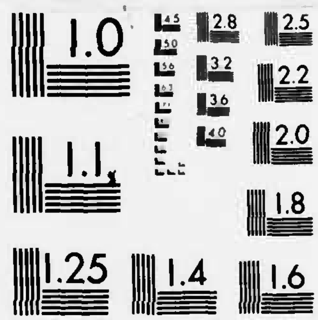
AD-A139 089 ESTIMATING THE SEAKEEPING QUALITIES OF DESTROYER TYPE HULLS(U) DAVID W TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER BET.. W R MCCREIGHT JAN 84 1/1

UNCLASSIFIED DTNSRDC/SPD-1074-01 F/G 20/4 NL

END
DATE FILMED
4-84
DTIC



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

12

DTNSRDC/SPD-1074-01

DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Maryland 20084

AD A139089

ESTIMATING THE SEAKEEPING QUALITIES OF DESTROYER TYPE HULLS

BY

W.R. McCREIGHT

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

SHIP PERFORMANCE DEPARTMENT

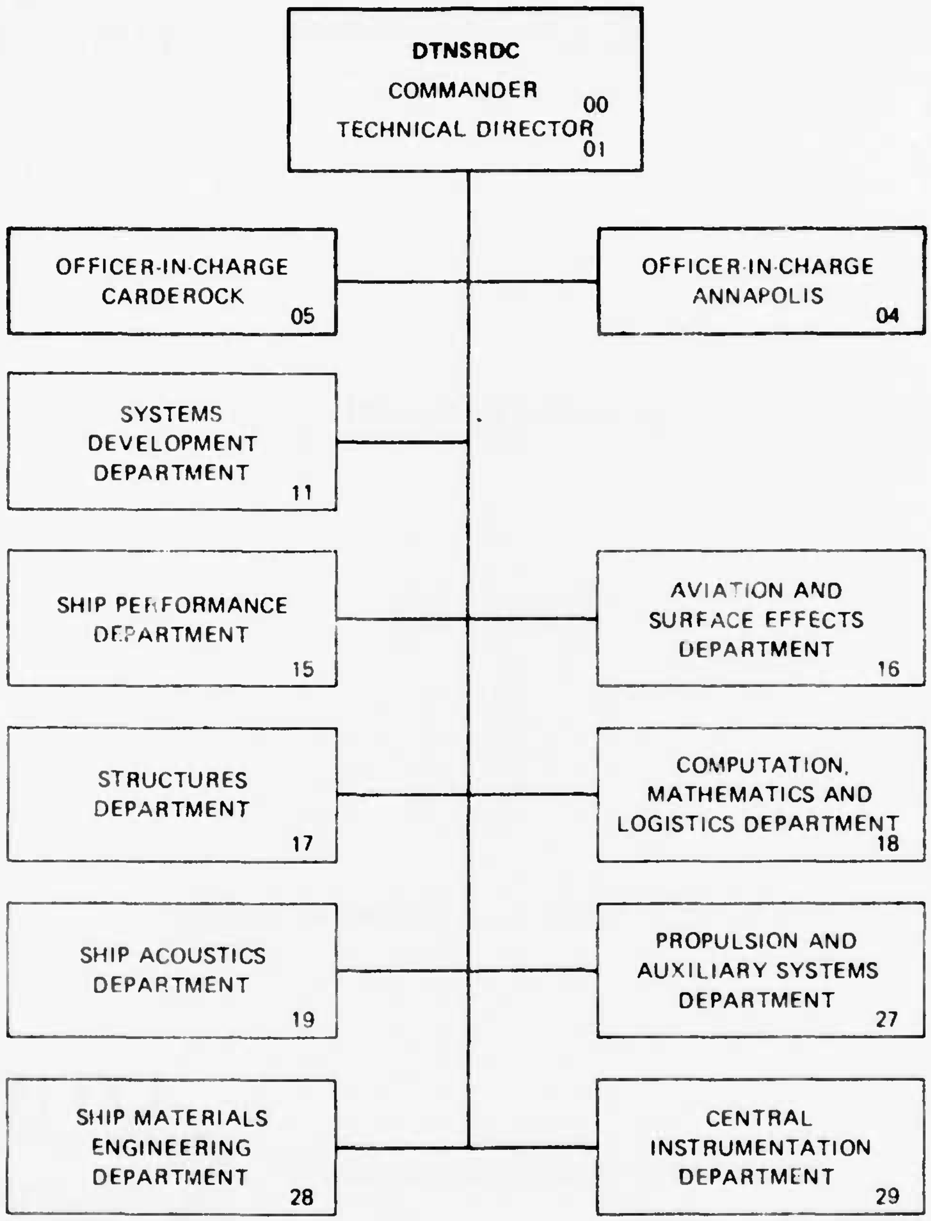
January 1984

DTNSRDC/SPD-1074-01

ESTIMATING THE SEAKEEPING QUALITIES OF DESTROYER TYPE HULLS

NDW-DTNSRDC 5602/30 (2-80)
(supersedes 3960/46)

MAJOR DTNSRDC ORGANIZATIONAL COMPONENTS



UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER DTNSRDC/SPD-1074-01	2. GOVT ACCESSION NO. AD-A139 089	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) ESTIMATING THE SEAKEEPING QUALITIES OF DESTROYER TYPE HULLS		5. TYPE OF REPORT & PERIOD COVERED FINAL 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) W.R. McCREIGHT		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS DAVID W. TAYLOR NAVAL SHIP R&D CENTER BETHESDA, MARYLAND 20084		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Work Unit No. 1-1561-866, Task No. T2A/001
11. CONTROLLING OFFICE NAME AND ADDRESS NAVAL SEA SYSTEMS COMMAND (SEA 05R14) WASHINGTON, D.C. 20362		12. REPORT DATE January 1984 13. NUMBER OF PAGES 44
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) NAVAL SEA SYSTEMS COMMAND (SEA 55W3) WASHINGTON, D.C. 20362		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Ship Motion
Seakeeping
Destroyer
Ranking Performance

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A procedure for estimating the relative seakeeping ability of destroyers in head seas has been developed. Several alternate methods of ranking seakeeping performance are considered. The data base of ship hull forms was greatly expanded beyond that of previous similar work. An improved analysis of seakeeping performance data was carried out considering a large number of parameters describing the hull geometry, including the effect of displacement.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOTATION

a_i	Coefficients in regression equation for seakeeping rank
a(x)	Sectional area at longitudinal position x
A_W	Waterplane area
A_{WA}	Waterplane area aft of midships
A_{WF}	Waterplane area forward of midships
A_x	Midship area
B	Beam
BM_L	Vertical distance of longitudinal metacenter above center of buoyancy
B_i	Coefficient of variate X_i in general regression equation
c	Longitudinal location of cutup, aft of forward perpedicular
C_B	Block coefficient
C_{BA}	Block coefficient aft of midships
C_{BF}	Block coefficient forward of midships
C_I	$BM_L \nabla / BL^3$
C_P	Prismatic coefficient
C_{PA}	Prismatic coefficient aft of midships

C_{PF}	Prismatic coefficient forward of midships
C_s	Slamming coefficient
C_{s_i}	Slamming coefficient for ith ship
C_{VI}	Second longitudinal moment of sectional area about the center of buoyancy
C_{VP}	Vertical prismatic coefficient
C_{VPA}	Vertical prismatic coefficient aft of midships
C_{VPF}	Vertical prismatic coefficient forward of midships
C_W	Waterplane area coefficient
C_{WA}	Waterplane area coefficient aft of midships
C_{WF}	Waterplane area coefficient forward of midships
e	Difference between observed and predicted value of the response
F	F ratio
g	Acceleration due to gravity
k	Number of independent variables in regression equation
L	Length
L_{CB}	Longitudinal center of buoyancy, aft of forward perpendicular
L_{CF}	Longitudinal center of flotation, aft of forward perpendicular

N	Number of observations used in deriving regression equation
n	Number of independent variables in regression equation
p_s	Probability of slamming
R^2	Square of the correlation coefficient
R_B	Seakeeping rank calculated by Bales' method
R_i	Seakeeping rank calculated by method i
r_{ij}	Response for ship i in mode j averaged over ship speed and seaway modal period
$\overline{r_{ij}}$	Average of r_{ij} taken over 20 ship data base
$\dot{r}_t$	Threshold slamming velocity
$\hat{R}_1$	Predicted value of seakeeping rank calculated by method 1
$r_{1/3}$	Significant relative vertical motion at station 3
$\dot{r}_{1/3}$	Significant relative vertical velocity at station 3
s	Variance
s_{ij}	Largest response for ship i in mode j taken over all ship speeds and seaway modal periods considered.
SS_{reg}	Sum of squares due to regression
SS_{res}	Residual sum of squares
T	Draft

T_o	Seaway modal period
t	Sectional draft
V	Ship speed
X_i	Independent variables in general regression equation
Y	Dependent variable in general regression equation
$\overline{Y}$	Average of Y
$\hat{Y}$	Value of Y predicted by regression equation
ΔSS	Change in sum of squares explained by regression equation due to addition of an additional term
α, β	Constants for converting raw rank into rank
ρ_{B_i}	Raw seakeeping rank calculated by Bales' method for ship i
ρ_{j_i}	Raw seakeeping rank calculated by method j for ship i
∇	Displaced volume
∇_A	Displaced volume aft of midships
∇_F	Displaced volume forward of midships
$(\zeta_w)_{1/3}$	Significant waveheight

ABSTRACT

A procedure for estimating the relative seakeeping ability of destroyers in head seas has been developed. Several alternate methods of ranking seakeeping performance are considered. The data base of ship hull forms was greatly expanded beyond that of previous similar work. An improved analysis of seakeeping performance data was carried out considering a large number of parameters describing the hull geometry, including the effect of displacement.

ADMINISTRATIVE INFORMATION

This work was funded by the Naval Sea Systems Command under the Surface Ship Continuing Concept Formulation Program, Task No. T2A/001. The work, identified under Work Unit Number 1-1561-866, was performed at the David W. Taylor Naval Ship Research and Development Center.

INTRODUCTION

For many years a need has been felt for including consideration of seakeeping performance in the early stages of ship design, as opposed to simply evaluating the performance of the final design. Only with the appearance of the pioneering work of Bales[1] on optimum seakeeping performance of destroyer hull forms was there an attempt to give the designer a simple tool suitable for estimating seakeeping performance on the basis of a few hull form coefficients. However, Bales' study had several limitations, most notably the small number of hull coefficients considered, the limited data base, and the restriction to head seas and to a single displacement. In this report the effects and relative importance of an increased number of hull form coefficients are examined, the hull form data base is expanded, and the effects of varying displacement are included. Alternate figures of merit for rating seakeeping performance are considered. Recommendations for further improvements, such as considering sea conditions other than longcrested head seas and including the effect of roll, are presented.

SEAKEEPING PERFORMANCE MEASURES

In developing a simplified seakeeping performance model it is first necessary to adopt a single numerical measure of seakeeping performance. In the present report four such figures of merit are considered. The first is a modification of Bales' rank R_B, the second is based on evaluating the limiting seakeeping performance in a seaway, the third is based on a simple average motion response and the fourth is a further variation on the Bales rank.

Bales developed a measure based on a combination of eight motion responses for unit significant wave height in head seas which were averaged over a range of ship speeds and seaways. These responses were: (1) heave (measured at the longitudinal center of gravity), (2) heave acceleration, (3) pitch, (4) relative motion at the bow (5) absolute acceleration at the bow, (6) absolute motion at the stern, (7) relative motion at the stern, (8) a slamming coefficient, C_s, measured at station 3. The slamming coefficient is defined in the following way. The probability of slamming is given by

$$p_s = \exp\left\{-2\left[\left(\frac{t}{r_{1/3}}\right)^2 + \left(\frac{\dot{r}_t}{\dot{r}_{1/3}}\right)^2\right]\right\} \tag{1}$$

where t is the local draft, $\dot{r}_t$ is the threshold velocity defined by Ochi[2], 3.66 m/sec (12.0 ft/sec) for a ship 158.5m (520 ft) long and Froude scaled to other ship lengths to obtain, in metric units, $\dot{r}_t = 0.291\sqrt{L}$, and $r_{1/3}$ and $\dot{r}_{1/3}$ are the significant single amplitude of relative motion and relative velocity, respectively. This is rewritten

$$p_s = \exp\left\{-2C_s/(\tilde{\zeta}_w)_{1/3}\right\} \tag{2}$$

and thus

$$C_s = \left(\frac{t}{r_{1/3}/(\tilde{\zeta}_w)_{1/3}}\right)^2 + \left(\frac{\dot{r}_t}{\dot{r}_{1/3}/(\tilde{\zeta}_w)_{1/3}}\right)^2 \tag{3}$$

Each of these responses was averaged over a range of Froude numbers, ($V/\sqrt{gL}$ = 0.05, 0.15, 0.25, 0.35 and 0.45), and modal periods, (T_o = 6.0, 8.0, 10.0, 12.0 and 14.0 sec.). Then these average responses were combined for each ship into a raw rank ρ_B,

$$\rho_{B_i} = \frac{1}{8}\left(\sum_{j=1}^{7} \frac{\min\{r_{kj},\ k=1,\ 20\}}{r_{ij}} + \frac{C_{s_i}}{\max\{C_{s_k},\ k=1,\ 20\}}\right) \tag{4}$$

where r_{ij} is the jth average response, as enummerated above, for the ith of 20 ships and C_{s_i} is slamming coefficient for the ith ship. Summing the inverse of the averaged responses, except for the slamming coefficient, yields a measure which is larger for ships with better performance. As can be seen from Equation 2, a larger C_s results in a lower probability of slamming and consequently each of the averaged responses is normalized with respect to the best value of that response among the set of 20 ships considered. Finally, these raw ranks, ρ_B, are scaled linearly so that they range from 1.0 to 10.0. The resulting Bales rank, R_B, considerably exaggerates the differences between ships since the raw ranks, ρ_B, range from 0.799 to 0.953. This procedure can be justified because interest is in the variations in performance and the raw rank tends to be dominated by contributions from responses which do not vary by a large percentage over the data base.

Four alternative figures of merit for rating seakeeping performance were examined. All are based on the first seven of the responses per unit wave height described above together with a modified slamming coefficient

$$r_{i8} = \frac{1}{\sqrt{C_s}}$$

$$= \left[\left(\frac{t}{r_{1/3}}\right)^2 + \left(\frac{\dot{r}_t}{\dot{r}_{1/3}}\right)^2\right]^{-1/2} (\tilde{\zeta}_w)^{-1}_{1/3} \tag{5}$$

where C_s is as defined previously. This form of the slamming response has the logical and computational advantage over C_s that it is also a response per unit significant wave height such that a large value represents better performance than a small value and thus is consistent with the form of the seven other responses. The four methods represent alternate ways of combining the responses. The first is Bales' method with the redefined slamming coefficient.

$$\rho_{1_i} = \frac{1}{8} \sum_{j=1}^{8} \frac{\min\{r_{kj}, k=1,20\}}{r_{ij}} \tag{6}$$

The second is an attempt to base the ranking on limiting seakeeping performance. Instead of averaging each of the seaway responses over speed and heading, the largest value, denoted s_{ij} for the ith ship and jth response, is taken to represent the ship's performance.

$$\rho_{2_i} = \frac{1}{8} \sum_{j=1}^{8} \frac{\min\{s_{kj}, k=1,20\}}{s_{ij}} \tag{7}$$

The motivation for this approach is the observation that the inverse of a response per unit significant wave height is proportional to the limiting significant wave height if there is a specified maximum allowable value for that response. Consequently, $1/s_{ij}$ is proportional to the minimum limiting significant wave height over all speeds and modal periods for that response. The third rank is simply the average response normalized with respect to the minimum response,

$$\rho_{3_i} = \frac{1}{8} \sum_{j=1}^{8} \frac{r_{ij}}{\min\{r_{kj}, k=1,20\}} \tag{8}$$

The fourth method is the same as the first with each response normalized with respect to the mean response rather than the minimum.

$$\rho_{4_i} = \frac{1}{8} \sum_{j=1}^{8} \frac{\overline{r_{ij}}}{r_{ij}} \tag{9}$$

where

$$\overline{r_{ij}} = \frac{1}{20} \sum_{k=1}^{20} r_{kj} \qquad (10)$$

These were tried to examine the effects of these alternate normalization procedures. In all cases the resulting raw ranks are scaled from 1 to 10 for the worst to the best.

In the evaluation of Equations (6) through (9) the required minimum and mean responses are evaluated for the 20 hull forms of the original Bales data base at a displacement of 4300 tons only. These values are then retained while ranking other hull forms at this displacement and all hull forms at other displacements so that the ranks will be consistent. Similarly, in scaling the raw ranks the scaling constants are calculated using only raw ranks from the original 20 hull form data base at 4300 tons displacement and are retained for the remainder of the computations.

HULL FORM AND MOTION DATA BASE

A data base consisting of motions data for 45 destroyer-type hull forms was computed. The characteristics of these hulls are listed in Table 1. The first 20 hulls are the 20 hulls of the Bales data base.[1] Hulls 21 through 27 are from various sources, including proposed ships and one constructed ship. In particular, ships 21 and 22 are Bales[1] optimum and anti-optimum hulls respectively, ship 25 is the U.S. Coast Guard HAMILTON Class High Endurance Cutter and ship 26 is ship 6, the best of the original 20 hulls, modified to increase the length to beam ratio 15 percent while holding the beam to draft ratio constant. The remainder of the hulls are taken from two systematic series of hulls which have been tested for seakeeping ability, ships 28 through 31 from a recent unpublished series* and ships 33 through 45 are from Schmitke and Murdey[3].

---

*Documented in a NSMB report by Blok with a restricted distribution.

Some of these additional hullforms are somewhat outside the range of typical forms of actual ships. This is an advantage because the resulting estimator will be valid for predicting the effect of hull geometry on seakeeping rank for the extended range of hullforms. The only limitation compared to Bales' approach is that it will not be possible to use the maxima and minima of the data base hull coefficients to define a hull as he did in deriving his optimum and anti-optimum hulls. This is a somewhat questionable method of obtaining "practical" hulls in any case due to the correlations between the various parameters.

The root-mean-square responses in longcrested head seas were computed for a very large range of speeds and modal periods, in most cases for a displacement of 4300 metric tons. The modal period range in particular is extreme but allows the scaling and interpolation of the responses to any desired displacement by the procedure described below. The responses calculated are those required for the ranking procedure, that is, the first seven responses as listed in the section describing this procedure together with relative motion at station 3 and relative velocity at station 3.

HULL FORM COEFFICIENTS

Bales investigated the effect of a small number of parameters selected on the basis of experience and intuition, and retained all of them in his model. These were:

1) Waterplane area coefficient forward of midships, C_{WF};
2) Waterplane area coefficient aft of midships, C_{WA};
3) Draft-to-length ratio, T/L, where T is draft and L is ship length;
4) Cut-up ratio, c/L, where c is the distance from the forward perpendicular to the cut-up point;
5) Vertical prismatic coefficient forward of midships, C_{VPF};
6) Vertical prismatic coefficient aft of midships, C_{VPA};

In this report all of the above coefficients are considered, except for c/L, together with the following additional coefficients:

1) Length, L;
2) Beam, B;
3) Draft, T;
4) Block coefficient, C_B;
5) Block coefficient forward of midships, C_{BF};
6) Block coefficient aft of midships, C_{BA};
7) Prismatic coefficient, C_P;
8) Prismatic coefficient forward of midships, C_{PF};
9) Prismatic coefficient aft of midships, C_{PA};
10) Vertical prismatic coefficient, C_{VP};
11) Waterplane area coefficient, C_W;
12) The height of the longitudinal metacenter above the center of buoyancy, BM_L;
13) The longitudinal center of buoyancy aft of the forward perpendicular, L_{CB};
14) The longitudinal center of flotation aft of the forward perpendicular, L_{CF};
15) The second moment of the hull volume about the L_{CB}, denoted C_{VI}.

Various combinations of these were also considered. A full list of the variables used and their definitions are listed in Table 2. All dimensions are in metric units. The cut-up ratio c/L was eliminated because (a) preliminary analysis with an expanded set of coefficients indicated that with an adequate selection of more conventional coefficients c/L did not appear in the equation, (b) even with the original set of coefficients c/L had little effect, and (c) in many cases it is not easy to define the location of c even from a set of hull lines; with automatic calculation of coefficients by the computer as used in this investigation it is even more difficult. All of the coefficients included can be calculated from the principal dimensions L, B, and T, and the waterplane and sectional area curves.

REGRESSION ANALYSIS

Regression analysis provides a means of determining the relation of a dependent variable to a number of independent variables. It can be used to summarize a large mass of data in a compact functional form. In simple terms, it consists of determining a least squares fit of an assumed functional form (the regression equation) involving the independent variables to the dependent variables, together with various measures of the overall goodness of fit, the importance of the various independent variables, and the validity of the calculated parameters in the model. For the case of linear regression, the dependent variable Y is approximated by a linear combination of independent variables X_i plus an error term e

$$\hat{Y} = B_o + B_1 X_1 + \ldots + B_n X_n + e \tag{11}$$

The coefficients B_i are chosen to minimize the total square error

$$\sum e^2 = \sum (Y - \hat{Y})^2 \tag{12}$$

where the summation is over all observations. The goodness of fit can be measured by the square of the correlation coefficient

$$R^2 = 1 - \frac{\sum (Y - \hat{Y})^2}{\sum (Y - \bar{Y})^2} \tag{13}$$

where $\bar{Y}$ is the mean response

$$\bar{Y} = \frac{1}{N} \sum Y. \tag{14}$$

This gives the proportion of the variance

$$s^2 = \frac{1}{N-1} \sum (Y - \bar{Y})^2 \tag{15}$$

which is explained by the regression equation and clearly a larger value of R^2 is better. The magnitude of the standard deviation, s, is another indication of the goodness of fit. The significance of each coefficient B_i can be judged using the statistic

$$F = \frac{\Delta SS/1}{SS_{res}/(N - k - 1)} \tag{16}$$

where

$$SS_{res} = \sum (Y - \hat{Y})^2 \tag{17}$$

and ΔSS is the change in the quantity

$$SS_{reg} = \sum (\hat{Y} - \bar{Y})^2 \tag{18}$$

due to the addition of the X_i term to the regression equation, N is the number of observations and k is the number of independent variables in the equation. This ratio follows an F distribution with 1 and N-k-1 degrees of freedom. If the computed F ratio exceeds the critical F ratio obtained from a table for a given significance level the variable is said to be significant at this level. See, for example, Draper and Smith[4] for a detailed discussion.

The computations were carried out using an available set of computer programs, the Statistical Package for the Social Sciences[5,6]. Except where noted, a stepwise procedure was used in which terms are entered into the regression equation one at a time, at each step selecting the variable which gives the greatest reduction in the error subject to the condition that the tolerance, or proportion of the variance of that variable which is not explained by the variables already in the equation, is greater than a specified amount. If at any step a variable in the equation fails a significance test, it is removed from the equation.

COMPUTATIONAL PROCEDURE

The ship motion reponses for the range of conditions described above are computed for each ship in the hull data base using the strip theory ship motion computer program PHM* and then merged onto a single file. This file is then used as input by a ranking program which reads the ship motion data base, scales the responses for each ship to a specified displacement, interpolates the data to obtain responses at specified speeds and modal periods, calculates the seakeeping ranks as described previously, calculates the hull coefficients described previously, and generates a data file containing the ranks and hull coefficients in a format suitable for the regression analysis program. The scaling and interpolation procedure is based on the fact that for a specific Froude number $V/\sqrt{gL}$ and nondimensional modal period $T_o\sqrt{g/L}$, linear displacements per unit waveheight are independent of ship length L. Angular displacements per unit waveslope are also independent of L, thus angular displacements per unit waveheight are inversely proportional to L. The velocities and accelerations are proportional to $L^{-1/2}$ and L^{-1} respectively times the shiplength dependence of the displacements. Thus it is easy to scale the responses appropriately to a new displacement and interpolate to obtain the responses at the required speed and modal period. This program has an option for reading in previously generated minimum or averaged responses and rank scaling factors as described above. The program also has an option for weighting the responses for different speeds and modal periods. This option was not used in the current investigation. This procedure was carried out at displacements of 4300, 5800, 7300 and 8800 tons and the resulting data files were merged. Finally, the regression analysis was performed using the SPSS package.[6]

RESULTS

The rankings R_1, R_2, R_3, and R_4 as defined by Equations (6) through (9), for ships 1 through 20 at a displacement of 4300 tons are presented in Table 3, together with the Bales rank R_B as computed from the data in his paper. Table 4 presents the same data with the ships sorted by rank. It can be readily seen that the various ranking methods give nearly the same results.

---

*Documented by Hubble in a report with a restricted distribution.

Table 5 lists the values of $\min\{r_{kj}, k=1, 20\}$ required to calculate the raw ranks ρ_1 using Equation (6) for an arbitrary ship and the linear scaling constants α and β required to convert this raw rank to the rank R_1 using the formula

$$R_1 = \alpha\rho_1 + \beta \tag{19}$$

The rank R_1, as obtained using raw ranks defined by Equation (6), calculated at displacements of 4300, 5800, 7300, and 8800 tons are presented in Table 6. The same data with ships sorted by rank is presented in Table 7.

It is readily seen from Table 7 that while increasing displacement increases the ranks of the hull forms, the relative position of the hulls at a given displacement is not much affected for most hull forms. It is also of interest to note that the best hull, ship 29, performs better at 4300 tons displacement than the 20 worst hulls at 8800 tons. However, considering only the original Bales 20 hull data base, this is no longer the case.

Long ships with full waterplanes perform best in head seas. The four best hulls, ships 28 to 31, have the lowest block coefficients in the series, which results in increased waterplane area for a given displacement.

A stepwise regression analysis was performed on the 180 ship data base consisting of the 45 hull forms each evaluated at displacements of 4300, 5800, 7300 and 8800 tons. The specified F ratio for entering of variables was 3.89 and for removing variables, 3.889, corresponding to a 5% confidence level, and the specified tolerance was 0.10. The resulting regression equation is

$$\begin{aligned}\hat{R}_1 = {} & a_0 + a_1 BM_L\nabla + a_2 C_{VPF} + a_3 C_{VPA} + a_4 C_I + a_5 L \\ & + a_6 T/B + a_7 A_{WA}/\nabla^{2/3} + a_8 (L_{CB} - L_{CF})\nabla \\ & + a_9 (L/2 - L_{CB})/\nabla^{1/3} + a_{10} L^2/BT\end{aligned} \tag{20}$$

where $C_I = BM_L / BL^3$.

The coefficients a_i are listed in Table 8. The standard deviation is 0.55975 and the R^2 is 0.99533. Figure 1 presents a plot of $\hat{R}_1$ versus R_1 for the 180 ship data base. The minimum and maximum values of the variables are listed in Table 9. The effect, or difference of maximum and minimum values times the corresponding coefficient, is also presented in Table 9. The effect, or difference of maximum and minimum values times the corresponding coefficient, is also presented in Table 9. In applying Equation (20) the variables should, strictly speaking, lie within these ranges for the equation to be valid. Other nondimensional variables should also lie within the ranges for the data base. These limits are listed in Table 10. Note that because of the correlation of the various hull form parameters it is not possible to simply regard each coefficient in the regression equation as indicating the relative importance of that variable independently of the others.

CONCLUSIONS AND RECOMMENDATIONS

A procedure for quickly estimating the relative seakeeping performance of a destroyer-type ship in head seas has been developed. This method, which is a considerably improved version of one developed earlier by Bales[1], requires only quantities easily calculated from the length, beam, draft and sectional area and waterplane curves. In applying this method it should be noted that small differences in predicted rank should not be considered significant, due to the small errors in fitting the equation to the data base. Some evidence was also found that the interpolation procedure used in scaling the motion data base responses to a specific displacement also introduced some variation in the calculated ranks.

The exact form of the raw performance rank calculation does not greatly alter the relative ranking of the ships. Variation of hull displacement also has a relatively small affect on the relative ranking. Generally for a given displacement, long ships with large waterplane area perform the best.

Extension of the procedure to include the effects of roll is clearly desirable. However, there will be some difficulty in carrying this out. A much more extensive data base must be generated. Meaningful measures of roll response must be selected for inclusion in the rank. The principal difficulty, however, will be choosing parameters to be included in the regression equation. It will not be possible to use only overall geometric quantities of the hull. Mass distribution properties such as the vertical center of gravity and the roll radius of gyration are obviously important. Many small details of the hull such as rudder, skeg, and bilge keels will also be quite important. One possible approach would be to use roll natural period and roll damping, perhaps as estimated by some simple procedure, as independent variables in the regression analysis.

Another useful development of the present work would be to derive regression equations for criteria-based rankings for specific design projects based on a (pre-computed) hull and motion data base together with the seakeeping criteria for the specific design.

Finally, extension of even the present approach to other hull forms would also be of considerable value to the Navy.

REFERENCES

1. Bales, N.K., Optimizing the Seakeeping Performance of Destroyer-Type Hulls, Thirteenth Symposium on Naval Hydrodynamics, Tokyo, Japan, October, 1980.

2. Ochi, M.K., Extreme Behavior of a Ship in Rough Seas, Trans. Society of Naval Architects and Marine Engineers, Vol. 79 (1964).

3. Schmitke, R.T., and D.C. Murdey, Seakeeping and Resistance Trade-Offs in Frigate Hull Form Design, Thirteenth Symposium on Naval Hydrodynamics, Tokyo, Japan, October, 1980.

4. Draper, N.R., and H. Smith, Applied Regression Analysis, John Wiley and Sons, New York, 1966.

5. Nie, N.H., C.H. Hull, J.G. Jenkins, K. Steinbrenner and D.H. Brent, Statistical Package for the Social Sciences, 2nd. Ed., McGraw-Hill, New York, 1975.

6. Hohlen, Mina, SPSS-6000 Release 8.0 Update Manual, Document 457, Vogelback Computer Center, Northwestern University, Evanston, Ill., July 1979.

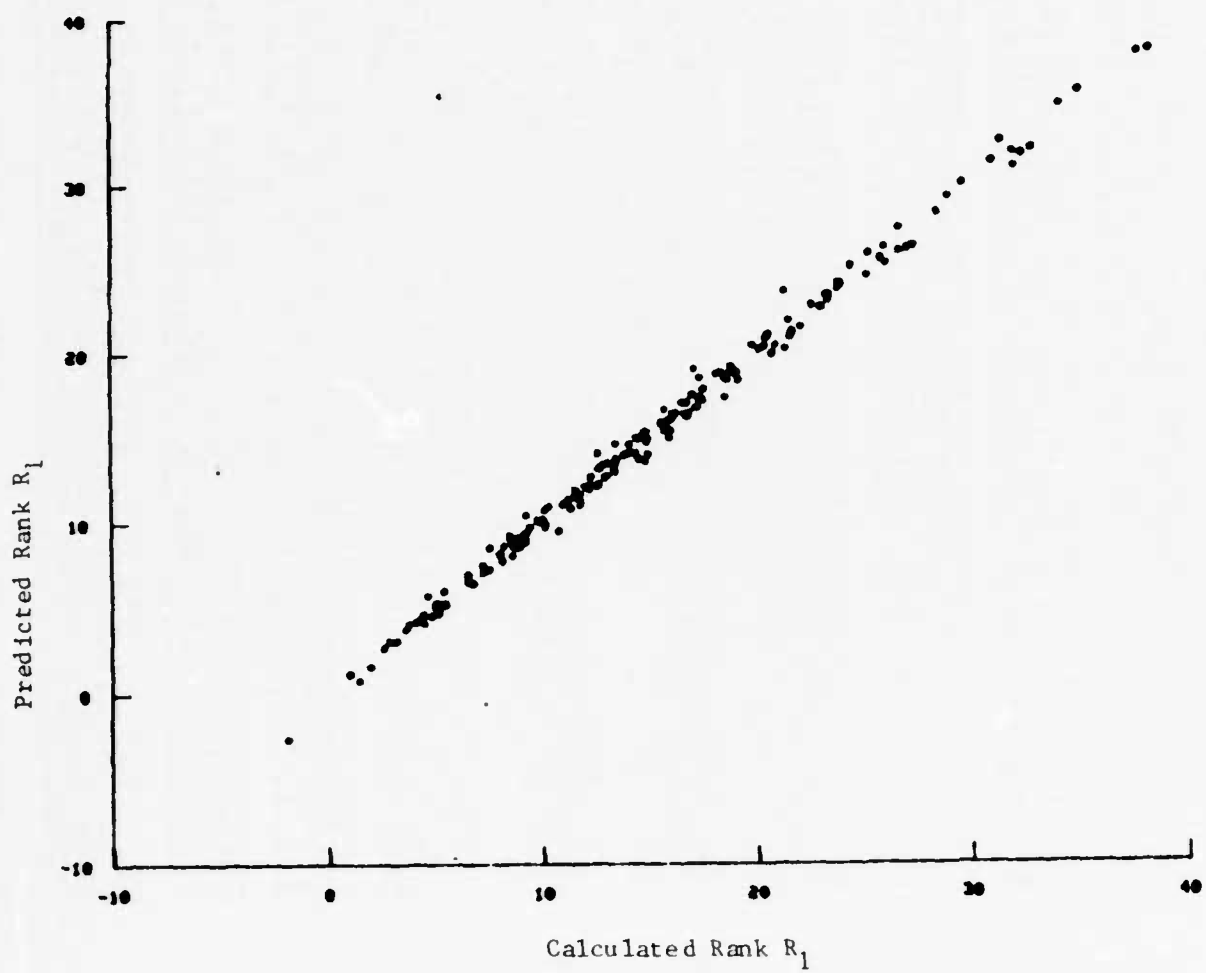


Figure 1 - Predicted versus Computed Rank R_1 for 180 Ship Data Base

TABLE 1 - SHIP CHARACTERISTICS FOR HULL FORM DATA BASE

Ship	L	B	T	BM_L	C_{VPF}	C_{VPA}	C_{WF}	C_{WA}	L_{CB}	L_{CF}	C_I	C_{BF}	C_{BA}
1	124.47	13.01	4.682	292.12	.74329	.64706	.69446	.91049	64.72	68.24	.0483	.516	.589
2	135.80	14.26	4.280	361.61	.73682	.61716	.63447	.88071	70.04	75.04	.0424	.467	.544
3	128.22	14.94	4.202	300.33	.80259	.64189	.58271	.89342	67.55	73.10	.0400	.466	.573
4	127.10	14.21	4.750	284.11	.79982	.57660	.60232	.85934	62.87	70.88	.0406	.486	.495
5	122.08	12.69	4.953	268.37	.77022	.61315	.69802	.90541	61.70	66.60	.0487	.535	.555
6	134.36	13.80	4.261	364.58	.73692	.63896	.68738	.86783	68.88	72.68	.0457	.507	.555
7	118.67	13.52	4.878	250.89	.72911	.65971	.64122	.91434	63.68	65.56	.0465	.466	.603
8	126.82	14.88	4.053	311.40	.77239	.69319	.67436	.83004	64.99	68.21	.0430	.521	.575
9	129.91	15.05	4.526	303.16	.72623	.61787	.58361	.84767	67.83	72.52	.0365	.424	.524
10	130.16	13.89	4.615	335.23	.72386	.58401	.64903	.91644	67.39	72.77	.0459	.470	.535
11	129.46	14.29	4.557	311.27	.75089	.58981	.61097	.90746	67.22	73.30	.0420	.459	.535
12	126.01	14.76	4.622	296.37	.71844	.60626	.61441	.88028	65.29	70.52	.0421	.441	.534
13	126.66	13.12	5.145	259.15	.78709	.59080	.57313	.89514	65.58	72.48	.0407	.451	.529
14	132.18	14.51	4.800	322.93	.72132	.55392	.61436	.84336	66.86	72.90	.0404	.443	.467
15	134.39	13.70	4.262	362.16	.74770	.63896	.68734	.86783	68.47	72.69	.0457	.514	.555
16	123.61	14.57	4.792	268.98	.74821	.58634	.63685	.84401	62.25	67.66	.0410	.476	.495
17	131.26	14.80	4.593	332.39	.67848	.59218	.65349	.83776	67.26	71.21	.0416	.443	.496
18	117.40	14.73	4.662	245.42	.74520	.63889	.63499	.88701	61.65	65.43	.0432	.473	.567
19	131.69	13.64	4.677	295.83	.78335	.58022	.56500	.88695	67.67	75.38	.0398	.443	.515
20	125.40	14.53	4.661	274.20	.72585	.63672	.59170	.87548	66.82	70.46	.0401	.429	.557
21	136.42	14.79	4.299	432.65	.67428	.55020	.69038	.91044	69.65	74.90	.0483	.466	.501
22	117.48	14.21	4.827	202.91	.81451	.69651	.56600	.83114	62.12	65.70	.0369	.461	.579
23	118.03	14.68	4.640	276.28	.73589	.60740	.67385	.89988	59.96	65.41	.0460	.406	.547
24	120.18	15.82	4.484	247.34	.82136	.60757	.55957	.86177	61.50	69.43	.0378	.460	.524
25	119.24	14.17	4.923	249.48	.71673	.62951	.64054	.87140	62.35	65.86	.0435	.459	.549
26	147.48	13.17	4.067	460.19	.73692	.63896	.68738	.86783	75.61	79.77	.0457	.507	.555
27	129.69	14.31	4.472	359.58	.69966	.59361	.68036	.89958	66.72	71.55	.0483	.476	.534
28	138.87	17.36	4.340	518.70	.54856	.48582	.60393	.96728	76.69	80.65	.0468	.331	.470
29	138.64	17.33	4.333	494.26	.54486	.51596	.61127	.91535	76.47	78.70	.0449	.333	.472
30	139.17	17.40	4.349	527.53	.58055	.45657	.58987	.99277	75.74	82.25	.0471	.342	.453
31	128.71	16.09	4.022	431.75	.62719	.60430	.66827	.97196	70.64	73.18	.0528	.419	.587
32	109.37	20.36	3.914	267.67	.70976	.59223	.62344	.87711	56.70	61.01	.0421	.442	.519
33	109.36	18.30	4.355	240.55	.70976	.59223	.62344	.87711	56.69	61.01	.0421	.442	.519
34	109.32	16.17	4.931	212.29	.70976	.59223	.62344	.87711	56.67	60.98	.0421	.442	.519
35	127.52	18.88	3.621	393.42	.70976	.59223	.62344	.87711	66.11	71.14	.0421	.442	.519
36	127.56	16.95	4.032	353.56	.70976	.59223	.62344	.87711	66.13	71.16	.0421	.442	.519
37	127.53	14.97	4.565	312.05	.70976	.59223	.62344	.87711	66.11	71.14	.0421	.442	.519
38	108.12	20.13	3.866	316.23	.65656	.56361	.69188	.96163	56.45	60.50	.0521	.454	.542
39	108.10	18.08	4.306	283.76	.65656	.56361	.69188	.96163	56.44	60.48	.0521	.454	.542
40	108.07	15.98	4.873	250.61	.65656	.56361	.69188	.96163	56.42	60.47	.0521	.454	.542
41	126.04	18.66	3.579	464.19	.65656	.56361	.69188	.96163	65.81	70.52	.0521	.454	.542
42	126.06	16.75	3.985	416.99	.65656	.56361	.69188	.96163	65.82	70.54	.0521	.454	.542
43	126.04	14.80	4.512	368.18	.65656	.56361	.69188	.96163	65.81	70.52	.0521	.454	.542
44	123.70	14.52	4.453	275.23	.78716	.64349	.62564	.86342	63.78	68.73	.0420	.492	.556
45	127.76	15.00	4.574	321.60	.69456	.59127	.58471	.92472	68.70	73.85	.0431	.410	.547

TABLE 2 - INDEPENDENT VARIABLES USED IN REGRESSION ANALYSIS

A_W	B/L	$C_{BF} = \frac{2\nabla_F}{LBT}$
$A_W \nabla$	BM_L	$C_P = \frac{\nabla}{LA_X}$
$A_W/\nabla^{2/3}$	$BM_L \nabla$	$C_{PA} = \frac{2\nabla_F}{LA_X}$
A_{WA}	$BM_L \nabla^2$	$C_{PA}\nabla$
A_{WA}/A_W	$\frac{BM_L \nabla}{BL^3}$	$C_{PF} = \frac{2\nabla_F}{LA_X}$
$A_{WA}\nabla$	$\frac{BM_L \nabla^2}{BL^3}$	$C_{PF}\nabla$
$A_{WA}/\nabla^{2/3}$	$BM_L/\nabla^{1/3}$	$C_{VI} = \int_L (x-L_{CB})^2 a(x)dx$
A_{WF}	$\frac{BT}{L^2}$	$C_{VP} = \frac{\nabla}{TA_W}$
A_{WF}/A_W	B/T	$C_{VPA} = \frac{\nabla_A}{TA_{WA}}$
$A_{WF}\nabla$	$B/\nabla^{1/3}$	$C_{VPF} = \frac{\nabla_F}{TA_{WF}}$
$A_{WF}/\nabla^{2/3}$	$C_B = \frac{\nabla}{LBT}$	$C_W = \frac{A_W}{LB}$
B	$C_{BA} = \frac{2\nabla_A}{LBT}$	$C_{WA} = \frac{2A_{WA}}{LB}$

TABLE 2 (Continued)

$C_{WF} = \frac{2A_{WF}}{LB}$	$L_{CF}/\nabla^{1/3}$	$\frac{T\nabla}{B}$
L	$L_{CB} - L_{CF}$	$T/\nabla^{1/3}$
L/B	$(L_{CB} - L_{CF})\nabla$	∇
L/T	$(L_{CB} - L_{CF})/\nabla^{1/3}$	$\nabla^{1/3}$
$L/\nabla^{1/3}$	$\frac{L}{2} - L_{CB}$	$\nabla^{2/3}$
$\frac{L^2}{BT}$	$\frac{L}{2} - L_{CF}$	∇^2
$\frac{L^3BT\ C_B}{BM_L V}$	$\left(\frac{L}{2} - L_{CB}\right)\nabla$	∇^3
$\left(\frac{L^3BT\ C_B}{BM_L\nabla}\right)^2$	$\left(\frac{L}{2} - L_{CF}\right)\nabla$	∇_A
L_{CB}	T	∇_A/∇
$L_{CB}\nabla$	T/B	∇_F
$L_{CB}/\nabla^{1/3}$	T/L	∇_F/∇
L_{CF}	$\frac{TC_B}{C_W}$	
$L_{CF}\nabla$	$\left(\frac{TC_B}{C_W}\right)^2$	

TABLE 3 - RANKS OF 20 SHIP DATA BASE CALCULATD BY FIVE METHODS

Ship	R_B	R_1	R_2	R_3	R_4
1	8.40245	7.54101	7.25196	8.10851	7.56702
2	7.90045	7.58579	7.69525	7.99351	7.54648
3	3.45393	4.13824	4.32133	4.65187	4.08966
4	2.76411	3.22289	3.95355	3.53556	3.17355
5	6.06257	5.33692	4.59312	5.94190	5.39557
6	10.00000	10.00000	10.00000	10.00000	10.00000
7	4.54720	4.48139	3.83337	5.16454	4.50960
8	6.94394	6.80826	7.39825	7.32944	6.79929
9	4.55345	5.02092	4.86580	5.76328	5.04119
10	8.45633	8.61691	8.54675	9.01385	8.59007
11	5.07200	5.43713	5.58465	6.08152	5.40251
12	4.36359	4.68494	4.60068	5.25739	4.64447
13	1.00000	1.00000	1.00000	1.00000	1.00000
14	6.53180	6.53675	6.06918	7.21470	6.55356
15	9.20056	9.43636	9.37852	9.55917	9.43026
16	4.58598	4.32626	4.62704	4.97078	4.36189
17	8.95102	8.73470	9.30273	9.13545	8.77011
18	4.31830	3.67356	4.20365	4.27663	3.67556
19	2.47542	2.88847	2.70684	3.26975	2.85380
20	3.99186	4.19248	3.80100	4.94601	4.22705

TABLE 4 - SORTED RANKS OF 20 SHIP DATA BASE CALCULATED BY FIVE METHODS

Ship	R_B	Ship	R_1	Ship	R_2	Ship	R_3	Ship	R_4
6	10.00000	6	10.00000	6	10.00000	6	10.00000	6	10.00000
15	9.20056	15	9.43636	15	9.37852	15	9.55917	15	9.43026
10	8.95638	17	8.73470	17	9.30273	17	9.13545	17	8.77011
17	8.95102	10	8.61691	10	8.54675	10	9.01385	10	8.59007
1	8.40245	2	7.58579	2	7.69525	1	8.10851	1	7.56702
2	7.90645	1	7.54101	8	7.39825	2	7.99351	2	7.54648
8	6.94394	8	6.80826	1	7.25196	8	7.32344	8	6.79929
5	6.60257	14	6.53675	14	6.06918	14	7.21470	14	6.55356
14	5.63186	11	5.43713	11	5.58465	11	6.08152	11	5.40251
11	5.07200	5	5.33692	9	4.86580	5	5.94190	5	5.39557
16	4.80598	9	5.02092	16	4.62704	9	5.76328	9	5.04119
9	4.55345	12	4.68494	12	4.60068	12	5.25739	12	4.64447
7	4.54720	7	4.48139	5	4.59312	7	5.16454	7	4.50960
12	4.36359	16	4.32626	3	4.32133	16	4.97078	16	4.36189
18	4.31630	20	4.19248	18	4.20365	20	4.94601	20	4.22705
20	3.99186	3	4.13824	4	3.95355	3	4.65187	3	4.08966
3	3.45393	18	3.67356	7	3.83337	18	4.27663	18	3.67556
4	2.70411	4	3.22289	20	3.80100	4	3.53556	4	3.17355
19	2.47542	19	2.88847	19	2.70684	19	3.26975	19	2.85380
13	1.00000	13	1.00000	13	1.00000	13	1.00000	13	1.00000

TABLE 5 - CONSTANTS FOR CALCULATING RANK R_1

Response j	$\min\{r_{kj}, k=1, 20\}$
1	0.22430351
2	0.21245666
3	0.47220716
4	0.89245372
5	0.74351939
6	0.49375601
7	0.42188321
8	0.093131903
α	56.047364
β	-44.362856

TABLE 6 - RANKS R_1 FOR 180 SHIP DATA BASE

Ship	4300 tons	5800 tons	7300 tons	8800 tons
1	7.54101	12.63153	17.25579	21.54949
2	7.58579	12.57841	17.11224	21.31736
3	4.13824	8.62471	12.71937	16.53637
4	3.22289	7.46520	11.33088	14.93091
5	5.33692	10.13528	14.49435	18.54454
6	10.00000	15.51377	20.53654	25.20995
7	4.46139	9.14753	13.39066	17.33632
8	6.80825	11.73631	16.22179	20.39315
9	5.02392	9.76225	14.08975	18.12410
10	8.61591	13.80778	18.54451	22.95986
11	5.43713	10.11848	14.39321	18.37942
12	4.68494	9.25309	13.43860	17.36368
13	1.00000	5.06195	8.76019	12.20565
14	6.53575	11.53299	16.09197	20.34101
15	9.43536	14.85758	19.79534	24.38926
16	4.32626	8.84026	12.95015	16.77548
17	8.73470	13.99665	18.79272	23.25847
18	3.67356	8.03405	11.99394	15.67226
19	2.88347	7.22960	11.19080	14.88341
20	4.19248	8.83410	13.07059	17.02190
21	14.51659	20.48910	25.92407	30.97479
22	-1.84690	1.99344	5.47303	8.70254
23	6.58494	10.96522	14.94242	18.63416
24	1.45185	5.20265	8.61248	11.78202
25	4.51334	8.99883	13.06774	16.84375
26	14.79393	21.32704	27.27662	32.80913
27	11.71247	17.13187	22.05113	26.64058
28	19.06441	25.77809	31.95221	37.72689
29	19.15367	26.02306	32.34349	38.26109
30	17.49246	23.79445	29.58747	35.00049
31	17.29843	23.38790	28.93871	34.11104
32	5.51580	9.27190	12.63778	15.72318
33	4.67936	8.91798	12.57988	15.97559
34	2.64816	6.57252	10.12472	13.41562
35	10.74717	15.94415	20.69534	25.12702
36	9.25556	14.34133	18.98706	23.31870
37	7.25436	12.16515	16.65463	20.86029
38	11.50343	16.01296	20.11079	23.91178
39	10.26808	14.74254	18.80576	22.57439
40	8.45262	12.80998	16.74897	20.39039
41	15.87611	21.49698	26.61642	31.37223
42	15.69310	21.59313	26.98203	32.00958
43	13.43368	18.86410	23.79801	28.38670
44	3.80363	8.23708	12.26448	16.07073
45	8.15730	13.03233	17.48859	21.66031

TABLE 7 - SORTED RANKS R_1 FOR 180 SHIP DATA BASE

4300 tons		5800 tons		7300 tons		8800 tons	
Ship	R_1	Ship	R_1	Ship	R_1	Ship	R_1
29	19.15367	29	26.02306	29	32.34349	29	38.26109
28	19.06441	28	25.77809	28	31.95221	28	37.72689
30	17.49248	30	23.79445	30	29.58747	30	35.00049
31	17.29843	31	23.38790	31	28.93871	31	34.11104
41	15.87611	42	21.59313	26	27.27662	26	32.80913
42	15.69910	41	21.49698	42	26.98203	42	32.00958
26	14.79393	26	21.32704	41	26.51642	41	31.37223
21	14.51659	21	20.48910	21	25.92407	21	30.97479
43	13.43368	43	16.66410	43	23.79801	43	28.38670
27	11.71247	27	17.13187	27	22.06113	27	26.64058
38	11.50343	38	16.01296	35	20.69534	6	25.20995
35	10.74717	35	15.94415	6	20.53654	35	25.12702
39	10.26808	6	15.51377	38	20.11079	15	24.38926
6	10.00000	15	14.85758	15	19.79534	38	23.91178
15	9.43636	39	14.74254	36	18.98706	36	23.31870
36	9.25556	36	14.34133	39	18.80576	17	23.25847
17	8.73470	17	13.99665	17	18.79272	10	22.95986
10	8.51691	10	13.80778	10	18.54451	39	22.57439
40	8.45262	45	13.03233	45	17.48859	45	21.66031
45	8.15700	40	12.80999	1	17.25579	1	21.54949
2	7.58579	1	12.63153	2	17.11224	2	21.31736
1	7.54101	2	12.57641	40	16.74897	37	20.86029
37	7.25436	37	12.16515	37	16.65463	8	20.39315
8	6.80826	8	11.73631	8	16.22179	40	20.39038
23	6.58494	14	11.53299	14	16.09197	14	20.34101
14	6.53675	23	10.36522	23	14.94242	23	18.63416
32	5.51580	5	10.13528	5	14.49435	5	18.54454
11	5.43713	11	10.11848	11	14.39321	11	18.37942
5	5.33692	9	9.76225	9	14.08975	9	18.12410
9	5.02092	32	9.27190	12	13.43860	12	17.36368
33	4.87336	12	9.25309	7	13.39066	7	17.33632
12	4.68494	7	9.14753	20	13.07059	20	17.02190
25	4.51334	25	8.99883	25	13.06774	25	16.84375
7	4.48139	33	8.91798	16	12.95015	16	16.77548
16	4.32626	16	8.84026	3	12.71937	3	16.53637
20	4.19243	20	8.83410	32	12.63778	44	16.07073
3	4.13824	3	8.62471	33	12.57988	33	15.97559
44	3.80363	44	8.23708	44	12.28448	32	15.72318
18	3.67356	18	8.03405	18	11.99394	18	15.67226
4	3.22289	4	7.46520	4	11.33089	4	14.93091
19	2.88847	19	7.22960	19	11.19080	19	14.88341
34	2.64816	34	6.57252	34	10.12472	34	13.41562
24	1.45185	24	5.20265	13	8.76019	13	12.20565
13	1.00000	13	5.06195	24	8.61248	24	11.78202
22	-1.84690	22	1.99344	22	5.47303	22	9.70254

TABLE 8 - REGRESSION COEFFICIENTS FOR RANK R_1

a_0	9.43595
a_1	3.10450×10^{-6}
a_2	-8.42980
a_3	-37.5995
a_4	590.435
a_5	0.287418
a_6	-57.3460
a_7	-6.08436
a_8	9.18775×10^{-5}
a_9	-6.03225
a_{10}	-6.41495×10^{-3}

TABLE 9 - RANGES AND EFFECTS OF VARIABLES IN REGRESSION EQUATION

	Maximum	Minimum	Effect
$BM_L\nabla$	.57447E+07	.85042E+06	15.19
C_{VPF}	.82136	.54486	2.33
C_{VPA}	.69651	.45657	9.022
$\frac{BM_L\nabla}{BL^3}$	.52757E-01	.36905E-01	9.360
L	187.25	108.07	22.76
T/B	.39201	.19182	11.48
$A_{WA}/\nabla^{2/3}$	4.6232	2.6691	11.89
$(L_{CB} - L_{CF})\nabla$	-9355.3	-87181.	7.150
$\left(\frac{L}{2} - L_{CB}\right)/\nabla^{1/3}$	.41964E-01	-.45002	2.968
$\frac{L^2}{BT}$	406.00	149.00	1.649

TABLE 10 - RANGES OF MAJOR COEFFICIENTS NOT IN REGRESSION EQUATION

	Maximum	Minimum
A_W	3133.9	1166.3
$A_W \nabla$	.26880E+08	.48883E+07
$A_W/\nabla^{2/3}$	7.4791	4.4867
A_{WA}	1937.2	693.83
A_{WA}/A_W	.62729	.55174
$A_{WA}\nabla$	.16616E+08	.29080E+07
A_{WF}	1311.3	472.49
A_{WF}/A_W	.44826	.37271
$A_{WF}\nabla$	.11248E+08	.19803E+07
$A_{WF}/\nabla^{2/3}$	3.1295	1.8176
B	25.850	12.686
B/L	.18621	.89295-01
BM_L	669.75	202.91
$BM_L\nabla^2$	.49274E+11	.35643E+10
$\frac{BM_L\nabla^2}{BL^3}$	452.51	154.68
$BM_L/\nabla^{1/3}$	32.719	12.585
$\frac{BT}{L^2}$	.67114E-02	.24631E-02
B/T	5.2133	2.5509

TABLE 10 (Continued)

	Maximum	Minimum
$B/\nabla^{1/3}$	1.2628	.78682
C_B	.55266	.39786
C_{BA}	.60320	.45327
C_{BF}	.53763	.33129
C_P	.68714	.57263
C_{PA}	.75355	.60989
$C_{PA}\nabla$	6463.4	2556.2
C_{PF}	.66037	.52162
$C_{PF}\nabla$	5664.2	2186.2
C_{VI}	1692.9	518.39
C_{VP}	.74431	.50278
C_W	.82675	.69857
C_{WA}	.99277	.83004
C_{WF}	.69802	.55957
L/B	11.199	5.3702
L/T	36.000	22.000
$L/\nabla^{1/3}$	9.1473	6.7027
$\frac{L^3BT\ C_B}{BM_L\nabla}$	86.341	34.231

TABLE 10 (Continued)

	Maximum	Minimum
$\left(\frac{L^3BT\ C_B}{BM_L\nabla}\right)^2$	7454.7	1171.8
L_{CB}	97.368	56.423
$L_{CB}\nabla$	.83516E+06	.23648E+06
$L_{CB}/\nabla^{1/3}$	4.7566	3.4996
L_{CF}	104.43	60.466
$L_{CF}\nabla$	.89572E+06	.25343E+06
$L_{CF}/\nabla^{1/3}$	5.1016	3.7503
$L_{CB} - L_{CF}$	-2.2321	-10.164
$(L_{CB} - L_{CF})/\nabla^{1/3}$	-.13844	-.49654
$\frac{L}{2} - L_{CB}$	.85901	-9.2120
$\frac{L}{2} - L_{CF}$	-4.7973	-16.081
$\left(\frac{L}{2} - L_{CB}\right)\nabla$	7368.0	-79014.
$\left(\frac{L}{2} - L_{CF}\right)\nabla$	-20106.	-.13793E+06
T	6.5317	3.5788
T/L	.45107E-01	.27578E-01
$\frac{TC_B}{C_W}$	4.5614	2.1562

TABLE 10 (Continued)

	Maximum	Minimum
$\left(\frac{TC_B}{C_W}\right)^2$	20.806	4.6494
$\frac{T\nabla}{B}$	3362.4	803.94
$T/\nabla^{1/3}$	.31908	.22197
∇	8577.3	4191.2
$\nabla^{1/3}$	20.470	16.123
$\nabla^{2/3}$	419.02	259.95
∇^2	.73571E+08	.17566E+08
∇^3	.63104E+12	.73623E+11
∇_A	5031.0	2125.2
∇_A/∇	.58655	.50706
∇_F	4228.5	1732.9
∇_F/∇	.49298	.41346

DTNSRDC ISSUES THREE TYPES OF REPORTS

1. DTNSRDC REPORTS, A FORMAL SERIES, CONTAIN INFORMATION OF PERMANENT TECHNICAL VALUE. THEY CARRY A CONSECUTIVE NUMERICAL IDENTIFICATION REGARDLESS OF THEIR CLASSIFICATION OR THE ORIGINATING DEPARTMENT.

2. DEPARTMENTAL REPORTS, A SEMIFORMAL SERIES, CONTAIN INFORMATION OF A PRELIMINARY, TEMPORARY, OR PROPRIETARY NATURE OR OF LIMITED INTEREST OR SIGNIFICANCE. THEY CARRY A DEPARTMENTAL ALPHANUMERICAL IDENTIFICATION.

3. TECHNICAL MEMORANDA, AN INFORMAL SERIES, CONTAIN TECHNICAL DOCUMENTATION OF LIMITED USE AND INTEREST. THEY ARE PRIMARILY WORKING PAPERS INTENDED FOR INTERNAL USE. THEY CARRY AN IDENTIFYING NUMBER WHICH INDICATES THEIR TYPE AND THE NUMERICAL CODE OF THE ORIGINATING DEPARTMENT. ANY DISTRIBUTION OUTSIDE DTNSRDC MUST BE APPROVED BY THE HEAD OF THE ORIGINATING DEPARTMENT ON A CASE-BY-CASE BASIS.

DATE
FILME