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A Comparison of Hull Resistance and Effective Power by Different Methods

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Abstract: ***Proper estimation and calculation of ship resistance, is an elemental step in the process of ship design. It is mandatory to properly calculate the various forms of resistant forces (which include Frictional Resistance, Wave Resistance, Wave Making Resistance, Eddy Making Resistance etc.) in order to determine the minimum Power requirements of the vessel in accordance with its Principal Particulars. Resistance calculation is a prerequisite to choose suitable engine and other propulsion equipment for the vessel. There are various methods available for calculations in this field, which include statistical, numerical, empirical methods and also computerized models and simulations. In our findings below, we have attempted to make a comparative study of the results attained by using these different methods on a hull. At first, the nature and advent of the various resistance components are described briefly. Following on, resistance parameters are attained from each of the models over a given range of ship speed. The results can be compared for insight into the effectiveness of each method and for choosing an optimal method for the respective vessel.***

Keywords: Ship resistance, Hull, ITTC, Power, Maxsurf 20, Holtrop and Mennen Method, Hollenbach Method, Wymen Method, Slender Body Method

1. Introduction

The accomplishment of vessel design depends on the ability of withstanding various resisting factors. Resistance based on hull form is an important parameter that influences ship performance form, making it more economical.

The analysis of the power and the resistance helps to select a suitable engine and also help to predict a large portion of machinery cost at the beginning of the design process. When a ship moves forward through the water at a constant velocity, its forward motion is going to create tangential stresses and dynamic pressure on the hull. Dynamic pressure produces a resultant force in the longitudinal direction and opposite to the advancing direction. On the other hand, tangential stresses are applied on the immersed surface due to viscosity. The resultant force due to both is also opposite to the ship's moving direction. The total force is in the reverse direction to the motion which is called the resistance of the ship, or simply, drag.

Wave making resistance belongs to the category of normal dynamic pressures. Because of these dynamic pressures waves are generated on the surface of water and then spread away from a ship. Wave making resistance plays an important role for surface ships which are of high speed. Frictional resistance is propagated due to the viscosity of water and the reasons behind this are tangential stresses. Because of the viscosity and velocity gradient in the direction normal to the ship hull, there is a mass of fluid being dragged along with a ship. The work done by the ship against frictional resistance is the energy required to drag the mass of fluid. Normal pressure applied on a hull contributes to Eddy making resistance. Because of the viscosity of the fluid, the flow separates from the surface of a hull. Then the eddies are formed which make a change in the velocity field. This in turn changes the normal pressures on the hull, and consequently the pressure field around a ship, resulting in the eddy-making resistance. Air resistance is occurred due to blowing of the air around the ship. Appendage resistances are caused by the appendages of a ship (propellers, rudders and bilge keels etc.)

2. Methods of Resistance Calculations

2.1 Holtrop and Mennen Method

Holtrop and Mennen's method is perhaps the most popular method to estimate resistance and powering of displacement type ships. It is based on the regression analysis of a vast range of model tests and trial data which give it a wide applicability. Holtrop's series of papers in this field [1, 2, 3]. The Holtrop method computes a dimensional total resistance which is broken down into several components: frictional resistance, appendage resistance, wave resistance, resistance due to bulbous bow near the water surface, pressure resistance due to immersed transom, model-ship correlation resistance. In this method, the total ship hull resistance is calculated by:

$$\boldsymbol{R_T = R_F(1+K_1) + R_{App} + R_B + R_W + R_{TR} + R_A} \quad (1)$$

Here, the frictional resistance ($\boldsymbol{R_F}$)is calculated by 1957ITTC formulation and the form factor(1+k1) is calculated by:

$$(1+K_1) = c_{13}\left[0.93 + c_{12}\left[\left(\frac{B}{L_R}\right)^{0.92497} \times (0.95 - C_p)^{-0.521} \times (1 - C_p + 0.0225LCB)^{0.6906}\right]\right] \quad (2)$$

2.2 Hollenbach Method

Hollenbach [4] analyzed model tank tests for433 ships performed by the Vienna Ship ModelBasin during the period from 1980 to 1995 to improve the reliability of the performance prognosis of modern cargo ships in the preliminary design stage. Hollenbach gives the formulae for the "best-fit" curve, but also for a curve describing the lower envelope, i.e. the minimum resistance that a designer may hope to achieve after extensive optimization of the ship lines if its design is not subject to restrictions. In addition to L_{PP} and L_{WL}, which are defined as usual, Hollenbach uses the length over surface L_{OS} which is, for design draft, defined as the length between the aft end of design waterline and the most forward point of the ship below design waterline. The resistance is analyzed without using a form factor. The residual resistance is given by:

$$R_R = \frac{1}{2} \times C_R \times \rho V^2 \times \frac{BT}{10} \quad (3)$$

The maximum total resistance is given by:

$$R_{T,max} = h_1 \times R_{T,min} \quad (4)$$

The relevant coefficients are given in [4]. The Hollenbach method is the most modern, easily programmed and is at least as good as other traditional methods with general applicability for modern hull forms.

2.3 Slender Body Method

A slender body method [5], based on the work of Tuck et al (1999) and Couser et al (1996) is available in MAXSURF Resistance. This method uses a Michell (1898) based approach to compute the wave resistance of a port/starboard symmetrical mono-hull. This method may be applied to many different hull forms including multihull. However, the individual hulls should be slender and should be symmetrical about their local center line. Planning forces are neglected in the slender body method which limits speed range applicability for this method. In general, sensible results can be obtained for a wide range of mono and multi-hull vessels operating at normal Froude numbers. This method predicts only the wave pattern resistance component. To calculate the total resistance, MAXSURF Resistance calculates and adds the viscous resistance components using the ITTC'57 friction coefficient calculation method and the specified form factor.

2.4 Wymen Method

A universal formulation used for calculating the resistance of hull forms in both planning and displacement modes. The original method as set out by Wymen [6] results in an Engine Power being calculated. In MAXSURF Resistance to accurately predict the hull resistance for ship; an overall efficiency must be added in the Efficiency dialog. The overall efficiency accounts for losses between the power developed at the engine (Brake Power) and the Effective Power (hull resistance). From the Masthead issue of June 2008, the Wymen speed formula assumes the hull is the correct type and of normal form for the intended use. This includes proper location of the longitudinal center of gravity and buoyancy and a prismatic coefficient in the suitable range. The formula also assumes that the running gear (propeller, reduction gear, shaft, strut, rudder) are properly sized and matched for best performance. There are many common variants of hulls and propulsion package and the following adjustments can be used to further refine the results:

Round bilge planing hulls (over Speed length ratio 2.9)	Reduce speed by 6 %
Deep veeplaning hulls (deadrisemidships aft >19 degrees)	Reduce speed by 3 %
Low-deadriseplaning hulls (deadrisemidships aft <8 degrees)	Increase speed by 4%
Outboard and stern drive boats	increase speed by 5%
Displacement full-keel sailboats	Reduce speed by 2 %

Here, Speed length ratio= $\frac{V(Speed)}{\sqrt{L_{WL}}}$ where, velocity of ship in knots and L_{WL} in ft. These effects can be added in a single design to create and net increase/reduction in speed.

3. Effective Power

As the propeller of a ship is propelling the ship through water, the 'useful' or 'effective' work is done in overcoming the resistance of the ship by its speed of advance. The resistance concerned is conventionally taken to be that of the 'naked' hull. i.e. without any appendage. This leads to the following definition: The effective power of a ship is the product of the resistance of the naked hull and the speed of the hull. Therefore,

$$P_E \; R_T \times V_s \quad (5)$$

4. Result

A hull form is chosen for the research [7]. Principal particulars are given in the table-1 and the hull's 3D model created by Rhinoceros software is given in Figure-1. In this research, we calculated data set for speed rage 12 knots to 17 knots. Sinkage and trim effects are neglected.

Table 1: Principal Particulars of ship hull

Particulars	*Measurement (Unit)*
L_{PP}	169.00 m
L_{WL}	172.42 m
B (Beam)	32.00 m
T (Draft)	10.00 m
∇	42455.0 m^3
Δ	43506.0 tones
CB	0.785
LCB	+2.35% L_{PP}

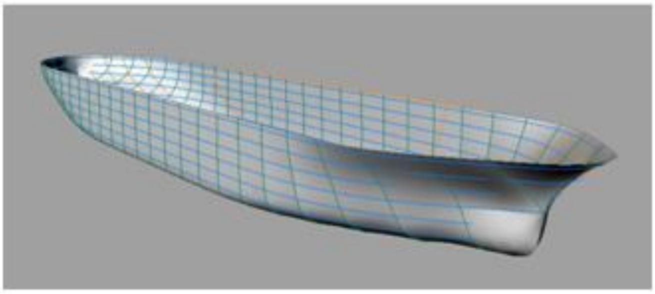

Figure 1: Hull's 3D model created by Rhinoceros software

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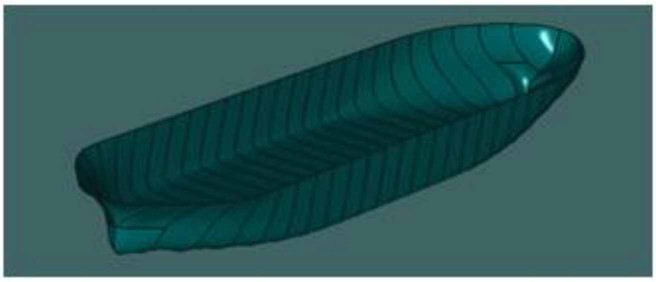

Figure 2: Generated hull sections in MAXSURF Design Analysis Software

Table 2: Resistance determined by several methods

Speed (knot)	*Model Test (KN)*	*Hollenbach (KN)*	*Holtrop (KN)*	*Slender Body (KN)*	*Wymen (KN)*
12.0	444.4	456.4	355.2	1142.1	1599.3
12.5	493.8	498.5	388.3	1085.7	1735.3
13.0	545.0	548.2	424.5	1634.4	1876.9
13.5	599.0	600.0	464.5	1568.2	2024.1
14.0	653.7	625.1	508.9	1881.8	2176.8
14.5	710.8	731.0	558.5	2687.0	2335.1
15.0	773.6	803.1	614.0	2293.0	2498.9
15.5	845.3	878.1	676.5	2771.7	2668.2
16.0	925.0	981.1	746.8	4241.3	2843.2
16.5	1020.8	1078.4	826.3	4616.5	3023.6
17.0	1136.5	1996.8	916.0	3953.1	3209.7

Table 3: Power determined by several method

Speed (Knot)	*Model Test (KW)*	*Hollenbach (KW)*	*Holtrop (KW)*	*Slender Body (KW)*	*Wymen (KW)*
12.0	2741.1	2815.2	2192.8	2192.8	9872.9
12.5	3172.6	3203.0	2496.9	2496.9	11159.1
13.0	3641.4	3663.2	2839.1	2839.1	12552.5
13.5	4156.7	4163.1	3225.9	3225.9	14057.3
14.0	4704.2	4498.2	3665.1	3665.1	15677.7
14.5	5297.7	5448.3	4165.8	4165.8	17418.2
15.0	5964.4	6191.6	4738.3	4738.3	19282.9
15.5	6734.2	6995.9	5394.1	5394.1	21276.2
16.0	7607.0	8068.5	6146.8	6146.8	23402.3
16.5	8657.8	9145.7	7013.9	7013.9	25665.6
17.0	9930.9	17447.6	8010.7	8010.7	28070.2

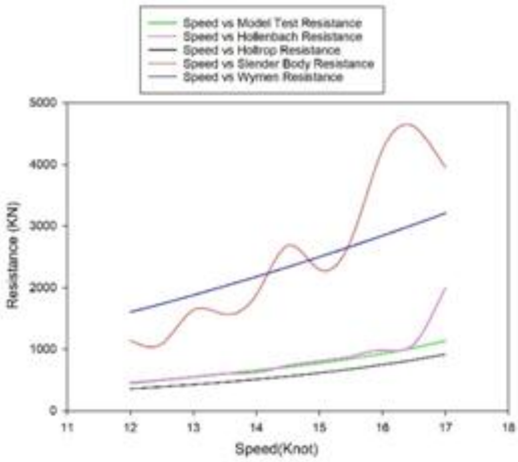

Figure 3: Comparison of hull resistance by several methods

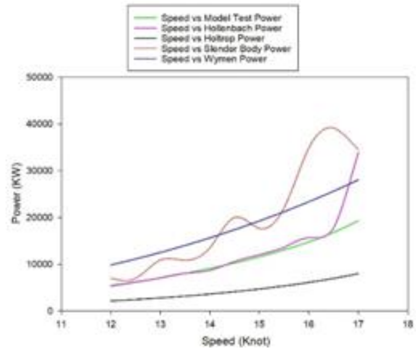

Figure 4: Comparison of required effective Power in several methods

5. Conclusion

The contrast of the resistance and effective power of singles crew ship has been determined by various methods which is shown on above data table. The value of resistance which is found from the model test report [7] has been compared with the results attained using the Hollenbach, Holtrop Mennen, Slender body and Wymen methods. The Table- 2, 3 indicates the values measured by different methods are close to each other. As the hull block coefficient is large and the hull shape is fuller the ship is a slow speed cargo ship, the numerical calculation has functioned well from a computational point of view and the achieved results have authorized the comparison in resistance and power. The Hollenbach, Holtrop Mennen, Slender body and Wymen methods are trustworthy traditional methods for the prediction of the resistance of current cargo ship in the preliminary design stage. In the end, we can conclude the maximum resistance values for a certain range of operating speed, and, predict power requirements and suitable engine for the ship.

Table 4: List of Symbols

Symbol	*Unit*	*Full Form*
B	m	Breadth
T	m	Draft
L_{PP}	m	Length between perpendiculars
L_{WL}	m	Length of the waterline
L_{OS}	m	Length over surface
L_R	m	Length of run
C_B		Block coefficient
C_P		Prismatic coefficient
F_n		Froude number
g	ms^{-2}	Gravitational acceleration
$1+k_1$		Hull form factor
LCB	m	Position of the center of buoyancy
V_S	ms^{-1}	Ship speed
∇	m^3	Displacement volume
Δ	Tons	Displacement mass
P_E	KW	Effective power
R_T	KN	Total resistance
R_F	KN	Frictional resistance
R_{APP}	KN	Appendage resistance
R_B	KN	Additional pressure resistance of bulbous bulb
R_{TR}	KN	Additional pressure resistance due to transom immersion
R_A	KN	Model-ship correlation resistance
R_R	KN	Residual resistance
C_R		Residual resistance coefficient
ρ	kgm^{-3}	Water density

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