A Comparison of Monohull, Catamaran, Trimaran Vessels Based on Operational Review of Fuel Use

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***Abstract*— Resistance is the most important component on a ship. In general, a large slope ratio is required to reduce resistance. The hull of the ship must be as lean as possible to reach high speeds. However, the main drawback of this downsizing is the reduction in transverse stability. Therefore, to cover the shortcomings of the single body it must be changed to a multihull with the right distance between the hulls. On a trimaran ship there is an interesting phenomenon related to the obstacles that occur. By assuming that the trimaran ship consists of 3 hulls, namely the mainhull and sidehull, there will be resistance interference between the hulls of the ship. This of course will affect the amount of resistance trimaran ships. The amount of ship resistance will also affect the consumption of fuel used. Today's numerical calculations use what is called Computational Fluid Dynamic (CFD) which takes advantage of high-speed technological developments. The CFD technique allows the investigation of a model with very high accuracy but consequently requires a high computer memory capacity. The choice of transportation mode is made to obtain a suitable mode for these waters. One approach is based on the Barriers characteristics using CFD. Furthermore, the power required to be able to run this mode of transportation is carried out. From the Monohull, Catamaran, Trimaran ships, it was found that multihull ships (catamaran and trimaran) had sufficient criteria to be operated in Maluku waters.**

***Keywords*— CFD, Monohull, Catamaran, Trimaran, Fuel Use.**

I. INTRODUCTION

Maluku waters are typical of relatively calm waters between adjacent islands and very wavy for open seas and relatively far apart islands. By having two sea zones with different characteristics, namely limited seas which are still categorized as calm seas because the wave height is still below 1 meter. On the other hand, open sea shipping lanes with climatic conditions and weather changes very rapidly and wave heights can reach a height of 3-5 meters which tends to make inconveniences and even threatens the safety of life at sea. The shipping lanes that are often of concern to many parties, both the Government and ship operators, are the shipping channel from Ambon to Southeast Maluku and the shipping route from Ambon to Halmahera Island, North Maluku, which must be passed through the open sea shipping lanes.

In line with the development of ship design technology, which is very rapidly developing, in the last thirty years there has been a great deal of increasing demand for ships, both monohull, two-body ships (catamaran) and three-body ships (trimaran). applications for passenger vessels (ferries), sports facilities (sporting craft) and oceanographic research vessels as well as trawlers [1]. the three types of ships above, each has advantages and disadvantages that need to be considered when we are going to use them.

Monohull ships have been around for a long time and have been widely used for passenger ships, container and liquid cargo carriers, warships, and others, see Figure 1(a). When compared to monohull ships, catamaran-type ships have several advantages, including a more attractive accommodation layout, an increase in transverse stability and in a number of cases being able to reduce the propulsion capacity of the ship to reach a certain service speed [2][3], see Figure 1(b). In Figure 1(c) the Trimaran ship is a multihull ship, consisting of one main hull and two sidehulls which tend to be shorter in size and are located on both sides of the main hull. The trimaran hull form is a development of the single hull form which aims to increase the speed of the ship followed by a reduction in the power required. Investigations into trimaran hulls have shown that the trimaran hull form has less resistance at high speeds when compared to the trimaran hull and single hull [4][5][6].

(a) Monohull

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(b) Katamaran

(c) Trimaran

Figure 1 Type of Ship Transportatsion, ,

II. SHIP RESISTANCE

2.1 Monohull

William Froude [7] first introduced total ship resistance which consists of two components, namely residual resistance and friction. The residual resistance in this case includes the component of the wave-making system barriers energies, eddy and viscous energy losses due to the shape of the hull. Meanwhile, the ship friction resistance is assumed to be the same as the friction resistance of a 2-dimensional flat plate which has the same wet surface area and moves in the water at the same speed as the ship's speed.

$$C_T = C_F + C_R \tag{1}$$

The 2-dimensional analysis method mentioned above does not adequately reflect the contribution of the shape / contour of the hull (which is 3-dimensional) to the viscous resistance, so then Hughes [8] introduced a method to be used in ship model correlation where the total resistance is the sum of 3 components:

a) Friction is the tangential stress force that arises between water molecules and the hull, which then acts as a surface area resistance with the same area and length as the model.
b) Form resistance is a component of resistance expressed in number 'k', which is an obstacle beyond the boundary of the item above in case the hull is submerged deep enough.
c) Free surface barriers as wave resistance (C_W) are obstacles that arise due to the movement of the ship relative to the water so that a pressure difference arises on the wet surface of the ship which in turn creates a wave pattern. The wave resistance is the reduction in total resistance (C_T) from the sum of the friction resistance (CF) and the shape resistance (CF_0) of the model.

$$C_T = C_F + C_{FO} + C_W \quad \text{where} \quad C_{FO} = kC_F \tag{2}$$

$$C_T = (1+k)C_F + C_W \tag{3}$$

(1 + k) is called the form factor and can be obtained from experiments at low speed (Fr <0.1) where Cw can be ignored, so the form factor can be calculated by:

$$(1+k) = \frac{C_T}{C_{F0}} \tag{4}$$

Furthermore, the international standard from ITTC[9]classifies ship resistance in calm water, practically, into 2 (two) main resistance components, namely viscous resistance (viscous resistance) associated with the Reynolds number and wave resistance (wave- making resistance) which depends on Froude's number, where the correlation of the two resistance components is shown in the equation below.

$$C_T = (1+k)C_F + C_W \tag{5}$$

2.2 Catamaran

Catamaran ship resistance has a more complex phenomenon than monohull, due to the influence of interference and interactions between the two hulls of the ship.

The hull interference is a symmetrical flow of water around the hull (demihull) which is asymmetrical due to the interaction of the flow between the hulls, namely the amount of pressure that arises around the hull is symmetrical relative to the hull centerline. Check that the flow rate around the hull (demihull) increases, especially in the inner area (tunnel side). The increase in speed causes an increase in skin friction resistance and modifies the fom factor. the height of the waves on the back of the inner and outer stem is different, so the water flow on the stem shows an inward or outward direction. This results in a spray on the back of the hull which in turn creates a drag component.

Wave interference occurs in the hull of the catamaran which travels side by side at a certain speed, so the effect of interference and the resulting wave resistance interaction can be observed. Due to changes in ambient pressure, it causes waves (wavemaking). In the demihull can change. In other words, the wave formation of the hull can differ from the isolated hull. The wave interactions caused by the

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hull can occur. The transverse waves from one hull are always amplified by the other, whereas the scattering waves that occur in front (bow) of one hull can be negated by the scattering of waves behind (stem) from the other side or by the reflection of the same front wave from the other side.
From this description, it shows that the effect of viscous and wave interference is very significant on catamaran ships. Viscous interference is caused by asymmentric-flow around the hull which affects the boundary layer formation, while wave interference is caused by the interaction of the waves generated by each hull.

In this section, the components of the inhibition interaction coefficient on the demihull (catamaran) are described as follows:

$$(C_T)_{CAT} = (1+k_{CAT})(C_F)_{CAT} + (C_W)_{CAT}$$
$$= (1+\emptyset k)\sigma C_F + \tau C_W \quad (6)$$

Where:
$\emptyset$ = form factor interference, which is caused by change the pressure that occurs between the two hulls
σ = friction interference factor (friction), which is caused by the occurrence increased flow velocity between the two hulls.
τ = interference factor of wave resistance (wave), which is caused by the meeting two wave modes (of bow) between the two hulls.

2.3. Trimaran

The enhanced design features of a trimaran leads to reducing the residual resistance, however the consequence is a new form of resistance: 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 Main hull. The Total resistance for the original hull was R_T however this has now been divided into two equal resistances $R_{TSidehull}$ and $R_{TMainhull}$.

$$R_T = 2R_{TSidehull} + R_{TMainhull} \quad (7)$$

As mentioned, the interaction of the waves is due to the position of the various hulls with reference to separation, 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. 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, there are some positions when the interference produce favourable situations when and the complete vessel would experience less resistance than that addition of the individual hulls acting separately.

This interference resistance can be calculated, such that:

$$R_T = 3R_{THull} + \Delta R_{TV} + \Delta R_{TW} \quad (8)$$

$$R_T = 3R_{THull} + R_{interfernce} \quad (9)$$

where ΔR_{TV} and ΔR_{TW} can be grouped as the interference resistance due to the trimaran effect".

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

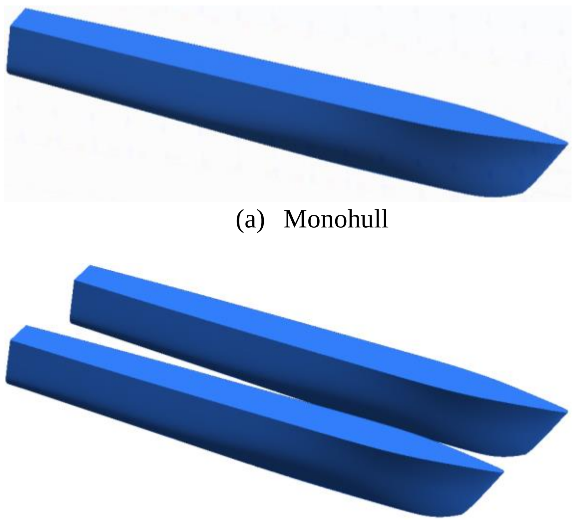
III. METHOD

3.1 Ship Model

This research was conducted on passenger ships with variations of monohull, catamaran, and trimaran ships with the following dimensions at table 1 and shown at Figure 2:

Table 1 Dimensions of the ship

Parameter	Unit	Monohull	Katamaran	Trimaran
L_{OA}	m	75	75	75
L_{WL}	m	73.5	74.56	74.5
B	m	16.3	24.56	34.55
T	m	6.5	4.7	4.6
H	m	12	12	12
Displasmen	kg	**1550**	**1550**	**1550**



(a) Monohull

(b) katamaran

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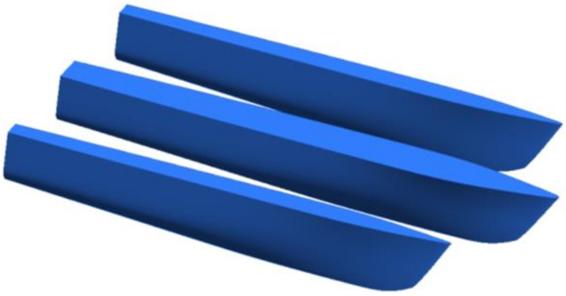


(c) Trimaran
Figure 2Type of ship Model

3.2 Numerical Simulation

The averaged continuity and momentum equations for incompressible flows may be given as in the following two equations [10]. The instantaneous equations of mass, momentum can be written as follows in Equations (10) and (11):

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho U) = 0 \quad (10)$$

$$\frac{\partial (\rho U)}{\partial t} + \nabla.(\rho U\ x\ U) = -\nabla p + \nabla.\tau + S_M \quad (11)$$

where the stress tensor, τ is related to the strain rate as follows:

$$\tau = \mu\left(\nabla U + (\nabla U)^T - \frac{2}{3}\delta \nabla.U\right) \quad (12)$$

The computation which is applied uses the SST model that provides boundary layer modelling with high accuracy because it uses k-ε and k-ω combined for numerical simulations. The SST model equation provides high accuracy by separating fluid flow in turbulent flow areas. By applying those two models, it includes the boundary layer area that is close to the model wall and which is far from the model wall can be appropriately covered. Bradshaw's relationship is also applied in SST model to perform predictive turbulence with good separation [11], as following Equations (13) and (14);

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}\left(\Gamma\omega\frac{\partial \omega}{\partial x_j}\right) + G^{\sim}k + Yk + Sk \quad (13)$$

$$\frac{\partial}{\partial t}(\rho\omega) + \frac{\partial}{\partial x_i}(\rho\omega u_i) = \frac{\partial}{\partial x_j}\left(\Gamma\omega\frac{\partial \omega}{\partial x_j}\right) + G^{\sim}\omega - Y\omega + D\omega + S\omega \quad (14)$$

where $G^{\sim}k$ represents the generation of turbulence kinetic energy due to mean velocity gradients, Gω represents the generation of ω, Γk and Γω represent the effective diffusivity of k and ω, respectively. Sk and Sω are user-defined source terms. Yk and Yω represent the dissipation of k and ω due to turbulence. Dω represents the cross-diffusion term.

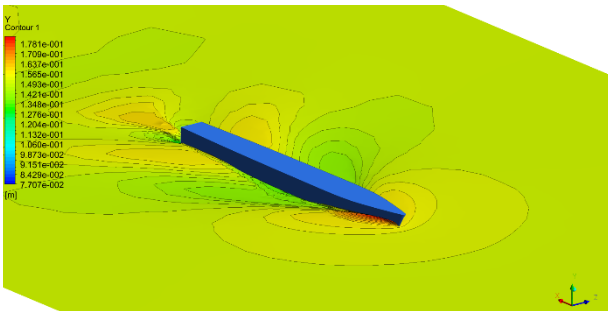
IV. RESULT AND DISCUSSION

4.1 Ship Resistance

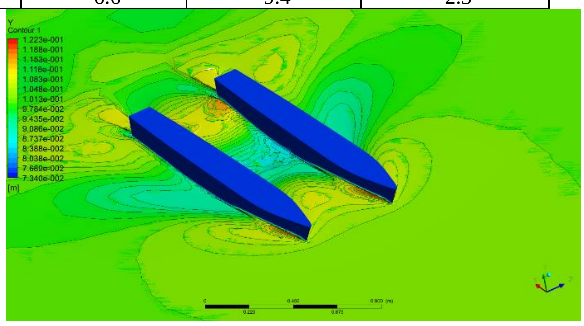
The results of the calculation of resistance show that ships with trimaran hulls have the smallest resistance. With a resistance of 98.5 kN at a speed of 12 knots. Trimaran ship resistance has an average difference of 9.4% with monohull vessels and 2.3% against catamaran vessels (In Table 2, the negative value (-) indicates a smaller price than the comparison vessel).

Table 2 Total Resistance

Speed (knot)	Resistance (kN)			Diference (%)		
	Monohull	Catamaran	Trimaran	Monohull-Catamaran	Monohull-Trimaran	Catamaran-Trimaran
6	28.3	27.2	26.9	-3.8	-5.1	-1.1
8	37.8	35.1	34.7	-7.1	-8.9	-1.3
10	74.7	69.5	66.6	-6.9	-11.7	-4.2
12	107.8	101.9	98.5	-5.4	-9.1	-3.4
14	149.7	135.4	133.2	-9.5	-12.2	-1.7
Average				-6.6	-9.4	-2.3



(a) Monohull



(b) Katamaran

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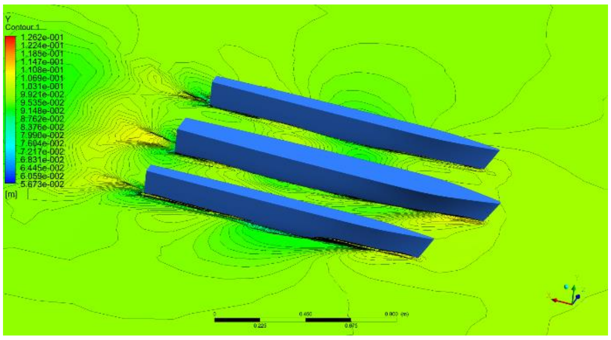

(c) Trimaran

Figure 3 CFD Simulation of Ship

The Engine Effective Power (EHP) calculation also shows the same trend, namely, trimaran vessels require the least power among other comparison vessels. This is shown in Figure 4, where the Trimaran ship at a speed of 12 knots requires a power of 608.08 kW, while the catamaran ship requires 629.16 kW power, and the monohull ship requires 665.43 kW power. This shows the trimaran ship has the advantage of using less engine power.

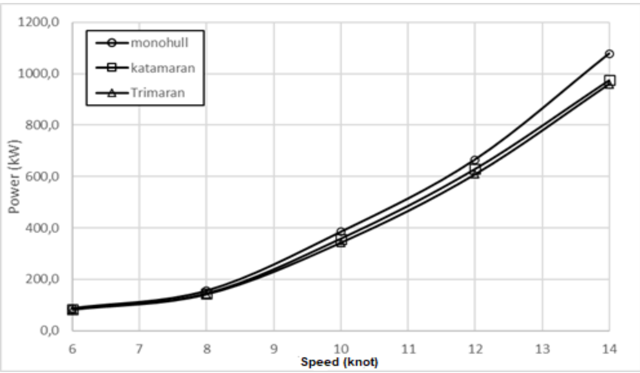

Figure 4 Fuel Consumption

The shape of the flat hull or thin ship hull (L / B >>), the contribution of the resistance is greater than the wave resistance to the total resistance. Viscous resistance (which is dominated by friction resistance) increases with increasing hull length [12]. With the increase in the length or area of the wet area, the surface friction force will also increase. As for the wave resistance, in general, it becomes smaller as the length of the hull increases (for a fixed displacement).

4.2 Estimation of Fuel Consumption and Operational Costs

The fuel consumption on a ship can be estimated by the following formula.

$$Fuel\ Consumption = \frac{P_s\ x\ b_{me}\ x\ C_R x\ 10^{-6}}{V_s} \qquad (15)$$

Where Ps is the ship's power (kW), bme is the specific fuel (bme oil = 135 g/BPHPh), C_R is the cruise range (nautical miles) and Vs is the ship speed (m/s).

The calculation of the fuel consumption of the ship's power in this calculation is taken the specific fuel consumption value of 135 g/BHPh. This value is considered a problem limitation. Calculation. The power obtained from the calculation is the effective power (EHP) so that for the calculation, break horsepower (BHP) must be sought, which is the power that must be released by the engine to achieve effective thrust. The power obtained is the maximum continuous range (MCR) of the engine to be used. The results of the calculation of fuel consumption and the ratio to the DWT weight. The price of diesel fuel for ships is still fluctuating with a price range of USD 0.63 The calculations were made with a shipping distance of 500 miles.

Table 3 calculation of fuel consumption and operational costs

Speed (kn)	Fuel Consumption (Ton)			Operational Cost (USD)		
	Monohull	Catamaran	Trimaran	Monohull	Catamaran	Trimaran
6	1.91	1.84	1.82	120.2	115.5	114.2
8	2.55	2.37	2.34	160.5	149.1	147.2
10	5.04	4.69	4.49	317.2	295.2	282.8
12	7.28	6.88	6.65	457.7	432.8	418.3
14	10.0	9.14	8.99	635.6	575.1	565.4
Average	5.38	4.98	4.86	338.2	313.5	305.6

The calculation of fuel consumption and ship operating costs is shown in Table 3. The Trimaran ship has the smallest average fuel consumption of 4.86 tons, while the catamaran is 4.98 tons and 5.38 tons on the monohull. This shows that the trimaran ship has the advantage of low fuel consumption (saving).

This has a correlation with ship operating costs. As shown in Table 3, the Operational Cost (Fuel Consumption) is USD305.6 on trimaran ships and USD313.5 on Catamaran ships and USD338.2 on monohull vessels. Trimaran vessels require the least operational costs than other types of vessels.

V. CONCLUSION

The calculation of ship operational costs based on fuel consumption is obtained from the calculation of ship hedging and can be concluded as follows:

1. The Trimaran ship has the smallest resistance, which is 98.5 kN at a speed of 12 knots. Trimaran ship resistance has an average difference of 9.4% with monohull vessels and 2.3% against catamaran vessels.

2. Fuel Consumption and Ship Operating Costs are shown in Table 4.5. The Trimaran ship has the smallest average fuel consumption of 4.86 tons, while the catamaran is 4.98 tons and 5.38 tons on the monohull.

3. Operational Costs (Fuel Consumption) of USD305.6 on a trimaran ship; Rp. USD313.5 on Catamaran ships and USD338.2 on monohull vessels. Trimaran vessels require the least operational costs than other types of vessels.

4. The Trimaran ship has a good enough potential to be developed as a passenger transport ship in Maluku waters.

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