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Predictive Analysis of Bare-Hull Resistance of a 25,000 Dwt Tanker Vessel

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ABSTRACT

This paper presents an estimation of bare hull resistance of a 25,000 DWT tanker vessel. It includes the study of the influences of various ship hull parameters in relations to the bare hull resistance. This work was done by numerical and model test technique based on the ITTC and ATTC recommendation. The model experiment carried shows a progressive increase in the bare hull resistance as the model speed increases, given a predictive variation in ITTC & ATTC for the actual ship at 53.748kN, 24.079kN, 44.522kN, 60.607kN and 68.819kN. This estimation serves as an operational guide for the ship as well as power performance evaluation in operation.

Keywords: *Ship Resistance, Tanker Vessel, Power, Hull, Displacement, ITTC, ATTC*

1. INTRODUCTION

The success of a tanker vessel design ultimately depends on its ability to sustain its operation despite the various resisting factors. Hull based resistance is an important parameter that influence ship performance as the economic effect on ship operation. The knowledge of a predictive estimation of the various resistive factors on the hull form is paramount to optimize ship performance and operation (Journess, 1976).

The analysis of the resistance and the powering data indicated that the bare hull resistance of the group of steerable drives ferries was similar to the bare hull resistance of the conventionally propelled ferries. The necessity of the bare hull parameters on the ship performance was crucial. The process give information as to the availability in the technical literature of observed data on models and ships of many types, particularly those tested on systematic or methodological series, model test, law of comparison as an extension of model result to ship to determine the effect of variables.

The effect of ship resistance on ship power performance is of importance to ship designer. The resistance of a ship at a given speed is the force required to tow the ship at that speed in smooth water, assuming no interference from the towing ship. If the hull has no appendages, this is called the bare-hull, or towing resistance, and although very near to, it is not exactly the same as the propulsion resistance due to hull-propeller interactions.

This total resistance is made up of a number of different components, which are caused by a variety of factors and which interact with each other in a complex fashion. Analyzing the bare-hull resistance in calm water, we considered four main resistance components.

Frictional resistance on the hull is due to the motion of the hull through viscous fluid. Eddy resistance on the hull is due to energy carried away by eddies shed from the hull. This is severe at the astern where the water may be unable to follow the curvature and will break away from the hull, giving rise to eddies and separation resistance. Wave making resistance is due to energy that must be supplied continuously by the ship to the wave system created on the free surface. Air resistance experienced by the above water part of the main hull and the super structures due to the motion of the ship through the air.

The wave making resistance and eddy resistance are commonly considered together under the residuary resistance. Although the wave making resistance dominate the total ship resistance and do create practical barrier in operation. The wave amplitude $A(\emptyset)$ is always predicted from theory. Mitchell in 1898 presented an analytical approach for predicting the wave resistance of ships. Its essential assumption is that the hull is thin, that is the beam is small compared to all other characteristics lengths of the problem. The resulting solution of the approach can be expressed in terms of a distribution of sources and sinks on the center plane of the hull, with local source strength proportional to the longitudinal slope of the hull. Its approach is analogous to the thickness problem of thin wing theory in aerodynamics.

In practical situation, the fluid velocity distribution past the hull will be greater than the speed of advance along the mid-portion, and the region of bow and stern will be less. The pressure distribution also demonstrated a pattern of impact: it is higher at the bow and stern, and lower in the mid –portion. The resulting pressure distribution on the hull results in the creation of a wave system which spreads out astern of the vessel and has to be continuously recreated. Bare –hull resistance is essence, so as to guide in the estimation of the vessel required power, taken into consideration thrust deduction fraction and achievable performance of the propeller.

Effects of shallow water on ship resistance and power are of importance for inland vessels, for larger vessels in shallower waterway. Limited water depth can affect viscous and wave resistance, sinkage and trim, propulsive efficiency and far-field wave systems. This also account for slight and sudden resistance increase for ship in shallow waters.

2. THE HULL FORM EFFECT OF RESISTANCE REDUCTION

- The Bulbous Bows

On of the ways in which the wave –making resistance could be reduced on vessels is the used of bulbous bow as indicated in model test experiment with reference to those ships that sail at high speed-length ratios. By the incorporation of large bulbous bow, many tankers can reduce resistance problems especially when the bulbous are large enough to have a section area equal to 8% of their amid ship section area.

- Length

The wave-making resistance is reduced by increasing the length of a vessel, which in turn reduced the speed-length. Increases this has the tendency to increase the wetted surface area which could increase the frictional resistance

- Beam –Draught Ratio

This is usually expressed as B/H, which is equal to about 3. For a continuous increase of the beam, the draught decreases sequentially, but when at a low rate. Finally, if the resistance decreases lightly, the ratio become smaller as observed in model test results.

- Displacement – Length Ratio

For the fast moving vessels, the lower the displacement length ratio, the easier the vessel will drive in proportion to her displacement.

2.1 The Model Test Similarity Theory

Froude William in the nineteen century undertook a basic investigation as regards frictional resistance of smooth planks in his tank at Torquacy. He gave an empirical formula for the frictional resistance in the form $R = f.S^n$ where n=1.825, R is the resistance (Ib), S is the total surface (wetted area) in ft^2. He tried the experiments with different surfaces and discovered that for a smooth varnished surface the value of the exponent "n" decreased from 2.0 for the short plank to 1.83 for 50 foot plank. Again, the value of "f" decreased with increasing length and for a given length it increased with surface toughness.

Froude in his work found that the actual ship resistance was higher than the predicted from the model, the percentage increase becoming less with increasing speed. The difference R/V^3, however was almost the same at all speeds except that lowest decrease slowly with increasing speed as might occur if this additional resistance were of the division type and varying some power less than speed.

The ITTC (International Towing Tank Conference) adopted the Froude method for model extrapolation based on certain conditions. Reynold suggested that two separate flows require expression is possibly associated with different resistance law.

Blasius and Prandl Ludring formulated their own equations for laminar and turbulent flows which take into consideration frictional coefficient, speed and fluid density.

The ATTC method also contributed for the estimation of the bare hull resistance of the vessel

The Gertler Series provided estimation for the residuary resistance coefficient (R_{rs}) from charts. The charts parameters include draught ratio, volume, displacement-length ratio and Froude number.

The taylor's Series indicated the variation of bare-hull resistance of the ship-length ratio.

2.3 Model Experiment

The resistance tests in calm water and regular waves pattern were carried out in the towing tank 60m x2m x 1.5m. The residuary resistance of geometrically similar ship in the ratio of the cube of their speeds was analysed, and also in the ratio of the square root of their linear dimensions.

$$\lambda^3 = \frac{R_{rs}}{R_{rm}} \qquad 2.1$$

Williams Froude incorporate the law of mechanical similarities and wave –pattern of model to give

$$\lambda = \frac{L_s}{L_m} \qquad 2.2$$

The speed ratio gives

$$\frac{V_s}{V_m} = \left(\frac{L_s}{L_m}\right)^{1/2} = \lambda^{1}/_{2} \qquad 2.3$$

$$\frac{S_s}{S_m} = \lambda^2 \qquad 2.4$$

The most important analysis used here to examine the ship resistance components, for instance, the residuary, frictional resistance, air resistance and the like could be obtained by the similarity theory of Froude. Thus an analytical modeling is considered together with the experiment to distinguish the wave resistance influence on the ship and the friction factor. To achieve this, the following steps are taken:

- The model is made to a linear scale ratio (**λ**) to run over a range of stipulated corresponding speeds with resistance
- The model total resistance R_{TM} is measured
- The opposing frictional resistance R_{fm} of the model is measured

- The residuary resistance R_{rm} of the model is evaluated
- The total and bare- hull resistance of the ship are model by $R_{TS} = R_{fs} + R_{rs}$

By reflecting the linear ratio due to resistance of model and ship

$$R_{rs} = \lambda^3 R_{rm}$$

Guldharmer and Harvald in ship resistance effect of form and principal dimesnsion (Akademisk Forlag, Capenhagen 1974), defines the total resistance R_T as

$$R_T = C_T \cdot \frac{1}{2} \cdot \rho \cdot S \cdot V^2 \; and \; C_T = R_f + R_r$$

The relationship of the resistance is expressed as

$$R_{TS} = R_{BH_T} + R_{Air} + R_{App} + \ldots . R_n \qquad 2.5$$

$$R_{BH_T} = R_f + R_n$$

Frictional Resistance for the Ship

$$R_f = R_{fs} = \frac{1}{2} \cdot C_{fs} \cdot \rho_{sw} \cdot S_s \cdot V_s^2 \qquad 2.6$$

Frictional Resistance for the model

$$R_f = R_{fm} = \frac{1}{2} \cdot C_m \cdot \rho_{sw} \cdot S_m \cdot V_m^2 \qquad 2.7$$

$$C_{fn} = \frac{0.075}{(\log R_n - 2)^2} \; where \; R_n = Reynold \; number = \frac{VL}{\vartheta}$$

For Air Resistance of the model

$$R_{am} = \frac{1}{2} \cdot C_{air} \cdot \rho_{air} \cdot A_T \cdot V_{air}^2$$

For this experiment study, a model of a product tanker was used. The main particulars of the ship and model are shown in Table 2.1.

ITEMS	SHIP	MODEL
Volume Displacement	6703m^3	0.872m^3
Length of Water line	121m	6m
Wetted Surface Area (S)	2363m^2	5.81m^2
Design Speed (V)	12knots	2.672knots
Air Resistance Coefficient	0.003	0.003
Density of Sea water	1025kg/m^3	1025kg/m^3
Temperature of water	119^{0C}	119^{0C}
Seawater Kinematic viscosity	1.07854 x10^{-6}	1.07854 x10^{-6}
Model Ship Correlation Coefficient (C_A)	0.0004	0.0004
Acceleration due to gravity (g)	10m/s^2	10m/s^2
Block Coefficient C_B	0.745	0.745
Midship Coefficient C_m	0.950	0.950

2.4 Theoretical Approximation

Several theoretical methods and assumptions have been used to model the bare-hull resistance of tanker vessel in calm water and regular wave pattern.

Aribas (2006) and Strom-Jejsen et al., (1973) presented the prediction of added resistance effect on vessel performance using Gerritsma and Beukelmen method. They were able to model the resistance using sectional offsets or sectional geometric coefficients.

3. RESULT AND DISCUSSION

The experiment was carried out for 5 model speeds which are 2.227, 2.449, 2.692, 2.8895, 3.118 knots. These speeds are equivalent to 10, 11, 12, 13 and 14 knots of ship speed according to the Froude's Law of Similitude. For this experiment regular resistance measurement was taken covering a wave length to ship length ratio from 1.0 to 2.50. The measurement was taken varying the model speed accordingly.

The model/ship resistance parameter modeling was also carried out using ITTC line data and ATTC chart. And result comparison was made.

Table 3.1 and 3.2 gives detail result of the resistance at various modeling speeds. This indicated that the profile drag of a streamlined body varies with the Reynolds number of the fluid. At higher Reynolds number values th air floe is turbulent causing higher wave formation in the operating medium. The large load fluctuations resulted in the air streams velocity occur close to the surface, and turbulent flow conditions results in higher energy loss and resistance on the vessel.

From figure 3.3, the bare hull resistance is plotted against the speed, and there show a gradual increase in the ATTC curve and steep increase in the ITTC curve. This also shows the progression of resistance with higher wave formation and fluctuation. The bare hull resistance increase in turbulence, which is the wave induced disturbance, the speed of the vessel tends to inconsistently following the speed –load profile of the vessel.

The variation in value of the bare- hull resistance from the curve provide a systematic and guiding concept for the ship operation and personnel onboard. At certain off design speed of the ship, which are the operational speeds, the result gathered from this model test analysis was used for the prediction of resistance phenomenon on a 25000 DWT Tanker.

Model / Ship Resistance Parameter Modeling Using ITTC Line Data at 31KN Bare- Hull Resistance of the Model

Table 3.1: Resistance at various modeling speeds

V_s	V_m	R_{BTHS}	R_{TS}
10	2.277	98.731kN	101.706kN
11	2.449	161.963kN	167.024kN
12	2.692	172.506kN	177.855kN
13	2.895	183.435kN	189.086kN
14	3.118	193.375kN	199.301kN

Table 3.2: Reynolds No at various modeling speeds

V_s	V_m	Reynolds No. model	Reynolds No. Ship
10	2.277	6.37×10^6	5.77×10^8
11	2.449	7.03×10^6	6.34×10^8
12	2.692	7.64×10^6	6.92×10^8
13	2.895	8.28×10^6	7.49×10^8
14	3.118	$8.9 \times 2\ 10^6$	8.07×10^8

Model / Ship Resistance Parameter Modeling Using ATTC Line Data at 31KN Bare- Hull Resistance of the Model

Table 3.3: Resistance at various modeling speeds

V_s	V_m	R_{BTHS}	R_{TS}
10	2.277	152.479kN	157.156kN
11	2.449	186.042kN	192.529kN
12	2.692	217.028kN	223.740kN
13	2.895	244.042kN	251.488kN
14	3.118	262.194kN	270.234kN

Table 3.4 Resistance variations at various modeling speeds

V_s	V_m	Variation in R_{BTHS}
10	2.277	53.748kN
11	2.449	24.079kN
12	2.692	44.522kN
13	2.895	60.607kN
14	3.118	68.819kN

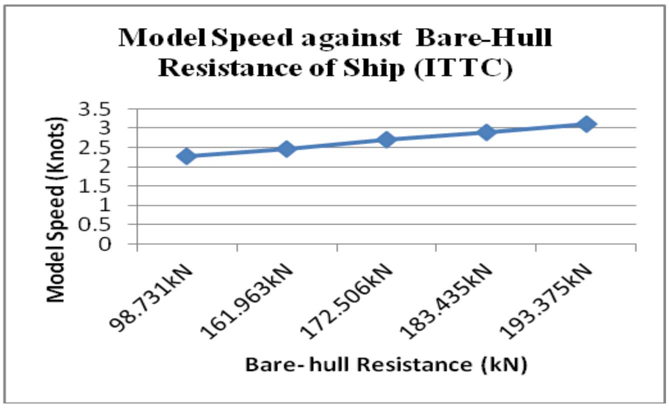

Figure 3.1 Model speed against Bare-hull Resistance of Ship (ITTC)

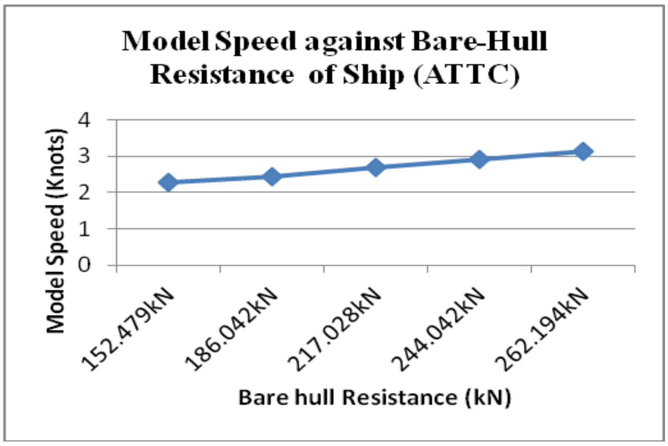

Figure 3.2 Model speed against Bare-hull Resistance of Ship (ATTC)

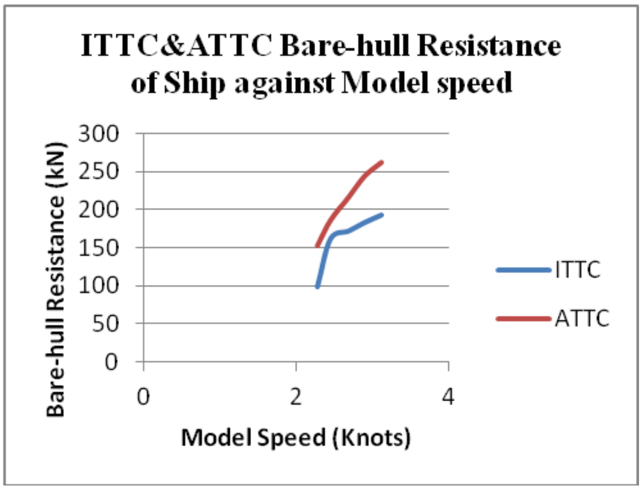

Figure 3.3: ITTC and ATTC Bare-hull Resistance of Ship against Model Speed

4. CONCLUSION

It was indicated from the model that there exit an improved correlation with the data of measurement to the approximated results. It is however show that the result of the models confirmed by the similarity check exhibited a general applicability.

The two different series used in the analysis (ITTC & ATTC) show a progressives increase in the bare hull resistance as the degree of turbulence increase as well as the increase in speed. This was applied at the same beam to draft and length to beam ratio. The residuary resistance was also factored in the expression of the total resistance on the vessel in operation. The figures 3.1, 3.2 model the trend of resistance increment with speed at an even interval. The values from the towing tank experiment on the model are quite good with a good degree of precision.

Therefore introduction of the bare hull resistance data for the 25,000 tonnage tanker enable a better prediction of the actual ship experience in operation. It is then concluded that a fair approximated and predicted values of the upright resistance of the un-appended hull for a tanker is possible by the comparative application of the ITTC & ATTC models. This research provides a guide to ship designers, engineers and operators within the industry.

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