PRACTICAL COMPUTER PROGRAMME FOR SHIP-WAVE DRAG INVESTIGATION OF ULTRA LARGE CONTAINER CARRIER

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ABSTRACT

Wave drag is referred as the energy loss caused by the waves created when the vessels move through the water, which is also known as a wave-making resistance, RW. It is a component of ship's resistance associated with the expenditure of energy spends by the engine in moving the body of the ship. It is a crucial effort to investigate the drag produced during preliminary design stage. Prediction using computer programme is one of the methods that could significantly give a fast and quick output at the preliminary stage. This paper is aimed to discuss the output of wave-making resistance computational programme, using MATLAB. The Holtrop and Mennen prediction method is applied and a 397m length Ultra Large Container Carrier (ULCC) is used in this investigation as a case study. The output is compared with the results produced by a commercial Computational Fluid Dynamics (CFD) code at various ship speed. This CFD code SHIPFLOW computed the flow and the pressure distribution around the hull, thus the wave-making resistance of systematically varied speed were computed for validation purpose.

Keywords: Computer programme; Holtrop and Mennen prediction; Ship resistance; Wave-making resistance.

INTRODUCTION

When an object is moving near or on free surface of the fluid, a pressure variation will be created around it, which are called waves on the surface. The generated waves are continuously created, hence energy is needed for that and this leads to the resistance. At the same time, due to the viscosity of the fluid itself, an object movement through it causes a tangential force, also known as frictional force. In breaking down the ship resistance components, the existence of these two dominant forces is referred and summarized as a wave-making resistance and frictional resistance

The viscosity of fluid also modifies the flow around the hull, inhibiting the buildup of pressure around the after end of the body. This leads to an effect known as viscous pressure resistance. Since it is dependent on the form of the ship, it is sometimes termed as form resistance. Due to the complexity of the typical ship's form, the flow of the streamline along the body sometimes varies and breaks away especially at the end of the form, which leads to the existence of eddies. The formation of eddies absorbs energy, thus causes an additional resistance. Besides, the appendages attached to the ship create some additional submerged areas, thus collectively results in an appendages resistance (Tupper, 2013).

The nature of the wave system created by a ship is similar to that which Kelvin demonstrated for a moving pressure point (Van Manen and Van Oossanen, 1988). It is expressed in two main features; diverging waves and transverse waves. Diverging waves created on each side of the pressure point with their crests inclined at an angle of less than 20 degrees to the direction of motion, while transverse waves with curved crests intersecting the centerline at right angles. It similarly can be visualized by looking in the plan view of a travelling ship in calm sea, as shown in Figure 1. The height of the wave systems formed decreases fairly rapidly as they spread out laterally because the energy contained in the wave is constant and it has to be spread out over an increasingly greater length. More energy is absorbed by the transverse system than by the divergent system, and this inequality increases with increasing speed (Hafidz, 2011)

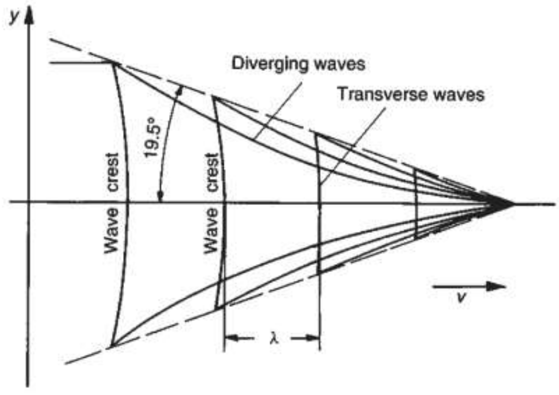

Figure 1. Pressure Point Wave System (Tupper, 2013)

SHIP RESISTANCE INVESTIGATION

Over the decades, there have been several approaches and methods discussed on how ships resistance could be estimated during ship design stage. However, the accuracy produced is influenced by the investigation time required, input data availability, or to the extent of cost required. One of the well-known methods that could considerably provide accurate output is a model test. It is the traditional method for investigating total resistance of the ship's total hull, as well as the effective power, P_E. In this method, the carriage tows the ship model in the towing tank, and the total longitudinal force acting on the model is measured at various speeds. The extrapolation of the model results is then needed to scale up for full size results, by complying to Froude's hypothesis and the similarity laws.

On the other hand, as computers become more powerful and the interest of computational fluid dynamics (CFD) continues to grow, designers alternatively opt for hull resistance evaluation using 3D-modeling. A code that could optimize hull design for applied conditions becomes preference for designers as it would minimize any need for model testing. Although this method requires a large amount of computer memory, it has an ability to solve thousands of simultaneous equations and the results accuracy could possibly be obtained with a few considerations. Every problem needs to be set-up carefully, including by having sufficient nodes within the boundary layer, correct mesh for high gradient zones and suitable time step sizes (Yasser et al., 2015).

Nevertheless, the detailed requirement of information and data seems far away especially at very early design stage. Practically, it is essential for the ship designer to access a quick and reasonably accurate prediction of the resistance of the ship, by considering a reduction in time required and minimum input data availability. With only a few combinations of parameters (displacement, length, breath and draught etc.), it still can be considered as promising effort at very early stage (Kristoffer, 2015). For this purpose, empirical resistance prediction methods are often applied. For this particular research, a revised method of Holtrop and Mennen is chosen. The Holtrop and Mennen method was written in a programme using MATLAB and the results were compared against CFD simulations from Hafidz (2011) and Nuruddin et al. (2017).

HOLTROP AND MENNEN PREDICTION METHOD

Ship resistance prediction based on statistical analysis methods has been the subject of some interest for a number of years, and Holtrop and Mennen is one of them. The method traced the development of a resistance prediction method based on the regression analysis of model and full-scale test data. A collection of 334 models ranging from tankers, bulk carriers, cargo ships, fishing vessels, tugs, container ships and military vessels. Fundamentally, the results are analysed by applying the basis of the ship resistance equation (Holtrop, 1982):

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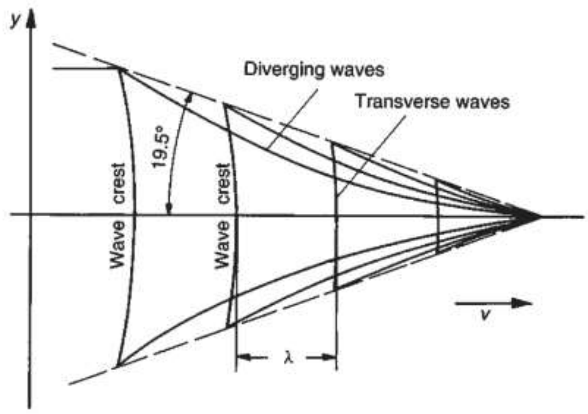

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$$R_{total} = R_F(1+k_1) + R_{APP} + R_W + R_B + R_{TR} + R_A \text{ --- } (1)$$

where ;

R_F frictional resistance according to the ITTC 1957 friction formula
1+k form factor describing the viscous resistance of the hull form in relation to R_F
R_{APP} resistance of appendages
R_W wave-making and wave-breaking resistance
R_B additional pressure resistance of bulbous bow near the water surface
R_{TR} additional pressure resistance of immersed transom stern
R_A model- ship correlation resistance

Holtrop and Mennen gives very complex expressions, which are not presented in detail here. Nevertheless, the method provides good quality, and consistent prediction of resistance for a broad range of hull parameters. For this particular paper, the resistance component that will be mainly focused on is a wave-making resistance, R_W.

$$Rw - A = C1C2C5\nabla\rho g\, exp\{m1F_n^d + m4\, cos(\lambda F_n^{-2}\} \text{ ------ } (2)$$

where

$$C1 = 2223105C7^{3.78613}(T/B)^{1.07961}(90 - iE)^{-1.37565} \text{ ------ } (3)$$

$$C7 = 0.229577(B/L)^{0.33333} \text{ ------ } (4)$$

when B/L < 0.11

$$C_7 = B/L \text{ ------ } (5)$$

when 0.11 < B/L < 0.25

$$C_7 = 0.5 - 0.0625L/B \text{ ------ } (6)$$

when B/L > 0.25

$$C_2 = exp(-1.89\sqrt{C_3}) \text{ ------ } (7)$$

$$C3 = 0.56A_{BT}^{1.5}/\{BT(0.31\sqrt{A_{BT}} + TF + hB)\} \text{ ------ } (8)$$

$$C5 = (1 - 0.8AT/(BTCM)) \text{ ------ } (9)$$

$$m1 = 0.0140407L/T - 1.75254\nabla^{1/3}/L - 4.79323B/L - C16 \text{ ------ } (10)$$

$$C16 = 8.07981CP - 13.8673C_P^2 + 6.984388C_P^3 \text{ ------ } (11)$$

when Cp < 0.8

$$C16 = 1.73014 - 0.7067CP \text{ ------ } (12)$$

when Cp > 0.8

$$d = -0.9 \text{ ------ } (13)$$

$$n4 = C_{15}0.4\, exp(-0.034F_n^{-3.29}) \text{ ------ } (14)$$

$$C_{15} = -1.69385 \text{ ------ } (15)$$

when L^3/∇ <512

$$C15 = -1.69385 + (L/\nabla^{1/3} - 8)/2.36 \text{ ------ } (16)$$

when 512< L^3/∇ <1726.91

$$C_{15} = 0 \text{ ------ } (17)$$

when L^3/∇ >1726.91

$$\lambda = 1.446C_P - 0.03L/B \text{ ------ } (18)$$

when L/B<12

$$\lambda = 1.446C_P - 0.36 \text{ ------ } (19)$$

when L/B>12

A_T : Transverse immersed transom area at rest.
A_{BT} : Cross-sectional area of the bulb.
A_T : Transverse immersed transom area at rest.
h_B : Position of the centre of the transverse area A_{BT} above the keel line.

CASE STUDY USING ULCC

A 397 meter ULCC was chosen as a case study in this investigation. The ULCC is a full displacement ship with a pronounced delta shape bulbous bow and a stern bulb. The hull lines and the particulars of the 397 meter ULCC are shown in Figure 2 and Table 1 respectively. This hull form was chosen for this case study because of the comprehensive amount of CFD simulations data which are available from Hafidz (2011) and Nuruddin et al. (2017).

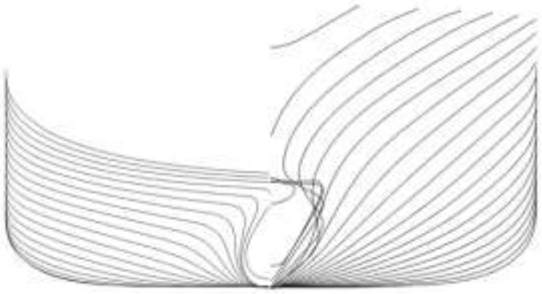

Figure 2. The body plan of the 397 meter Ultra Large Container Carrier. Note that the pronounced delta shape bulbous bow at the forward section and the stern bulb at the stern section.

Table 1. Ship particulars of the 397m ULCC

Description	Unit	Particulars
Length of waterline	m	380.088
Breadth on waterline	m	56.0
Draft at midship	m	15.499
Volume displacement	m^3	189608.47
Trim angle	deg	0
Wetted surface area	m^2	24986.86
Block coefficient, C_B	-	0.575
Prismatic coefficient, C_P	-	0.604
Waterplane area coefficient, C_{WP}	-	0.842

MATLAB MATHEMATICAL MODELLING

Resistance prediction using Holtrop and Mennen method was thoroughly formulated and mathematically modelled in MATLAB, as shown in Figure 3. For input value, main particulars of the ship, hydrostatics data, fluid properties, ratio parameters and trim condition have been defined earlier in MS Excel. The components of resistance as expressed by Holtrop and Mennen will be presented individually as the output before the result of total resistance at various speeds. Although it represents a work flow of the total resistance algorithm, the discussion of this paper will be focused specifically on the wave-making resistance, R_W

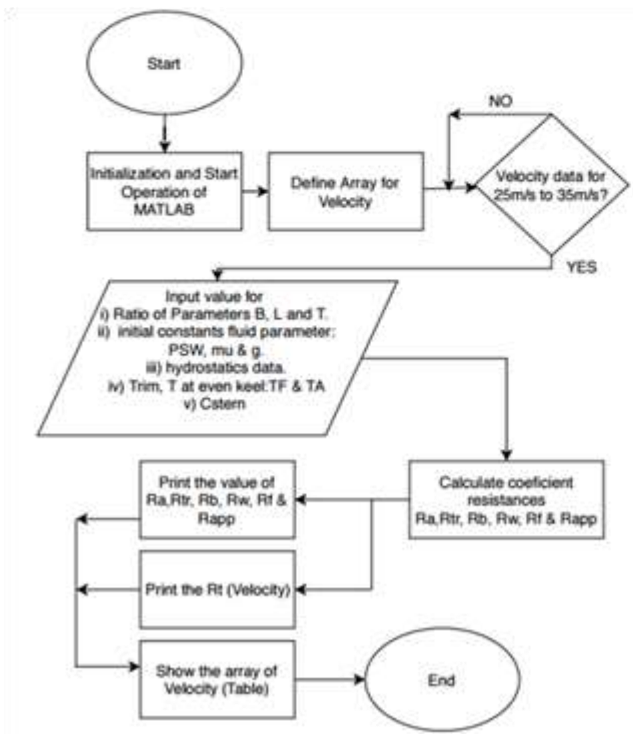

Figure 3. Flowchart of Holtrop and Mennen Mathematical Model

RESULT AND DISCUSSION

The wave resistance values were computed using the Holtrop and Mennen programme. The computations were arrayed for speed from 20 to 25 knots at steps of 1 knot using the 'for-end' loop i.e. 'for velocity = 20:1:25…..end'. The input values were initially stored in a separate Excel file, which contained all the particulars of the vessel i.e. length, breadth, and draught etc. as shown in Figure 3. The results were then tabulated in a table in the MATLAB workspace.

For comparison purpose, the results of the wave resistance values were compared with the results computed using Shipflow-XPAN, which is a potential flow CFD code available in the Shipflow Basic package from Flowtech AB. The results were obtained from a previous work which can be found in Hafidz (2011) and Nuruddin et al. (2017). There are two results of wave resistance in coefficient form that are made non-dimensional, which are coefficient of wave resistance, C_W from the pressure integration method and coefficient of wave resistance, C_{WTWC} from the wave cut method.

In Figure 4, the results computed using the Holtrop and Mennen programme were made non-dimensional by using the formula of coefficient of wave resistance, $C_W = R_W / ½ \rho S V^2$, where R_W is the wave resistance in N, ρ is the density of sea water in kg/m^3 and V is the ship speed in m/s. The comparison in Figure 4 shows that the results computed using the Holtrop and Mennen programme are in close agreement with the results of the coefficient of wave resistance, C_W from the pressure integration method rather than the coefficient of wave resistance, C_{WTWC} from the wave cut method. The estimates of wave resistance coefficient using the Holtrop and Mennen method are higher than the coefficient of wave resistance, C_W using Shipflow-XPAN at Froude number 0.17 and 0.18. The estimates of wave resistance using the Holtrop and Mennen method are lower than the coefficient of wave resistance, C_W using Shipflow-XPAN beyond Froude number 0.182.

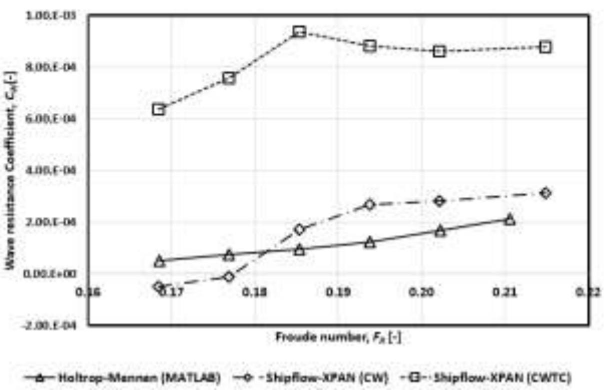

Figure 4. The comparison of wave resistance coefficient with respect to the Froude number

It is obvious that the regression analysis done by Holtrop and Mennen (1982) of random model experiments and sea-trial data was based on the pressure integration method. The wave resistance estimates of Holtrop and Mennen is a function of Froude number, midship coefficient, prismatic coefficient, displacement to length ratio, length to breadth ratio, breadth to draught ratio, transversal section of transom at rest, the transversal section of bulbous bow, vertical distance from the bulbous section centre to the keel line and the draught at the bow.

CONCLUSION

In this paper, the estimation of wave resistance using the Holtrop and Mennen method was explored and discussed. The estimation of wave resistance using the Holtrop and Mennen method was compared with results from CFD simulation using a potential flow solver code, Shipflow-XPAN. The case study selected for this investigation is a 397 meter length ULCC. The comparison showed that the results computed using the Holtrop and Mennen programme are in close agreement with the results of the coefficient of wave resistance, C_W from the pressure integration method rather than the coefficient of wave resistance, C_{WTWC} from the wave cut method. The estimates of wave resistance coefficient using the Holtrop and Mennen method are higher than the coefficient of wave resistance, C_W using Shipflow-XPAN at Froude number 0.17 and 0.18. The estimates of wave resistance using the Holtrop and Mennen method are lower than the coefficient of wave resistance, C_W using Shipflow-XPAN beyond Froude number 0.182.

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