Design and analysis of Trimaran feeder ships as a connector for small islands in the Maluku

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Abstract. Maluku waters have limited seas, which are still categorized as calm seas because the wave height is about 1.0 meter. The existence of feeder ships for transportation services from and to areas that are still considered remote, outermost and border will behave more smoothly in operation. The selection of three-body vessel (Trimaran) has the advantage of having a large deck area so that it can function as a feeder between small islands effectively and efficiently. This paper focuses on analysing resistance and seakeeping of Trimaran vessel for limited seas using CFD techniques with variations in transverse distance S/L = 0.2, 0.3, 0.4, 0.5 and at a speed designated by the Froude number Fr = 0.21. The results of numerical analysis show that at S/L = 0.4 the vessel has very good characteristics in resistance and seakeeping. Therefore, results of the calculation can be adopted as preliminary data for the preliminary design.

1. Introduction

The shipping lane that is often concerned by many parties, especially by the government and ship operators, is the one from Ambon to Seram Island, in Maluku Province, Indonesia, as shown in Figure 1 and 2. This particular shipping lane must pass through a limited sea water. Table 1 provides data on the distances between the islands in Maluku Province. These are the shipping routes of passenger and cargo ships that are centered at the Yos Sudarso port of Ambon.

The large demand for ships to meet the needs of sea transportation in Maluku Province is proven by the increasing number of ships operating in the waters of Maluku, both car go ships and cargo passenger vessels. According to the data from Sea Transportation Agency of Maluku Province in 2014, most of the ships operating in this region are below 60 m. In fact, these ships cannot operate optimally when encountering certain climatic and weather conditions, especially in January and June. In these two months when referring to the data provided by the meteorological climatological and geophysical agency of Indonesia (BMKG), the wave height reaches sea state 1–4 [1].

Monohull ships have indeed existed since the very old time and have since been widely used for the application of today passenger ships, container and liquid cargo carriers, warships, and others. Trimaran is a multihull ship consisting of one main hull and two sidehulls whose size tends to be shorter and are located on both sides of the main hull. The shape of the Trimaran hull is the development of a single hull shape which aimed at increasing the speed of the ship followed by the reduction in the required power. Investigations on Trimaran have proven that the hull shape of this type of vessel has smaller resistance at high speeds compared to catamaran hulls and single hulls [2]. However, not many people have done the research on displacement-type Trimaran vessels.
The calculation of power required by the Trimarans needs an investigation into the resistance characteristics entirely in order to obtain the most efficient solution in the ship design [3]. The resistance of Trimaran presents complex phenomena to ship designers, particularly with the appearance of interaction between the sidehull and mainhull of Trimaran. Therefore, it has been a basic need to obtain the breakdown and understanding of correct ship resistance components to obtain accurate calculation based on scaling transformation from model to the real ship.

A systematic investigation has been made [4] showing that there is a certain separation between sidehull and mainhull causing very small interaction, or in practice it can be said that there is no interaction. The small interaction occurs at separation to length ratio ($S/L$) of 0.2 to 0.5 and this provides
an idea that a Trimaran with similar displacement to comparable monohull could have smaller resistance.

The enhanced design features of a Trimaran lead to reducing the residual resistance. However, the consequence is a new form of resistance, that is the close positioning of the separate hulls leads to interaction in both the total resistance. This means that the following may be constructed. Consider a hull of beam $B$ split into two equivalent hulls each having a beam of $B/2$ and a main hull. The total resistance for the original hull was $R_T$, however this has now been divided into two equal resistances, namely $R_{TSidehull}$ and $R_{TMainhull}$. Therefore, the total resistance can be written in an equation of:

$$R_T = 2R_{TSidehull} + R_{TMainhull}$$

As mentioned, the interaction of the hull generated waves is due to the position of the various hulls with reference to separation ($S$), implying that if the hulls are positioned in such a way that there is no interaction between the hulls, then no interference resistance would be experienced [5]. By investigating the variations in separation, this interference resistance can be reduced, eliminated and even taken advantage of. An interesting point is that although an interference would cause the hull to be inefficient.

This interference resistance can be calculated, such that:

$$R_T = 3R_{T Hull} + \Delta R_{TV} + \Delta R_{TW}$$

(2)

$$R_T = 3R_{T Hull} + R_{Interference}$$

(3)

where $\Delta R_{TV}$ and $\Delta R_{TW}$ can be grouped as the interference resistance due to the Trimaran effects.

Empirical formulation to estimate the total resistance of Trimaran is so far not known and depends highly on the experimental results [4]. This is also attributed to the minimum publications of Trimaran resistance both experimentally and numerically.

Computational Fluid Dynamics (CFD) technique, with a varying degree of complexity, may be used to predict various resistance components. The method would provide some insight into the pressure form drag. Full Reynolds-Averaged Navier-Stokes (RANS) codes may be used to predict the flow where separation and circulation occur, thus potentially providing good estimates of form factor and possible scale effect. However, these methods are highly computationally intensive, in particular for the computation of high Reynolds number flow [4].

2. Methodology

The geometrical configuration of the test model used is a symmetrical hull shape with several variations of the distance between the hull (transversely) with the same displacement, as shown in Figure 3.

![Figure 3. Trimaran configuration](image)

The NPL modelling is used for analysing fluid flow phenomena. In this case variations are used variations of $S/L = 0.2, 0.3, 0.4, \text{and} 0.5$ with detail dimensions are described in Table 2. In the next step is the calculation of resistance and motion of the ship at the flow speed with $Fr = 0.19$ to 0.27 as configured in Table 3.
Table 2. Principal particulars of the test model

| Parameter                              | Symbol | Dimension | Unit |
|----------------------------------------|--------|-----------|------|
| Length Mainhull                        | L<sub>MH</sub> or L | 1,252.50 | mm   |
| Length of Sidehull                     | L<sub>SH</sub>      | 1,058.20 | mm   |
| Breath of Mainhull                     | B<sub>MH</sub>     | 167.50   | mm   |
| Breath of Sidehull                     | B<sub>SH</sub>     | 965.00   | mm   |
| High                                   | H       | 121.00    | mm   |
| Draft                                  | T       | 6.67      | mm   |
| Transverse Distance at Separation Ratio = 0.2 | S<sub>S/L=0.2</sub> | 583.60   | mm   |
| Transverse Distance at Separation Ratio = 0.3 | S<sub>S/L=0.3</sub> | 827.40   | mm   |
| Transverse Distance at Separation Ratio = 0.4 | S<sub>S/L=0.4</sub> | 1,070.70 | mm   |
| Transverse Distance at Separation Ratio = 0.5 | S<sub>S/L=0.5</sub> | 1,316.60 | mm   |
| Wetted Surface Area                    | WSA     | 3,904.00  | mm<sup>2</sup> |
| Displacement                           | Δ       | 6.94      | kg   |

Table 3. Configuration and various speed of test

| Froude Numbers (Fr) | Angle (deg) | Clearance (S/L) |
|---------------------|-------------|-----------------|
| 0.15, 0.17, 0.19, 0.21, 0.23, 0.25, 0.27 | 0, 45, 90, 135, 180 | 0.2, 0.3, 0.4, 0.5 |

2.1 Resistance

The research methodology that will be used to solve the problem of Trimaran ship is numerical simulations by applying the Computational Fluid Dynamic (CFD). The geometry configuration of the simulated model is the displacement type with symmetrical hull shown in Figure 3. Numerical simulations are carried out using the CFD model developed from the Navier-Stokes equation which is able to explain the phenomenon of flow around the hull so that the causes of the ship has high or low resistance will be acknowledged.

The choice of turbulence models is found to be very crucial in the simulation of wake fields. The turbulence model used in the current study is the SST (Shear Stress Transport) model developed by Luhulima [6]. This SST model has been validated by several researchers as described in [7] with successful results. The viscous flow field is solved using RANS (Reynolds Averaged Navier-Stokes) solver implemented in ANSYS CFX. The RANS, turbulence k-ω and turbulence SST are shown in equations (4), (5) and (6).

The RANS equation is given by:

\[
\frac{\partial \left( \rho U \right)}{\partial t} + \frac{\partial}{\partial x_j} (\rho U U_j) = - \frac{\partial p}{\partial x_j} + \frac{\partial}{\partial x_j} \left( \tau_{ij} - \bar{\rho} u_i u_j \right) + S_M
\]

The left-hand side of equation (4) represents the change in mean momentum of fluid element to the unsteadiness in the mean flow. This change is balanced by the mean body force, the mean pressure field, the viscous stresses, and apparent stress to the fluctuating velocity field. The k-ω equation is expressed as:

\[
\frac{\partial (\rho k)}{\partial t} + \frac{\partial}{\partial x_i} (\rho ku_i) = \frac{\partial}{\partial x_i} \left( \Gamma_k \frac{\partial k}{\partial x_i} \right) + G^- k + Y k + S k
\]

Further, the computing and simulation of SST turbulence models applied the method as introduced by Menter [8] and [9]. Here the Menter’s SST equation has the form of:

\[
\frac{\partial}{\partial t} (\rho \omega) + \frac{\partial}{\partial x_i} (\rho \omega u_i) = \frac{\partial}{\partial x_i} \left( \Gamma_\omega \frac{\partial \omega}{\partial x_i} \right) + G^- \omega - Y_\omega + D_\omega + S_\omega
\]

where \(G^- k\) represents the generation of turbulence kinetic energy due to mean velocity gradients, \(G\) represents the generation of \(\omega\), \(I k\) and \(I \omega\) represent the effective diffusivity of \(k\) and \(\omega\), respectively. \(S_k\) and \(S_\omega\) are user-defined source terms. \(Y_k\) and \(Y_\omega\) represent the dissipation of \(k\) and \(\omega\) due to turbulence. \(D_\omega\) represents the cross-diffusion term.
The SST turbulence model has been validated in a number of studies among others by Bardina [10] and Swennberg [11], and is considered as the most accurate models for various flow applications. This turbulent model solves the turbulence based ($k$-$\omega$) on walls and turbulence based ($k$-$\varepsilon$) on the mass flow.

2.2 Seakeeping

Seakeeping analysis was carried out numerically using ANSYS AQWA. The parameters of seakeeping are represented by response amplitude operators (RAO). Investigation was conducted on heave, pitch and roll motions at the direction for following sea ($0^\circ$) to head sea ($180^\circ$) (see Table 2). The separation between the hulls for analysing was made as $S/L = 0.2, 0.3, 0.4, \text{ and } 0.5$. The mathematical formulation of heave and pitch RAOs are given in equations (7) and (8).

$$RAO_{Heave} = \frac{Z_a}{\zeta_a} = \frac{F_0}{\rho g A_W} \frac{\omega^2}{\omega_n^2} \left( 1 - \frac{\omega^2}{\omega_n^2} \right)$$

(7)

Where: $Z_a$= heave amplitude; $\zeta_a = \text{wave spectrum elevation}; F_0 = \text{heave force}; \rho = \text{density}; g = \text{acceleration due to gavity}; A_W = \text{wetted surface area}; \omega = \text{encounter frequency}; \omega_n = \text{heave natural frequency}.$

$$RAO_{Pitch} = \frac{\theta_a}{\zeta_a} = \frac{\theta_a}{\left( \frac{360 \zeta_a}{\lambda} \right)}$$

(8)

where: $\theta_a =$ pitch amplitude; $\zeta_a = \text{wave spectrum elevation}; \lambda = \text{wave encounter angle}$

Further results on motion analysis may be described as follows. It is obvious that both following and head seas conditions provide almost the same response, either obtained from numerical approach or experimental approach. However, the RAO of CFD analysis is slightly higher than that of the experimental test and the reason for this is possibly due to the grid quality of the CFD modeling which is not perfect.

Furthermore, in term of hull separation ($S/L$), there are increase of RAO as the separation increases and these may lead into worse situation as the separation gets bigger. The increase is less significant for heave motion, but more excessive for pitch motion. Because heave and pitch motions normally make a coupled motion, the effect of $S/L$ increase can be even worse, in term Trimaran safety.

3. Results and Discussions

CFD analysis was carried out for the Trimaran ship model shown in Figure 3. The model was simulated at speed from 8.0 knots to 15.0 knots, and which correspond to the Froude numbers of about 0.21 to 0.27. The Trimaran model was tested at space to length ($S/L$) ratio of 0.2, 0.3, 0.4, and 0.5. Details of the results can be found in [12], and the summary of the results is tabulated in Table 4 and illustrated in Figure 4. These describe the correlation of total resistance coefficient and speeds of ship as represented by the $Fr$ for each $S/L$ so investigated.

| Fr | $S/L = 0.2 \times 10^{-3}$ | $S/L = 0.3 \times 10^{-3}$ | $S/L = 0.4 \times 10^{-3}$ | $S/L = 0.5 \times 10^{-3}$ |
|----|-----------------|-----------------|-----------------|-----------------|
| 0.15 | 4.491 | 4.391 | 4.291 | 4.120 |
| 0.17 | 4.848 | 4.648 | 4.648 | 4.288 |
| 0.19 | 5.258 | 5.003 | 4.803 | 4.623 |
| 0.21 | 5.965 | 5.446 | 5.265 | 5.135 |
| 0.23 | 6.295 | 6.195 | 5.947 | 5.508 |
| 0.25 | 6.443 | 6.393 | 6.293 | 5.901 |
| 0.27 | 6.653 | 6.533 | 6.333 | 5.965 |
Figure 4. Coefficient of the total resistance \( (C_T) \) as function of \( Fr \) for 4 variations of \( S/L \)

At the \( Fr = 0.21 \), the highest total resistance coefficient \( C_T \) is found at \( S/L = 0.2 \), i.e. \( 5.965 \times 10^{-3} \) if compared to the smallest of \( C_T = 5.135 \times 10^{-3} \) at \( S/L = 0.5 \), where difference is about 16.16%. Thus, there is significant reduction of resistance by Trimaran with \( S/L=0.5 \). This fact is in a good agreement with the previous work presented in [13].

Correlation of ship motion response using ANSYS AQWA and resistance was shown in Table 5. The results were shown in Figure 4. The simulation was carried out up to sea-state 4 where waves propagate in regular mode with wave height up to about 1.0 m. From each \( S/L \) variation on the Trimaran vessel, numerical calculations and optimizations are performed, which are shown in Table 4 and Figure 5. Figure 5 shows the value of each heave, pitch and roll motion. Optimization is done by combining all three graphs.

| S/L  | \( C_T \times 10^{-3} \) | Heave | Pitch | Roll |
|------|----------------|-------|-------|------|
| 0.20 | 5.97           | 0.30  | 0.51  | 2.68 |
| 0.30 | 5.45           | 0.31  | 0.52  | 2.51 |
| 0.40 | 5.27           | 0.30  | 0.52  | 2.00 |
| 0.50 | 5.14           | 0.34  | 0.54  | 1.98 |

Table 5 shows the correlation coefficient of total resistance and seakeeping. Where the optimal heave RMS is found at \( S/L = 0.4 \), which is equal to 0.30 m with \( C_T = 5.27 \times 10^{-3} \). Furthermore RMS pitch has an optimal value at \( S/L = 0.5 \) with 0.51 deg and has a \( C_T \) of \( 5.27 \times 10^{-3} \), while RMS roll has an optimal value of 1.98 deg and correlates to \( C_T \) of \( 5.14 \times 10^{-3} \) at \( S/L = 0.5 \).
Furthermore, in term of hull separation (S/L), there are increase of RAO as the separation increases and these may lead into worse situation as the separation gets bigger. The increase is less significant for heave motion, but more excessive for pitch motion. Because heave and pitch motions normally make a coupled motion, the effect of S/L increase can be even worse, in term Trimaran safety.

4. Conclusions

The calculation and analysis show that the Trimaran configuration is highly possible to provide lower total resistance at S/L=0.5. The main and most significant factor is the geometry of ship hull and arrangement of ship wetted surface area. The Trimaran mode consistently shows lower resistance and hence power effective due to lower interaction on total resistance.

The Trimaran mode demonstrates higher resistance and less power effective at S/L = 0.2 and 0.3. This is because the main hull of Trimaran is bluff enough to cause higher flow interaction between the hulls, hence causes higher resistance and less power effective. However, at S/L = 0.4 the interaction decreases significantly, and hence total resistance and seakeeping has optimal result.

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