World Journal of Advanced Engineering Technology and Sciences
eISSN: 2582-8266
Cross Ref DOI: 10.30574/wjaets
Journal homepage: https://wjaets.com/

(RESEARCH ARTICLE)

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Viscous interference analysis of trimaran vessel using computational fluid dynamic

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World Journal of Advanced Engineering Technology and Sciences, 2023, 09(01), 096–103

Publication history: Received on 08 April 2023; revised on 14 May 2023; accepted on 17 May 2023

Article DOI: https://doi.org/10.30574/wjaets.2023.9.1.0148

Abstract

Multihull vessels such as trimaran have been well known to have better transverse stability and can provide wider deck area and have been found to be quite successful when operated as passenger carriers. Trimaran has also been known to produce lower resistance, and hence lower power and less fuel consumption, compared to monohulls. The current research investigates the viscous interference hull of a displacement trimaran at various spacing configuration (up to S/L = 0.5) and Froude numbers (up to 0.27). Due to viscous interference between trimaran hulls, the viscous form greatly affects trimaran ship resistance. The trimaran's hull form ratio affects viscous drag more than velocity or hull clearance. Increases in hull distance (S/L) minimize interference and enhance viscous resistance by 1.57%. This study will present the interference effect of trimaran ship models' viscous resistance components, which can be used directly in the resistance calculation used to determine trimarans' engine power at the design stage.

Keywords: Trimaran; Viscous resistance; Interference viscous resistance; CFD

1. Introduction

Since the beginning of the previous century, there has been a steady rise in the use of ships to transport both goods and people in an effort to cut down on the amount of energy that is consumed. There have been many innovations made to the shape and configuration of hulls, some of which include the creation of mono- and multi-hull varieties of vessels. It has been noted by [1] and [2] that the usage of multihulls, which include catamarans and trimarans, have gained a large amount of interest because of their superior transverse stability and broader deck areas when compared to monohulls. Among these boats, the use of multihulls has gotten the most attention.

The increase use of vessels for carrying cargoes and passengers in order to decrease the use of energy has been intensively grown since the last 40 years. Various hull form and configuration has been developed and these include the development of mono- and multi-hull types of vessel. Among those vessels, the use of multihulls (catamaran and trimaran) have received significant attention due to its better transverse stability and providing wider deck area compared to the monohulls. Multihulls also demonstrate unique resistance characteristics and several work had been conducted in the past such as made by [3] described the powering of large size catamaran; Ref [4] discussed the breakdown of resistance into its components; Refs [5], [6], and [7] explained the determination of estimation of resistance interference of a catamaran, Ref [8] introduced the breakdown of catamaran resistance and proposed a mathematical formulation on the prediction of its resistance; Ref [9] expressed the estimation of catamaran viscous resistance using experimental and computational fluid dynamics (CFD) approaches; and Ref [10] discussed the resistance estimation of river catamaran and trimaran.

Trimaran, in particular, is a kind of multihull type of vessels consisting of one main-hull placed inside and two side-hulls with lower length compared to the main-hull. Several works indicated that trimaran can offer lower resistance at higher speeds compared to monohulls [11] and even to catamaran [12]. Meanwhile, Ref [13] did a study into the wave-making

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resistance and wave resistance interference of trimaran experimentally and numerically, and Ref [14] investigated the resistance of trimaran at various configurations of separation and draught. Both discovered interesting phenomenon related to wave resistance and wave resistance interference.

Overall, the work into the improvement of hull-form, including trimaran, have been carried out intensively world-wide in order to increase the speed in one hand, and reduce the energy consumption in the other hand [15]. Those work especially explains that trimaran hull form has interesting phenomena, in term of resistance characteristics, compared to monohulls and even to catamarans. The resistance of catamaran, in one hand, has been formulated well such as the work by [16] and followed by other work to enrich and improve the formulation such as the work done by [17]. The resistance of trimaran, in the other hand, cannot be formulated yet such as the expression of because the number of its configuration can be a lot. The current work is attempted to provide such detail information on trimaran resistance based on certain configuration of separation. In this case, the position of the two side-hulls is made parallel and in one line with the main hull.

2. Material and methods

The investigation was conducted numerical analysis for resistance estimation usig CFD investigation was conducted using a commercial CFD code called ANSYS CFX

2.1. Model

The particulars model of trimaran is shown in Figure 1 and table 1 and 2 respectively. The test was conducted at various speed (and Froude numbers) and space to length ratios or clearances (S/L) as shown in Table 1

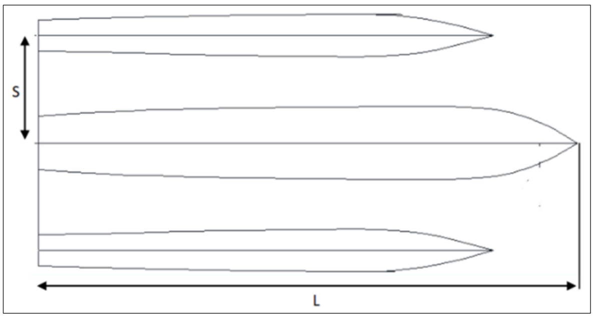


Figure 1 Trimaran Model

Table 1 Principal particulars of trimaran vessel and model

Particular Dimension	unit	trimaran vessel	Model
LOA	m	74.14	1.2525
LPP	m	72.09	1.2178
$B_{Mainhull}$	m	9.91	0.1675
$B_{Sidehull}$	m	5.71	0.0965
B (S/L = 0.2)	m	34.55	0.5836
B (S/L = 0.3)	m	48.98	0.8274
B (S/L = 0.4)	m	63.38	1.0707
B (S/L = 0.5)	m	77.94	1.3166
H	m	7.16	0.1210
T	m	3.951	0.0667
WSA	m^2	1367.93	0.3904
Displacement	ton	1440.00	0.006942

Table 2 Configuration and Various Speed of Test

Froude Numbers (Fr)	Type of ship	Clearance (S/L)
0.15, 0.17, 0.19, 0.21, 0.23, 0.25, 0.27	Trimaran	0.2, 0.3, 0.4, 0.5

2.2. CFD Analysis

Computational Fluid Dynamics (CFD) technique, of a varying degree of complexity, may be used to predict various resistance components. Potential code may be applied to derive the pressure resistance due to inviscid flow characteristics (wave pattern resistance). The boundary layer integral method may be used to estimate the boundary layer growth in areas where separation and circulation do not occur. 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 extremely computationally intensive, particularly for the computation of high Reynolds number flow.

The boundary conditions are set as follows as suggested by [9] and [36]. The inlet boundary, located at 1.5L upstream from the ship, is defined as a uniform flow with velocity equals the ship velocity. The outlet boundary, at a location of 4L downstream from the ship, is given as that the pressure equals the undisturbed pressure, ensuring no upstream propagation of disturbances. Furthermore, the distance with two sides of boundary is made 1.5L and distance with bottom boundaries is set 2.5L. The boundary condition at the hull surface is defined as no-slip boundary and at the (parallel to the flow direction) horizontal and vertical walls bounding the flow domain as free-slip boundary. Details of the description can be seen in Figure 4. In the simulation, it will be known the magnitude of the resistance component acting on the trimaran hull. To calculate the viscous resistance, the ship's hull is immersed (in water media) up to the water draft assuming the top boundary conditions are solid wall and free slip. Then the wave resistance can be calculated from the difference in the value of the total resistance and the viscous resistance.

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 and the SST model has been used and validated by several researchers with successful results. The viscous flow field is solved using RANS (Reynolds Averaged Navier-Stokes) solver implemented in ANSYS CFX. The RANS, turbulence k-ε and turbulence SST equations are shown in Equations (1), (2) and (3).

RANS Equation

$$\rho\bar{u}_j\frac{\partial \bar{u}_i}{\partial x_j} = \rho\bar{f}_i + \frac{\partial}{\partial x_j}\left[-\bar{p}\delta_{ij} + \mu\left(\frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i}\right) - \rho\overline{u_i' u_j'}\right] \quad \text{..(1)}$$

k-ω, equation

$$\frac{\partial k}{\partial t} + U_j\frac{\partial k}{\partial x_j} = P_k - \beta^* k\omega + \frac{\partial}{\partial x_j}\left[(\nu + \sigma_k\nu_T)\frac{\partial k}{\partial x_j}\right] \quad \text{.. (2)}$$

Menter’s SST Equation

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho u_j k)}{\partial x_j} = P - \beta^*\rho\omega k + \frac{\partial}{\partial x_j}\left[(\mu + \sigma_k\mu_t)\frac{\partial k}{\partial x_j}\right] \quad \text{.. (3)}$$

2.3. Resistance of Trimaran

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 $R_{TMainhull}$ (eq.4).

$$R_T = 2R_{TSidehull} + R_{TMainhull} \quad \text{.. (4)}$$

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:

$$R_T = 3R_{THull} + R_{interfernce} \quad \text{... (5)}$$

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

The value of C_F may be estimated using ITTC-1957 correlation line:

$$C_F = \frac{0.075}{(\log(Re) - 2)^2} \quad \text{... (6)}$$

Resistance of a trimaran can be calculated from the resistance of each individual hull (mainhull and sidehulls). However, when the three hulls are combined together and forming a trimaran, its total resistance is higher than the summation of individual resistance. The difference is attributed to resistance interference or interaction. Certain formulation to calculate the total resistance and its interference is not available yet, but simple formulation by [5] may be used and expressed as:

$$IF = \frac{R_{T2}}{R_{T1}} \quad \text{... (7)}$$

Where IF is interference factor, R_{T2} is total resistance of trimaran configuration, and R_{T1} is total resistance of individual hull forming a trimaran.

3. Results and discussion

3.1. Viscous Resistance Coefficients

The recommended method to obtain the values of 'k' can be done by conducted a low speed test where C_W closes to zero hence $(1+k) = C_T/C_F$. In this case, the method of Prohaska as discussed was used:

$$C_T = (1+k)\,C_F + a\,Fr^n \quad \text{... (8)}$$

It is assumed that $C_W = aFr^n$ for low-speed test (generally $Fr < 0.2$), and *form factor (1+k)* can be calculated through *straight-line plot* between C_T/C_F and Fr^4/C_F coincides at $Fr=0$, and the values of $n = 4 – 6$ and generally used as n=4 [45] as shown in Figure 2.

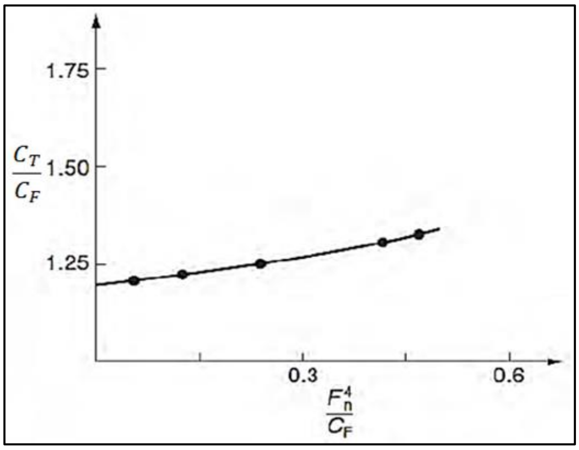


Figure 2 Prohaska method to estimate form factor (1+k)

The results of form factor estimation are tabulated in Table 3 indicating form factor of individual trimaran (1+k) and trimaran at various spacings (1+βk).

Table 3 Viscous form factor from tank test results

1+k	**1+βk**			
Trimaran Hull	***Trimaran Hull Clearances (S/L)***			
	0.2	0.3	0.4	0.5
1.274	1.287	1.285	1.279	1.277

The results of CFD investigation was summarized in Tables 4 and figured out in detail in Figure 3 showing the viscous resistance at different Fr with variation ratio spacing to length ratio (S/L).

Table 4 Viscous resistance coefficient

Fr	**Viscous Resistance Coefficient**				
	Trimaran Hull ($x10^{-3}$)	**S/L = 0.2 ($x\ 10^{-3}$)**	**S/L = 0.3 ($x\ 10^{-3}$)**	**S/L = 0.4 ($x\ 10^{-3}$)**	**S/L = 0.5 ($x\ 10^{-3}$)**
0.15	3.206	3.241	3.221	3.212	3.209
0.17	3.192	3.234	3.214	3.204	3.196
0.19	3.170	3.174	3.174	3.194	3.161
0.21	3.111	3.149	3.149	3.186	3.116
0.23	3.097	3.139	3.139	3.163	3.103
0.25	3.080	3.151	3.121	3.121	3.091
0.27	3.094	3.075	3.105	3.106	3.064

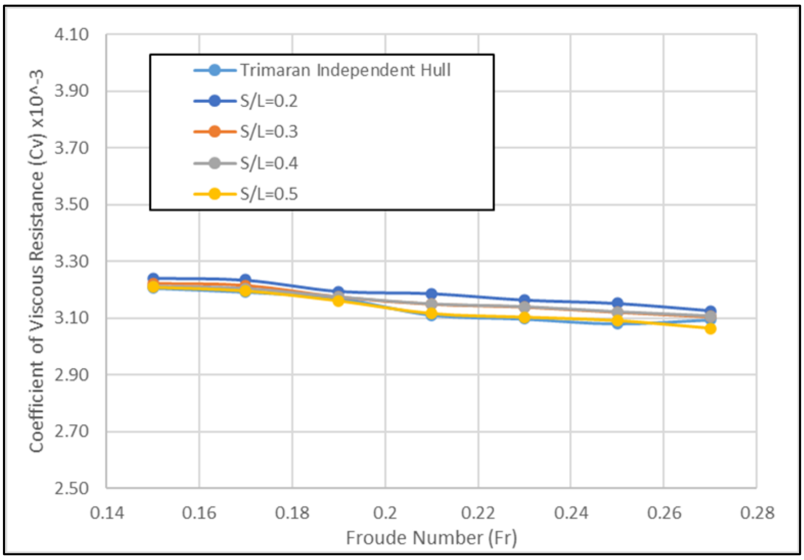


Figure 3 Viscous Resistance of Trimaran Models

Due to the fact that the form of the hull is that of a thin ship hull (L/B>>) and close S/L distance, the contribution of viscous resistance to the overall resistance is larger contribution. The amount of viscous resistance, which is dominated by frictional resistance, rises as the length of the hull grows. The surface friction force will rise in proportion to either the length or the size of the wet region that is being considered. When it comes to wave resistance, the general rule is that it decreases with increasing hull length (given that the displacement remains the same).

3.2. Viscous Hull Interference

The interaction phenomenon of viscous interference is caused by the distribution of boundary layer changes and the increase in flow velocity around the trimaran hull, and the distribution of the effect of pressure changes in the area (between) the trimaran hulls. The CFD results show the interference of the viscous resistance on the trimaran hull with changes in the transverse distance between the hulls (S/L) where at high speeds it shows an increase in interference. This shows that the interaction of viscous resistance on the hull at higher speeds has a fairly strong interaction as shown at Figure 4.

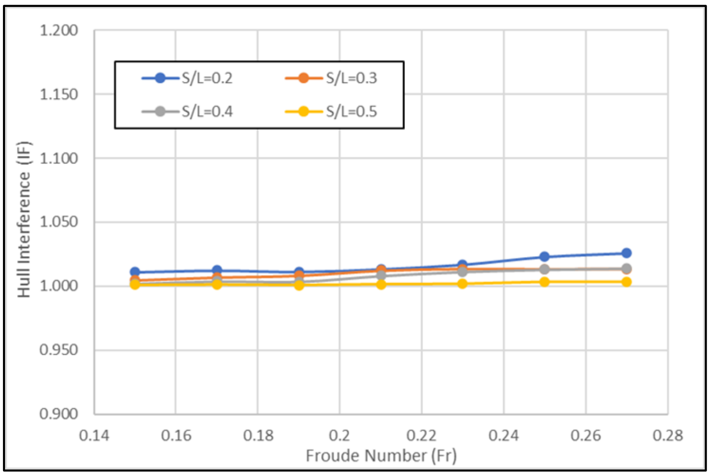
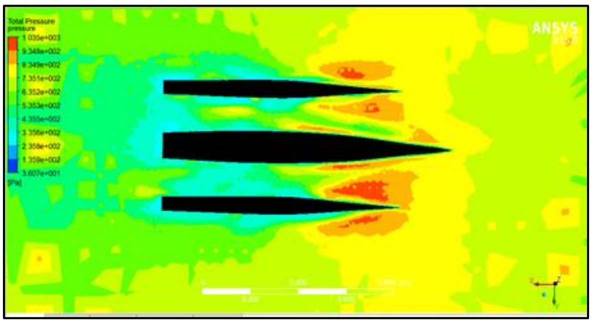
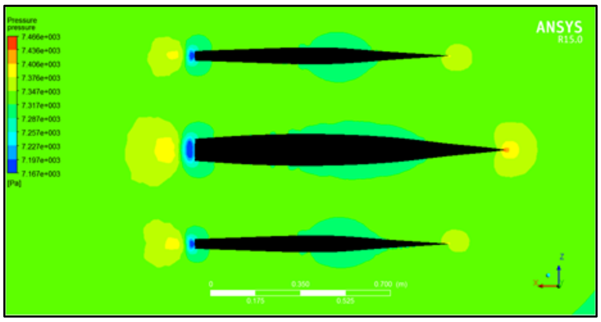


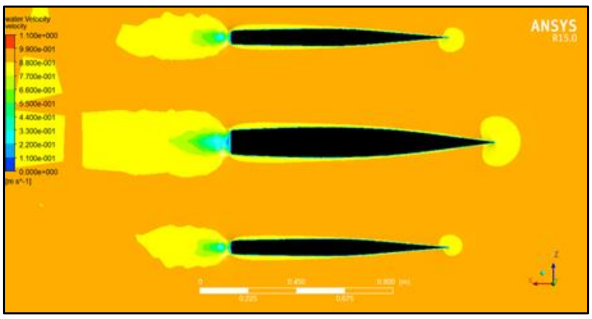
Figure 4 Hull Viscous Interference



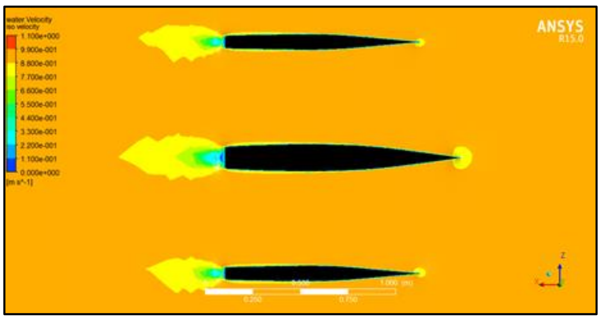
(a) S/L = 0.2



(b) S/L = 0.3



(c) S/L = 0.4



(d) S/L = 0.5

Figure 5 Vicious Interference Hull of Trimaran Models

The effect of the interaction between the ship's hulls causes the water flow around the symmetrical hull to become asymmetrical due to the relatively unequal pressure and flow velocity that occurs around the hull, as shown Figure 5. Viscous interference causes the flow velocity around the hull to increase in the inner area (between the hulls) thereby changing the structure of the boundary layer and the wet area of the hull. The physical changes in the structure of the boundary layer and the wet area of the hull cause an increase in skin friction

4. Conclusion

The use of CFD for performing a calculation of viscous resistance on a model of a trimaran ship gives quite a strong benefit in that it demonstrates the phenomena of flow and interference between the hulls of the trimaran ship model. The viscous form has a significant impact on the resistance of trimaran ships, and this effect is amplified for trimarans because of the viscous interference that occurs between trimaran hulls. It was discovered that the interference caused by viscous drag depends not only on velocity and hull clearance but also, and more significantly, on the trimaran's hull shape ratio. In addition, the amount of interference that takes place is reduced in direct proportion to the increase in the ratio of hull distance (S/L) with an increase in viscous resistance up to 1.57%.

Compliance with ethical standards

Acknowledgments

The authors would like to thank the Universitas Pattimura and all those who have contributed to this research

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