1.147 | 0.641 |
| 0.851 | 21.0 | 93.8 | 26810 | 0.281 | 0.168 | 1.157 | 0.636 |
| 0.871 | 21.5 | 98.2 | 31550 | 0.275 | 0.151 | 1.171 | 0.629 |
| 0.891 | 22.0 | 104.0 | 38430 | 0.286 | 0.157 | 1.18 | 0.6 |

All Figures are for Ship of 400 Ft Length BP

$$
\begin{aligned}
& \text { Results of Resistance and Self-Propulsion Experiments } \\
& \text { Model Number 4221, } C_{B}=0.70, L / B=7.00, B / H=2.5 \text {, Propeller Number } 3376
\end{aligned}
$$

(ㄷ)

TABLE B-9

Model Number 4247, $C_{B}=0.70, L / B=8.0, B / H=2.5$, Propeller Number 3565
Results of Resistance and Self-Propulsion Experiments
 All Figures are for Ship of 600 Ft Length BP

| $v / \sqrt{L_{W L}}$ | $v$ | N | SHP | ${ }^{W}$ T | t | ${ }^{\text {e }} \mathrm{h}$ | ${ }^{\text {ep }}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0.364 | 9.0 | 45.6 | 1472 | 0.411 | 0.279 | 1.225 | 0.556 |
| 0.405 | 10.0 | 50.8 | 1949 | 0.382 | 0.261 | 1.195 | 0.576 |
| 0.445 | 11.0 | 58.0 | 2548 | 0.368 | 0.248 | 1.188 | 0.586 |
| 0.486 | 12.0 | 61.2 | 3277 | 0.360 | 0.234 | 1.196 | 0.590 |
| 0.526 | 13.0 | 66.6 | 4159 | 0.354 | 0.228 | 1.194 | 0.593 |
| 0.566 | 14.0 | 72.1 | 5215 | 0.348 | 0.229 | 1.182 | 0.594 |
| 0.607 | 15.0 | 77.6 | 6464 | 0.344 | 0.228 | 1.176 | 0.595 |
| 0.628 | 15.5 | 80.3 | 7153 | 0.344 | 0.228 | 1.180 | 0.594 |
| 0.648 | 16.0 | 83.1 | 7922 | 0.341 | 0.224 | 1.177 | 0.595 |
| 0.668 | 16.5 | 86.0 | 8765 | 0.339 | 0.223 | 1.175 | 0.595 |
| 0.688 | 17.0 | 88.9 | 9886 | 0.336 | 0.225 | 1.168 | 0.595 |
| 0.708 | 17.5 | 91.8 | 10710 | 0.338 | 0.228 | 1.167 | 0.592 |
| 0.729 | 18.0 | 95.0 | 11890 | 0.335 | 0.228 | 1.159 | 0.592 |
| 0.749 | 18.5 | 88.6 | 13320 | 0.329 | 0.225 | 1.156 | 0.591 |
| 0.769 | 19.0 | 102.3 | 14990 | 0.329 | 0.216 | 1.167 | 0.587 |
| 0.790 | 19.5 | 106.3 | 16840 | 0.322 | 0.210 | 1.166 | 0.586 |
| 0.810 | 20.0 | 110.1 | 18740 | 0.318 | 0.212 | 1.155 | 0.584 |
| 0.830 | 20.5 | 115.1 | 20940 | 0.310 | 0.219 | 1.132 | 0.584 |
| 0.851 | 21.0 | 118.7 | 23490 | 0.302 | 0.225 | 1.110 | 0.583 |
| 0.891 | 22.0 | 130.7 | 31810 | 0.308 | 0.236 | 1.103 | 0.570 | All Figures are for Ship of $\mathbf{4 0 0} \mathrm{Ft}$ Length BP

EHP/SHP

0.688
0.703
0.714
0.730
0.737
0.738
0.739
0.742
0.741
0.740
0.736
0.732
0.727
0.726
0.725
0.724
0.716
0.700
0.688
0.669
 ..... $\stackrel{8}{\circ}$
TABLE B-10

| Results of Resistance and Self-Propulsion Experiments 1 Number 4268, $C_{B}=0.75, L / B=5.75, B / H=2.5$, Propeller Number 3156 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| All Figures are for Ship of 400 Ft Length BP |  |  |  |  | All Figures are for Ship of 600 Ft Length BP |  |  |  |  |  |  |  |  |
| $v / \sqrt{L_{W L}}$ | $C_{t} \times 10^{3}$ | (K) | (C) | $v / \sqrt{L_{W L}}$ | V | N | SHP | $W_{T}$ | $t$ | $e_{h}$ | $\mathbf{e p}_{p}$ | $\mathbf{e r r r}^{\text {r }}$ | EHP/SHP |
| 0.35 | 3.193 | 0.816 | 0.734 | 0.405 | 10.0 | 34.8 | 3055 | 0.323 | 0.174 | 1.219 | 0.650 | 1.011 | 0.801 |
| 0.40 | 3.166 | 0.932 | 0.728 | 0.445 | 11.0 | 38.0 | 3970 | 0.330 | 0.186 | 1.215 | 0.648 | 1.016 | 0.801 |
| 0.45 | 3.144 | 1.049 | 0.723 | 0.486 | 12.0 | 41.2 | 5103 | 0.340 | 0.192 | 1.225 | 0.645 | 1.018 | 0.803 |
| 0.50 | 3.154 | 1.166 | 0.725 | 0.526 | 13.0 | 44.9 | 6587 | 0.337 | 0.199 | 1.209 | 0.644 | 1.021 | 0.795 |
| 0.55 | 3.186 | 1.282 | 0.732 | 0.566 | 14.0 | 48.9 | 8416 | 0.326 | 0.202 | 1.184 | 0.646 | 1.027 | 0.786 |
| 0.575 | 3.206 | 1.340 | 0.737 | 0.587 | 14.5 | 50.9 | 9463 | 0.323 | 0.202 | 1.178 | 0.646 | 1.030 | 0.784 |
| 0.60 | 3.238 | 1.399 | 0.744 | 0.607 | 15.0 | 52.8 | 10620 | 0.321 | 0.201 | 1.176 | 0.646 | 1.029 | 0.781 |
| 0.625 | 3.275 | 1.457 | 0.753 | 0.628 | 15.5 | 54.8 | 11890 | 0.322 | 0.203 | 1.175 | 0.644 | 1.029 | 0.778 |
| 0.65 | 3.330 | 1.515 | 0.765 | 0.648 | 16.0 | 56.8 | 13320 | 0.319 | 0.199 | 1.177 | 0.643 | 1.027 | 0.778 |
| 0.675 | 3.407 | 1.574 | 0.783 | 0.668 | 16.5 | 59.1 | 15010 | 0.316 | 0.201 | 1.169 | 0.642 | 1.028 | 0.771 |
| 0.70 | 3.545 | 1.632 | 0.815 | 0.688 | 17.0 | 61.5 | 16980 | 0.316 | 0.206 | 1.160 | 0.638 | 1.033 | 0.764 |
| 0.725 | 3.815 | 1.690 | 0.877 | 0.708 | 17.5 | 64.3 | 19500 | 0.316 | 0.208 | 1.158 | 0.631 | 1.038 | 0.758 |
| 0.75 | 4.177 | 1.748 | 0.960 | 0.729 | 18.0 | 67.1 | 22760 | 0.320 | 0.206 | 1.168 | 0.621 | 1.040 | 0.754 |
| 0.775 | 4.525 | 1.807 | 1.040 | 0.749 | 18.5 | 70.4 | 26840 | 0.324 | 0.204 | 1.177 | 0.609 | 1.039 | 0.745 |
| 0.80 | 4.824 | 1.865 | 1.109 | 0.769 | 19.0 | 74.0 | 31780 | 0.317 | 0.194 | 1.181 | 0.603 | 1.031 | 0.734 |
| 0.825 | 5.063 | 1.923 | 1.164 | 0.790 | 19.5 | 77.8 | 37330 | 0.303 | 0.183 | 1.171 | 0.602 | 1.022 | 0.721 |
| 0.85 | 5.277 | 1.982 | 1.213 | 0.810 | 20.0 | 81.2 | 42980 | 0.293 | $0.17 \%$ | 2.168 | 0.600 | 1.014 | 0.710 |
| 0.875 | 5.491 | 2.040 | 1.262 | 0.830 | 20.5 | 84.7 | 48720 | 0.278 | 0.168 | 1.152 | 0.602 | 1.011 | 0.701 |
|  |  |  |  | 0.851 | 21.0 | 87.6 | 54240 | 0.276 | 0.163 | 1.155 | 0.599 | 1.010 | 0.699 |
|  |  |  |  | 0.871 | 21.5 | 90.7 | 59880 | 0.276 | 0.156 | 1.164 | 0.594 | 1.012 | 0.700 |
|  |  |  |  | 0.891 | 22.0 | 93.4 | 66280 | 0.276 | 0.152 | 1.170 | 0.591 | 1.016 | 0.702 |

TABLE B-11
Results of Resistance and Self-Propulsion Experiments Model Number 4213, $C_{B}=0.75, L / B=6.75, B / H=2.5$, Propeller Number 3379
SHP/EHP

0.840
0.844
0.821
0.812
0.808
0.803
0.800
0.798
0.792
0.788
0.780
0.775
0.764
0.750
0.733
0.719
0.711
0.701
0.691
0.673
0.682
0.653


| V | All Figures are for Ship of 600 Ft Length BP |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | N | SHP | ${ }^{W}$ T | t | $\theta_{\text {b }}$ | ${ }^{\text {e }}$ p |
| 9.0 | 36.1 | 1638 | 0.337 | 0.140 | 1.299 | 0.650 |
| 10.0 | 40.1 | 2204 | 0.329 | 0.139 | 1.282 | 0.656 |
| 11.0 | 44.4 | 2955 | 0.313 | 0.149 | 1.289 | 0.663 |
| 12.0 | 48.7 | 3895 | 0.310 | 0.154 | 1.224 | 0.683 |
| 13.0 | 53.1 | 5064 | 0.311 | 0.161 | 1.218 | 0.659 |
| 14.0 | 57.5 | 6408 | 0.307 | 0.164 | 1.206 | 0.659 |
| 14.5 | 59.8 | 7223 | 0.307 | 0.168 | 1.203 | 0.658 |
| 15.0 | 62.1 | 8172 | 0.311 | 0.168 | 1.208 | 0.652 |
| 15.5 | 64.5 | 9143 | 0.307 | 0.171 | 1.198 | 0.658 |
| 16.0 | 67.0 | 10340 | 0.309 | 0.173 | 1.197 | 0.648 |
| 16.5 | 70.0 | 11820 | 0.305 | 0.178 | 1.186 | 0.644 |
| 17.0 | 72.9 | 13470 | 0.306 | 0.178 | 1.185 | 0.638 |
| 17.5 | 76.2 | 15410 | 0.298 | 0.180 | 1.169 | 0.636 |
| 18.0 | 80.0 | 18100 | 0.293 | 0.179 | 1.162 | 0.680 |
| 18.5 | 84.1 | 21380 | 0.287 | 0.178 | 1.153 | 0.623 |
| 19.0 | 88.5 | 25410 | 0.280 | 0.171 | 1.152 | 0.616 |
| 19.5 | 93.3 | 30830 | 0.280 | 0.158 | 1.170 | 0.604 |
| 20.0 | 98.2 | 38110 | 0.271 | 0.151 | 1.164 | 0.597 |
| 20.5 | 102.5 | 41200 | 0.258 | 0.146 | 1.152 | 0.596 |
| 21.0 | 108.9 | 48890 | 0.242 | 0.147 | 1.126 | 0.598 |
| 21.5 | 111.0 | 53090 | 0.238 | 0.148 | 1.119 | 0.594 |
| 22.0 | 115.0 | 60290 | 0.244 | 0.147 | 1.129 | 0.584 |


| All Figures are for Ship of 400 Ft | Length BP |  |  |
| :--- | :---: | :---: | :---: |
| $\mathrm{V} / \sqrt{L_{W L}}$ | $\mathrm{C}_{\mathrm{t}} \times 10^{3}$ | K | C |
| 0.85 | 2.911 | 0.861 | 0.705 |
| 0.40 | 2.881 | 0.984 | 0.697 |
| 0.45 | 2.876 | 1.107 | 0.696 |
| 0.50 | 2.902 | 1.280 | 0.702 |
| 0.55 | 2.834 | 1.352 | 0.710 |
| 0.575 | 2.947 | 1.414 | 0.713 |
| 0.80 | 2.977 | 1.475 | 0.720 |
| 0.625 | 3.046 | 1.537 | 0.737 |
| 0.65 | 3.135 | 1.598 | 0.759 |
| 0.675 | 3.222 | 1.660 | 0.780 |
| 0.70 | 3.357 | 1.721 | 0.812 |
| 0.725 | 3.568 | 1.783 | 0.862 |
| 0.75 | 3.871 | 1.844 | 0.937 |
| 0.775 | 4.230 | 1.908 | 1.024 |
| 0.80 | 4.623 | 1.967 | 1.119 |
| 0.825 | 4.983 | 2.029 | 1.206 |
| 0.85 | 5.272 | 2.080 | 1.276 |
| 0.875 | 5.562 | 2.152 | 1.846 |

TABLE B-12
Results of Resistance and Self-Propulsion Experiments
Model Number 4271, $C_{B}=0.75, L / B=7.75, B / H=2.5$, Propeller Nımber 3375

|  | All P1gures are for Ship of 600 Ft Longth BP |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | v | N | SHP | ${ }^{4}$ | $t$ | ${ }_{0}$ | ${ }^{\circ}$ |
| 0.364 | 9.0 | 46.4 | 1499 | 0.300 | 0.110 | 1.272 | 0.633 |
| 0.405 | 10.0 | 51.0 | 1995 | 0.310 | 0.118 | 1.278 | 0.634 |
| . 445 | 11.0 | 55.9 | 2632 | 0.316 | 0.124 | 1.280 | 0.633 |
| 0.486 | 12.0 | 61.3 | 3428 | 0.315 | 0.133 | 1.266 | 0.632 |
| 0.526 | 13.0 | 67.4 | 4417 | 0.308 | 0.15 | 1.226 | 0.63 |
| 0.566 | 14.0 | 73. | 5658 | 0.311 | $0.17{ }^{17}$ | 1.198 | 0.625 |
| 0.587 | 14.5 | 76.3 | 6363 | 0.315 | 0.182 | 1.194 | 0.621 |
| 0.607 | 15.0 | 79.1 | 7222 | 0.315 | 0.181 | 1.196 | 0.616 |
| 0.628 | 15.5 | 82. | 8130 | 0.314 | 0.180 | 1.194 | 0.613 |
| 0.648 | 16.0 | 85.6 | 9200 | 0.311 | 0.180 | 1.190 | 0.613 |
| 0.668 | 16.5 | 89. | 10380 | 0.306 | 0.179 | 1.183 | 0.61 |
| 0.688 | 17.0 | 93.4 | 12000 | 0.302 | 0.178 | 1.177 | 0.610 |
| 0.708 | 17.5 | 97 | 14090 | 0.302 | 0.179 | 1.175 | 0.606 |
| . 729 | 18.0 | 102.3 | 16330 | 0.299 | 0.177 | 1.174 | 0.59 |
| 0.749 | 18.5 | 107. | 19530 | 0.299 | 0.181 | 1.168 | 0.58 |
| 0.769 | 19.0 | 113. | 23720 | 0.302 | 0.182 | 1.172 | 0.573 |
| 0.790 | 19.5 | 120.2 | 28600 | 0.304 | 0.184 | 1.173 | 0.560 |
| 0.810 | 20.0 | 126.3 | 33430 | 0.298 | 0.178 | 1.171 | 0.554 |
| 0.830 | 20.5 | 231.5 | 38150 | 0.294 | 0.172 | 1.173 | 0.549 |
| 0.851 | 21.0 | 236.3 | 42510 | 0.291 | 0.170 | 1.170 | 0.546 |
| 0.871 | 21.5 | 141.9 | 47510 | 0.278 | 0.176 | 1.140 | 0.547 |
| . 891 | 22.0 | 149.2 | 53390 | 0.231 | 0.172 | 1.076 | 0.56 | 111 Figures are for Ship of 400 Ft Length BP




TABLE B-13

| $v / \sqrt{L_{W L}}$ | $c_{t} \times 10^{3}$ | (1) | (C) | $\mathrm{V} / \sqrt{L_{W L}}$ | V | $N$ | SHF | $W_{T}$ | t | ${ }^{6}$ | ${ }^{\bullet} \mathrm{p}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0.35 | 3.563 | 0.795 | 0.808 | 0.364 | 9.0 | 31.8 | 2788 | 0.429 | 0.238 | 1.334 | 0.548 |
| 0.40 | 3.533 | 0.909 | 0.802 | 0.405 | 10.0 | 35.0 | 3665 | 0.428 | 0.238 | 1.331 | 0.552 |
| 0.45 | 3.508 | 1.022 | 0.796 | 0.445 | 11.0 | 38.4 | 4774 | 0.428 | 0.233 | 1.342 | 0.553 |
| 0.50 | 3.489 | 1.136 | 0.791 | 0.465 | 11.5 | 40.1 | 5440 | 0.426 | 0.232 | 1.339 | 0.555 |
| 0.525 | 3.485 | 1.193 | 0.791 | 0486 | 12.0 | 41.8 | 6151 | 0.426 | 0.228 | 1.345 | 0.556 |
| 0.55 | 3.508 | 1.250 | 0.796 | 0.506 | 12.5 | 43.6 | 6950 | 0.421 | 0.223 | 1.342 | 0.559 |
| 0.575 | 3.566 | 1.306 | 0.809 | 0.526 | 13.0 | 45.5 | 7829 | 0.417 | 0.219 | 1.339 | 0.562 |
| 0.60 | 3.664 | 1.363 | 0.831 | 0.546 | 13.5 | 47.3 | 8843 | 0.417 | 0.216 | 1.346 | 2.560 |
| 0.625 | 3.793 | 1.420 | 0.860 | 0.566 | 14.0 | 49.3 | 10010 | 0.415 | 0.215 | 1.344 | 0.559 |
| 0.65 | 3.982 | 1.477 | 0.903 | 0.587 | 14.5 | 51.4 | 11390 | 0.413 | 0.215 | 1.336 | 0.558 |
| 0.675 | 4.237 | 1.534 | 0.961 | 0.607 | 15.0 | 53.7 | 12980 | 0.414 | C. 216 | 1.340 | 0.552 |
| 0.70 | 4.585 | 1.590 | 1.040 | 0.628 | 15.5 | 56.1 | 14940 | 0.412 | 0.220 | 1.327 | 0.548 |
| 0.75 | 5.567 | 1.704 | 1.263 | 0.648 | 16.0 | 58.8 | 17290 | 0.404 | 0.220 | 1.309 | 0.548 |
| 2.80 | 7.029 | 1.818 | 1.594 | 0.688 | 17.0 | 64.9 | 23580 | 0.393 | 0.216 | 1.293 | 0.539 |
|  |  |  |  | 0.729 | 18.0 | 72.4 | 33870 | 0.375 | 0.199 | 1.283 | 0.529 |
|  |  |  |  | 0.769 | 19.0 | 82.4 | 51360 | 0.349 | 0.175 | 1.268 | 0.514 |
|  |  |  |  | 0.810 | 20.0 | 93.8 | 80720 | 0.349 | 0.155 | 1.298 | 0.488 |

TABLE B-14

| Results of .lesistance and Self-Propulsion Experiments el Number 4214, $C_{B}=0.80, L / B=6.5, B / H=2.5$, Propeller Number 3377 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 111 Figures | for Ship | or 400 | t Length PP |  |  |  | $\mathrm{Figu}^{\text {g }}$ |  |  |  |  |  |  |
| $\nabla / \sqrt{10 \sqrt{1}}$ | $c_{t} \times 10^{3}$ | (ᄌ) | (C) | $\nabla / \sqrt{L_{\text {WI }}}$ | $\nabla$ | N | SHP | $W_{T}$ | t | ${ }^{0} \mathrm{~h}$ | ${ }^{\circ} \mathrm{p}$ | ${ }^{9} \mathbf{r r}$ | SHP/SHF |
| 0.35 | 3.006 | 0.841 | 0.719 | 0.364 | 9.0 | 38.4 | 1959 | 0.363 | 0.164 | 1.313 | 0.624 | 1.005 | 0.824 |
| 0.40 | 2.991 | 0.961 | 0.715 | 0.405 | 10.0 | 42.6 | 2640 | 0.359 | 0.171 | 1.293 | 0.628 | 1.011 | 0.821 |
| 0.45 | 2.992 | 1.081 | 0.716 | 0.445 | 11.0 | 46.8 | 3491 | 0.356 | 0.177 | 1.279 | 0.630 | 1.008 | 0.813 |
| 0.50 | 3.009 | 1.201 | 0.720 | 0.466 | 11.5 | 48.9 | 3983 | 0.357 | 0.182 | 1.272 | 0.630 | 1.009 | 0.809 |
| 0.525 | 3.025 | 1.261 | 0.724 | 0.486 | 12.0 | 51.2 | 4543 | 0.352 | 0.186 | 1.256 | 0.632 | 1.011 | 0.802 |
| 0.55 | 3.056 | 1.321 | 0.731 | 0.506 | 12.5 | 53.4 | 5193 | 0.355 | 0.191 | 1.255 | 0.629 | 1.010 | 0.798 |
| 0.575 | 3.116 | 1.381 | 0.745 | 0.526 | 13.0 | 55.8 | 5951 | 0.357 | 0.197 | 1.250 | 0.626 | 1.013 | 0.792 |
| 0.60 | 3.236 | 1.441 | 0.774 | 0.546 | 13.5 | 58.2 | 6692 | 0.350 | 0.199 | 1.233 | 0.628 | 1.016 | 0.788 |
| 0.625 | 3.387 | 1.502 | 0.810 | 0.566 | 14.0 | 60.7 | 7671 | 0.352 | 0.200 | 1.235 | 0.624 | 1.014 | 0.783 |
| 0.65 | 3.585 | 1.562 | 0.857 | 0.587 | 14.5 | 63.4 | 8767 | 0.350 | 0.198 | 1.234 | 0.622 | 1.015 | 0.780 |
| 0.675 | 3.857 | 1.622 | 0.922 | 0.607 | 15.0 | 66.5 | 10170 | 0.348 | 0.196 | 1.233 | 0.618 | 1.020 | 0.777 |
| 0.70 | 4.210 | 1.682 | 1.007 | 0.628 | 15.5 | 69.7 | 11800 | 0.341 | 0.191 | 1.228 | 0.616 | 1.018 | 0.770 |
| 0.75 | 5.003 | 1.802 | 1.196 | 0.648 | 16.0 | 73.3 | 13750 | 0.336 | 0.190 | 1.219 | 0.611 | 1.024 | 0.763 |
| 0.80 | 6.538 | 1.922 | 1.564 | 0.688 | 17.0 | 81.2 | 19110 | 0.329 | 0.188 | 1.211 | 0.596 | 1.029 | 0.743 |
|  |  |  |  | 0.729 | 18.0 | 90.8 | 27650 | 0.315 | 0.184 | 1.192 | 0.581 | 1.022 | 0.708 |
|  |  |  |  | 0.769 | 19.0 | 102.4 | 41790 | 0.309 | 0.183 | 1.183 | 0.555 | 1.011 | 0.664 |

TABLE B-15
Results of Resistance and Self-Propulsion Experiments Model Number 4215, $C_{B}=0.80, L / B=7.5, B / H=2.5$, Propeller Number 3378

| $v / \sqrt{4 \times \pi}$ | V | 111 Figures are for ship of 600 Ft Length BP |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | צ | stip | $\omega_{\mathbf{r}}$ | t | $O_{6}$ | P |
| 0.364 | 9.0 | 40.9 | 1624 | 0.378 | 0.199 | 1.287 | 0.585 |
| 0.405 | 10.0 | 45.1 | 2149 | 0.372 | 0.208 | 1.260 | 0.593 |
| 0.445 | 11.0 | 49.7 | 2866 | 0.363 | 0.213 | 1.235 | 0.602 |
| 0.466 | 11.5 | 52.4 | 3295 | 0.353 | 0.214 | 1.215 | 0.607 |
| 0.486 | 12.0 | 54.7 | 3754 | 0.348 | 0.213 | 1.208 | 0.607 |
| 0.506 | 12.5 | 57.4 | 4304 | 0.337 | 0.210 | 1.192 | 0.608 |
| 0.526 | 13. | 60.0 | 4916 | 0.334 | 0.204 | 1.195 | 0.608 |
| 0.546 | 13.5 | 62.7 | 5628 | 0.331 | 0.198 | 1.199 | 0.607 |
| 0.566 | 14.0 | 65.5 | 6439 | 0.331 | 0.194 | 1.206 | 0.604 |
| 0.587 | 14.5 | 68.3 | 7440 | 0.336 | 0.194 | 1.212 | 0.598 |
| 0.607 | 15.0 | 71.6 | 8684 | 0.334 | 0.194 | 1.210 | 0.594 |
| 0.628 | 15.5 | 75.0 | 10170 | 0.333 | 0.198 | 1.202 | 0.588 |
| 0.648 | 16.0 | 78.9 | 11980 | 0.328 | 0.199 | 1.192 | 0.583 |
| 0.688 | 17.0 | 87.4 | 16780 | 0.317 | 0.195 | 1.177 | 0.572 |
| 0.729 | 18.0 | 97.4 | 23730 | 0.304 | 0.182 | 1.176 | 0.552 |
| 0.769 | 19.0 | 109.4 | 34910 | 0.293 | 0.174 | 1.168 | 0.538 |
| 0.810 | 20.0 | 123.6 | 52840 | 0.274 | 0.166 | 1.149 | 0.519 |

111 Figures are for Ship of 400 Ft Length BP

TABLE B-16
Results of Resistance and Self-Propulsion Experiments

$$
\text { Model Number 4252, } C_{B}=0.60, L / B=6.5, B / H=3.0, \text { Propeller Number } 3375
$$


TABLE B-17



-







| $\mathrm{V} / 4 \mathrm{hin}$ |
| :--- |
| 0.445 |
| 0.486 |
| 0.526 |
| 0.566 |
| 0.607 |
| 0.628 |
| 0.648 |
| 0.668 |
| 0.688 |
| 0.708 |
| 0.729 |
| 0.749 |
| 0.769 |
| 0.790 |
| 0.810 |
| 0.830 |
| 0.851 |
| 0.872 |
| 0.891 |
| 0.911 |
| 0.932 |
| 0.952 |
| 0.972 |
| 0.992 |
| 1.013 |
| 1.033 |
| 1.053 |
| 1.074 |
| .094 |

All Figures are for Ship of 400 Ft Length BP
(*)


| Model Number 4254, $C_{B}=0.60, L / B=8.5, B / H=3.0$, Propeller Number 2765 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\triangle 11$ figures are for Ship |  | or 400 | Pt Lensth PP |  | 111 Flgures are for Ship of 600 Ft Length BP |  |  |  |  |  |  |  |  |
| $7 / \sqrt{4}$ | $c_{8} \times 10^{3}$ | (1) | © | V/ $\sqrt{20}$ | V | * | SHP | ${ }_{T}$ | $t$ | \% | ${ }^{\bullet} \mathrm{p}$ | ${ }^{\text {r }}$ r | EHP/SEP |
| 0.45 | 2.526 | 1.278 | 0.698 | 0.445 | 11.0 | 71.5 | 2000 | 0.321 | 0.147 | 1.256 | 0.609 | 0.901 | 0.689 |
| 0.50 | 2.505 | 1.420 | 0.692 | 0.486 | 12.0 | 77.7 | 2516 | 0.325 | c.162 | 1.242 | 0.609 | 0.919 | 0.695 |
| 0.55 | 2.488 | 1.563 | 0.688 | 0.526 | 13.0 | 84.0 | 3130 | 0.326 | 0.167 | 1.235 | 0.610 | 0.931 | 0.701 |
| 0.60 | 2.484 | 1.705 | 0.686 | 0.566 | 14.0 | 91.0 | 3905 | 0.319 | 0.170 | 1.219 | 0.612 | 0.945 | 0.704 |
| 0.65 | 2.507 | 1.847 | 0.693 | 0.607 | 15.0 | 98.0 | 4810 | 0.316 | 0.168 | 1.217 | 0.611 | 0.958 | 0.713 |
| 0.70 | 2.541 | 1.989 | 0.708 | 0.628 | 15.5 | 102.0 | 5361 | 0.308 | 0.169 | 1.201 | 0.613 | 0.966 | 0.712 |
| 0.75 | 2.567 | 2.131 | 0.709 | 0.648 | 16.0 | 105.5 | 5919 | 0.307 | 0.169 | 1.199 | 0.612 | 0.970 | 0.712 |
| 0.80 | 2.601 | 2.273 | 0.719 | 0.668 | 16.5 | 109.5 | 6583 | 0.305 | 0.172 | 1.192 | 0.612 | 0.978 | 0.712 |
| 0.825 | 2.632 | 2.344 | 0.727 | 0.688 | 17.0 | 113.2 | 7238 | 0.307 | 0.174 | . 1.192 | 0.610 | 0.985 | 0.714 |
| 0.850 | 2.687 | 2.415 | 0.743 | 0.708 | 17.5 | 116.8 | 7948 | 0.309 | 0.177 | 1.190 | 0.607 | 0.991 | 0.716 |
| 0.875 | 2.789 | 2.486 | 0.771 | 0.729 | 18.0 | 120.8 | 8730 | 0.301 | 0.178 | 1.176 | 0.610 | 0.993 | 0.712 |
| 0.90 | 2.939 | 2.556 | 0.812 | 0.749 | 18.5 | 124.4 | 9540 | 0.299 | 0.178 | 1.173 | 0.610 | 0.994 | 0.710 |
| 0.925 | 3.144 | 2.628 | 0.869 | 0.769 | 19.0 | 128.0 | 10370 | 0.296 | 0.177 | 1.169 | 0.612 | 0.994 | 0.711 |
| 0.95 | 3.329 | 2.699 | 0.920 | 0.790 | 19.5 | 231.5 | 11190 | 0.293 | 0.177 | 1.165 | 0.612 | 0.994 | 0.709 |
| 0.975 | 3.481 | 2.770 | 0.962 | 0.810 | 20.0 | 135.3 | 12130 | 0.286 | 0.176 | 1.153 | 0.615 | 0.993 | 0.704 |
| 1.000 | 3.598 | 2.841 | 0.995 | 0.830 | 20.5 | 139.4 | ? 3130 | 0.278 | 0.172 | 1.147 | 0.618 | 0.998 | 0.707 |
| 1.025 | 3.671 | 2.912 | 1.015 | 0.851 | 21.0 | 144.3 | . 14350 | 0.274 | 0.166 | 1.149 | 0.618 | 1.001 | 0.710 |
| 1.050 | 3.689 | 2.983 | 1.000 | 0.871 | 21.5 | 148.6 | 15930 | 0.273 | 0.164 | 1.151 | 0.614 | 1.005 | 0.709 |
| 1.075 | 3.678 | 3.054 | 1.017 | 0.891 | 22.0 | 154.2 | 17940 | 0.271 | 0.154 | 1.161 | 0.609 | 1.005 | 0.711 |
| 1.100 | 3.681 | 3.125 | 1.017 | 0.911 | 22.5 | 159.6 | 20520 | 0.265 | 0.158 | 1.145 | 0.605 | 1.005 | 0.697 |
|  |  |  |  | 0.932 | 23.0 | 168.0 | 23650 | 0.257 | 0.158 | 1.133 | 0.599 | 1.005 | 0.683 |
|  |  |  |  | 0.952 | 23.5 | 175.2 | 27200 | 0.249 | 0.164 | 1.113 | 0.596 | 1.005 | 0.666 |
|  |  |  |  | 0.972 | 24.9 | 181.2 | 30170 | 0.249 | 0.164 | 1.113 | 0.590 | 1.005 | 0.660 |
|  |  |  |  | 0.992 | 24.5 | 186.6 | 33290 | 0.247 | 0.158 | 1.118 | 0.587 | 0.999 | 0.656 |
|  |  |  |  | 1.013 | 25.0 | 190.9 | 35950 | 0.252 | 0.152 | 1.133 | 0.583 | 0.998 | 0.659 |
|  |  |  |  | 1.033 | 25.5 | 195.4 | 38470 | 0.252 | 0.150 | 1.136 | 0.582 | 0.997 | 0.659 |
|  |  |  |  | 1.053 | 26.0 | 199.3 | 40820 | 0.251 | 0.148 | 1.137 | 0.582 | 1.002 | 0.663 |
|  |  |  |  | 1.074 | 26.5 | 203.1 | 43290 | 0.252 | 0.152 | 1.134 | 0.581 | 1.006 | 0.663 |
|  |  |  |  | 1.094 | 27.0 | 207.5 | 45970 | 0.249 | 0.152 | 1.129 | 0.582 | 1.009 | 0.663 |


|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $v / \sqrt{4 \times L}$ | $c_{t} \times 10^{3}$ | (3) | (C) | $\mathrm{V} / \sqrt{\text { w/ }}$ | v | N | SHP | $\mathrm{w}_{\mathrm{T}}$ | $t$ | ${ }^{*} \mathrm{~h}$ | ${ }^{4} \mathrm{p}$ | ${ }^{*} \mathrm{rr}$ | BHP/SFP |
| 0.40 | 2.854 | 1.012 | 0.703 | 0.405 | 10.0 | 46.1 | 2072 | 0.341 | 0.214 | 1.190 | 0.600 | 1.146 | 0.819 |
| 0.45 | 2.847 | 1.139 | 0.702 | 0.445 | 11.0 | 49.7 | 2660 | 0.355 | 0.220 | 1.211 | 0.600 | 1.121 | 0.815 |
| 0.50 | 2.844 | 1.265 | 0.701 | 0.486 | 12.0 | 53.7 | 3427 | 0.362 | 0.218 | 1.226 | 0.601 | 1.093 | 0.805 |
| 0.55 | 2.841 | 1.392 | 0.700 | 0.526 | 13.0 | 58.0 | 4396 | 0.363 | 0.214 | 1.233 | 0.602 | 1.073 | 0.79 |
| 0.60 | 2.844 | 1.518 | 0.701 | 0.566 | 24.0 | 62.5 | 5605 | 0.362 | 0.207 | 1.242 | 0.603 | 1.050 | 0.786 |
| 0.625 | 2.860 | 1.582 | 0.705 | 0.587 | 14.5 | 54.9 | 6323 | 0.357 | 0.202 | 1.241 | 0.605 | 1.040 | 0.781 |
| 0.65 | 2.882 | 1.645 | 0.710 | 0.607 | 15.0 | 67.4 | 7126 | 0.353 | 0.200 | 1.237 | 0.605 | 1.033 | 0.774 |
| 0.675 | 2.912 | 1.708 | 0.718 | 0.628 | 15.5 | 70.1 | 7987 | 0.346 | 0.197 | 1.227 | 0.608 | 1.031 | 0.769 |
| 0.70 | 2.935 | 1.771 | 0.723 | 0.648 | 16.0 | 72.8 | 8935 | 0.341 | 0.194 | 1.222 | 0.609 | 1.028 | 0.765 |
| 0.725 | 2.963 | 1.835 | 0.730 | 0.668 | 16.5 | 75.5 | 9978 | 0.336 | 0.194 | 1.213 | 0.610 | 1.026 | 0.759 |
| 0.75 | 2.992 | 1.898 | 0.737 | 0.688 | 17.0 | 78.3 | 11030 | 0.332 | 0.194 | 1.205 | 0.610 | 1.033 | 0.760 |
| 0.775 | 3.000 | 1.961 | 0.739 | 0.708 | 17.5 | 81.0 | 12190 | 0.327 | 0.196 | 1.194 | 0.611 | 1.036 | 0.755 |
| 0.80 | 3.024 | 2.024 | 0.745 | 0.729 | 18.0 | 83.7 | 13370 | 0.323 | 0.197 | 1.185 | 0.611 | 1.040 | 0.753 |
| 0.825 | 3.076 | 2.088 | 0.758 | 0.749 | 18.5 | 86.2 | 14610 | 0.322 | 0.198 | 1.182 | 0.611 | 1.040 | 0.751 |
| 0.85 | 3.197 | 2.151 | 0.788 | 0.769 | 19.0 | 88.6 | 15900 | 0.322 | 0.198 | 1.183 | 0.610 | 1.042 | 0.752 |
| 0.875 | 3.482 | 2.214 | 0.858 | 0.790 | 19.5 | 90.9 | 17140 | 0.324 | 0.198 | 1.187 | 0.609 | 1.044 | 0.755 |
| 0.90 | 3.916 | 2.277 | 0.965 | 0.810 | 20.0 | 93.2 | 18620 | 0.329 | 0.197 | 1.197 | 0.605 | 1.045 | 0.757 |
| 0.925 | 4.481 | 2.341 | 1.104 | 0.830 | 20.5 | 96.3 | 20570 | 0.327 | 0.197 | 1.193 | 0.604 | 1.044 | 0.752 |
| 0.95 | 5.061 | 2.404 | 1.247 | 0.851 | 21.0 | 100.1 | 23300 | 0.325 | 0.199 | 1.187 | 0.597 | 1.045 | 0.740 |
| 0.975 | 5.631 | 2.467 | 1.388 | 0.871 | 21.5 | 105.0 | 27170 | 0.313 | 0.194 | 1.174 | 0.594 | 1.040 | 0.725 |
| 1.000 | 6.146 | 2.530 | 1.514 | 0.891 | 22.0 | 110.8 | 32600 | 0.304 | 0.183 | 1.173 | 0.586 | 1.036 | 0.713 |
| 1.025 | 6.531 | 2.594 | 1.610 | 0.911 | 22.5 | 117.8 | 40170 | 0.293 | 0.176 | 1.164 | 0.576 | 1.027 | 0.689 |
|  |  |  |  | 0.932 | 23.0 | 125.3 | 49860 | 0.280 | 0.167 | 1.156 | 0.568 | 1.016 | 0.667 |
|  |  |  |  | 0.952 | 23.5 | 133.2 | 61450 | 0.264 | 0.163 | 1.138 | 0.561 | 1.003 | 0.640 |
|  |  |  |  | 0.972 | 24.0 | 140.7 | 73760 | 0.248 | 0.163 | 1.112 | 0.557 | 0.994 | 0.616 |
|  |  |  |  | 0.992 | 24.5 | 148.2 | 87180 | 0.230 | 0.160 | 1.092 | 0.556 | 0.988 | 0.600 |
|  |  |  |  | 1.013 | 25.0 | 155.1 | 101400 | 0.212 | 0.154 | 1.075 | 0.555 | 0.979 | 0.584 |
|  |  |  |  | 1.033 | 25.5 | 162.1 | 118200 | 0.197 | 0.153 | 1.057 | 0.554 | 0.977 | 0.572 |
|  |  |  |  | 1.053 | 26.0 | 169.5 | 134700 | 0.194 | 0148 | 1.057 | 0.547 | 0.978 | 0.566 |




TABLE B-21






| $7 / \sqrt{18}$ | $c_{t}=$ | (3) | (C) |
| :---: | :---: | :---: | :---: |
| 0.40 | 2.571 | 1.110 | 0.695 |
| 0.45 | 2.546 | 1.249 | 0.688 |
| 0.50 | 2.524 | 1.388 | 0.682 |
| 0.55 | 2.519 | 1.527 | 0.681 |
| 0.60 | 2.536 | 1.666 | 0.685 |
| 0.625 | 2.550 | 1.735 | 0.689 |
| 0.65 | 2.568 | 1.804 | 0.694 |
| 0.675 | 2.585 | 1.874 | 0.698 |
| 0.70 | 2.606 | 1.943 | 0.704 |
| 0.725 | 2.628 | 2.012 | 0.710 |
| 0.75 | 2.650 | 2.082 | 0.716 |
| 0.775 | 2.672 | 2.151 | 0.722 |
| 0.80 | 2.704 | 2.221 | 0.730 |
| 0.825 | 2.748 | 2.290 | 0.742 |
| 0.85 | 2.822 | 2.359 | 0.762 |
| 0.875 | 2.987 | 2.429 | 0.807 |
| 0.90 | 3.281 | 2.498 | 0.886 |
| 0.925 | 3.664 | 2.568 | 0.990 |
| 0.950 | 4.041 | 2.637 | 1.092 |
| 0.975 | 4.376 | 2.706 | 1.182 |
| 2.000 | 4.621 | 2.776 | 1.248 |
| 1.025 | 4.751 | 2.845 | 1.284 |

TABLE B-22
Results of Resistance and Self-Propulsion Experiments
Model Number 4256, $C_{B}=0.70, L / B=6.0, B / H=3.0$, Propeller Number 3380



| $7 / \sqrt{4 \pi}$ | 111 Firures are for ship of 600 Ft Length Bp |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | v | N | siP | $\mathrm{H}_{T}$ | $t$ | ${ }^{2}$ | ${ }^{\circ}$ |
| 0.364 | 9.0 | 39.8 | 1918 | 0.397 | 0.211 | 1.308 | 0.555 |
| - +0.05 | 10.0 | 43.6 | 2491 | . 0.402 | 0.219 | 1.307 | 0.557 |
| 0.445 | 11.0 | 47.8 | 3255 | 0.400 | 0.222 | 1.298 | 0.561 |
| 0.486 | 12.0 | 52.1 | 4204 | 0.401 | 0.218 | 1.306 | 0.560 |
| 0.526 | 13.0 | 56.8 | 5410 | 0.395 | 0.215 | 1.298 | 0.562 |
| 0.566 | 14.0 | 61.6 | 6916 | 0.388 | 0.211 | 1.289 | 0.564 |
| 0.607 | 15.0 | 66.7 | 8712 | 0.38 | 0.210 | 1.272 | 0.566 |
| 0.628 | 15.5 | 69.1 | 9751 | 0.377 | 0.208 | 1.272 | 0.566 |
| 0.648 | 16.0 | 71.6 | 10810 | 0.374 | 0.210 | 1.262 | 0.566 |
| 0.668 | 16.5 | 74.1 | 11940 | 0.373 | 0.210 | 1.260 | 0.566 |
| 0.688 | 17.0 | 76.6 | 13240 | 0.370 | 0.211 | 1.254 | 0.566 |
| 0.708 | 17.5 | 79.3 | 14690 | 0.369 | 0.211 | 1.251 | 0.565 |
| 0.729 | 18.0 | 82.1 | 16290 | 0.366 | 0.210 | 1.246 | 0.564 |
| 0.749 | 18.5 | 85.2 | 18110 | 0.357 | 0.210 | 1.227 | 0.566 |
| 0.769 | 19.0 | 88.4 | 20250 | 0.347 | 0.209 | 1.212 | 0.568 |
| 0.790 | 19.5 | 91.7 | 22550 | 0.342 | 0.211 | 1.199 | 0.567 |
| 0.810 | 20.0 | 94.9 | 25180 | 0.340 | 0.213 | 1.192 | 0.565 |
| 0.830 | 20.5 | 98.0 | 28200 | 0.343 | 0.206 | 1.208 | 0.559 |
| 0.851 | 21.0 | 101.8 | 32010 | 0.341 | 0.198 | 1.216 | 0.554 |
| 0.891 | 22.0 | 213.5 | 44610 | 0.298 | 0.169 | 1.183 | 0.594 |

TABLE B-23
Results of Resistance and Self-Propulsion Experiments Model Number 4259, $C_{B}=0.70, L / B=7.0, B / H=3.0$, Propeller Number 2502
11 Figures are for ship of 400 Ft Length if $\quad 111$ Figures are for Ship of 600 Ft Langth 19

| $5 / \sqrt{4 \times 1}$ | $c_{t} \times 10^{3}$ | (1) | (C) | 1/540 | V | 1 | SHP | ${ }_{T}$ | $t$ | ${ }_{\text {\% }}$ | ${ }^{\circ} \mathrm{p}$ | ${ }^{\text {r }}$ r | STP/ / SiP |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0.40 | 2.903 | 1.038 | 0.744 | 0.364 | 9.0 | 48.3 | 1858 | 0.319 | 0.193 | 1.185 | 0.547 | 0.983 | 0.638 |
| 0.45 | 2.901 | 1.168 | 0.743 | 0.405 | 10.0 | 52.9 | 2407 | 0.330 | 0.189 | 1.210 | 0.947 | 0.991 | 0.656 |
| 0.50 | 2.896 | 1.298 | 0.742 | 0.445 | 11.0 | 57.9 | 3140 | 0.337 | 0.184 | 1.230 | 0.552 | 0.980 | 0.665 |
| 0.55 | 2.933 | 1.428 | 0.751 | 0.486 | 12.0 | 63.2 | 4074 | 0.340 | 0.181 | 1.242 | 0.552 | 0.980 | 0.672 |
| 0.60 | 2.975 | 1.557 | 0.762 | 0.526 | 13.0 | 68.8 | 5209 | 0.342 | 0.183 | 1.242 | 0.550 | 0.989 | 0.675 |
| 0.625 | 2.990 | 1.622 | 0.766 | 0.566 | 14.0 | 74.3 | 6525 | 0.346 | 0.188 | 1.241 | 0.941 | 2.012 | 0.679 |
| 0.65 | 2.996 | 1.687 | 0.767 | 0.607 | 15.0 | 80.2 | 8170 | 0.339 | 0.191 | 1.224 | 0.541 | 1.015 | 0.671 |
| 0.675 | 3.044 | 1.752 | 0.769 | 0.628 | 15.5 | 82.9 | 9081 | 0.340 | 0.191 | 1.225 | 0.539 | 1.016 | 0.67 |
| 0.70 | 3.023 | 1.817 | 0.774 | 0.648 | 16.0 | 85.8 | 10030 | 0.332 | 0.189 | 1.215 | 0.543 | 1.017 | 0.670 |
| 0.725 | 3.059 | 1.882 | 0.783 | 0.668 | 16.5 | 88.7 | 11020 | 0.328 | 0.184 | 1.211 | 0.546 | 2.017 | 0.672 |
| 0.75 | 3.121 | 1.947 | 0.799 | 0.688 | 17.0 | 91.4 | 12000 | 0.319 | 0.176 | 1.212 | 0.551 | 1.015 | 0.678 |
| 0.775 | 3.207 | 2.012 | 0.821 | 0.708 | 17.5 | 4.2 | 13160 | 0.315 | 0.169 | 1.223 | 0.553 | 2.010 | 0.678 |
| 0.80 | 3.307 | 2.076 | 0.847 | 0.729 | 18.0 | 9.9 | 14510 | 0.321 | 0.166 | 1.228 | 0.549 | 1.003 | 0.677 |
| 0.825 | 3.398 | 2.141 | 0.870 | 0.749 | 18.5 | 100.2 | 16120 | $0: 322$ | 0.169 | 1.226 | 0.546 | 1.001 | 0.670 |
| 0.85 | 3.517 | 2.206 | 0.901 | 0.769 | 19.0 | 104.4 | 18150 | 0.315 | 0.178 | 1.200 | 0.945 | 1.005 | 0.657 |
| 0.875 | 3.737 | 2.271 | 0.957 | 0.790 | 19.5 | 108.8 | 20470 | 0.310 | 0.184 | 1.183 | 0.542 | 1.009 | 0.647 |
| 0.90 | 4.276 | 2.336 | 1.095 | 0.810 | 20.0 | 113.2 | 23140 | 0.305 | 0.188 | 1.169 | 0.539 | 1.008 | 0.635 |
|  |  |  |  | 0.830 | 20.5 | 117.3 | 25890 | 0.301 | 0.191 | 1.156 | 0.536 | 1.010 | 0.625 |
|  |  |  |  | 0.851 | 21.0 | 121.7 | 28950 | 0.298 | 0.196 | 1.143 | 0.531 | 1.017 | 0.617 |
|  |  |  |  | 0.891 | 22.0 | 132.8 | 38460 | 0.294 | 0.164 | 1.183 | 0.516 | 1.012 | 0.617 |

TABLE B-24
Results of Resistance and Self-Propulsion Experiments
Model Number 4258, $C_{B}=0.70, L / B=8.0, B / H=3.0$, Propeller Number 3488

| $v / \sqrt{L_{W L}}$ | $C_{t} \times 10^{3}$ | (K) | (C) | $v / \sqrt{L_{W L}}$ | v | N | SHP | ${ }^{W}$ T | t | $e_{h}$ | $e_{p}$ | ${ }_{\text {err }}$ | EHP/SHP |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0.40 | 2.539 | 1.086 | 0.677 | 0.364 | 9.0 | 55.7 | 1336 | 0.386 | 0.168 | 1.355 | 0.849 | 0.973 | 0.724 |
| 0.45 | 2.545 | 1.221 | 0.679 | 0.405 | 10.0 | 61.2 | 1747 | 0.388 | 0.184 | 1.333 | 0.553 | 0.962 | 0.723 |
| 0.50 | 2.562 | 1.357 | 0.683 | 0.445 | 11.0 | 67.1 | 2266 | 0.379 | 0.188 | 1.300 | 0.560 | 0.993 | 0.727 |
| 0.55 | 2.592 | 1.492 | 0.691 | 0.486 | 12.0 | 73.7 | 2940 | 0.365 | 0.19 | 1.27 | 0.567 | 1.001 | 0.720 |
| 0.60 | 2.636 | 1.628 | 0.702 | 0.526 | 13.0 | 80.3 | 3757 | 0.357 | 0.191 | 1.258 | 0.570 | 1.012 | 0.725 |
| 0.625 | 2.661 | $1.6 \%$ | 0.710 | 0.566 | 14.0 | 87.3 | 4755 | 0.346 | 0.189 | 1.240 | 0.573 | 1.022 | 0.725 |
| 0.65 | 2.689 | 1.764 | 0.717 | 0.607 | 15.0 | 94.4 | 5936 | 0.338 | 0.191 | 1.221 | 0.574 | 1.034 | 0.725 |
| 0.675 | 2.713 | 1.832 | 0.724 | 0.628 | 15.5 | 98.0 | 6575 | 0.334 | 0.191 | 1.215 | 0.575 | 1.042 | 0.727 |
| 0.70 | 2.742 | 1.900 | 0.731 | 0.648 | 16.0 | 101.5 | 7275 | 0.331 | 0.19 | 1.205 | 0.575 | 1.046 | 0.725 |
| 0.725 | 2.781 | 1.967 | 0.742 | 0.668 | 16.5 | 104.8 | 8049 | 0.330 | 0.193 | 1.205 | 0.575 | 1.041 | 0.721 |
| 0.75 | 2.851 | 2.035 | 0.760 | 0.688 | 17.0 | 108.3 | 8925 | 0.328 | 0.195 | 1.190 | 0.575 | 1.036 | 0.73 |
| 0.775 | 2.953 | 2.103 | 0.788 | 0.708 | 17.5 | 112.2 | 9939 | 0.324 | 0.200 | 2.183 | 0.575 | 1.034 | 0.76 |
| 0.80 | 3.051 | 2.171 | 0.814 | 0.729 | 18.0 | 116.3 | 11060 | 0.318 | 0.200 | 1.173 | 0.575 | 1.035 | 0.698 |
| 0.825 | 3.140 | 2.239 | 0.837 | 0.749 | 18.5 | 120.6 | 12340 | 0.312 | 0.197 | 1.167 | 0.575 | 1.036 | 0.695 |
| 0.85 | 3.242 | 2.307 | 0.865 | 0.769 | 19.0 | 125.2 | 13750 | 0.306 | 0.191 | 1.165 | 0.574 | 1.039 | 0.698 |
| 0.875 | 3.432 | 2.374 | 0.915 | 0.790 | 19.5 | 129.9 | 15400 | 0.301 | 0.186 | 1.165 | 0.573 | 1.040 | 0.693 |
| 0.90 | 3.781 | 2.442 | 1.008 | 0.810 | 20.0 | 134.6 | 17190 | 0.300 | 0.189 | 1.159 | 0.569 | 1.041 | 0.686 |
|  |  |  |  | 0.830 | 20.5 | 139.4 | 19210 | 0.297 | 0.190 | 1.153 | 0.566 | 1.039 | 0.678 |
|  |  |  |  | 0.851 | 21.0 | 144.2 | 21510 | 0.303 | 0.191 | 1.161 | 0.559 | 1.037 | 0.673 |
|  |  |  |  | 0.891 | 22.0 | 157.8 | 28560 | 0.286 | 0.181 | 1.148 | 0.550 | 2.035 | 0.653 |

TABLE B-25
Results of Resistance and Self-Propulsion Experiments


 All Pigures are for Ship of 400 Ft Length BP



TABLE B-26



$\Delta 11$ P1gures are for shif of 400 It Length BP


$V / \sqrt{4 x} \quad c_{t} \times 10^{3}$



$\begin{array}{lllll}1.1 & 1734 & 0.392 & 0.197 & 1.322\end{array}$

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$\begin{array}{lllll}.0 & 3152 & 0.386 & 0.196 & 1.31 \\ 1 & 4204 & 0.383 & 0.198 & 1.301\end{array}$

692. T 202.0 โLE.O टSE9 サ'

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$\cdots$

Model Number 4278, $C_{B}=0.75, L / B=7.75, B / H=3.0$, Propeller Number 3648



$\stackrel{N}{7}$




A11. Figures are for Ship of 400 Ft Length BP
$\begin{array}{lll}\text { All Figures are for Ship of } 400 \\ \text { v/ } \sqrt{L_{w}} & c_{t} \times 10^{3} & \text { (x) } \\ 0.35 & 2.726 & 0.929 \\ 0.40 & 2.696 & 1.062 \\ 0.45 & 2.683 & 1.195 \\ 0.50 & 2.719 & 1.327 \\ 0.525 & 2.751 & 1.394 \\ 0.550 & 2.78 \varepsilon & 1.460 \\ 0.575 & 2.828 & 1.526 \\ 0.60 & 2.874 & 1.593 \\ 0.625 & 2.938 & 1.659 \\ 0.65 & 3.028 & 1.725 \\ 0.675 & 3.152 & 1.792 \\ 0.70 & 3.312 & 1.858 \\ 0.725 & 3.500 & 1.925 \\ 0.75 & 3.772 & 1.991 \\ 0.775 & 4.12 c & 2.057 \\ 0.80 & 4.551 & 2.124 \\ 0.825 & 4.878 & 2.190 \\ 0.85 & 5.127 & 2.256 \\ 0.875 & 5.292 & 2.323\end{array}$
TABLE B-28
Results of Resistance and Self-Propulsion Experiments Model Number 4260, $C_{B}=\mathbf{0 . 8 0}, L / B=5.5, B / H=3.0$, Propeller Number 3377
All Pigures are for Ship of 600 Ft Length BP




112 Figuras are for ship of 400 Ft Length BP
$\begin{array}{llll}\nabla / \sqrt{N L} & C_{t} \times 10^{3} & \text { ( } & \text { C } \\ 0.35 & 3.343 & 0.820 & 0.788 \\ 0.40 & 3.313 & 0.937 & 0.781 \\ 0.45 & 3.288 & 1.054 & 0.775 \\ 0.50 & 3.276 & 1.17 & 0.772 \\ 0.525 & 3.281 & 1.230 & 0.774 \\ 0.55 & 3.311 & 1.288 & 0.781 \\ 0.575 & 3.369 & 1.347 & 0.795 \\ 0.60 & 3.464 & 1.405 & 0.817 \\ 0.625 & 3.600 & 1.464 & 0.849 \\ 0.65 & 3.785 & 1.522 & 0.892 \\ 0.675 & 4.032 & 1.581 & 0.951 \\ 0.70 & 4.395 & 1.640 & 1.036 \\ 0.75 & 5.402 & 1.757 & 1.274 \\ 0.80 & 6.659 & 1.874 & 1.570\end{array}$
TABLE B-29
Results of Resistance and Self-Propulsion Experiments
Model Number 4263, $C_{B}=0.80, L / B=6.5, B / H=3.0$, Propeller Number 3375
All Figures are for Ship of 600 Ft Length BP








All Figures are for Ship of 400 Ft Length BP

TABLE B-30
Model Number 4262, $C_{B}=0.80, L / B=7.5, B / H=3.0$, Propeller Number 2501

TABLE B-31


;tance and Self-Propulsion Experiments

|  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0.4es | 12.0 | 80.3 | 393 | 0.36 | 0.29 | 1.39 | 0.56 |
| 0.826 | ${ }^{13.0}$ | 86,4 | ${ }^{240}$ | ${ }^{0.37}$ | 0.209 | ${ }^{1.278}$ |  |
| O. 0.68 | ${ }^{1.0}$ | ${ }^{9.6}$ | ${ }_{538}$ | ${ }^{0.360}$ | 0.26 | ${ }^{1.2255}$ |  |
|  | 15,5 | 10.5 | 729 | ${ }_{0}^{0.358}$ | 0.290 | 1.22 |  |
| 0.68 | 13.0 | 20.5 | 日108 | 0.358 | 0.18 | 1.226 |  |
|  | 16.5 | 112.0 | $8{ }_{89}$ | 0.35 | 0.195 | 1.226 |  |
|  | 27.0 | 115.5 | sem | 0.35 | 0.12 | ${ }^{1.22}$ |  |
|  | 17.5 | 19.5 | 970 | 0.36 | 0.38 | 1.222 |  |
|  | ${ }^{28.0}$ | 123.2 | 1170 | 0.34 | 0.18 | 1.237 |  |
|  | 18.5 | 127.0 | 1275 | 0.36 | 0.188 | 1.22 |  |
|  | 19.0 | 130.8 | zemo | 0.334 | 0.18 | 1.216 |  |
| 0.180 | 19.5 | 13,5 | 120 | 0.32 | 0.18 | 1.29 |  |
| 0.810 | 20.0 | 138.6 | 12350 | 0.330 | 0.191 | 1.120 |  |
|  | 20.5 | ${ }^{122.5}$ | ${ }^{1726} 3$ | 0.330 | 0.195 | 1.123 |  |
|  | ${ }_{2}^{2.0}$ | ${ }^{1772}$ | ${ }^{2980}$ | C.319 | 0.20 | ${ }^{1.1275}$ |  |
|  | ${ }^{2.5}$ | 122.0 | ${ }^{21830}$ | 0.317 | ${ }^{0.201}$ | 1.220 |  |
|  | ${ }^{22.0}$ | 19.6 | ${ }^{28880}$ | 0.315 | 0.201 | 1.167 |  |
|  | ${ }^{22.5}$ | 166.0 | 2800 | 0.33 | 0.20 | 1.124 |  |
|  | ${ }^{23.0}$ | 17.0 | 3360 | 0.309 | 0.198 | 1.129 |  |
|  | 23.5 | 188.2 | 3230 | 0.305 | 0.200 | 1.17 |  |
|  | 2.0 | 188.0 | ${ }^{2316}$ | 0.303 | 0.202 | 1.45 |  |
| 0.992 | ${ }^{2.5} 5$ | 199.6 | 42eo | 0.295 | 0.202 |  |  |
| 1.013 | 25.0 | 199.8 | 2230 | .223 | 0.20 |  |  |
| $1.033$ | 225.5 | 20.5 | \%230 | ${ }^{0.288}$ | 0.20 |  |  |
|  | 23.0 | 20.5 | 460 |  |  |  |  |
|  | 26.5 | 215.5 | ${ }_{6330} 6$ | 0.288 | 0.15 |  |  |
|  |  |  |  |  |  |  |  |

$\left[^{\mathrm{nseg}}\right.$ Model Numbe
111 Pigures are for ship of 400 Ft Length Bp



TABLE B-32
Results of Resistance and Self-Propulsion Experiments


| $v / / \longdiv { w L }$ | All Pigurea are for ship of 600 Ft length BP |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | V | N | SHP | $W_{T}$ | $t$ | ${ }^{6}$ | ${ }^{6} \mathrm{p}$ |
| 0.486 | 12.0 | 79.7 | 2429 | 0.312 | 0.119 | 1.281 | 0.607 |
| 0.526 | 13.0 | 86.1 | 3070 | 0.319 | 0.128 | 1.280 | 0.604 |
| 0.566 | 14.0 | 93.2 | 3900 | 0.316 | 0.141 | 1.256 | 0.605 |
| 0.607 | 15.0 | 100.8 | 4858 | 0.307 | 0.155 | 1.219 | 0.605 |
| 0.628 | 15.5 | 104.8 | 5427 | 0.301 | 0.160 | 1.202 | 0.606 |
| 0.648 | 16.0 | 108.7 | 6034 | 0.296 | 0.164 | 1.189 | 0.607 |
| 0.668 | 16.5 | 112.5 | 6704 | 0.293 | 0.167 | 1.178 | 0.607 |
| 0.688 | 17.0 | 116.2 | 7381 | 0.293 | 0.17 | 1.175 | 0.606 |
| 0.708 | 17.5 | 119.5 | 8129 | 0.297 | 0.169 | 1.182 | 0.604 |
| 0.729 | 18.0 | 123.5 | 8972 | 0.290 | 0.165 | 1.176 | 0.607 |
| 0.749 | 18.5 | 127.3 | 9871 | 0.284 | 0.160 | 1.173 | 0.609 |
| 0.769 | 19.0 | 131.5 | 10820 | 0.273 | 0.147 | 1.172 | 0.614 |
| 0.790 | 19.5 | 135.0 | 11830 | 0.266 | 0.141 | 1.170 | 0.617 |
| 0.810 | 20.0 | 139.2 | 12940 | 0.258 | 0.140 | 1.159 | 0.619 |
| 0.830 | 20.5 | 143.5 | 14200 | 0.254 | 0.146 | 1.145 | 0.619 |
| 0.850 | 21.0 | 147.5 | 15600 | 0.261 | 0.151 | 1.149 | 0.614 |
| 0.871 | 21.5 | $15 i .7$ | 17440 | 0.262 | 0.153 | 1.148 | 0.609 |
| 0.891 | 22.0 | 159.0 | 19850 | 0.256 | 0.152 | 1.139 | 0.605 |
| 0.911 | 22.5 | 16:.0 | 22680 | 0.248 | 0.152 | 1. 127 | 0.604 |
| 0.932 | 23.0 | $17 \%$. 5 | 26360 | 0.240 | 0.153 | 1.115 | 0.595 |
| 0.952 | 23.5 | 180.8 | 30220 | 0.238 | 0.153 | 1.111 | 0.588 |
| 0.972 | 24.0 | 186.9 | 33590 | 0.234 | 0.152 | 1.108 | 0.585 |
| 0.992 | 24.5 | 192.4 | 36730 | 0.234 | 0.146 | 1.114 | 0.582 |
| 13 | 25.0 | 197.0 | 39680 | 0.228 | 0.145 | 1.108 | 0.581 |
| 3 | 25.5 | 202. 5 | 42940 | 0.225 | 0.144 | 1.105 | 0.582 |
| 53 | 26.0 | $20 \% .2$ | 46270 | 0.222 | 0.142 | 1.104 | 0.582 |
| . 74 | 26.5 | 212.5 | 49500 | 0.222 | 0.142 | 1.103 | 0.580 |
| 994 | 27.0 | 216.5 | 53230 | 0.224 | 0.142 | 1.106 | 0.578 |

[^5]
○
Model Number 4242, $C_{B}=0.60, L / B=8.5, B / H=3.5$, Propeller Number 2837
111 Fgares are for Bhip of 400 Pt hength ap

TABLE B-34

TABLE B-35
Results of Res:, tance and Self-Propulsion Experiments
Model Number 4273, $C_{B}=0.65, L / B=7.25, B / H=3.5$, Propeller Number 2765

|  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0.488 | 12.0 | ${ }^{81.0}$ | ${ }^{2374}$ | 0.343 | 0.117 | 1.345 |  |
|  | ${ }^{13.0}$ | ${ }^{88.0}$ | ${ }^{364}$ | .30 |  |  |  |
|  | ${ }^{14.0}$ | 95. | ${ }^{4} 18$ |  |  |  |  |
|  | ${ }_{1250}$ | 130.7 | s5s5 | ${ }_{0}^{0.330}$ | 0.13 |  |  |
|  | 15.5 | 106.5 | ${ }_{618}$ | 0.32 | 0.14 | 1.282 |  |
| 0.488 | 16.0 | 12.3 | bexs | 0.329 | 0.44 | 1.278 |  |
| 0.668 | 16.5 | 124 | ${ }^{737}$ | 0.327 | 0.47 | 1.26 |  |
|  | 27.0 | 128.3 | ars |  | ${ }^{0.24}$ | ${ }^{1.288}$ |  |
|  | 17.5 |  |  | ${ }^{0.312}$ | 0.1 |  |  |
|  | 28.0 | ${ }^{126.5}$ | 108 |  |  |  |  |
| $0 . \nless$ | 18.5 | 130.4 | 11380 | 0.314 | 0.145 | 1.216 |  |
| 0.7 | 19.0 | ${ }^{13} 4.5$ | 2490 | 0.311 | 0.146 | 1.220 |  |
|  | 19.5 | 139.0 | 1370 | 0.36 | 0.126 | 1.229 |  |
|  | ${ }^{20.0}$ | ${ }^{143.34}$ |  |  |  |  |  |
| 0.830 | 20.5 | ${ }^{148.81}$ | 12550 | 0.29 | 0.448 | ${ }^{1.228}$ |  |
|  | ${ }_{2}^{21.5}$ | 123.9 | 2060 | ${ }_{0}^{0.2}$ | 0.150 | 1.167 |  |
| 0.991 | 22.0 | 166.2 | 2770 | 0.26 | 0.150 | ${ }^{2} .259$ |  |
|  | 22.5 | 177.4 |  |  | 0.350 |  |  |
|  | 23.0 | 188.1 | 3045 |  |  |  |  |
| 0.952 | ${ }^{23.5}$ | 129.2 |  |  | ${ }^{0.140}$ |  |  |
|  |  | 207.5 |  |  |  |  |  |
|  |  | 227.0 |  | 0.220 |  |  |  |
|  | 22.5 | 235 | 7360 | 0.201 |  |  |  |

111 Figures are for Ship of 400 Ft Length BP

## TABLE B-36

Results of Resistance and Self-Propulsion Experiments

| Model Number 4266, $C_{B}=0.65, L / B=8.25, B / H=3.5$, Propeller Number 3646 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 411 Figures are for Ship of 400 pt Length BP |  |  |  |  |  | All Pigures are for Ship or 600 Pt Length BP |  |  |  |  |  |  |  |
| $\mathrm{V} / / \sqrt{\text { VI }}$ | $c_{t} \times 10^{3}$ | (1) | (c) | 8/ $/ 2$ wid | $\checkmark$ | N | SKP | $\mathrm{w}_{\mathrm{I}}$ | $t$ | $e_{n}$ | ${ }^{6}$ | ${ }^{9} \mathbf{r r}$ | ERP/SKP |
| 0.400 | 2.669 | 1.139 | 0.747 | 0.445 | 11.00 | 9.02 | 1936 | 0.365 | 0.159 | 1.325 | 0.533 | 1.068 | 0.754 |
| 0.450 | 2.644 | 1.282 | 0.740 | 0.486 | 12.00 | 98.2 | 2496 | 0.369 | 0.158 | 1.335 | 0.534 | 1.042 | 0.744 |
| 0.500 | 2.622 | 1.424 | 0.733 | 0.526 | 13.00 | 106.7 | 3216 | 0.359 | 0.160 | 1.312 | 0.540 | 1.025 | 0.727 |
| 0.550 | 2.601 | 1.566 | 0.728 | 0.566 | 14.00 | 115.9 | 4137 | 0.345 | 0.164 | 1.276 | 0.546 | 1.012 | 0.705 |
| 0.575 | 2.594 | 1.638 | 0.726 | 0.587 | 14.50 | 120.2 | 4650 | 0.346 | 0.163 | 1.281 | 0.545 | 1.006 | 0.702 |
| 0.600 | 2.593 | 1.709 | 0.725 | 0.607 | 15.00 | 125.0 | 5245 | 0.338 | 0.163 | 1.264 | 0.548 | 0.999 | 0.692 |
| 0.625 | 2.600 | 1.780 | 0.727 | 0.628 | 15.50 | 130.1 | 5927 | 0.329 | 0.163 | 1.247 | 0.551 | 0.991 | 0.681 |
| 0.650 | 2.618 | 1.851 | 0.732 | 0.648 | 16.00 | 135.1 | 6650 | 0.322 | 0.168 | 1.228 | 0.553 | 0.986 | 0.669 |
| 0.675 | 2.637 | 1.922 | 0.738 | 0.668 | 16.50 | 140.1 | 7416 | 0.315 | 0.170 | 1.224 | 0.554 | 0.983 | 0.661 |
| 0.700 | 2.659 | 1.994 | 0.744 | 0.688 | 17.00 | 145.4 | 8245 | 0.207 | 0.173 | 1.193 | 0.557 | 0.983 | 0.654 |
| 0.725 | 2.680 | 2.065 | 0.750 | 0.708 | 17.50 | 150.2 | 9044 | 0.303 | 0.174 | 1.186 | 0.559 | 0.987 | 0.653 |
| 0.750 | 2.700 | 2.136 | 0.755 | 0.729 | 18.00 | 155.1 | 9903 | 0.299 | 0.174 | 1.179 | 0.559 | 0.990 | 0.652 |
| 0.775 | 2.715 | 2.207 | 0.760 | 0.749 | 18.50 | 160.0 | 10820 | 0.295 | 0.174 | 1.171 | 0.559 | 0.995 | 0.652 |
| 0.800 | 2.732 | 2.278 | 0.764 | 0.769 | 19.00 | 165.0 | 11770 | 0.293 | 0.175 | 1.168 | 0.559 | 1.003 | 0.655 |
| 0.825 | 2.766 | 2.350 | 0.774 | 0.790 | 19.50 | 170.2 | 12810 | 0.290 | 0.176 | 1.161 | 0.559 | 1.012 | 0.657 |
| 0.850 | 2.827 | 2.421 | 0.791 | 0.810 | 20.00 | 175.5 | 13930 | 0.286 | 0.175 | 1.156 | 0.558 | 1.021 | 0.659 |
| 0.875 | 2.964 | 2.492 | 0.829 | 0.830 | 20.50 | 180.7 | 15240 | 0.285 | 0.174 | 1.155 | 0.557 | 1.021 | 0.657 |
| 0.900 | 3.186 | 2.563 | 0.891 | 0.851 | 21.00 | 186.1 | 16830 | 0.287 | 0.175 | 1.157 | 0.554 | 1.016 | 0.651 |
| 0.925 | 3.471 | 2.634 | 0.971 | 0.871 | 21.50 | 193.5 | 19090 | 0.281 | 0.178 | 1.144 | 0.550 | 1.013 | 0.638 |
| 0.950 | 3.776 | 2.706 | 1.056 | 0.891 | 22.00 | 202.5 | 22100 | 0.270 | 0.185 | 1.118 | 0.547 | 1.010 | 0.617 |
| 0.975 | 4.036 | 2.777 | 1.129 | 0.911 | 22.50 | 213.0 | 25920 | 0.264 | 0.190 | 1.101 | 0.541 | 3.011 | 0.602 |
| 1.000 | 4.256 | 2.848 | 1.191 | 0.932 | 23.00 | 223.5 | 30180 | 0.256 | 0.189 | 1.091 | 0.532 | 1.020 | 0.592 |
| 1.025 | 4.456 | 2.919 | 1.247 | 0.952 | 23.50 | 233.8 | 35020 | 0.250 | 0.188 | 1.082 | 0.526 | 1.026 | 0.584 |
| 1.050 | 4.697 | 2.991 | 1.314 | 0.972 | 24.00 | 24.0 | 40150 | 0.242 | 0.186 | 1.074 | 0.521 | 1.028 | 0.576 |
|  |  |  |  | 0.992 | 24.50 | 254.0 | 45330 | 0.236 | 0.180 | 1.073 | 0.516 | 1.030 | 0.570 |
|  |  |  |  | 1.013 | 25.00 | 263.5 | 50240 | 0.228 | 0.171 | 1.075 | 0.512 | 1.036 | 0.570 |
|  |  |  |  | 1.033 | 25.50 | 271.5 | 54590 | 0.220 | 0.170 | 1.065 | 0.512 | 1.043 | 0.569 |


| TABLE F-37 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Results of Resistance and Self-Propulsion Experiments |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Model Number 4245, $C_{B}=0.70, L / B=6.0, B / H=3.5$, Propeller Number 2502 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Figures are for Ship |  | Ft Length BP |  |  | 111 Figures are for Ship of 600 Ft Length BP |  |  |  |  |  |  | ${ }^{9} \mathbf{r t}$ | ESP/878 |
| $v / \sqrt{1+\sqrt{x}}$ | $c_{t} \times 10^{3}$ | (1) | (C) | $v / \sqrt{4 \sqrt{2}}$ | V | . | SHP | $\mathrm{w}_{T}$ | $t$ | ${ }_{6}$ | P |  |  |
| 0.40 | 2.901 | 1.012 | 0.732 | 0.364 | 9.0 | 47.5 | 1795 | 0.436 | 0.197 | 1.425 | 0.476 | 1.034 | 0.702 |
| 0.45 | 2.886 | 1.138 | 0.728 | 0.405 | 10.0 | 52.3 | 2378 | 0.442 | 0.189 | 1.455 | 0.475 | 1.041 | 0.720 |
| 0.50 | 2.892 | 1.265 | 0.730 | 0.445 | 11.0 | 57.6 | 3143 | 0.435 | 0.182 | 1.448 | 0.480 | 1.049 | 0.730 |
| 0.55 | 2.936 | 1.391 | 0.741 | 0.486 | 12.0 | 63.0 | 4110 | 0.430 | 0.174 | 1.451 | 0.403 | 1.045 | 0.732 |
| 0.60 | 3.005 | 1.518 | 0.758 | 0.526 | 13.0 | 68.8 | 5343 | 0.417 | 0.178 | 1.410 | 0.490 | 1.041 | 0.718 |
| 0.625 | 3.040 | 1.581 | 0.767 | 0.566 | 14.0 | 75.1 | 6925 | 0.399 | 0.181 | 1.362 | 0.497 | 1.038 | 0.708 |
| 0.65 | 3.077 | 1.644 | 0.777 | 0.607 | 15.0 | 81.6 | 8831 | 0.384 | 0.184 | 1.326 | 0.501 | 1.039 | 0.690 |
| 0.675 | 3.110 | 1.708 | 0.785 | 0.628 | 15.5 | 85.0 | 9915 | 0.374 | 0.183 | 1.307 | 0.504 | 1.042 | 0.687 |
| 0.70 | 3.143 | 1.771 | 0.793 | 0.648 | 16.0 | 88.1 | 11050 | 0.376 | 0.184 | 1.306 | 0.502 | 1.044 | 0.684 |
| 0.72 | 3.190 | 1.834 | 0.805 | 0.668 | 16.5 | 91.3 | 12340 | 0.371 | 0.184 | 1.296 | 0.503 | 1.040 | 0.678 |
| 0.75 | 3.264 | 1.897 | 0.824 | 0.688 | 17.0 | 94.4 | 13630 | 0.372 | 0.182 | 1.302 | 0.500 | 1.042 | 0.679 |
| 0.775 | 3.370 | 1.360 | 0.851 | 0.708 | 17.5 | 97.: | 15030 | 0.372 | 0.182 | 1.304 | 0.499 | 1.040 | 0.677 |
| 0.80 | 3.481 | 2.024 | 0.879 | 0.729 | 18.0 | 100.6 | 16580 | 0.369 | 0.184 | 1.293 | 0.500 | 1.038 | 0.671 |
| 0.825 | 3.593 | 2.087 | 0.907 | 0.749 | 18.5 | 104.2 | 28430 | 0.362 | 0.184 | 1.280 | 0.508 | 1.037 | 0.665 |
| 0.85 | 3.725 | 2.150 | 0.940 | 0.769 | 19.0 | 108.5 | 20830 | 0.361 | 0.185 | 1.276 | 0.490 | 1.041 | 0.659 |
| 0.875 | 3.940 | 2.213 | 0.994 | 0.790 | 19.5 | 113.0 | 23590 | 0.356 | 0.183 | 1.269 | 0.493 | 1.042 | 0.652 |
| 0.90 | 4.481 | 2.277 | 1.131 | 0.810 | 20.0 | 116.5 | 26040 | 0.355 | 0.182 | 1.267 | 0.494 | 1.035 | 0.648 |
|  |  |  |  | 0.830 | 20.5 | 120.2 | 28910 | 0.358 | 0.176 | 1.283 | 0.486 | 1.030 | 0.643 |
|  |  |  |  | 0.851 | 21.0 | 124.9 | 32510 | 0.362 | 0.178 | 1.288 | 0.478 | 1.036 | 0.638 |
|  |  |  |  | 0.891 | 22.0 | 139.5 | 46460 | 0.332 | 0.173 | 1.237 | 0.471 | 1.017 | 0.592 |




| Model Number 4257, $C_{B}=0.70, L / B=7.0, B / H=3.5$, Propeller Number 2815 |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 111 Figures | for Shi | or 400 | Length BP |  | All Figures are fo |  |  |  | Ship of 600 Ft Length BP |  |  |
| $v / \sqrt{1 / 4 \mathrm{~L}}$ | $c_{t} \times 10^{3}$ | (1) | (c) | $\nabla / \sqrt{W L}$ | V | H | SHP | $W_{T}$ | t | ${ }^{6}$ | ${ }^{\circ} \mathrm{p}$ |
| 0.40 | 2.706 | 1.066 | 0.716 | 0.364 | 9.0 | 54.0 | 1430 | 0.405 | 0.152 | 1.425 | 0.538 |
| 0.45 | 2.712 | 1.199 | 0.718 | 0.405 | 10.0 | 59.8 | 1879 | 0.404 | 0.174 | 1.386 | 0.541 |
| 0.50 | 2.724 | 1.332 | 0.721 | 0.445 | 11.0 | 65.8 | 2462 | 0.399 | 0.178 | 1.368 | 0.544 |
| 0.55 | 2.750 | 1.465 | 0.728 | 0.486 | 12.0 | 72.1 | 3199 | 0.398 | 0.185 | 1.355 | 0.542 |
| 0.60 | 2.821 | 1.598 | 0.747 | 0.526 | 13.0 | 78.9 | 4131 | 0.393 | 0.189 | 1.337 | 0.542 |
| 0.625 | 2.858 | 1.665 | 0.756 | 0.566 | 14.0 | 86.1 | 5309 | 0.384 | 0.189 | 1.317 | 0.542 |
| 0.65 | 2.888 | 1.732 | 0.764 | 0.607 | 15.0 | 93.6 | 6745 | 0.375 | 0.197 | 1.284 | 0.543 |
| 0.675 | 2.910 | 1.798 | 0.770 | 0.628 | 15.5 | 97.5 | 7554 | 0.368 | 0.197 | 1.272 | 0.544 |
| 0.70 | 2.926 | 1.865 | 0.774 | 0.648 | 16.0 | 101.2 | 8413 | 0.364 | 0.204 | 1.253 | 0.544 |
| 0.725 | 2.959 | 1.931 | 0.783 | 0.668 | 16.5 | 104.7 | 9302 | 0.364 | 0.204 | 1.250 | 0.543 |
| 0.75 | 3.014 | 1.998 | 0.798 | 0.688 | 17.0 | 108.0 | 10260 | 0.364 | 0.200 | 1.258 | 0.542 |
| 0.775 | 3.125 | 2.064 | 0.827 | 0.708 | 17.5 | 111.4 | 11320 | 0.364 | 0.202 | 1.255 | 0.541 |
| 0.80 | 3.237 | 2.132 | 0.857 | 0.729 | 18.0 | 115.2 | 12550 | 0.363 | 0.203 | 1.251 | 0.540 |
| 0.825 | 3.345 | 2.198 | 0.885 | 0.749 | 18.5 | 120.3 | 14150 | 0.345 | 0.204 | 1.216 | 0.545 |
| 0.85 | 3.450 | 2.264 | 0.913 | 0.769 | 19.0 | 125.7 | 16080 | 0.329 | 0.202 | 1.190 | 0.548 |
| 0.875 | 3.669 | 2.331 | 0.971 | 0.790 | 19.5 | 130.6 | 18090 | 0.324 | 0.206 | 1.176 | 0.546 |
| 0.90 | 4.081 | 2.398 | 1.080 | 0.810 | 20.0 | 135.1 | 20180 | 0.324 | 0.202 | 1.180 | 0.542 |
|  |  |  |  | 0.830 | 20.5 | 139.6 | 22470 | 0.325 | 0.199 | 1.188 | 0.538 |
|  |  |  |  | 0.851 | 21.0 | 144.5 | 25170 | 0.326 | 0.193 | 1.197 | 0.533 |
|  |  |  |  | 0.891 | 22.0 | 158.3 | 33470 | 0.304 | 0.179 | 1.180 | 0.527 |

TABLE B-39
Results of Resistance and Self-Propulsion Experiments
Model Number 4246, $C_{B}=0.70, L / B=8.0, B / H=3.5$. Propeller Number 3564

| $\nabla / \sqrt{\text { arc }}$ | 111 Pigures are for Shid of 600 Ft Length BP |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $\nabla$ | 5 | SFP | $\mathrm{H}_{\mathrm{T}}$ | $t$ | ${ }_{6}$ | \% |
| 0.364 | 9.0 | 74.2 | 1082 | 0.375 | 0.163 | 1.340 | 0.528 |
| 0.405 | 10.0 | 81.8 | 144 | 0.371 | 0.164 | 1.331 | 0.534 |
| 0.445 | 11.0 | 89.9 | 1926 | 0.368 | 0.163 | 1.324 | 0.537 |
| 0.486 | 12.0 | 98.2 | 2544 | 0.368 | 0.164 | 1.323 | 0.536 |
| 0.526 | 13.0 | 107.2 | 3321 | 0.361 | 0.172 | 1.295 | 0.538 |
| 0.566 | 14.0 | 116.2 | 4296 | 0.359 | 0.177 | 1.284 | 0.537 |
| 0.607 | 15.0 | 125.4 | 5441 | 0.353 | 0.173 | 1.278 | 0.538 |
| 0.628 | 15.5 | 130.3 | 6124 | 0.347 | 0.175 | 1.264 | 0.540 |
| 0.648 | 16.0 | 134.9 | 6867 | 0.345 | 0.172 | 1.263 | 0.540 |
| 0.668 | 16.5 | 139.9 | 7689 | 0.342 | 0.173 | 1.260 | 0.539 |
| 0.688 | 17.0 | 144.7 | 8593 | 0.340 | 0.168 | 1.262 | 0.539 |
| 0.708 | 17.5 | 149.9 | 9595 | 0.336 | 0.167 | 1.256 | 0.539 |
| 0.729 | 28.0 | 155.4 | 10720 | 0.333 | 0.172 | 1.242 | 0.538 |
| 0.749 | 18.5 | 161.4 | 12000 | 0.326 | 0.180 | 1.218 | 0.538 |
| 0.769 | 19.0 | 168.1 | 13500 | 0.317 | 0.188 | 1.188 | 0.538 |
| 0.790 | 19.5 | 174.8 | 15160 | 0.310 | 0.192 | 1.170 | 0.536 |
| 0.810 | 20.0 | 181.0 | 16870 | 0.309 | 0.192 | 1.170 | 0.532 |
| 0.830 | 20.5 | 186.9 | 18750 | 0.311 | 0.186 | 1.181 | 0.528 |
| 0.851 | 21.0 | 193.3 | 20950 | 0.314 | 0.186 | 1.187 | 0.522 |
| 0.891 | 22.0 | 212.1 | 28260 | 0.291 | 0.186 | 1.149 | 0.516 | 111 Figuras are for ship of 400 Ft length BP


| V/ $\sqrt{L_{W L}}$ | $v$ | N | SHP | ${ }^{W}$ T | $t$. | ${ }^{\circ} \mathrm{b}$ | ${ }^{\circ} \mathrm{p}$ | ${ }^{6} \pi$ | EHP/SH |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0.364 | 9.0 | 49.1 | 2075 | 0.441 | 0.191 | 1.44 | 0.501 | 0.966 | 0.701 |
| 0.405 | 10.0 | 58.8 | 662 | 0.447 | 0.188 | 1.469 | 0.508 | 0.991 | 0.732 |
| 0.445 | 11.0 | 58.8 | 3392 | 0.448 | 0.178 | 1.490 | 0.505 | 1.010 | 0.760 |
| 0.488 | 12.0 | 64.0 | 4326 | 0.456 | 0.169 | 1.527 | 0.500 | 1.029 | 785 |
| 0.526 | 18.0 | 69.8 | 5567 | 0.450 | 0.10 | 1.517 | 0.501 | 1.035 | 0.787 |
| 0.568 | 14.0 | 76.6 | 7219 | 0.425 | 0.169 | 1.44 | 0.512 | 1.048 | 0.771 |
| 0.587 | 14.5 | 80.2 | 8218 | 0.412 | 0.175 | 1.404 | 0.517 | 1.044 | 0.758 |
| 0.607 | 15.0 | 83.5 | 9264 | 0.410 | 0.188 | 1.880 | 0.516 | 1.044 | . 748 |
| 0.628 | 15.5 | 80.9 | 0490 | 0.408 | $0.192^{\circ}$ | 1.368 | 0.518 | 1,043 | 0.788 |
| 0.648 | 16.0 | 90.0 | 11780 | 0.412 | 0.190 | 1.878 | 0.508 | 1.04 | 0.730 |
| 0.668 | 16.5 | 94.5 | 13400 | 0.401 | 0.184 | 1.868 | 0.509 . | 1.047 | 0.727 |
| 0.688 | 17.0 | 98.4 | 15220 | 0.397 | 0.178 | 1.864 | 0.508 | 1.045 | 0.724 |
| 0.708 | 17.5 | 103.0 | 17470 | 0.888 | 0.170 | 1.85 | 0.509 | 1.043 | 717 |
| 0.729 | 18.0 | 107.4 | 20190 | 0.388 | 0.175 | 1.8 | 0.498 | 1.050 | 0.700 |
| 0.748 | 18.5 | 114.3 | 23920 | 0.877 | 0.179 | 1.818 | 0.494 | 1.058 | 0.688 |
| 0.769 | 19.0 | 120.9 | 28640 | 0.374 | 0.182 | 1.808 | 0.484 | 1.058 | 0.688 |
| 0.780 | 19.5 | 126.8 | 33780 | 0.377 | 0.180 | 1.315 | 0.472 | 1.053 | 0.654 |
| 0.810 | 20.0 | 133.2 | 39190 | 0.370 | 0.177 | 1.307 | 0.467 | 1.055 | 0.644 |
| 0.830 | 20.5 | 138.6 | 44800 | 0.865 | 0.176 | 1.297 | 0.464 | 1.053 | 0.634 |
| 0.851 | 21.0 | 145.2 | 51440 | 0.358 | 0.178 | 1.271 | 0.463 | 1.055 | 0.621 |
| 0.871 | 21.5 | 151.7 | s8950 | 0.846 | 0.177 | 1.258 | 0.459 | 1.054 | 0.609 |
| 0.891 | 22.0 | 158.3 | 87710 | 0.858 | 0.188 | 1.268 | 0.4 | 1.000 | 0.507 |

TABLE B-41

| $V / \sqrt{L_{W L}}$ | v | N | SHP | ${ }^{W}$ T | $t$ | $0_{h}$ | ${ }^{\text {ep }}$ | ${ }^{\circ}$ | EHP/SHP |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0.364 | 9.0 | 58.5 | 1421 | 0.384 | 0.157 | 1.368 | 0.528 | 1.088 | 0.786 |
| 0.405 | 10.0 | 64.6 | 1932 | 0.387 | 0.144 | 1.398 | 0.529 | 1.075 | 0.785 |
| 0.445 | 11.0 | 71.2 | 2558 | 0.382 | 0.138 | 1.395 | 0.531 | 1.088 | 0.805 |
| 0.486 | 12.0 | 78.3 | 3374 | 0.373 | 0.138 | 1.372 | 0.534 | 1.093 | 0.801 |
| 0.526 | 13.0 | 85.6 | 4420 | 0.373 | 0.153 | 1.350 | 0.580 | 1.095 | 0.784 |
| 0.568 | 14.0 | 93.2 | 5786 | 0.374 | 0.165 | 1.334 | 0.525 | 1.088 | 0.761 |
| 0.587 | 14.5 | 97.4 | 6608 | 0.373 | 0.171 | 1.323 | 0.522 | 1.087 | 0.750 |
| 0.607 | 15.0 | 101.5 | 7577 | 0.374 | 0.174 | 1.318 | 0.518 | 1.078 | 0.737 |
| 0.628 | 15.5 | 105.8 | 8698 | 0.376 | 0.180 | 1.313 | 0.514 | 1.070 | 0.721 |
| 0.648 | 18.0 | 110.4 | 9998 | 0.375 | 0.186 | 1.300 | 0.512 | 1.060 | 0.705 |
| 0.668 | 16.5 | 115.3 | 11520 | 0.373 | 0.191 | 1.290 | 0.506 | 1.054 | 0.688 |
| 0.688 | 17.0 | 120.8 | 13250 | 0.364 | 0.192 | 1.271 | 0.505 | 1.055 | 0.677 |
| 0.708 | 17.5 | 126.7 | 15300 | 0.357 | 0.187 | 1.265 | 0.501 | 1.058 | 0.671 |
| 0.729 | 18.0 | 133.0 | 17750 | 0.852 | 0.185 | 1.258 | 0.496 | 1.060 | 0.662 |
| 0.740 | 18.5 | 139.9 | 20760 | 3.345 | 0.184 | 1.246 | 0.401 | 1.061 | 0.640 |
| 0.768 | 19.0 | 147.4 | 24540 | 0.848 | 0.180 | 1.248 | 0.482 | 1.060 | 0.637 |
| 0.790 | 19.5 | 155.4 | 29130 | 0.341 | 0.178 | 1.247 | 0.473 | 1.056 | 0.623 |
| 0.810 | 20.0 | 163.6 | 34840 | 0.340 | 0.177 | 1.247 | 0.462 | 1.052 | 0.607 |
| 0.830 | 20.5 | 172.0 | 40760 | 0.335 | 0.181 | 1.232 | 0.456 | 1.047 | 0.589 |
| 0.851 | 21.0 | 180.3 | 47250 | 0.334 | 0.187 | 1.221 | 0.448 | 1.040 | 0.569 |
| 0.871 | 21.5 | 188.2 | 53500 | 0.311 | 0.188 | 1.179 | 0.453 | 1.041 | 0.556 |
| 0.891 | 22.0 | 195.5 | 59460 | 0.289 | 0.192 | 1.136 | 0.460 | 1.044 | 0.545 |

All Figures are for Ship of 400 Ft Length BP
TABLE B-42
Results of Resistance and Self-Propulsion Experiments
镸

$V / \sqrt{W L}$
0.364
0.405
0.445
0.486
0.526
0.586
0.587
0.607
0.628
0.848
0.868
0.688
0.708
0.729
0.749
0.789
0.790
0.810
0.830
0.851
0.871
0.891

[^6]
## TABLE B-43

Results of Resistance and Self-Propulsion Experiments Model Number 4249, $C_{B}=0.80, L / B=5.5, B / H=3.5$, Propeller Number 2944

| $v / \sqrt{4 w x}$ |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $\nabla$ | N | SHP | $\mathrm{w}_{\mathrm{T}}$ | $t$ | ${ }^{\circ} \mathrm{h}$ | ${ }^{\circ} \mathrm{p}$ |
| 0.364 | 9.0 | 51.9 | 2017 | 0.466 | 0.234 | 1.431 | 0.496 |
| 0.405 | 10.0 | 57.7 | 2776 | 0.448 | 0.211 | 1.430 | 0.510 |
| 0.445 | 11.0 | 63.5 | 3766 | 0.437 | 0.210 | 1.403 | 0.519 |
| 0.466 | 11.5 | 66.6 | 4356 | 0.432 | 0.214 | 1.385 | 0.521 |
| 0.486 | 12.0 | 69.6 | 5022 | 0.428 | 0.215 | 1.372 | 0.523 |
| 0.506 | 12.5 | 72.5 | 5730 | 0.429 | 0.211 | 1.382 | 0.523 |
| 0.526 | 13.0 | 75.5 | 6493 | 0.430 | 0.213 | 1.381 | 0.522 |
| 0.546 | 13.5 | 78.7 | $73 \div 8$ | 0.425 | 0.205 | 1.383 | 0.524 |
| 0.566 | 14.0 | 81.9 | 8286 | 0.422 | 0.197 | 1.391 | 0.524 |
| 0.587 | 14.5 | 85.6 | 9497 | 0.417 | 0.192 | 1.386 | 0.524 |
| 0.607 | 15.0 | 90.0 | 10980 | 0.405 | 0.194 | 1.355 | 0.526 |
| 0.628 | 15.5 | 94.7 | 12830 | 0.396 | 0.195 | 1.334 | 0.525 |
| 0.648 | 16.0 | 99.9 | 15020 | 0.388 | 0.189 | 1.325 | 0.522 |
| 0.688 | 17.0 | 110.4 | 20970 | 0.379 | 0.184 | 1.314 | 0.511 |
| 0.729 | 18.0 | 123.5 | 30160 | 0.361 | 0.178 | 1.285 | 0.500 |
| 0.769 | 19.0 | 138.4 | 43980 | 0.351 | 0.172 | 1.276 | 0.482 |
| 0.810 | 20.0 | 155.2 | 64600 | 0.349 | 0.144 | 1.314 | 0.4 |

111 Figures are for Sh1p of 400 Ft Length BP

TABLE B-44
Results of Resistance and Self-Propulsion Experiments



$\Delta 11$ Figures are for Ship of 400 Ft Length BP
TABLE B-45
Results of Resistance and Self-Propulsion Experiments
Model Number 4250, $C_{B}=0.8, L / B=7.5, B / H=3.5$, Propeller Number 2765
0.86
0.668
0.674
0.668
0.664
0.660
0.663
0.670
0.673
0.673
0.670
0.660
0.650
0.635
0.607
0.583
0.556


111 P1sures are for ship of 400 ft Length Bp

| $\nabla / \sqrt{L_{L}}$ | $c_{t} \times 10^{3}$ | $Q$ | $C$ |
| :--- | :--- | :--- | :--- |
| 0.35 | 2.799 | 0.933 | 0.761 |
| 0.40 | 2.769 | 1.066 | 0.753 |
| 0.45 | 2.759 | 1.199 | 0.750 |
| 0.50 | 2.804 | 1.332 | 0.762 |
| 0.525 | 2.855 | 1.399 | 0.776 |
| 0.55 | 2.945 | 1.466 | 0.801 |
| 0.575 | 3.066 | 1.532 | 0.834 |
| 0.60 | 3.216 | 1.599 | 0.874 |
| 0.625 | 3.398 | 1.666 | 0.924 |
| 0.65 | 3.620 | 1.732 | 0.984 |
| 0.675 | 3.870 | 1.799 | 1.052 |
| 0.70 | 4.155 | 1.866 | 1.129 |
| 0.75 | 4.915 | 1.999 | 1.335 |
| 0.80 | 6.049 | 2.132 | 1.644 |

Table B-46 - Effective Horsepower Estimate from Series $60 \frac{R_{R}}{\Delta}$ Contours


Table B-47-(C) Estimate from Series 60 (C) Contours
Ship SSPEMMSYLVAMII Model No. 4057

Ship Dimensions

| LwL | 600.03 | $C_{B}\left(L_{B P}\right)$ | 0.165 |
| :---: | :---: | :---: | :---: |
| $L_{\text {BP }}$ | 595.00 | $L_{\text {BP/ }} \mathrm{B}$ | 1.083 |
| B | 84.00 | B/H | 2.545 |
| H | 33.00 | $x$ | -0.9100 |
| $\nabla$ | 1262670 | $\mathrm{x}^{2}$ | 0.8281 |

(C) $400=$ (C) $400($ for $B / H=3.0)+a x+b x^{2}$
$x=2[B / H$ (of prototype ) - 3.0]
$a=\frac{\text { © } 400(3.5)-\text { © } 400(2.5)}{2}$
$b=\frac{C_{400(3.3)}+\text { © } 400(2.5)-2\left(C_{400(3.0)}\right.}{2}$

## Formuloe

| $A$ | $B$ | $c$ | $D$ | $E$ | $F$ | $G$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| (K) | (C) 400 trom contours |  |  | $\begin{gathered} 0 \\ \frac{D-B}{2} \end{gathered}$ | $\begin{gathered} \mathrm{b} \\ \frac{D+B-2 C}{2} \end{gathered}$ | $\begin{aligned} & \text { (C) } 400 \\ & C+E X+F X^{2} \end{aligned}$ |
|  | $B / H=2.5$ | $B / H=3.0$ | $B / H=3.5$ |  |  |  |
| 1.2 |  |  |  |  |  |  |
| 1.3 |  |  |  |  |  |  |
| 1.4 | . |  |  |  |  |  |
| 1.5 |  |  |  |  |  |  |
| 1.6 | 0.1735 | 0.7130 | 0.7883 | 0.0074 | 0.0679 | 0,1128 |
| 1.7 |  |  |  |  |  |  |
| 1.8 |  |  |  |  |  |  |
| 1.9 |  |  |  |  |  |  |
| 2.0 |  |  |  |  |  |  |
| 2.1 |  |  |  |  |  |  |
| 2.2 |  |  |  |  |  |  |
| 2.3 |  |  |  |  |  |  |
| 2.4 | . |  |  |  |  |  |

Table B48 - Approximate Corrections to (C) 400 Ft for Other Ship Lengths

| Wetted Surface Coefficient $S / \Delta^{2 / 3}$ | 65 |  |  | 75 |  |  | 85 |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Speed Length <br> Ratio $V / \sqrt{L}$ | 0.60 | 0.80 | 1.00 | 0.60 | 0.80 | 1.00 | 0.60 | 0.80 | 1.00 |
| Length $L$ in Ft | Additions to Basic (C) ${ }_{400 \mathrm{ft}}$ |  |  |  |  |  |  |  |  |
| 100 | 0.086 | 0.082 | 0.079 | 0.100 | 0.095 | 0.091 | 0.113 | 0.107 | 0.103 |
| 125 | 0.070 | 0.066 | 0.063 | 0.081 | 0.077 | 0.073 | 0.091 | 0.087 | 0.083 |
| 150 | 0.058 | 0.055 | 0.053 | 0.066 | 0.063 | 0.061 | 0.075 | 0.072 | 0.069 |
| 175 | 0.048 | 0.046 | 0.044 | 0.055 | 0.053 | 0.051 | 0.063 | 0.060 | 0.057 |
| 200 | 0.040 | 0.038 | 0.036 | 0.046 | 0.044 | 0.042 | 0.052 | 0.050 | 0.048 |
| 225 | 0.033 | 0.031 | 0.030 | 0.038 | 0.036 | 0.035 | 0.043 | 0.041 | 0.040 |
| 250 | 0.027 | 0.025 | 0.024 | 0.031 | 0.030 | 0.029 | 0.035 | 0.034 | 0.033 |
| 275 | 0.021 | 0.020 | 0.019 | 0.025 | 0.024 | 0.023 | 0.028 | 0.027 | 0.026 |
| 300 | 0.017 | 0.016 | 0.015 | 0.019 | 0.018 | 0.017 | 0.022 | 0.021 | 0.020 |
| 325 | 0.012 | 0.011 | 0.011 | 0.014 | 0.013 | 0.013 | 0.016 | 0.015 | 0.014 |
| 350 | 0.008 | 0.007 | 0.007 | 0.009 | 0.008 | 0.008 | 0.010 | 0.009 | 0.009 |
| 400 |  |  | ---- | --- | ---- | --- | --- |  |  |
| Deductions from Basic (C) 400 ft |  |  |  |  |  |  |  |  |  |
| 450 | 0.007 | 0.006 | 0.006 | 0.008 | 0.007 | 0.007 | 0.009 | 0.008 | 0.008 |
| 500 | 0.013 | 0.012 | 0.011 | 0.015 | 0.014 | 0.013 | 0.016 | 0.015 | 0.015 |
| 550 | 0.018 | 0.017 | 0.016 | 0.021 | 0.020 | 0.019 | 0.023 | 0.022 | 0.022 |
| 600 | 0.023 | 0.022 | 0.021 | 0.026 | 0.025 | 0.024 | 0.030 | 0.028 | 0.027 |
| 650 | 0.027 | 0.026 | 0.025 | 0.032 | 0.030 | 0.029 | 0.035 | 0.034 | 0.033 |
| 700 | 0.032 | 0.030 | 0.029 | 0.037 | 0.035 | 0.033 | 0.041 | 0.039 | 0.038 |
| 750 | 0.036 | 0.034 | 0.032 | 0.041 | 0.039 | 0.038 | 0.046 | 0.044 | 0.043 |
| 800 | 0.039 | 0.037 | 0.036 | 0.045 | 0.043 | 0.041 | 0.051 | 0.049 | 0.047 |
| 850 | 0.043 | 0.041 | 0.039 | 0.049 | 0.047 | 0.045 | 0.056 | 0.053 | 0.051 |
| 900 | 0.046 | 0.044 | 0.042 | 0.053 | 0.050 | 0.048 | 0.060 | 0.056 | 0.055 |
| 950 | 0.048 | 0.046 | 0.044 | 0.056 | 0.053 | 0.051 | 0.063 | 0.060 | 0.058 |
| 1000 | 0.051 | 0.048 | 0.046 | 0.058 | 0.056 | 0.053 | 0.066 | 0.063 | 0.060 |

## APPENDIX C

## METHODS OF ANALYSIS AND FAIRING OF RESULTS

For each $\frac{B}{H}$ value, 15 models were built and tested, the three models at each block coefficient covering a range of $\frac{L}{B}$ values. It is desirable to have sets of contours to facilitate the interpolation of the results given in this paper. The contours also will give ship designers a visual picture to guide them in choosing the principal proportions and coefficients of the ship.

Consider the contours of $\frac{R_{R}}{\Delta}$. A two-way interpolation is involved-f irst between $\frac{L}{B}$ values at each block coefficient and then across the block coefficient at each $\frac{L}{B}$ value. Such interpolation could be done by drawing curves through the test points as shown in Figures C1 and C2. Then Figure C2 would be reploted by using constant $\frac{R_{R}}{\Delta}$ values as parameter, $C_{B}$ as abscissa and $\frac{L}{B}$ as ordinate to obtain the final contours. However, it is not easy to follow this procedure. In general, the points taken along any horizontal line in Figure C2 will be quite scattered in the final plot. A tedious cross fairing is then necessary among these three plots. This process has to be done for many values of $\frac{V}{\sqrt{L}}$. At the end, a plot of $\frac{R_{R}}{\Delta}$ against $\frac{V}{\sqrt{L}}$ as lifted from the contours for fixed values of $C_{B}$ and $\frac{L}{B}$ may not be a fair curve. Further refairing among the four plots is necessary. With the experience of fairing a set of ship lines between two plots, body plan and waterlines, it is quite evident that it would be extremely tedious and frustrating to obtain a set of consistent $\frac{R_{R}}{\Delta}$ contours by manual fairing. Accordingly, it was decided to interpolate between $\frac{L}{B}$ and across the block coefficients mathematically and to program the computation work into a UNIVAC computer, by the method devised by Dr. P.C. Pien.

For interpolating between $\frac{L}{B}$ values, three values of $\frac{R_{R}}{\Delta}$ corresponding to three $\frac{L}{B}$ values at each block coefficient and a fixed value of $\frac{B}{H}$, are known from the model tests. It was rather difficult to decide how the interpolation should be done since an infinite number of curves can be drawn to pass through three given points. Without any definite knowledge as to how such a curve should look, a simple curve expressed as follows was chosen

$$
\frac{R_{R}}{\Delta}=a+b\left(\frac{L}{B}\right)+c\left(\frac{L}{B}\right)^{2}
$$

With this equation, $\frac{R_{R}}{\Delta}$ values for $\frac{L}{B}$ values between 5.5 and 8.5 at intervals of 0.25 were computed for each block coefficient at constant values of $\frac{V}{\sqrt{L}}$.

For interpolation between block coefficients, there are five points, one for each block coefficient for given values $\frac{L}{B}$ and $\frac{V}{\sqrt{\mathrm{~L}}}$. The polynomial

$$
\frac{R_{R}}{\therefore}=A+B \cdot C_{B}+C \cdot C_{B}^{2}+D \cdot C_{B}^{3}+E \cdot C_{B}^{4}
$$

could be used for this interpolation. However, it was felt that the interpolation near one end of the curve might be influenced unduly by the values near the other end. It was decided to use two equations of the following type, one for each end of the curve:

$$
\frac{R_{R}}{\Delta}=A+B \cdot C_{B}+C \cdot C_{B}^{2}+D \cdot C_{B}^{3}
$$

The coefficients of the equations were so determined that each equation would pass through three points and have equal ordinates and first and second derivatives where they joined at the midpoint. Values of $\frac{R_{R}}{\Delta}$ at intervals of 0.01 in $C_{B}$ values were computed by using these two equations. Figures C 1 and C 2 show the interpolating curves between the $\frac{L}{B}$ values and across block coefficient, respectively, as obtained by using the foregoing equations.

If we consider a three-dimensional surface plot with $C_{B}$ as $x, \frac{L}{B}$ as $y$, and $\frac{R_{R}}{\Delta}$ as 2, then Figure C 1 indicates the cuts of this surface by a series of planes with constant $\alpha$-values, and Figure C2 indicates the cuts of this surface by a series of planes with constant $y$-values. The cuts of this surface by a series of planes with constant $z$-values are the required contours of $\frac{R_{R}}{\Delta}$.

Figure C3 shows the contours of $\frac{R_{R}}{\Delta}$ obtained in this way for a $\frac{V}{\sqrt{L}}$ of 0.60 and a $\frac{B}{H}$ value of 3.0. Also shown are the actual values of $\frac{R_{R}}{\Delta}$ for the 15 models (having three values of $\frac{L}{B}$ at each of five block coefficients) from which the contours were derived. It will be agreed that the contours show an excellent interpolation among these 15 points and give confidence in their use for power estimates.

The three-dimensional surface mentioned is determined by 15 points from model testing. Each of the points follows a faired curve as $\frac{V}{\sqrt{L}}$ changes. Any spot at fixed values of $x$ and $y$, therefore, will follow a faired curve of its own as $\frac{V}{\sqrt{L}}$ changes. That is to say, the
$R_{R}$ $\frac{R_{R}}{\Delta}$ values of any particular model lifted from the contours at various $\frac{V}{\sqrt{L}}$ values will give a faired curve when they are plotted against $\frac{V}{\sqrt{L}}$.


Figure C1 - Interpolation Curves of $\frac{R_{r}}{\Delta}$ between $\frac{L}{B}$ Values


Figure C2 - Interpolation Curves of $\frac{R_{r}}{\Delta}$ between $C_{B}$ Values


All the $\frac{R_{R}}{\Lambda}$ contours show only the portion covered by the range of model tests. The tests were not conducted to as high a speed range for models of higher block coefficients, as for those of lower block coefficient. Hence the contours at higher $\frac{V}{\sqrt{L}}$ values cover only the lower block coefficient range.

The contours of (C), thrust deduction $t$, and wake fraction $w$, were obtained in the same manner as those of $\frac{R_{R}}{\Delta}$ except that the original 15 points were taken at constant $(<)$ and constant ship speed, respectively.

All the computation work was done by the Applied Mathematics Laboratory on a UNIVAC computer; this not only saved a great deal of time and money but also greatly reduced the chance of errors. The choice of the interpolation equations was somewhat arbitrary, but the comparison made in Figure C3 suggests that they do give a very good presentation of the data. However, the original results are all included in Appendix B and may be used to carry out any other form of plotting or interpolation desired.

## APPENDIX D

## NUMERICAL EXAMPLE OF USE OF SERIES 60 CHARTS

In order to illustrate the use of the Series 60 Charts in preparing lines plans and power estimates, a numerical example is worked out in this appendix.

The design chosen is that of a ship corresponding in main dimensions with SCHUYLER OTIS BLAND. It was selected because a model of the resultant Series 60 equivalent of this ship had been made and run, as described in the report, so that actual model data are available for comparison with the Series 60 estimates.

The principal particulars of SCHUYLER OTIS BLAND as built are given in the first column of Table D1.

Table D1 - Principal Design Data of SCHUYLER OTIS BLAND

|  | SCHUYLER OTIS BLAND | SERIES 60 EQUIV ALENT |
| :---: | :---: | :---: |
| $L_{W_{L}}, \mathrm{ft}$ | 453.0 | 457.6 |
| $L_{B P}, \mathrm{ft}$ | 450.0 | 450.0 |
| Beam, ft | 66.0 | 66.0 |
| Draft, ft | 27.0 | 27.0 |
| Displacement, tons | 14,920 | 14,920 |
| $C_{B}$ | 0.651 | 0.651 |
| $C_{X}$ | 0.980 | 0.982 |
| $C_{P}$ | 0.664 | 0.663 |
| $1 / 2^{\boldsymbol{a}_{E}}$, deg | 9.5 | 9.3 |
| $x / L$ | 0.510 | 0.510 |
| $L_{E} / L$ | 0.503 | 0.472 |
| $L_{X} / L$ | 0 | 0.036 |
| $L_{R} / L$ | 0.497 | 0.492 |
| $K_{R}$ |  | 0.204 |
| $L C B$ | $\begin{aligned} & 4.5 \mathrm{ft} \text { aft } \varnothing \\ = & 1 \text { percent } L_{B P} \text { aft } \end{aligned}$ | $\begin{gathered} 4.5 \mathrm{ft} \text { att } \\ =1 \text { percent } L_{B P} \text { aft } \end{gathered}$ |

Knowing the value of the block coefficient (0.651), the midship area coefficient, prismatic coefficient and bilge radius coefficient can be obtained from Figure 3. The values are 0.982 , 0.663 and 0.204 respectively as given in the second column of the table. They correspond to the characteristics chosen for Series 60, and so differ a little from those of the type ship.

From Figures 4 and 9 the half-angle of entrance on the load waterline $\frac{1 / 2}{\alpha_{E}} \boldsymbol{\alpha}_{E}$ is found to be 9.3 deg , the parallel body is 3.6 percent of the $L B P \cdot\left(\frac{L_{X}}{L_{B} P}=0.036,\right)$ and the length of entrance $L_{E}$ is given by the ratio $\frac{L_{\delta}}{L_{B P}}=0.472$. Hence the length of run is determined by the ratio $\frac{L_{R}}{L_{B P}}=0.492$.

The $L C B$ is required to be at 1.0 percent $L B P$ aft of a midships, between perpendiculars. For this position and a block coefficient of 0.651 , Figure 10 shows that the ratio of prismatics of entrance and run must be 0.916 .

We then have two conditions to determine $C_{P E}$ and $C_{P R}$ :

$$
\begin{gathered}
\frac{C_{P E}}{C_{P R}}=0.916 \\
C_{P} \times L=C_{P E} \times L_{E}+L_{X}+C_{P R} \times L_{R} \\
\text { i.e., } 0.663=C_{P E} \times 0.472+0.036+C_{P R} \times 0.492
\end{gathered}
$$

Substituting for $C_{P R}$

$$
0.663-0.036=(0.472+0.537) C_{P E}
$$

and

$$
\begin{aligned}
C_{P E} & =0.621 \\
C_{P R} & =0.678
\end{aligned}
$$

and
The form particulars are now

$$
\begin{array}{ll}
L_{E}=0.472 \times 450=212.4 & C_{P E}=0.621 \\
L_{P}=0.036 \times 450=16.2 & C_{P X}=1.000 \\
L_{R}=0.492 \times 450=\underline{221.4} & C_{P R}=0.678 \\
L_{B P} & =450.0
\end{array}
$$

The offsets for the area curve can now be obtained from Figures $5 a$ and 5 b . The charts must be entered with the correct coefficient, $C_{P E}$ or $C_{P R}$, as necessary, and the area ordinates obtained are to be equally spaced along the lengths of entrance and run respectively.

In this particular case, the ordinates are:

| RL'N |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Station | 1 (AP) | 2 | 3 | $t$ | 5 | 6 | 7 | 8 | $\theta$ | 10 | 11 |
| Dist. from $\pm P, f t$ | 0 | 22.14 | 44.28 | 68.42 | 88.56 | 110.70 | 132.84 | 154.88 | 177.12 | 199.26 | 221.40 |
| Area <br> Coefficient | 0.006 | 0.129 | 0.313 | 0.505 | 0.672 | 0.803 | 0.900 | 0.960 | 0.888 | 0.998 | 1.000 |
| ENTRANCE |  |  |  |  |  |  |  |  |  |  |  |
| Station | 21 (FP) | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 |
| Dist. from FP, ft | 0 | 21.24 | 42.48 | 63.79 | 84.96 | 106.20 | 127.44 | 148.68 | 168.92 | 191.16 | 212.40 |
| Area <br> Coefficient | 0 | 0.102 | 0.233 | 0.385 | 0.551 | 0.707 | 0.830 | 0.920 | 0.970 | 0.995 | 1.000 |

The parallel middle body is inserted between the entrance and run. An area curve is now plotted, area coefficients lifted at equally spaced stations, and a calculation made to check that the right prismatic coefficient and $L C B$ position have been obtained. (Figure D1).

This calculation is shown in Table D2.


Figure D1 - Area Curves for Series 60 Equivalent of SCHUYLER OTIS BLAND

Table D2 - Check on $C_{P}$ and $L C B$ Position
(New ordinates at equal spacing, 22.5 ft )

| Station | Ordinates | SM: | $f$ (vol) | lever | $f$ (moment) |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 1 AP | 0.006 | 1 | 0.006 | 10 | 0.060 |
| 2 | 0.135 | 4 | 0.540 | 9 | 4.860 |
| 3 | 0.322 | 2 | 0.644 | 8 | 5.152 |
| 4 | 0.514 | 4 | 2.056 | 7 | 14.392 |
| 5 | 0.683 | 2 | 1.366 | 6 | 8.196 |
| 6 | 0.815 | 4 | 3.260 | 5 | 16.300 |
| 7 | 0.910 | 2 | 1.820 | 4 | 7.280 |
| 8 | 0.965 | 4 | 3.860 | 3 | 11.580 |
| 9 | 0.990 | 2 | 1.980 | 2 | 3.960 |
| 10 | 0.999 | 4 | 3.996 | 1 | 3.996 |
| 118 | 1.000 | 2 | 2.000 | 0 | 75.776 |
| 12 | 0.999 | 4 | 3.996 | 1 | 3.996 |
| 13 | 0.985 | 2 | 1.970 | 2 | 3.940 |
| 14 | 0.947 | 4 | 3.788 | 3 | 11.364 |
| 15 | 0.868 | 2 | 1.736 | 4 | 6.944 |
| 16 | 0.750 | 4 | 3.000 | 5 | 15.000 |
| 17 | 0.590 | 2 | 1.180 | 6 | 7.080 |
| 18 | 0.416 | 4 | 1.664 | 7 | 11.648 |
| 19 | 0.250 | 2 | 0.500 | 8 | 4.000 |
| 20 | 0.110 | 4 | 0.440 | 9 | 3.960 |
| 21 FP | - | 1 | 0 | 10 | - |
| $\begin{aligned} & \underline{\underline{C_{P}=0.663}} \\ L C B=\frac{60) 39.802}{39.802} \times 22.5 & =4.434 \mathrm{ft} \text { aft } 母 \\ & =\underline{0.985 \text { percent } L \text { aft } \otimes B_{P}} \end{aligned}$ |  |  |  |  |  |
|  |  |  |  |  |  |

The resultant prismatic coefficient is 0.663 , as desired, and the $L C B$ is 0.985 percent $L_{B P}$ aft of midships, as compared with 1.00 percent required, which is sufficiently close for practical purposes. It is significant that this close agreement was obtained immediately from the contours without any adjustment or personal factor being involved. This shows the usefulness of the Series to the designer for obtaining a set of lines which will fulfill the design requirements at a very early stage and from which stábility, capacities and similar quantities can be obtained.

A similar procedure can now be used to draw the lines plan; half-breadths on different waterlines and stations can be obtained from Figures $6 a$ to $6 p$ and the bow and stern contours from Figure 11. The half-breadths must be set off at stations equally spaced along the entrance and run.

An estimate of the resistance and ehp can now be made from the contour charts, using the format given in Tables B46 and B47.

The information required to complete the tables is as follows:

| $L_{W L} \mathrm{ft}$ | $=457.6$ | $\sqrt{L_{W L}}$ | $=21.39$ |
| :---: | :---: | :---: | :---: |
| $L_{B P} \mathrm{ft}$ | $=450.0$ | $\sqrt{L_{B P} P}$ | $=21.21$ |
| $B \quad \mathrm{ft}$ | $=66.0$ | $L_{M} \mathrm{ft}$ | $=20.338$ on WL |
| $H \mathrm{ft}$ | $=27.0$ | $\lambda$ | $=22.5$ |
| $\Delta$, tons | $=14,920$ | $\Delta^{2 / 3}$ | $=606.19$ |
| $S$, sq ft | $=39,994$ | $\Delta^{1 / 3}$ | $=24.621$ |
| $C_{B}$ | $=0.651$ | $\Delta^{1 / 6}$ | $=4.962$ |
| $\frac{L_{B P}}{B}$ | $=\frac{450}{66}=6.82$ | $\nabla$ | $=522,200 \mathrm{cu} \mathrm{ft}$ |
| $\frac{B}{H}$ | $=\frac{66}{27}=2.444$ | $\nabla^{2 / 3}$ | $=648.35$ |
| H | 27 | $\nabla^{1 / 3}$ | $=80.52$ |
|  |  | $\frac{S}{\nabla^{2 / 3}}$ | $=\frac{39994}{648.35}=6.168$ |

For the interpolation process, we need the values of $X$ and $X^{2}$, where

$$
\begin{gathered}
X=2\left(\frac{B}{H}-3.0\right)=2(2.444-3.0)=-1.112 \\
X^{2}=+1.2365
\end{gathered}
$$

The value of the wetted surface $S$ used above was calculated from the lines drawing. An approximate value can be obtained from the contours shown in Figures B124 to B126 for use in the first ehp estimates, which will probably be made for a number of forms before any lines are drawn.

| COLUMN |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| B | C | D | E | F | G |
| $\text { for } \frac{B}{H} \text { of }$ |  |  | $\frac{D-B}{2}$ | $\frac{D+B-2 C}{2}$ | $\begin{aligned} & \frac{S}{\nabla^{2 / 3}} \text { for } \frac{B}{H}=2.444 \\ & =C+E \cdot X+F \cdot X^{2} \\ & =6.38-0.228+0.031 \end{aligned}$ |
| 2.5 | 3.0 | 3.5 | $2$ |  | $\begin{aligned} & =C+E \cdot X+F \cdot X^{2} \\ & =6.38-0.228+0.031 \end{aligned}$ |
| 6.20 | 6.38 | 6.61 | +0.205 | +0.025 | 6.183 |

This compares with a value of $\frac{S}{\boldsymbol{\nabla}^{2 / 3}}$ of 6.168 from the calculated wetted surface, a difference
of only 0.24 percent. of only 0.24 percent.

Table D3 shows the calculation of ehp and ship (C) values from the $\frac{R_{R}}{\Delta}$ contours given in Figures B1 to B39. The table is largely self-explanatory. Columns B, C, and D give the values of $\frac{R_{R}}{\Delta}$ lifted from the contours for different values of $\frac{V}{\sqrt{L_{W L}}}$ and $\frac{B}{H}$. These are corrected to the desired $\frac{B}{H}$ for the ship in columns E, F, and G by the interpolation process described in the text and illustrated above in its application to the $\frac{S}{\nabla^{2 / 3}}$ contours.

Column J shows the values of $\frac{R_{F}}{S}$ obtained from the nomograph in Figure B127.
The final ehp in column M is for the bare hull, without bilge keels, rudder, or other a ppendages.

For comparison with other models, the values of (C) and (B) for the actual ship are given in columns $\mathbf{P}$ and Q .

Estimates of the (C) value for a 400 -ft standard ship ( (C) 400 ft ) can be made directly from $\left(C_{400} \mathrm{ft}\right.$ contours given in Figures B40 through B78. These are useful for estimates and comparisons with other data when considering various alternative choices of length, beam, draft, fullness, etc., before the design is finalized and an actual ehp for the ship is required.

The calculation is shown in Table D4; it follows the same method of interpolation as used in Table D3 but is much shorter for the purpose in view.

The (C) and ehp estimates made up to this point are for a ship having the $L C B$ in the position chosen for the parents of the $\frac{L}{B}, \frac{B}{H}$ series. For a block coefficient of 0.65 , this position was 1.54 percent $L_{B P}$ aft of midships, whereas for this particular ship SCHUYLER
Table D3 - Effective Horsepower Estimate from Series $60 \frac{R_{R}}{\Delta}$ Contours


Table D4-(C) Estimate from Series 60 (C) Contours

Ship
SERIES 60 MODEL NO. 4484W
Equivalent of SCHUYLER OTIS BLAND

Ship Dimensions

| $L_{W L}$ | $\frac{457.6}{}$ | $C_{B}\left(L_{B P}\right)$ | 0.651 |
| :--- | :--- | :--- | :--- |
| $L_{B P}$ | $\frac{450.0}{}$ | $L_{B P} / B$ | -6.82 |
| $B$ | -66.0 | $B / H$ | -2.444 |
| $H$ | -27.0 | $X$ | -1.112 |
| $\nabla$ | 522,200 | $X^{2}$ | +1.2365 |

## Formulae

$C_{400}=C_{400(f \text { or } B / H=3.0)}+a X+b X^{2}$
$X=2[B / H$ (of prototype) -3.0$]$
$a=\frac{C_{400(3.5)}-C_{400(2.5)}}{2}$
$b=\frac{C_{400(3.5)}+C_{400(2.5)}-2 C_{400(3.0)}}{2}$
$S / \nabla^{2 / 3}$ 6.168


OTIS BLAND, the required position is 1.00 percent $L_{B P}$ aft. The correction can be made from the data given in Tables 49-53, and the resultant ehp and ©alues are shown in Table D5. The parent model of $0.65 C_{B}$ had the $L C B 1.54$ percent $L_{B P}$ aft of midships, whereas the position required in the Series 60 equivalent of SCHUYLER OTIS BLAND is 1.00 percent $L_{B P}$ aft.

The corrections given in Tables 49-53 were cross plotted to a base of $L C B$ position and the values lifted off at the desired point are shown in Table D5. Because of the erratic variation of $(C$ with $L C B$ position, linear interpolation is not possible.

These values are plotted in Figures D2 and D3. The two (Curves in Figure D2 are in very good agreement, remembering that the one for the $450-\mathrm{ft}$ ship should be lower than that for the $400-\mathrm{ft}$ ship because of the difference in skin friction coefficient. This agreement is of considerable interest because one (C) curve is derived from the $\frac{R_{R}}{\Delta}$ contours, the other from the (C) 400 ft contours, and although both sets of contours are based ultimately on the same model experiment results, the subsequent fairing to obtain the contours was done quite independently. The agreement indicates that both sets represent the results very closely.

In the course of the analysis of the Series 60 original parents, a comparison was made between the model of the actual SCHUYLER OTIS BLAND and a model of the Series 60 equivalent. It is thus possible to make a direct comparison between these model results and the estimates made from the Series 60 contours. The actual model results are shown in Table D6 and plotted in Figures D2 and D3. They give considerable confidence in estimates made from the Series 60 contours.

For propulsion data, the wake and thrust deduction fractions and the relative rotative efficiencies can be obtained from the respective contours in Figures B79 through B123, using the same method of interpolation as with the $\frac{R_{R}}{\Delta}$ and (C) contours. With this information and suitable propeller design charts, estimates can easily be made of propulsive efficiencies for different engine conditions, provided the propeller diameter is about 0.7 of the draft. For any other diameter/draft ratio, corrections can be made from the data given in Chapter X of this report.

Much of the model data in the world is published in the form of $(C)_{400 \mathrm{ft}}$ using the Froude $O_{M}$ and $O_{S}$ frictional coefficients in the extrapolation from model to ship. As stated in the text, Gertler has given a quick method of converting (C) 400 $_{\mathrm{ft}}$ from the Froude values to the ATTC values, or vice versa, ${ }^{47}$ and his chart is reproduced in Figure D4.

As an example, take the case of the Series 60 equivalent of SCHUYLER OTIS BLAND at a (K) value of 2.0 .

$$
l_{m}=20.338 \mathrm{ft}
$$

$\Delta=14,920$ tons for $450-\mathrm{ft}$ ship and $\Delta=14,920 \times\left(\frac{400}{450}\right)^{3}$ for $400-\mathrm{ft}$ ship
$(S)=6.168 \quad=10,473$ tons.

Table D5a - Correction to Actual Ship(C) and EHP for Shift in LCB Position

| $\frac{V}{\sqrt{L_{W L}}}$ | Percent Correction <br> from Series 60 <br> LCB Position | Uncorrected <br> C.Ship from <br> Table D3 | C) Ship <br> Corrected | Uncorrected <br> EHP from <br> Table D3 | EHP <br> Corrected |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 0.40 | +1.0 | 0.653 | 0.659 | 580 | 586 |
| 0.45 | +0.4 | 0.653 | 0.655 | 827 | 830 |
| 0.50 | -0.2 | 0.660 | 0.659 | 1145 | 1143 |
| 0.55 | -0.5 | 0.664 | 0.661 | 1534 | 1526 |
| 0.60 | --- | 0.667 | 0.667 | 2001 | 2001 |
| 0.65 | -0.3 | 0.681 | 0.679 | 2597 | 2589 |
| 0.70 | -1.0 | 0.699 | 0.692 | 3330 | 3297 |
| 0.75 | -0.4 | 0.716 | 0.713 | 4198 | 4181 |
| 0.80 | +0.1 | 0.720 | 0.721 | 5119 | 5124 |
| 0.85 | +0.5 | 0.763 | 0.767 | 6508 | 6540 |
| 0.90 | +0.7 | 0.976 | 0.983 | 9885 | 9954 |

Table D5b - Correction to © $C_{400 \mathrm{ft}}$ Ship and EHP for Shift in LCB Position

| $(R)$ | $\frac{V}{\sqrt{L_{W L}}}$ | Percent Correction <br> from Series 60 <br> LCB Position | $C_{400 \mathrm{ft}}$ <br> Uncorrected <br> from Table D4 | $C_{400 \mathrm{ft}}$ <br> Corrected |
| :---: | :---: | :---: | :---: | :---: |
| 1.2 | 0.477 | +0.1 | 0.667 | 0.668 |
| 1.3 | 0.517 | -0.3 | 0.671 | 0.669 |
| 1.4 | 0.557 | -0.5 | 0.676 | 0.673 |
| 1.5 | 0.596 | --- | 0.678 | 0.678 |
| 1.6 | 0.636 | -0.2 | 0.683 | 0.682 |
| 1.7 | 0.676 | -0.7 | 0.694 | 0.689 |
| 1.8 | 0.716 | -0.9 | 0.711 | 0.705 |
| 1.9 | 0.755 | -0.4 | 0.716 | 0.713 |
| 2.0 | 0.795 | --- | 0.730 | 0.730 |
| 2.1 | 0.835 | +0.4 | 0.759 | 0.762 |
| 2.2 | 0.875 | +0.6 | 0.844 | 0.849 |
| 2.3 | 0.915 | +0.8 | 1.052 | 1.060 |
| 2.4 | 0.954 | +1.0 | 1.318 | 1.331 |




Figure D2 - Comparison of (C) Curves from (C) and
$\frac{R_{R}}{\Delta}$ Contours for SCHUYLER OTIS BLAND

Table D6 - Model Results for Series 60 Equivalent of SCHUYLER OTIS BLAND

| $V$, Knots | EHP for Ship | K | $C_{400 \mathrm{ft}}$ Ship |
| :--- | :---: | :---: | :---: |
| 8 | 514 | 1.058 | 0.711 |
| 9 | 725 | 1.176 | 0.706 |
| 10 | 987 | 1.293 | 0.701 |
| 11 | 1305 | 1.352 | 0.698 |
| 11.5 | 1486 | 1.411 | 0.696 |
| 12 | 1683 | 1.470 | 0.695 |
| 12.5 | 1899 | 1.528 | 0.698 |
| 13 | 2144 | 1.587 | 0.702 |
| 13.5 | 2415 | 1.646 | 0.704 |
| 14 | 2691 | 1.705 | 0.713 |
| 14.5 | 3044 | 1.764 | 0.720 |
| 15 | 3403 | 1.822 | 0.719 |
| 15.5 | 3749 | 1.881 | 0.717 |
| 16 | 4115 | 1.940 | 0.716 |
| 16.5 | 4505 | 1.999 | 0.718 |
| 17 | 4943 | 2.058 | 0.724 |
| 17.5 | 5433 | 2.116 | 0.763 |
| 18 | 6213 | 2.175 | 0.830 |
| 18.5 | 7372 | 2.234 | 0.925 |
| 19 | 8906 | 2.293 | 1.046 |
| 19.5 | 10908 | 2.352 | 1.200 |
| 20.0 | 13517 | 2.410 | 1.373 |



Figure D4 - The Difference $\delta$ (C) between the Froude (C) and the Schoenherr (C) with a Roughness Allowance of 0.0004
The values given in the contours are for a 400 -foot ship having a $S$ of 6.00 and operating in salt water of $59^{\circ} \mathrm{F}$. A positive $\delta(C$ indicates that the Schoenherr $C$ is higher than the Froude C.

The chart is drawn for $59^{\circ} \mathrm{F}$ and a ship correlation allowance of +0.0004 on the ATTC $C_{F}$ values.

Entering the chart at $\mathbb{K}=2.0$, going across to a displacement of 10,473 tons, up to the model length of 20.338 ft and across to the scale of $\delta$ (C), we find $\delta$ (C) has a value of 0.017 , to be subtracted from the ATTC value to obtain the Froude value. This is for a standard (S) of 6.0 ; for the actual (S) of 6.168 , the correction will be

$$
\delta(C)=\frac{6.168}{6.000} \times 0.017=0.0175
$$

Hence the Froude value of $\mathbb{C}_{400 \mathrm{ft}}=0.730-0.017$ $=0.713$
or 2.3 percent less than the ATTC value with +0.0004 correlation allowance. One other calculation may be necessary-the conversion from ATTC to ITTC correlation lines. The procedure for doing this is set out in full in Appendix E, to which reference may be made for details.

The calculation for the SCHUYLER OTIS BLAND Series 60 equivalent is given below to illustrate the difference between the final ehp obtained by the two methods.

At a speed defined by $\frac{V}{\sqrt{L_{W L}}}=0.70$, we have from Table D3

$$
\frac{R_{R}}{\Delta}=1.5429 \text { and } R_{R}=23,020 \mathrm{lbs}
$$

For the ship, $V L=14.973 \times 457.6=6852$, and entering the nomograph in Figure E1 with this value, the corresponding value of $C_{F \text { ship }}^{\prime}+0.0004=0.001950$ for the ITTC line.

The model length is 20.338 ft , so that the scale is 22.5 , and the model speed corresponding to a ship speed of 14.973 knots is

$$
\frac{14.973}{\sqrt{22.5}}=3.16 \mathrm{knots}
$$

Hence for the model, $V L=3.16 \times 20.338=64.3$. Entering the same chart at this value of $V L$ gives a value for the ITTC line of $C_{F \text { model }}^{\circ}+0.0004=0.003490$.

For the same value of $V L$, but using the line at the extreme left of Figure E1, the corresponding value for the ATTC line is

$$
C_{F \text { model }}+0.0004=0.003415
$$

It is shown in Appendix $E$ that the value of $\left(C_{F S}^{\prime}+0.0004\right)$ for the ship for use with this chart when making a conversion of this kind is

|  | $\begin{aligned} & C_{E \text { ship }}^{\prime}+C_{F \text { model }}-C_{F \text { model }}^{\prime} \\ & \text { (ITTC) (ATTC) } \quad \text { (ITTC) } \end{aligned}$ |
| :---: | :---: |
| or | $0.001950+0.003415-0.003490$ |
| or | $0.001950-0.000075$ |
| or | 0.001875 |

Entering Figure E1 with this value for $\left(C_{F S}^{\prime}+0.0004\right)$ and a speed of 14.973 knots , the value of $\frac{R_{F}}{S}$ is 1.197 , whence $R_{F}=1.197 \times 39994=47873 \mathrm{lb}$. Hence $R_{T}=R_{R}+R_{F}$
$=23020+47873=70893 \mathrm{lb}$
Then ehp $=\frac{70893 \times 14.973}{325.6}$
$=3260$
The corresponding ehp using the ATTC line is 3330 (Table D3), so that using the ITTC line gives about 2 percent less ehp in this particular case.

## APPENDIXE

## INTERNATIONAL TOWING TANK CONFERENCE 1957 MODEL -SHIP CORRELATION LINE

Meeting in London in 1948, the ITTC* agreed that in future published work the extrapolation of model resistance results to estimate resistance and power for the ship would be carried out by using eitherthe Froude coefficients or the ATTC 1947 line, the latter being based upon the work of Schoenherr. In using this latter line, a ship correlation allowance is usually made of +0.0004 on $C_{F}$.

The 1948 Conference also set up a Skin Friction Committee which was instructed, inter alia, "to survey the problem of skin friction in general, and in particular to recommend what further research should be carried out to establish the minimum turbulent friction line for both model and ship use ${ }^{, 70}$

This committee finally reported to the 8 th ITTC in Madrid in 1957, making two alternative proposals. Both were designed to increase the slope of the ATTC line at the low values of Reynolds number associated with the use of small ship models while giving values close to the ATTC line at high Reynolds numbers. One of these proposals was, in effect, adopted by the Conference, which decided that "the line given by the formula

$$
C_{f}=\frac{0.075}{\left(\log _{10} R_{n}-2\right)^{2}}
$$

is adopted as the ITTC 1957 model-ship correlation line, it being clearly understood that this is to be regarded only as an interim solution to this problem for practical engineering purposes." 71

Tables of values of $C_{F}$ derived from this formula have been given at yarious times (see for example Reference 72), and the differences between them and those represented by the ATTC 1947 line can be illustrated by the following figures:

| $\log _{10} R_{n}$ | Values of $C_{F} \times 10^{3}$ |  |  |
| :---: | :---: | :---: | :---: |
|  | ATTC 1947 <br> Line | ITTC 1957 <br> Line | Difference |
| 6.0 | 4.410 | 4.688 | +0.278 |
| 7.0 | 2.934 | 3.000 | +0.066 |
| 8.0 | 2.072 | 2.083 | $+(.011$ |
| 9.0 | 1.531 | 1.531 | -- |
| 10.0 | 1.173 | 1.172 | -0.001 |

[^7]One or two points are worth mentioning in connection with this new formulation.
In the first place, the Conference was careful to label the line a "model-ship correlation line," thereby emphasising that the members did not consider it to be a line representing the skin friction of the hull nor of an equivalent plank. It is, as the resolution states, "for practical engineering purposes," and may be taken as including some allowance for form effect. At the time of the 1957 Conference, a great deal of research was in progress on the problem of extrapolation from model to ship, and it was generally felt that great developments were likely in the not too distant future-hence the emphasis on an "interim solution." These will probably take the shape of a three-dimensional system of extrapolation, allowing for the effects of hull form and proportions upon the viscous resistance. Such methods have been proposed, but the profession will no doubt wish to gain experience in their use before making what will be, after all, a radical departure from the practice of nearly a hundred years.

Secondly, the values of $C_{F}$ quoted above show that the 1957 ITTC line is everywhere steeper than the 1947 ATTC line, and it is this slope which is important in the extrapolation problem. Since the ITTC line is higher over the model range, the $C_{R}$ values derived from the model results will be smaller. When added to the ITTC $C_{F}$ values over the ship range, which are nearly equal to or less than the ATTC values, those $C_{R}$ values will result in a lower prediction of the total " smooth" ship resistance and corresponding ehp. This will apply whatever the model scale, but the effect will be larger with small models run at low Reynolds numbers.

In the third place, in adopting the new correlation line, the ITTC made no recommendation regarding the ship correlation allowance to be used in predicting ehp for the actual ship, contenting itself merely with a general recommendation to continue work "to improve model and ship correlation"' and "to determine roughness allowances." In adopting its line in 1947, the ATTC considered a number of model-ship correlations available at that time and while recognizing the sparseness of the data and the possible dependence of the allowance on a number of factors other than roughness, did finally recommend a "roughness" allowance of +0.0004 for all ships; this allowance has been used since in all published work based on the ATTC 1947 line. For most merchant ships of the seagoing types, the resultant ship ehp did not differ much from that obtained using the same model results and the Froude coefficients. For the same model results and the same full-scale ship trial results, the use of the ITTC line will call for a somewhat greater correlation allowance than would the use of the ATTC line in order to obtain the same agreement. If a new three-dimensional method of extrapolation is devised in the future, the value of the correlation allowance necessary to reconcile the same model and ship results will have a still different value. It is very obvious, as pointed out by the present author in 1957, that this factor is not just an allowance for the relative roughnesses of model and ship but involves such things as the method of extrapolation used, the relative sizes of model and ship, scale effect on wake, thrust deduction, and propeller

## E-2

efficiency, factors which are involved in the comparison of the resistance of the model with that of the ship as deduced from shaft horsepower measurements made on trial-and other quantities besides hull surface finish. ${ }^{73}$ The term "roughness" allowance is therefore very misleading, and for this reason has not been used in the present text. The more rational name "ship correlation allowance" or "factor" has been suggested and the ITTC Presentation Committee has proposed the symbol $C_{A}$, where the suffix stands for "additional." In Great Britain, where the Froude coefficients are still in general use, the NPL tanks have for some years used a "ship correlation factor" which has different values for different types of shell construction, these values being derived from comparisons of actual ship trial results with corresponding predictions from model tests. The British Admiralty tanks use a similar method of correlation in the form of a quasi-propulsive coefficient factor. The weight of evidence today is that the allowance of +0.0004 above the ATTC line is somewhat too high for modern merchant ships of good welded construction, with a clean, newly painted hull surface, using a standard commercial paint.

Hadler et al have recently given correlation allowances for 13 merchant ships for which good full-scale and model data were available. ${ }^{74}$ They found that the correlation $5^{1 \times}$ tances decreased in magnitude both with increase of length of ship and with the date of construction, but were unable to disentangle the relative importance of these two effects because of the small number of ships available. The newer the ship, the better the probable finish of hull surface, but also the newer ships in general are longer. When they considered only seven ships built since World War II, they found the average values of $C_{A}$ were +0.00015 for the ATTC line correlation and +0.00020 for the ITTC. This difference is small, and will be so for correlations carried out from experiments with large models of the order of 20 ft in length. Because of the divergence of the ATTC and ITTC lines at low Reynolds numbers, the differences in correlation allowances for the two methods will increase with the use of smaller models.

A large number of ship trials have been correlated with model experiments in Great Britain. ${ }^{75}$ The trials were carried out on some 69 single-screw and 21 twin-screw ships by the British Ship Research Association and the models were run in the NPL tanks. There was some variation in $C_{A}$ with speed, but no length effect was obvious. For all-welded hulls, the average value of $C_{A}$ using the ITTC line was +0.00015 (with a total scatter of 0.0004 ) and for half-welded hulls (generally welded butts and riveted seams) +0.0004 (with a total scatter of 0.0007 ). Using the ATTC line, the corresponding $C_{A}$ values were +0.00005 and +0.0003 . Clements pointed out in this paper that the best results achieved to date correspond to a correlation allowance $C_{A}$ of zero.

More recently, results of British ship trials embracing modern large tankers have suggested a definite trend towards lower correlation allowances with increasing length, and a proposal to represent this by the straight line

$$
C_{A}=0.00160-0.0000023 \cdot L_{B P}
$$

has been made by Moor (discussion on Reference 74). This equation leads to a value of +0.00045 for a ship with an $L B P$ of 500 ft , zero for 700 ft , and negative values for longer lengths, all based on the ITTC line.

In order that the Series 60 results based upon the ATTC line can be compared with others derived from model tests by the use of the ITTC line, it is desirable to provide a rapid method of conversion from one method to the other. This involves the choice of a correlation allowance $C_{A}$. In view of the above discussion, the ATTC allowance of +0.0004 would appear too high for modern ships, and moreover it should quite possibly be varied with length of ship, but there is no finality in these matters at present. Since there is little difference in the ship prediction from the Series 60 models whichever line is used for extrapolation, the only logical choice would seem to be to use the same allowance of +0.0004 with the ITTC line until such time as a more definite value is recommended by the ITTC.

A second nomograph has therefore been prepared on the basis of the ITTC line using a correlation allowance of +0.0004 ; see Figure E1. In any individual case, if some other value of $C_{A}$ is preferred, an appropriate allowance can be made.

The relative values of the frictional and residuary resistances for a given model total resistance will be different when using the ATTC and ITTC lines, so that it is not sufficient merely to correct the frictional part of the total.

Using the suffixes $t, r$, and $f$ for total, residuary and frictional, $m$ and $s$ for model and ship and $C$ and $C^{\prime}$ for resistance coefficients using ATTC and ITTC lines, respectively, we can write

$$
C_{t m}=C_{r m}+C_{f m}=C_{r m}^{\prime}+C_{f m}^{\prime}
$$

and
also

$$
C_{r m}^{\prime}=C_{r m}+C_{f m}-C_{f m}^{\prime}
$$

$$
\begin{aligned}
C_{i s}^{\prime} & =C_{i s}^{\prime}+C_{f s}^{\prime} \\
& =C_{r m}^{\prime}+C_{f s}^{\prime} \\
& =C_{r m}+C_{f m}-C_{f m}^{\prime}+C_{f s}^{\prime} \\
& =C_{r s}+C_{f s}^{\prime}+\left(C_{f m}-C_{f m}^{\prime}\right)
\end{aligned}
$$

$C_{r s}$ is the residuary resistance coefficient as obtained using the ATTC line, and so the values of $\frac{R_{R}}{\Delta}$ can be lifted from the contours and inserted in Column $G$ of Table D3 as before. The frictional resistance coefficient to use with the nomograph for the ITTC line will now be

$$
C_{f s}^{\prime}+\left(C_{f m}-C_{f m}^{\prime}\right)
$$

i.e., ITTC ship coefficient + (ATTC model coefficient-ITTC model coefficient)。


Figure E1 - Nomograph for $\frac{R_{F}}{S}$ Computation based on ITTC 1957 Model-Ship Correlation Line

In Figure E1 the $V \cdot L$ and $C^{\circ}$ scales have been extended to cover model values, so that $C_{f m}^{\prime}$ can be found. For convenience, extended scales of $V L$ and $C_{f}$ for the ATTC line are also given at the left-hand side, but these form no part of the nomograph itself.

As an example, consider a ship 500 ft in waterline length with a speed of 20 knots.

$$
\begin{aligned}
V & =20 \mathrm{knots} \\
L_{W L} & =500 \mathrm{ft} \\
V \cdot L & =10,000
\end{aligned}
$$

The Series 60 models have a WL length of 20.388 ft , so that the scale will be

$$
\lambda=\frac{500}{20.388}=24.52
$$

For the model, $\quad V=\frac{20}{\sqrt{\lambda}}=\frac{20}{\sqrt{24.52}}=\frac{20}{4.952}=4.039 \mathrm{knots}$
and

$$
L=20.388
$$

whence

$$
V L=4.039 \times 20.388=82.34
$$

For $V L=82.34$, from Figure E 1

$$
\begin{aligned}
& C_{f_{m}}+0.0004=0.00330 \text { for ATTC line } \\
& C_{f_{m}}^{\prime}+0.0004=0.00337 \text { for ITTC line }
\end{aligned}
$$

and for $V L=10,000$

$$
C_{f_{s}}^{\prime}+0.0004=0.001879 \text { for the ITTC }
$$

Hence the final value of the resistance coefficient to be used is

$$
\begin{aligned}
C_{f_{s}}^{\prime}+\left(C_{f_{m}}-C_{f_{m}^{\prime}}^{\prime}\right. & =0.001879+(0.00330-0.00337) \\
& =0.001879-0.00007 \\
& =0.001809
\end{aligned}
$$

On Figure E1, starting with this value of $C_{f s}^{\circ}$ for the ITTC line, a straight line through a speed of 20 knots on the $V$ scale will give a value of $\frac{R_{F}}{S}$ of 2.069 , which will be inserted in Column J of Table D3 and the calculation completed in the usual way.

## REFERENCES

The following standard abbreviations a:e used in these references:

| SSPA | - Statens Skepp sprovnings Anstalt (Swedish State Shipbuilding Experimental Tank), Goteborg |
| :---: | :---: |
| Trans. N | Transactions, North East Coast Institution of Engineers and Shipbuilders, Newcastle, England |
| Trans. IME | Transactions, Institute of Marine Engineers, London |
| Trans. IESS | - Transactions, Institution of Engineers and Shipbuilders in Scotland, Glasgow |
| NSMB | - Netherlands Ship Model Basin, Wageningen |
| SNAME | - Society of Naval Architects and Marine Engineers, New York |
| TMB | - David Taylor Model Basin |

1. Project 2 of the Hydromechanics Subcommittee of the Society of Naval Architects and Marine Engineers, "Model and Expanded Resistance Data Sheets."
2. Taylor, D.W., "Speed and Power of Ships," published by the Department of Commerce, Washington, D.C. (1933).
3. Kent, J.L., "Model Experiments on the Effect of Beam on the Resistance of Mercantile Ship Forms," Trans. INA (1919).
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[^0]:    

[^1]:    * The membership of the Panel is given in the Foreword.

[^2]:    *The chart in this report is reproduced as Figure D-4 in Appendix D.

[^3]:    *.t.h.p $=$ towrope horsepower or ehp

[^4]:    *Shaft horsepower is the power measured in the shafting, for example by torsionmeter. Delivered horsepower is the power absorbed by the propeller.

[^5]:    All Pigures are for Ship of 400 Pt Length BP

[^6]:    All Figures are for Ship of 400 Ft Length $\mathbf{B P}$

[^7]:    *Then called the "International Conference of Ship Tank Superintendents."

