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A Study on the Regression Analysis for the Prediction of Resistance and Propulsion Characteristics of Full Slow-Speed Ships

by

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저속 비대선의 저항 추진 특성 추정을 위한 회귀 분석에 대한 연구

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Abstract

Fifteen(15) series hull forms for full slow-speed ships were prepared by expanding the basic parent hull form developed through the extensive theoretical and experimental studies, and model tests were carried out for each of the series hull forms.

A set of systematic data was prepared from the test results and utilized to derive regression equations for the prediction of resistance and powering characteristics by statistical analysis.

Computer program has been prepared based on the results of analysis and a sample run is presented.

요 약

광범위한 이론적, 실험적 연구를 통하여 개발된 모선 선형을 확장하여 저속 비대선에 대한 15개의 Series 선형을 준비하고 그 각각에 대한 모형 시험을 수행하였다.

모형 시험에 의하여 저항 추진에 대한 체계적인 자료를 마련하였으며 이러한 자료에 대한 통계적인 분석에 의하여 저항 추진 특성을 추정하기 위한 회귀 방정식을 유도하였다.

또한 유도된 방정식을 활용하여 전산 프로그램을 준비하였으며 그 응용예를 들었다.

I. Introduction

The author has carried out a large scale R & D Project for the development of fuel-economic hull form of full slow-speed ships. The hull form design methodology has been fully discussed in reference[1].

After completing the parent hull form development, fifteen(15) series hull forms were prepared according to the variations of block coefficient (C_B), length-beam ratio (L/B) and beam-draft ratio (B/T) as shown in Table 1. A vast amount of data was obtained on the resistance and propulsion characteristics by model experiments for all fifteen series models and propulsion characteristics.

Based on such systematic test results, statistical analyses have been performed for the numerical prediction of resistance and propulsion characteristics

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Table 1 Principal characteristics for daewoo series I hull forms (full slow-speed ship series)

GR	L(LPP) (m)	B (m)	L/B	Design condition				Ballast condition					
				LWL (m)	T (m)	B/T	C_B	LWL (m)	T_F (m)	T_A (m)	T_m (m)	B/T_m	C_B
A1	186.72	37.34	5.0	190.88	10.67	3.50	0.750	184.59	5.11	6.11	5.61	6.66	0.713
A2	182.75	36.55	5.0	184.85	10.44	3.50	0.800	180.72	4.95	5.95	5.45	6.71	0.766
A3	179.09	35.82	5.0	182.03	10.23	3.50	0.851	176.92	4.79	5.79	5.29	6.77	0.822
B1	200.29	33.38	6.0	204.41	11.13	3.00	0.750	198.06	5.40	6.40	5.90	5.66	0.706
B2	196.03	32.67	6.0	200.22	10.89	3.00	0.800	194.00	5.20	6.20	5.70	5.73	0.764
B3*	193.20	32.20	6.0	196.62	10.80	3.00	0.831	191.16	5.11	6.11	5.61	5.74	0.800
B4	190.62	31.77	6.0	193.38	10.59	3.00	0.870	188.47	4.98	5.98	5.48	5.80	0.841
B5	182.22	30.37	6.0	185.98	12.15	2.50	0.830	180.02	5.86	6.86	6.36	4.78	0.795
B6	203.85	33.97	6.0	207.95	9.71	3.50	0.830	201.81	4.54	5.54	5.04	6.74	0.799
C1	208.88	29.84	7.0	212.43	11.94	2.50	0.749	206.63	5.83	6.83	6.33	4.71	0.707
C2	204.43	29.21	7.0	208.61	11.68	2.50	0.800	202.26	5.66	6.66	6.16	4.74	0.759
C3	200.35	28.62	7.0	204.44	11.45	2.50	0.851	198.19	5.43	6.43	5.93	4.83	0.821
C4	197.30	28.19	7.0	201.45	11.27	2.50	0.890	195.17	5.35	6.35	5.85	4.82	0.858
C5	224.13	32.01	7.0	228.33	9.15	3.50	0.850	222.31	4.24	5.24	4.74	6.75	0.821
D	190.84	34.70	5.5	195.04	9.91	3.50	0.851	188.73	4.63	5.63	6.13	5.76	0.822

* Parent hull form

for two different loading conditions (full load and ballast), two different ship length (length between perpendiculars and length on waterline) and two different object functions (standard deviation and square sum).

The method employed was a multiple regression analysis which makes standard deviation or square sum of differences from test data to be minimum.

An effort was made in such a way that the statistical analysis results can be used to predict the speed power for ships of different sizes. In order to do this, non-dimensional parameters have been adopted.

As well known, the prediction method by statistical analysis may be weak in theoretical basis, but generally very convenient in practical applications with the development of high speed computers. Furthermore, the method could provide accurate results if the data and the analysis itself are properly prepared and performed.

The full reports of over 460 pages for this research work have already been distributed both domestically and internationally[2]. Due to limited space, only the brief summary of the study shall be presented in this paper.

II. Preparation of Data

The necessary data for the regression analysis were prepared by careful review and re-analysis of the test results. The model tests were carried out at MARIN and the results are presented in references [3] to [7].

As shown in the above references, however, some of the test data are presented in the model scale or in unproper form for the regression analysis. Therefore, those data were transformed to proper non-dimensional forms. Furthermore, the accuracy and the consistency on the test data were carefully investigated with various parameters, in general. Figure 1 shows one typical example of such investigations. In most cases, some data always showed great deviation from the general trend, and those data were eliminated from the data set. More details for this process shall be discussed with the individual characteristics.

A considerable amount of time and effort has been spent in re-arranging, reviewing and selecting data.

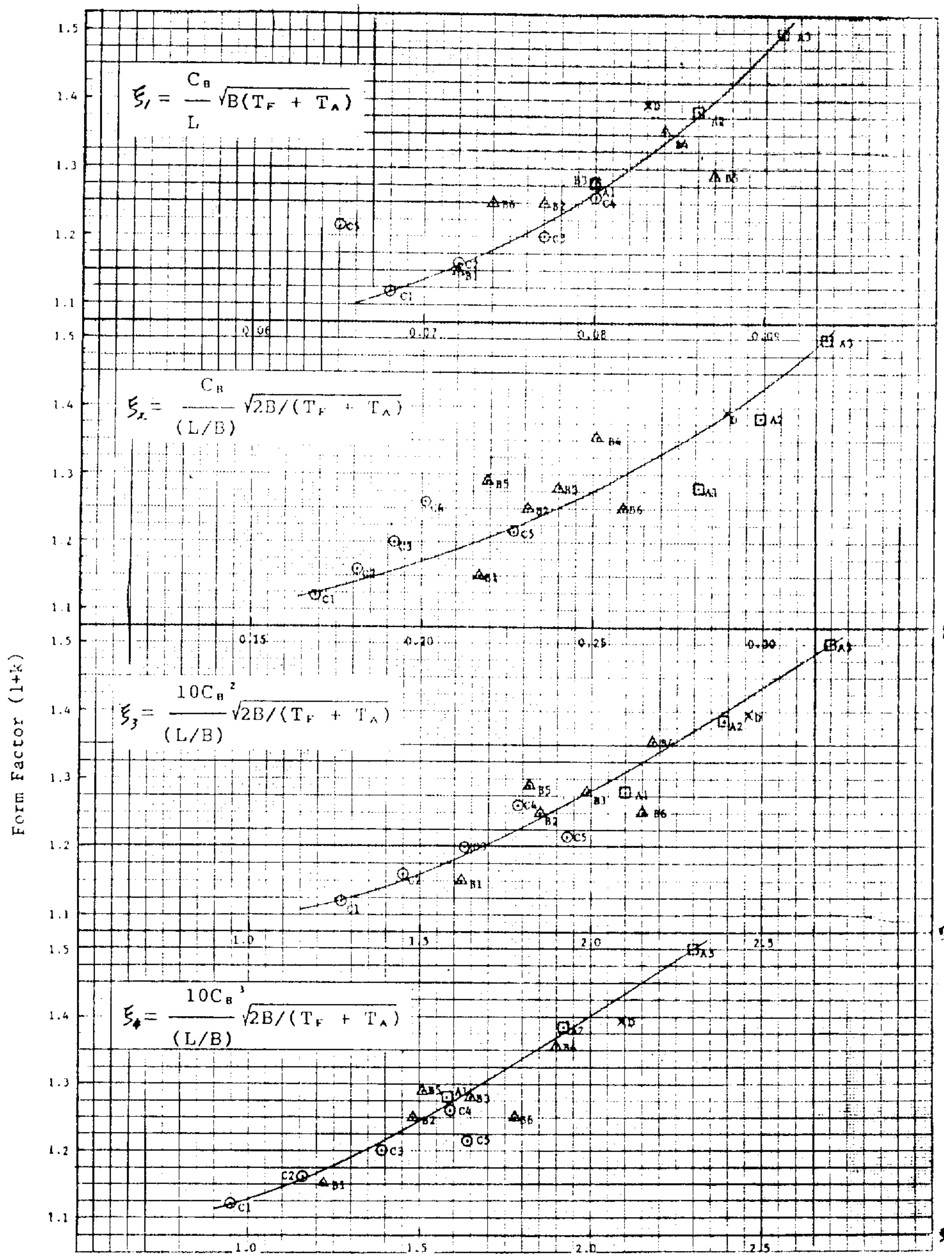

Fig. 1 Form factors plotted against various parameters (full load condition)

III. Methods of Analysis

1. Resistance

The total resistance coefficient of a ship (C_T) is subdivided into the following components using the form-factor concept:

$$C_T=(1+k)C_F+C_W+C_A$$

Where the various symbols denote the followings:

k : form factor

C_F : frictional resistance coefficient

C_W : wave resistance coefficient

C_A : model-ship correlation

In this study, the equivalent flat-plate resistance coefficient (C_F) is calculated by means of the ITTC-1957 formula.

Considering the above, it is concluded that resistance components or total resistance could be predicted if such factors as wetted surface area(S), form factor(k), wave resistance coefficient(C_W) and model-ship correlation(C_A) are estimated.

Therefore, discussions shall be made on the prediction method and regression analysis for each individual item.

(1) Wetted Surface Area

In order to derive a regression formula for the accurate prediction of wetted surface area, the following different cases have been considered and tried as mentioned in the introduction, that is, for two different loading conditions (full load and ballast conditions), two different ship lengths, three different regression equations and two different object functions, total twentyfour(24) different cases were investigated.

Three different regression equations adopted are as follows:

$$S=L(B+2T)C_M\times[a_1+a_2C_B+a_3C_M+a_4C_V+a_5(L/B)^{a_6}+a_7(B/T)^{a_8}] \quad (1)$$

$$S=L(B+2T)\times[a_1+a_2(C_P)^{a_3}+a_4(L/B)^{a_5}+a_6(B/T)^{a_7}+a_8(L/T)^{a_9}] \quad (2)$$

$$S=L(B+2T)[a_1+a_2(C_P)^{a_3}(L/B)^{a_4}(B/T)^{a_5}\cdot(L/T)^{a_6}] \quad (3)$$

In the above equations, the symbols of C_M, C_V and C_P represent midship coefficient, volumetric coefficient and prismatic coefficient, respectively.

(2) Form Factor

In order to derive prediction equation by correlating form factors to ship's geometrical form coefficients and ratios of main dimensions, the following investigations were made.

First, the test results for form factors were rearranged to examine the general trend between form factors and design parameters. As expected, the general trend is that form factor is proportional to block coefficient and inversely proportional to Length-Beam ratio. However, it was not possible to draw any general trend of form factors for the variation in Beam-Draft ratio.

In order to check the test accuracy and consistency, form factors were plotted with respect to four(4) different nondimensional parameters as shown in Figure 1. The parameters are defined as follows:

$$\xi_1=C_B\cdot\sqrt{B(T_F+T_A)}/L$$

$$\xi_2=C_B\cdot\sqrt{2B/(T_F+T_A)}/(L/B)$$

$$\xi_3=10(C_B)^2\cdot\sqrt{2B/(T_F+T_A)}/(L/B)$$

$$\xi_4=10(C_B)^3\cdot\sqrt{2B/(T_F+T_A)}/(L/B)$$

From the above investigation, it was found that some of data always showed too much deviation from the general trend. Therefore, those data were eliminated in the analysis. However, the number of data to be eliminated was restricted to be not more than three not to lose general balance.

The regression equations adopted for form factor prediction are as follows:

$$(1+k)=a_1+a_2(L/B)^{a_3}(B/T)^{a_4}(L/T)^{a_5}(C_B)^{a_6} \quad (1)$$

$$(1+k)=a_1+a_2+a_3\xi^2+a_4\xi^3 \quad (2)$$

$$(1+k)=a_1+a_2\xi^{(1+a_3)}+a_4\xi^{(2+a_5)}+a_6\xi^{(3+a_7)} \quad (3)$$

$$(1+k)=a_1+\frac{[a_2C_B+a_3(C_B)^2]^{a_4}}{[a_5(L/B)+a_6(L/B)^2]^{a_7}}\times[a_8+a_9(B/T)]^{a_{10}}\times a_{11}(L/T)^{a_{12}} \quad (4)$$

$$(1+k)=a_1+\frac{[a_2(C_B)+a_3(C_B)^2+a_4(C_B)^3]}{[a_5(L/B)+a_6(L/B)^2]}\times[a_7+a_8(B/T)+a_9(B/T)^2]\times[a_{10}(L/T)+a_{11}(L/T)^2] \quad (5)$$

In equations (2) and (3) among the above equations, four different parameters were successively applied. Therefore, total eighty-eight(88) different cases have been investigated for form factor study.

(3) Wave Resistance Coefficient

The regression formula for the wave resistance (R_W) was prepared following the theoretical expression. As mentioned in Chapter I, the resistance coefficient rather than resistance itself was adopted to be analyzed so that the results of analysis may be directly applied to predict the performance characteristics for ships of different sizes.

That is,

$$C_W=\frac{R_W}{1/2\ \rho S_T V^2}$$

Where ρ, S_T and V represent density of sea water, total wetted surface area and ship speed, respectively.

At the initial stage, two different regression equations of (a) and (b) were prepared. However, they were modified to equations (c) and (d) since there are more unknown coefficients and exponents in equations (a) and (b) than data points.

Initially prepared four different equations are as follows:

$$C_W=a_1(BT/S)(C_B)^{a_2}(L/B)^{a_3}(B/T)^{a_4}(L/T)^{a_5} \quad (a)$$
$$\times(a_6F_N^{a_7}+a_8F_N^{2+a_9}+a_{10}F_N^{4+a_{11}})$$
$$\times\exp[a_{12}+a_{13}(L/T)^{a_{14}}(F_N)^{a_{15}}]$$
$$\times[a_{16}+\cos(a_{17}+a_{18}(L/B)^{a_{19}}(F_N)^{a_{20}})]$$

$$C_W=a_1(BT/S)(C_B)^{a_2}(L/B)^{a_3}(B/T)^{a_4}(L/T)^{a_5} \quad (b)$$
$$\times(a_6F_N^{a_7}+a_8F_N^{2+a_9}+a_{10}F_N^{4+a_{11}})$$
$$\times\exp(a_{12}+a_{13}(L/T)^{a_{14}}(F_N)^{a_{15}})$$
$$\times\cos(a_{16}+a_{17}(L/B)^{a_{18}}(F_N)^{a_{19}})$$

$$C_W=a_1(BT/S)\ (C_B)^{a_2}(L/B)^{a_3}(B/T)^{a_4}$$
$$(L/T)^{a_5}(F_N)^{a_6} \quad (c)$$
$$\times\exp\ [a_7+a_8(L/T)^{a_9}(F_N)^{a_{10}}]$$
$$\times\cos(a_{11}+\cos(a_{12}+a_{13}(L/B)^{a_{14}}(F_N)^{a_{15}}))$$

$$C_W=a_1(BT/S)(C_B)^{a_2}(L/B)^{a_3}(B/T)^{a_4}$$
$$(L/T)^{a_5}(F_N)^{a_6} \quad (d)$$
$$\times\exp(a_7+a_8(L/T)^{a_9}(F_N)^{a_{10}})$$
$$\times\cos(a_{11}+a_{12}(L/B)^{a_{13}}(F_N)^{a_{14}})$$

In the above equations, F_N denotes Froude Number.

Furthermore, it has been decided to adopt equation (d) as a basic equation, since preliminary tests show that the results by equation (d) are always better than those by equation (c). Based on the selected equation, three more equations have been prepared as follows:

$$C_W=a_1(BT/S((C_B)^{a_2}(L/B)^{a_3}(B/T)^{a_4}$$
$$(L/T)^{a_5}(F_N)^{a_6} \quad (1)$$
$$\times\exp[a_7+a_8(L/T)^{a_9}(F_N)^{a_{10}}]$$
$$\times\cos[a_{11}+a_{12}(L/B)^{a_{13}}(F_N)^{a_{14}}]$$

$$C_W=(1000)a_1(BT/S)^{a_2}(B/L)^{a_3}(T/L)^{a_4}/$$
$$(F_N)^{a_5}(C_B)^{a_6} \quad (2)$$
$$\times\exp[(a_7(B/L)+a_8(T/L)^{a_9}+a_{10}C_V+a_{11}C_P)$$
$$(F_N)^{(-2+a_{12})}]$$
$$\times\cos[(a_{13}C_P+a_{14}(B/L))(F_N)^{(-2+a_{15})}]$$

$$C_W=(1000)a_1[(BT/S)(B/L)(T/L)]^{a_2}/$$
$$(F_N)^{a_3}(C_B)^{a_4} \quad (3)$$
$$\times\exp[(a_5+a_6(B/L)+a_7(T/L)^{a_8}+a_9C_V+a_{10}C_P)$$
$$(F_N)^{(-2+a_{11})}]$$
$$\times\cos[a_{12}+a_{13}C_P+a_{14}(B/L))(F_N)^{(-2+a_{15})}]$$

$$C_W=(1000)a_1(BT/S)^{a_2}(C_B)^{a_3}(B/L)^{a_4}$$
$$(T/L)^{a_5}(F_N)^{a_6} \quad (4)$$
$$\times\exp[(a_7+a_8(T/L)^{a_9}+a_{10}C_P)(F_N)^{(-2+a_{11})}]$$
$$\times\cos[(a_{12}+a_{13}(B/L)+a_{14}C_P)(F_N)^{(-2+a_{15})}]$$

Here, it should be mentioned that the term of half-entrance angle($1/2\alpha_E$) has been omitted in the above equations, since only the full slow-speed ships are dealt with in this study. For fine fast-speed ships, however, it is believed that the term of half-entrance angle should be included.

(4) Model-Ship Correlation Allowance

For the model-ship correlation allowance, a statistical analysis could not be made from this project, because full scale data are not available yet. From a large sample of trial data in the period of late 1970's and for the hull roughness of about 150μm, therefore, the following form of regression analysis for full load (design) condition was performed.

$$R_A=1/2\ \rho S_T C_A V^2$$
$$C_A=a_1(L+100)^{a_2}-a_3$$
$$a_1=4.22733$$
$$a_2=-0.17208$$
$$a_3=1.32199$$

For the sake of convenience, however, the model-ship correlation allowance has been arranged as the following step function, since the figures after 4th decimal place in the values calculated by the above formula does not have much meaning.

Since the C_A values in ballast condition are on the average higher than those in full load condition, it has been decided for C_A values in ballast condition to be modified by adding statistical figures to C_A values in full load condition.

Ship length	$C_A\times10^3$	$\Delta C_A\times10^3$
$L\leq100$m	0.40	0.20
100m$<L\leq200$m	0.30	0.10
200m$<L\leq300$m	0.20	0.05
300m$\leq L$	0.15	0.00

(C_A) ballast$=(C_A)$ full load$+\Delta C_A$

The above C_A values could be reduced greatly by reducing hull roughness. In fact, it is not unusual nowadays to have negative correlation allowances.

2. Propulsion

When the resistance is known, the required propulsive power can be predicted from the propulsion factors and the propeller efficiency. The propulsion factors are related to hull form, ship speed and loading of the propeller. Wake fraction(w), thrust deduction fraction(t) and relative-rotative efficiency (η_R)* are regarded as such propulsion factors.

Among them, the relative-rotative efficiency does not vary much for the given hull form and propeller, and generally maintain almost constant value with respect to ship speed and loading of propeller.

In this report, therefore, the effect of ship speed and loading on the relative-rotative efficiency was neglected, and it has been treated as a constant. However, the influence of the loading on the effective wake fraction and the thrust deduction fraction could not be ignored.

In the subsequent sections, detail discussions shall be made on the prediction method and the regression analysis for the propulsion factors.

(1) Wake Fraction

Nowadays, it is generally admitted that ship's wake is composed of the following main components:

$$w = w_v + w_p + w_w$$

w_v = viscous wake

w_p = potential flow wake

w_w = wake due to wave

Since model tests are performed based on the "thrust identity" concept, the viscous wake in the above wake components is subject to severe scale effects. Therefore, it was decided to divide wake fraction into two parts-one being subject to scale effect and the other being independent from scale effect.

Before preparing the regression equations, the effect of fullness and ratios of main dimensions on the wake was examined by re-arranging the test results. As expected, the general trend is such that wake fraction is proportional to block coefficient and inversely proportional to Length-Beam ratio. However, they do not show any general trend for the variation in Beam-Draft ratio. The re-arranged test data were also plotted in various different forms to check the accuracy or consistency of test results. However, those will not be presented in this paper due to limited space.

Those data which are too much deviated from the general trend have been eliminated in the analysis. However, the number of data points to be eliminated was also limited to be not more than three.

The regression equations prepared for the wake fraction prediction are as follows:

$$W = [(a_1 + a_2(L/B)^{a_3}(C_B)^{a_4}(B/T)^{a_5}(S/L/(B+2T))^{a_6}(D^2/B/T)^{c_7} \times [a_8 + a_9(C_V) + a_{10}(C_V)^2 + a_{11}(C_V)^3] \quad (1)$$

$$W = [a_1 + a_2(L/B)^{a_3}[a_4 + a_5(C_B)]^{a_6}(B/T_A)^{a_7}(S/L/(B+2T))^{a_8} \times (a_9 + a_{10}(D^2/B/T)a_{11}] \times [a_{12} + a_{13}(C_V) + a_{10}(C_V)^2 + a_{11}(C_V)^3] \quad (2)$$

$$W = BSC_V/(DT_A)[a_1/T_A + a_2(L/B) + a_3C_V/(D(1-C_B))] + a_4[L(1-C_B)/B]^{a_5} + [a_6 + a_7(L/B)]/(1-C_B) \quad (3)$$

$$W = a_1(BT_A/D^2)^{a_2}[1 + a_3(C_B) + a_4(C_B)^2 + a_5(C_B)^3]^{a_6} / [1 + a_7(L/B) + a_8(L/B)^2] \times [1 + a_9(B/T) + a_{10}(B/T)^2 + a_{11}(B/T)^3]^{a_{12}} \times [1 + a_{13}(C_V) + a_{14}(C_V)^2 + a_{15}(C_V)^3] \quad (4)$$

$$W = a_1(BT_A/D^2)^{a_2}([1 + a_3(C_B) + a_4(C_B)^2 + a_5(C_B)^3]^{a_6} + [1 + a_7(B/T) + a_8(B/T)^2 + a_9(B/T)^2]^{a_{10}}) / [1 + a_{11}(L/B) + a_{12}(L/B)^2] \times [1 + a_{13}(C_V) + a_{14}(C_V)^2 + a_{15}(C_V)^3] \quad (5)$$

In the above equations, the additional symbols represent the followings:

D = Propeller Diameter

$C_V = (1+k) \cdot C_F$

(2) Thrust Deduction Fraction

Thrust deduction fraction(t) mainly depends on the aft-shape and the loading of propeller. According to noway's general model test technique, i.e., "thrust identity" concept, the thrust deduction fraction of a full scale ship becomes identical to that of a model ship.

Also in this characteristics, the measured data were investigated before preparing the regression equations to examine the effect of design parameters.

The accuracy and consistency of measured data were also cross-checked by various different ways.

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* The terminology of "coefficient" is more meaningful than "efficiency" to this factor as in the case of "hull efficiency".

However, the results will not be presented here due to limited space. As was in the case of wake fraction, some data which were too much deviated from the general trend were also eliminated in the analysis.

The prepared regression equations for the thrust deduction fraction are as follows:

$$t=a_1(D^2/B/T_A)a_2\times[1+a_3(C_B)+a_4(C_B)^2]^{a_5} \quad (1)$$
$$\times[1+a_6(B/T)+a_7(B/T)^2]^{a_8}[1+a_9(P/D)]^{a_{10}}$$
$$/[1+a_{11}(L/B)+a_{12}(L/B)^2]$$
$$\times[1+a_{13}F_N+a_{14}F_N^2+a_{15}F_N^3]$$

$$t=a_1(D_2/B/T_A)^{a_2}\times[1+a_3(C_B)+a_4(C_B)^2$$
$$+a_5(C_B)^3] \quad (2)$$
$$\times[1+a_6(B/T)+a_7(B/T)^2+a_8(B/T)^3]$$
$$[1+a_9(P/D)+a_{10}(P/D)^2]$$
$$/\ [1+a_{11}(L/B)+a_{12}(L/B)^2]$$
$$\times[1+a_{13}F_N+a_{14}F_N^2+a_{15}F_N^3]$$

$$t=[a_1(L/B)^{a_2}(C_B)^{a_3}(B/T)^{a_4}(D^2/B/T)^{a_5}$$
$$(P/D)^{a_6} \quad (3)$$
$$+a_7(D^2/B/T)^{a_8}+a_9(P/D)^{a_{10}}]$$
$$\times[a_{11}+a_{12}F_N+a_{13}F_N^2+a_{14}F_N^3]$$

$$t=[a_1+(L/B)^{a_2}(a_3+a_4/(1-(C_B)))^{e_5}(B/T)^{a_6} \quad (4)$$
$$+a_7D^2/(BT)+a_8(P/D)]$$
$$\times[1+a_9F_N+a_{10}F_N^2+a_{11}F_N^3]$$

$$t=[a_1+a_2(L/B)^{a_3}\times(a_4+a_5C_B)^{a_6}(B/T)^{a_7}$$
$$+a_8D^2/(BT) \quad (5)$$
$$+a_9(P/D)]\times[a_{10}+a_{11}F_N+a_{12}F_N^2+a_{13}F_N^3]$$

In the above equations, the symbol, P/D, denotes propeller pitch-diameter ratio.

(3) Relative-Rotative Efficiency

It has been already mentioned that relative-rotative efficiency(η_R) does not vary much with respect to ship speed and propeller loading and is generally regarded as a constant for a given hull form and a propeller. In this report, therefore, the effects of ship speed and propeller loading on the relative-rotative efficiency was neglected, and it has been treated as a constant for the given hull form and propeller.

The prepared regression equations for the prediction of relative-rotative efficiency are as follows:

$$\eta_R=a_1+a_2(L/B)+a_3C_B+a_4(A_E/A_0)$$
$$+a_5(P/D) \quad (1)$$

$$\eta_R=a_1+a_2(L/B)^{a_3}+a_4(C_B)^{a_5}+a_6(A_E/A_0)^{a_7}$$
$$+a_8(P/D)^{a_9} \quad (2)$$

$$\eta_R=a_1+a_2(L/B)^{a_3}[a_4+a_5(C_B)^{a_6}][a_7$$
$$+a_8(B/T)^{a_9}] \quad (3)$$
$$\times[a_{10}+a_{11}(A_E/A_0)^{a_{12}}][a_{13}+a_{14}(P/D)^{a_{15}}]$$

$$\eta_R=a_1+a_2(L/B)^{a_3}[a_4+a_5(C_B)]^{a_6}[a_7$$
$$+a_8(B/T)]^{a_9} \quad (4)$$
$$\times[a_{10}+a_{11}(A_E/A_0)]^{a_{12}}[a_{13}+a_{14}(P/D)]^{a_{15}}$$

In the above equations, A_E/A_0 denotes the propeller blade area ratio.

(4) Propeller Open-Water Efficiency

In order to estimate the propeller open-water efficiency(η_P), a preliminary design of the propeller should be made or an information on the particular propeller should be prepared. This preparation could be done utilizing nowaday's highly advanced propeller theory. In the initial stage, however, it is common practice to use the data from stock propellers.

IV. Results of Analysis

In the way discussed in Chapter III, a vast amount of regression analysis has been carried out for each of characteristics. The unknown ocefficients and exponents in each of the regression equations for each of characteristics have been obtained through the Nelder-Mead Optimum technique. The optimum technique is briefly introduced in reference[8].

The characteristics for each cases were all computed again using thus derived regression equations and compared with the test results. Such vast amount of the results of analyses are well presented in reference[2] with more than 250 tables.

V. Selection of the Best Method

As discussed in Chapter IV, a vast amount of computations and comparisons have been made. In order to review and compare those results more vividly, overall comparison tables have been prepared for each of characteristics. Table 2 shows one typical example.

Here, one important dicision should be made regarding the selection of the method for the final application. This is by no means easy task due to various physical phenomena and mutual influence between design parameters. However, one best case was selected for each characteristics considering accuracy of the results, user's convenience, consistency of analysis and the relation with the future study.

Table 3 shows the summary of the selected cases,

Table 2 Comparison of the results of analysis for the relative rotative efficiency

Case	Full Load		Ballast	
	Rel. Diff.	Abs. Diff.	Rel. Diff.	Abs. Diff.
1	1.80	0.0186	1.83	0.0193
2	1.80	0.0186	1.84	0.0194
3	0.66	0.0068	1.82	0.0193
4	0.64	0.0066	1.80	0.0190
5	0.68	0.0070	1.88	0.0198
6	0.68	0.0070	1.85	0.0195
7	0.76	0.0078	1.00	0.0105
8	0.71	0.0073	1.03	0.0109
9	0.73	0.0076	1.96	0.0206
10	0.73	0.0075	1.96	0.0207
11	0.69	0.0072	1.87	0.0197
12	0.67	0.0069	1.87	0.0197
13	0.68	0.0070	1.34	0.0195
14	0.68	0.0070	1.87	0.0197
15	0.69	0.0072	1.01	0.0106
16	0.67	0.0069	1.00	0.0105

Table 3 Summary of selected cases

Item	Total Number of Cases Studied	Selected Case Number	Mean Relative*(1) Difference(%)	
			Full Load	Ballast
Wetted Surface Area	12	4	0.11	0.13
Form Factor	44	17	0.96	1.64
Wave Resistance Coefficient	16	8	28.90*(2)	21.95*(2)
Wake Fraction	20	8	2.80*(2)	8.99*(2)
Thrust Deduction Fraction	20	9	5.45*(2)	7.09*(2)
Relative Rotative Coefficient	16	8	0.71	1.03

* (1) Basis of Percentage: Test Value
(2) At the ship speed of 14 knots.

Table 4 Selected case for the wetted surface area full load condition Case 4 (LPP, Eq.(2), S)

GR	Model Test (1)	Reg. (2)	Diff. (3)*	Rel. Diff.(%) (4)**
A1	8906.0	8917.9	11.88	0.13
A2	8834.0	8850.8	16.80	0.19
A3	8847.0	8815.3	−31.69	−0.36
B1	9131.0	9125.7	−5.26	−0.06
B2	9072.0	9064.7	−7.31	−0.08
B3	9029.0	9023.0	−5.98	−0.07
B4	9017.0	9008.4	−8.62	−0.10
B5	8709.0	8713.4	4.41	0.05
B6	9377.0	9392.8	15.81	0.17
C1	9250.0	9240.0	−10.01	−0.11
C2	9174.0	9173.4	−0.59	−0.01
C3	9130.0	9137.9	7.85	0.09
C4	9092.0	9104.7	12.72	0.14
C5	9866.0	9860.1	−5.93	−0.06
D	9109.0	9114.8	5.78	0.06
Average of Abs. Diff.			10.04	0.11

* (3)=(2)−(1)
** (4)=[(3)/(1)]×100

—Selected Coefficients—

A(1)=−0.78877719 A(6)= 1.07523136
A(2)= 0.45843066 A(7)= 0.05100677
A(3)= 1.45023620 A(8)= 0.72606480
A(4)=−0.48900980 A(9)=−0.35548456
A(5)=−0.92772788

Table 5 Selected case for the form factor full load condition Case 17 (LPP, Eq.(3), S)

GR	Model Test (1)	Reg. (2)	Diff. (3)*	Rel. Diff.(%) (4)**
A1	1.2800	1.2639	−0.0161	−1.26
A2	1.3850	1.3609	−0.0241	−1.74
A3	1.5000	1.4926	−0.0074	−0.49
B1	1.1500	1.1709	0.0209	1.82
B2	1.2500	1.2371	−0.0129	−1.03
B3	1.2800	1.2834	0.0034	0.27
B4	1.3550	1.3563	0.0013	0.10
C1	1.1200	1.1108	−0.0092	−0.82
C2	1.1600	1.1575	−0.0025	−0.22
C3	1.2000	1.2144	0.0144	1.20
C4	1.2600	1.2671	0.0071	0.56
D	1.3930	1.4208	0.0278	2.00
Average of Abs. Diff.			0.0123	0.96

* (3)=(2)−(1)
** (4)=[(3)/(1)]×100

—Selected Coefficients—

A(1)= 0.88812866 A(5)=−0.06526475
A(2)= 0.19028261 A(6)= 0.00548547
A(3)=−0.29278926 A(7)= 0.17120913
A(4)= 0.03684587

Table 6 Selected case for the wave resistance coeff.

Full Load Condition
Case 8 (LPP, Eq.(4), S)

GR	Model Test (1)	Reg. (2)	Diff. (3)*	Rel. Diff.(%) (4)**
A 1	0.0900	0.0001	−0.0899	−99.90
	0.1400	0.0009	−0.1391	−99.34
	0.1900	0.0044	−0.1856	−97.69
	0.2500	0.0143	−0.2357	−94.30
	0.3200	0.0362	−0.2838	−88.70
A 2	0.0300	0.0023	−0.0277	−92.37
	0.0400	0.0117	−0.0283	−70.75
	0.0800	0.0372	−0.0428	−53.44
	0.0900	0.0902	0.0002	0.20
	0.1800	0.1817	0.0017	0.94
A 3	0.0400	0.0468	0.0068	17.07
	0.1000	0.1390	0.0390	38.97
	0.2100	0.3053	0.0953	45.40
	0.5000	0.5578	0.0578	11.55
	0.8600	0.8983	0.0383	4.45
B 1	0.0500	0.0001	−0.0499	−99.81
	0.0800	0.0007	−0.0793	−99.15
	0.1200	0.0030	−0.1170	−97.53
	0.1500	0.0095	−0.1405	−93.66
	0.2400	0.0244	−0.2156	−89.85
B 2	0.0100	0.0024	−0.0076	−76.25
	0.0200	0.0099	−0.0101	−50.73
	0.0300	0.0294	−0.0006	−2.00
	0.0700	0.0698	−0.0002	−0.25
	0.0900	0.1405	0.0505	56.15
B 3	0.0100	0.0150	0.0050	50.42
	0.0200	0.0468	0.0268	133.77
	0.0500	0.1120	0.0620	124.06
	0.1400	0.2238	0.0838	59.89
	0.1400	0.3917	0.2517	179.82
B 4	0.1900	0.1468	−0.0432	−22.74
	0.3200	0.3220	0.0020	0.63
	0.5900	0.5901	0.0001	0.02
	0.9700	0.9529	−0.0171	−1.76
	1.6800	1.4031	−0.2769	−16.49
B 5	0.0500	0.0227	−0.0273	−54.60
	0.0800	0.0661	−0.0139	−17.34
	0.1100	0.1512	0.0412	37.42
	0.2500	0.2914	0.0414	16.55
	0.5300	0.4956	−0.0344	−6.48
B 6	0.0500	0.0102	−0.0398	−79.68
	0.0900	0.0337	−0.0563	−62.60
	0.1100	0.0844	−0.0256	−23.26
	0.1700	0.1746	0.0046	2.72
	0.3100	0.3141	0.0041	1.32
C 1	0.0200	0.0001	−0.0199	−99.57
	0.0200	0.0005	−0.0195	−97.27
	0.0500	0.0023	−0.0477	−95.33
	0.1000	0.0075	−0.0925	−92.52
	0.1600	0.0193	−0.1407	−87.94
C 2	0.0100	0.0021	−0.0079	−79.24
	0.0100	0.0082	−0.0018	−17.98
	0.0400	0.0241	−0.0159	−39.67
	0.0800	0.0573	−0.0227	−28.33
	0.1700	0.1161	−0.0539	−31.69
C 3	0.0600	0.0460	−0.0140	−23.37
	0.1200	0.1148	−0.0052	−4.35
	0.2100	0.2358	0.0258	12.27
	0.3700	0.4201	0.0501	13.53
	0.7500	0.6727	−0.0773	−10.31
C 4	0.5300	0.4331	−0.0969	−18.28
	0.8100	0.7789	−0.0311	−3.84
	1.1900	1.2358	0.0458	3.85
	1.7100	1.7887	0.0787	4.60
	2.4000	2.4168	0.0168	0.70
C 5	0.0300	0.0213	−0.0087	−28.86
	0.0500	0.0592	0.0092	18.42
	0.1100	0.1320	0.0220	20.01
	0.2300	0.2510	0.0210	9.15
	0.4500	0.4240	−0.0260	−5.79
D	0.1200	0.0442	−0.0758	−63.13
	0.1800	0.1227	−0.0573	−31.85
	0.2900	0.2640	−0.0260	−8.96
	0.4600	0.4802	0.0202	4.39
	0.6700	0.7751	0.1051	15.69
Average of Abs. Diff.			0.0565	44.57

* (3)=(2)−(1)
** (4)=[(3)/(1)]×100

—Selected Coefficients—

A (1)= 0.04601620
A (2)=−0.11085414
A (3)=−1.00489022
A (4)= 0.32370961
A (5)= 0.27863102
A (6)=−0.28473413
A (7)=−1.52270739
A (8)=−0.04639221
A (9)= 0.14683469
A(10)= 1.59964559
A(11)= 0.27058981
A(12)= 0.00479841
A(13)= 0.09154874
A(14)=−0.01788254
A(15)=−0.44312903

Table 7 Selected case for the wake fraction(1)
full load condition
Case 8 (LPP, Eq. (4), S)

GR	Model Test (1)	Reg. (2)	Diff. (3)*	Rel. Diff.(%) (4)**
A1	0.3890	0.3707	−0.0183	−4.71
	0.3840	0.3700	−0.0140	−3.64
	0.3780	0.3694	−0.0086	−2.27
	0.3730	0.3689	−0.0041	−1.10
	0.3670	0.3684	0.0014	0.38
A2	0.4270	0.4432	0.0162	3.80
	0.4270	0.4424	0.0154	3.61
	0.4250	0.4416	0.0166	3.91
	0.4240	0.4409	0.0169	3.99
	0.4190	0.4403	0.0213	5.08
B1	0.3360	0.3210	−0.0150	−4.46
	0.3350	0.3205	−0.0145	−4.33
	0.3350	0.3200	−0.0150	−4.47
	0.3340	0.3196	−0.0144	−4.31
	0.3330	0.3192	−0.0138	−4.14
B2	0.3860	0.3856	−0.0004	−0.11
	0.3860	0.3849	−0.0011	−0.28
	0.3840	0.3843	0.0003	0.08
	0.3830	0.3838	0.0008	0.20
	0.3820	0.3833	0.0013	0.33
B3	0.4290	0.4271	−0.0019	−0.43
	0.4290	0.4264	−0.0026	−0.61
	0.4280	0.4257	−0.0023	−0.54
	0.4250	0.4251	0.0001	0.02
	0.4191	0.4245	0.0055	1.32
B5	0.3540	0.3983	0.0443	12.53
	0.3580	0.3976	0.0396	11.07
	0.3620	0.3970	0.0350	9.66
	0.3640	0.3964	0.0324	8.90
	0.3640	0.3959	0.0319	8.75
B6	0.4810	0.4536	−0.0274	−5.70
	0.4720	0.4528	−0.0192	−4.07
	0.4640	0.4521	−0.0119	−2.56
	0.4550	0.4515	−0.0035	−0.78
	0.4420	0.4509	0.0089	2.01
C2	0.3230	0.3246	0.0016	0.50
	0.3230	0.3241	0.0011	0.33
	0.3220	0.3236	0.0016	0.50
	0.3220	0.3232	0.0012	0.37
	0.3210	0.3228	0.0018	0.56
C3	0.3860	0.3856	−0.0004	−0.11
	0.3880	0.3849	−0.0031	−0.79
	0.3880	0.3844	−0.0036	−0.94
	0.3880	0.3838	−0.0042	−1.07
	0.3820	0.3834	0.0014	0.35
C4	0.4710	0.4412	−0.0298	−6.33
	0.4680	0.4404	−0.0276	−5.89
	0.4650	0.4397	−0.0253	−5.43
	0.4600	0.4391	−0.0209	−4.54
	0.4560	0.4385	−0.0175	−3.83
C5	0.4220	0.4411	0.0191	4.53
	0.4220	0.4404	0.0184	4.36
	0.4200	0.4397	0.0197	4.70
	0.4130	0.4391	0.0261	6.33
	0.4030	0.4386	0.0356	8.83
D	0.5460	0.5122	−0.0338	−6.19
	0.5400	0.5112	−0.0288	−5.33
	0.5310	0.5104	−0.0206	−3.89
	0.5200	0.5096	−0.0104	−2.01
	0.5090	0.5088	−0.0002	−0.03
Average of Abs. Diff.			0.0138	3.36

* (3)=(2)−(1)
** (4)=[(3)/(1)]×100

—Selected Coefficients—

A(1)= 0.02650076	A(9)= 1.23810423
A(2)=−0.20653058	A(10)= 1.08010455
A(3)= 1.50237127	A(11)= 1.30525643
A(4)= 1.41245335	A(12)= 0.13808491
A(5)= 2.10946048	A(13)=99.98368093
A(6)= 1.68015177	A(14)= 0.22015128
A(7)=−0.09751126	A(15)= 0.09073602
A(8)= 0.01580050	

Table 8 Selected case for the thrust deduction fraction

Full Load Condition
Case 9 (LPP, Eq. (5), S)

GR	Model Test (1)	Reg. (2)	Diff. (3)*	Rel. Diff.(%) (4)**
A1	0.1730	0.1702	−0.0028	−1.63
	0.1730	0.1683	−0.0047	−2.73
	0.1720	0.1664	−0.0056	−3.28
	0.1670	0.1645	−0.0025	−1.51
	0.1670	0.1626	−0.0044	−2.61
A2	0.2180	0.2227	0.0047	2.17
	0.2140	0.2202	0.0062	2.90
	0.2140	0.2177	0.0037	1.72
	0.2210	0.2152	−0.0058	−2.63
	0.2210	0.2128	−0.0082	−3.73
A3	0.3450	0.3537	0.0087	2.54
	0.3420	0.3497	0.0077	2.24
	0.3440	0.3456	0.0016	0.47
	0.3380	0.3416	0.0036	1.08
	0.3380	0.3377	−0.0003	−0.08
B1	0.1630	0.1688	0.0058	3.56
	0.1680	0.1670	−0.0010	−0.61
	0.1600	0.1652	0.0052	3.22
	0.1560	0.1633	0.0073	4.71
	0.1550	0.1616	0.0066	4.24
B2	0.1920	0.1931	0.0011	0.55
	0.1800	0.1909	0.0109	6.08
	0.1820	0.1888	0.0068	3.76
	0.1810	0.1867	0.0057	3.17
	0.1890	0.1847	−0.0043	−2.28
B3	0.1920	0.2182	0.0262	13.66
	0.1920	0.2158	0.0238	12.41
	0.1910	0.2134	0.0224	11.74
	0.1900	0.2110	0.0210	11.08
	0.1890	0.2087	0.0197	10.43
B5	0.1910	0.2105	0.0195	10.21
	0.1970	0.2081	0.0111	5.64
	0.1940	0.2057	0.0117	6.04
	0.1950	0.2034	0.0084	4.29
	0.1960	0.2011	0.0051	2.58
B6	0.2240	0.2257	0.0017	0.75
	0.2190	0.2233	0.0043	1.95
	0.2240	0.2208	−0.0032	−1.41
	0.2220	0.2184	−0.0036	−1.60
	0.2230	0.2161	−0.0069	−3.100
C1	0.1650	0.1733	0.0083	5.03
	0.1710	0.1715	0.0005	0.27
	0.1710	0.1696	−0.0014	−0.80
	0.1670	0.1678	0.0008	0.49
	0.1620	0.1660	0.0040	2.48
C2	0.1980	0.1888	−0.0092	−4.65
	0.1930	0.1868	−0.0062	−3.22
	0.1970	0.1848	−0.0122	−6.21
	0.1940	0.1828	−0.0112	−5.79
	0.2020	0.1808	−0.0212	−10.50
C3	0.2480	0.2149	−0.0331	−13.35
	0.2460	0.2126	−0.0334	−13.59
	0.2450	0.2102	−0.0348	−14.19
	0.2360	0.2079	−0.0281	−11.89
	0.2280	0.2057	−0.0223	−9.79
C4	0.2790	0.2517	−0.0273	−9.80
	0.2700	0.2489	−0.0211	−7.81
	0.2640	0.2462	−0.0178	−6.75
	0.2720	0.2435	−0.0285	−10.49
	0.2630	0.2408	−0.0222	−8.44
C5	0.2070	0.2375	0.0305	14.74
	0.2040	0.2351	0.0311	15.26
	0.2040	0.2327	0.0287	14.07
	0.2040	0.2303	0.0263	12.89
	0.2020	0.2279	0.0259	12.83
D	0.2830	0.2808	−0.0022	−0.79
	0.2810	0.2776	−0.0034	−1.19
	0.2870	0.2745	−0.0125	−4.34
	0.2850	0.2715	−0.0135	−4.75
	0.2830	0.2684	−0.0146	−5.15
Average of Abs. Diff.			0.0121	5.60

* (3)=(2)−(1)
** (4)=[(3)/(1)]×100

—Selected Coefficients—

A (1)=−3.05836696
A (2)= 6.79755302
A (3)=−6.54892436
A (4)=−0.06159892
A (5)= 2.14904167
A (6)= 16.18303707
A (7)=−0.67269045
A (8)= 8.09673454
A (9)= 4.34859365
A(10)= 0.27085801
A(11)=−0.09025697
A(12)=−0.92640704
A(13)= 2.18122454

Table 9 Selected case for the relative-rotativ eff. full load condition
Case 8 (LPP, Eq. (4), S)

GR	Model Test (1)	Reg. (2)	Diff. (3)*	Rel. Diff.(%) (4)**
A1	1.0280	1.0338	0.0058	0.56
A2	1.0270	1.0353	0.0083	0.80
A3	1.0320	1.0368	0.0048	0.46
B1	1.0500	1.0298	−0.0202	−1.92
B2	1.0390	1.0313	−0.0077	−0.74
B3	1.0390	1.0324	−0.0066	−0.63
B4	1.0340	1.0333	−0.0007	−0.06
B5	1.0300	1.0389	0.0089	0.86
B6	1.0400	1.0264	−0.0136	−1.31
C1	1.0220	1.0281	0.0061	0.60
C2	1.0230	1.0296	0.0066	0.64
C3	1.0360	1.0311	−0.0049	−0.47
C4	1.0340	1.0322	−0.0018	−0.18
C5	1.0090	1.0188	0.0098	0.97
D	1.0280	1.0316	0.0036	0.35
Average of Abs. Diff.			0.0073	0.70

* (3)=(2)−(1)
** (4)=[(3)/(1)]×100

—Selected Coefficients—

A(1)= 0.61273209	A(9)=−0.12130942
A(2)= 0.57865146	A(10)= 0.94270482
A(3)=−0.12997494	A(11)= 1.21751536
A(4)= 1.51524922	A(12)=−0.04785270
A(5)= 1.41040050	A(13)= 1.01603511
A(6)= 0.13718152	A(14)= 0.98923234
A(7)= 1.47119904	A(15)=−0.01552397
A(8)= 1.15676156	

and each of Tables 4 through 9 shows the selected case itself for each of characteristics. Due to limited space, only the results for the design condition have been presented. Those who are interested in the results for the ballast condition may consult reference[2].

As shown in the above tables, the length between perpendiculars (LPP) has been adopted as the basis of ship length for all cases. In order to be consistent, therefore, all the non-dimensional quantities and coefficients have been defined with respect to the length between perpendiculars (LPP).

VI. Computer Program and Sample Applications

In this way, regression equations ahve been derived to obtain all the necessary coefficients and factors for the predicion of ship's resistance and propulsion characteristics, and a computer program has been prepared utilizing the results of regression analyses.

The program is very simple and easy to use. In order to run the program, only the following informations are required as the input data:

Information on ship

—*LPP*

—*B*

—T(T_F and T_A in case of ballast condition)

—C_B

—C_M

—Ship speed(V_S) at the desired points

Information on propeller

—*D*

—*RPM*

—A_E/A_0

—P/D (at 70% of propeller radius)

—η_P

Other information

—Sea margin (if required)

—Power to drive shaft generator(s) (if exist)

It should be mentioned here that an iterative application is necessary for the accurate prediction of the speed/ power relationship. It is particularly true to simulate the correct power-RPM relation of main engine and the corresponding propeller open-water efficiency.

The computer program is also very useful to determine the ship speed when the available power is given as well as to determine the required power at the given ship speed. The program provides the calculated results in three different output formats (types) according to the desired information. Table 10 shows one of the three different formats.

Table 10 Typcial example of speed/power prognosis(Type 2)

<Speed/Power Prediction>

By Regression Analysis for Daewoo Series I(Elliptic-Straightline full slow speed ship series). type hull form(Single screw only)

Program developed by Dr. K-S. Min.

Original in August, 1984 and Revised in June, 1986.

<Design Condition>		Propeller Data:	
Primcipal Characteristic		Number of Blade	= 5
Length P.P.	= 193.20	Diameter	= 6.197
Waterline Length	= 196.87	Expanded Bar	= 0.529
Beam	= 32.20	Pitch-Diameter Ratio	= 0.659
Mean Draft	= 10.80	Coefficients:	
Draft at FP	= 10.80	CB	= 0.831
Draft at AP	= 10.80	CP	= 0.834
Displacement	=57,208	CM	= 0.996
Wetted Surface Area		Design Condition	
Bare Hull	= 9,025.3	Form Factor	= 1.283
Appendage	= 96.0	Correlation(CA)*E3	= 0.300
Total	= 9,121.3	Sea Margin	= 15.0%

V(KTS)	EHP	RPM	J	W	T	η_H	η_R	η_P	PC*	BHP (Trial)	BHP (SM)
11.00	2643.	78.8	0.398	0.427	0.218	1.366	1.033	0.532	0.743	3557.	4091.
12.00	3448.	85.9	0.399	0.427	0.215	1.368	1.033	0.532	0.744	4633.	5328.
13.00	4473.	93.3	0.398	0.426	0.213	1.371	1.033	0.532	0.746	6000.	6900.
14.00	5813.	101.6	0.395	0.425	0.211	1.373	1.033	0.528	0.741	7842.	9019.
15.00	7597.	111.5	0.385	0.425	0.209	1.376	1.033	0.520	0.731	10387.	11946.
16.00	9983.	124.3	0.369	0.424	0.206	1.378	1.033	0.505	0.712	14030.	16134.

* PC=η_H *η_R *η_P *η_t with η_t=0.99

VII. Conclusion

This research work on the regression analysis for the prediction of resistance and propulsion characteristics of full slow-speed hull forms has been successfully completed, and the full report of more than 460 pages containing all the results of analysis has been published and distributed.

The computer program prepared by the results of analysis is being actively utilized in the actual design works. The program not only can be applied promptly and effectively in predicting the required power at the given ship speed or the ship speed with the available power, but also has particular advantage of investigating the effect of variations in ship's principal dimensions and other coefficients on the resistance and propulsion characteristics within the extremely short time.

The resistance and propulsion characteristics for the series ships have been re-calculated using the computer program and compared with the test results. Table 11 shows one typical example. The differences in resistance and propulsion characteristics between the model test result and the result by the regression analysis are generally very small (within±3% in most cases) except only a few special cases. This difference of ±3% is almost identical to the nowa-

Table 11 Comparison of resistance and propulsion characteristics

Model No: A2 (L/B=5.0, B/T=3.50, CB=0.800)
Full load Condition

	Reg. Anal:	Test	%Diff⁽¹⁾
Wetted Surface Area	8352.	3834.	0.20
Form Factor	1.361	1.385	−1.72
Correlation (CA)*E3	0.300	0.300	0.00

VS(KTS)		CW*E3	EHP	RPM	J	W	T	EH	ERR	EP	PC*⁽²⁾	BHP
11	Reg. Anal	0.002	2752.	80.5	0.380	0.442	0.222	1.395	1.036	0.519	0.742	3707.
	Test	0.030	2789.	80.5	0.390	0.427	0.218	1.364	1.027	0.529	0.734	3799.
	% Diff	−92.35	−1.33	—	−2.56	3.51	1.83	2.27	0.88	−1.89	1.09	−2.42
12	Reg. Anal	0.012	3563.	87.6	0.381	0.441	0.219	1.397	1.036	0.520	0.745	4782.
	Test	0.040	3611.	87.6	0.391	0.427	0.214	1.371	1.027	0.530	0.739	4885.
	% Diff	−70.64	−1.33	—	−2.56	3.28	2.34	1.90	0.88	−1.89	0.91	−2.11
13	Reg. Anal	0.037	4558.	95.0	0.381	0.440	0.217	1.400	1.036	0.520	0.746	6106.
	Test	0.080	4612.	95.0	0.392	0.425	0.214	1.368	1.027	0.530	0.738	6249.
	% Diff	−53.29	−1.17	—	−2.31	3.53	1.40	2.34	0.88	−1.89	1.06	−2.29
14	Reg. Anal	0.090	5807.	102.6	0.381	0.440	0.214	1.402	1.036	0.520	0.748	7765.
	Test	0.090	5739.	102.6	0.391	0.424	0.221	1.352	1.027	0.530	0.729	7872.
	% Diff	0.45	1.13	—	−2.56	3.77	−3.17	3.70	0.88	−1.89	2.61	−1.36
15	Reg. Anal	0.182	7421.	111.4	0.376	0.439	0.212	1.405	1.036	0.515	0.742	10002
	Test	0.180	7279.	111.4	0.390	0.419	0.221	1.341	1.027	0.529	0.721	10101
	% Diff	1.12	1.95	—	−3˙59	4.77	−4.07	4.77	0.88	−2.65	2.91	−0.98
16	Reg. Anal	0.321	9565.	122.8	0.364	0.433	0.210	1.407	1.036	0.503	0.726	13175.
	Test	0.430	9626.	122.8	0.384	0.403	0.216	1.326	1.027	0.523	0.705	13645.
	% Diff	−25.32	−0.63	—	−5.21	7.09	−2.78	6.11	0.88	−3.82	2.98	−3.44

* (1) Basis of Percentage: Test Value
(2) PC=EH*ERR*EP*ET WITH ET=0.99

day's internationally accepted model test accuracy of ±2%.

However, it should be emphasized that this regression analysis and the above mentioned accuracy are applicable only to Daewoo Series I hull forms. For other type of hull forms, the result of this analysis could also be utilized as references.

It is believed that this research work is one of the major attempts in the world for the prediction of ship's resistance and propultion characteristics. Finally, the author wishes that this work would be an initial flame for the continuous research work in this field.

References

[1] Min, K-S. and Hong, S-K, "Systematic Study for New Ship Series", *The proceedings of the Second Internation Symposium on Practical Design in Shipbuilding*, Tokyo and Seoul, Oct., 17-22, 1983.

[2] Min, K-S., Shin, D-H. and Shin, J-S., "A Study

on the Regression Analysis for Speed/Power Prediction of Daewoo Series I Hull Forms", Daewoo Shipbuilding and Heavy Machinery, Ltd., Technical Report 87-001, January, 1987.

[3] NSMB, Daewoo New Ship Series Project, Model Test Report No. 04591-3-DT for Phase I A (V59892A/A59881A/B/C), May 1984.

[4] NSMB, Daewoo New Ship Series Project, Model Test Report No. 04591-4-Dt for Phase II B (Group B) (Ship Models 6283/84/85/86/87), June 1984.

[5] NSMB, Daewoo New Ship Series Project, Model Test Report No. 04591-6-DT for Phase II B (Group A) (Ship Models 6288/89/90), August 1984.

[6] NSMB, Daewoo New Ship Series Project, Model Test Report No. 04591-7-DT for Phase II D (Group C) (Ship Models 6291/92/93/94/95), August 1984.

[7] NSMB, Daewoo New Ship Series Project, Model Test Report No. 04591-8-DT for Phase II E (Group D) (Ship Model 6296), August 1984.

[8] Min, K-S, and Kim, K.J. "A Study on the Optimum Hull Form Development based on the Minimum Resistance Theory", *Journal of the Society of Naval Architects of Korea*, Vol. 21, No. 4, December 1984.