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Article

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Drag reduction of X-pentamaran ship model with asymmetric-hull outrigger configurations and hull separation

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Abstract

The needs to reduce energy consumption have to be applied to all sector, and one of them is transportation. Shipping is the most significant component of it, and therefore optimising a ship performance and reducing its resistance is a subject for many researchers. One of many ways to reduce drag is by utilising an alternative design such as multihull vessel, especially pentamaran, a vessel with five hulls. Destructive interference between their system of waves produced by their hulls is beneficial to reduce power consumption. An experimental test of X-pentamaran model in calm water condition had been conducted to investigate the interference resistance. Wigley hull-form of the model with four asymmetric-hull configurations and three variations of hull separation was investigated. The ship model was towed in a fixed towing condition and calm water condition with Froude number ranging from 0.2 to 0.7. The results showed that the hull separation made a slight alteration of the total resistant coefficient (in magnitude) on the same configuration. Even though not a single configuration outperformed the others in the entire range of Froude number, two configurations with $SL=0.11$ showed the highest drag reduction performance as the optimum model based on their Froude number range: configuration A3 from Froude number ranging from the initial to 0.6 and configuration C3 for the rest of the Froude number range.

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Keywords: Drag reduction; Asymmetric-hull configuration; Pentamaran; Wigley-hull form; Hull separation

1. Introduction

The needs to reduce energy consumption have to be applied to all sector, and one of them is transportation. Shipping is the most significant component of it, and therefore optimising a ship performance and reducing its resistance is a subject for many researchers. One of many ways to reduce drag is by utilising an alternative design. Multihull vessel is one of the alternatives which gives competitive advantages such as stability, deck area, and resistance on the high-speed range.

Brogli et al. [1] stated that in multihull vessel, hull separation and speed are the main components of the interaction between hulls which impact its total resistance. In trimaran, symmetrical side-hull form and its position

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and service speed are the critical factors affecting the resistance; the other elements are just a modest improvement to the performance as stated by Hafez and El-Kot [2]. Peng et al. [3] stated that the variation of side-hull longitudinal position, as well as transversal, affects mostly the multihull performance. From the investigation of Tuck and Lazauskas [4], side-hull position influenced interference resistance of any multihull configuration.

For unique or better characteristics and capabilities of the multihull, a vessel with five hulls was developed, called a pentamaran. The idea was initially developed in 1998 as an intention to exchange a conservative cargo ship to a high-speed cargo vessel that has more exceptional performance. Ikeda and Nakabayashi [5] proposed a concept of high-speed passenger ferry, troops transport vessel, fast patrol boat, and a fast RORO ship; many possibilities most likely emerged from this sort of multihull vessel.

A straightforward pentamaran hulls arrangement is like a trimaran; one main hull in the transverse centre and two pairs of side-hulls in every side, or outriggers. The outriggers can be configured with a combination of transversal and longitudinal positions. By using a Wigley hull-form, some variations of pentamaran configurations had been investigated by Peng [6], Dudson and Gee [7], and Tarafder et al. [8]. Surprisingly, not only its configuration but also hull-form of an outrigger will influence the vessel characteristic.

Moreover, one unusual shape that cannot be neglected is an asymmetry hull form. The asymmetry sidehull can be configured in two ways; asymmetric inboard where its chine placed inboard, and inversely, an asymmetric outboard. A trimaran with asymmetric-hull outboard configuration offers a lower interference resistance than the other one as investigated by Ackers et al. [9]. Over and above that, experimental investigation of pentamaran asymmetric-outboard configurations also has been studied by Yanuar et al. [10].

As an outcome of atop works, Yu et al. [11] stated that the critical parameters of multihull ship resistance depend on the longitudinal and transversal configuration as well as symmetry and asymmetry hull form of the outriggers. These variables influence the wave resistance component combined with the interaction between individual wave produced by each hull as proved by Muscat-Fenech and La Rosa [12].

Experiment on the interference effect of the multihull, especially pentamaran vessel, still stays unfinished. Therefore, the purpose of this investigation is to give additional analysis regarding a pentamaran configuration. An experimental of unstagger X-pentamaran model with a combination of symmetric and asymmetric outriggers had been investigated in calm water and fixed condition with a variety of hull separations at specific Froude number range.

2. Experimental setup

Four sidehulls in this investigation have a smaller dimension than the main hull. They were configured almost like a trimaran arrangement where each pair of the sidehulls was configured in every side of the main hull and longitudinally aligned with its pair. The Wigley-hull form of the model is depicted in Fig. 1; also, Table 1 shows the geometric characteristic of the ship model.

Table 1. Main dimension of the pentamaran model.

| Parameter | Symbol | Sub-hull | | |
|---------------------------------------|----------|----------|----------|-----------|
| | | Main | Side Sym | Side Asym |
| Length (m) | LoA | 1.8 | 1.35 | 1.35 |
| Beam (m) | B | 0.18 | 0.15 | 0.075 |
| Draft (m) | T | 0.06 | 0.02 | 0.02 |
| Block coefficient | Cb | 0.44 | 0.435 | 0.433 |
| Waterplane-area coefficient | Cw | 0.708 | 0.74 | 0.739 |
| Prismatic coefficient | Cp | 0.701 | 0.741 | 0.739 |
| Midship-section coefficient | Cm | 0.627 | 0.588 | 0.586 |
| Displacement (kg) | Δ | 6.565 | 0.728 | 0.362 |
| Wetted surface area (m ²) | Sa | 0.292 | 0.085 | 0.07 |

The model had been tested at three variations of hull separations and four asymmetric sidehull positions in Froude number ranged from 0.3 to 0.9. The experiment was conducted in a calm water condition. The towing tank has 50 m long, 10 m wide, and depth of 2 m. The experimental setup consisted of a load cell transducer to measure the total resistance of the ship model coupled with data acquisition to translate information from load cell to the

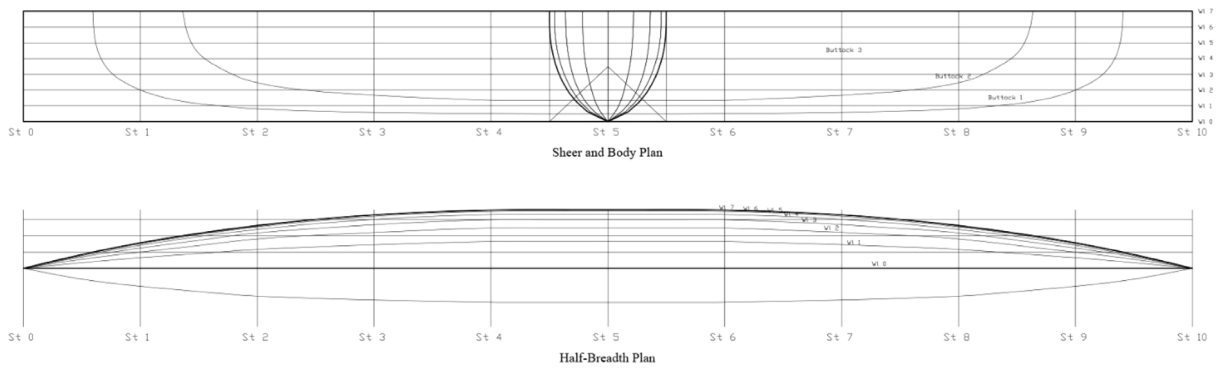


Fig. 1. Lines plan of Wigley hull of the model.

computer. The ship model was towed with a towing carriage which was maintained in a fixed model condition, ceasing the effect of trim and sinkage (see Fig. 2 (left)). Air resistance and correlation allowance were ignored in this investigation. The result of a coefficient is preferred in the analysis because it represents the essence of ship characteristic.

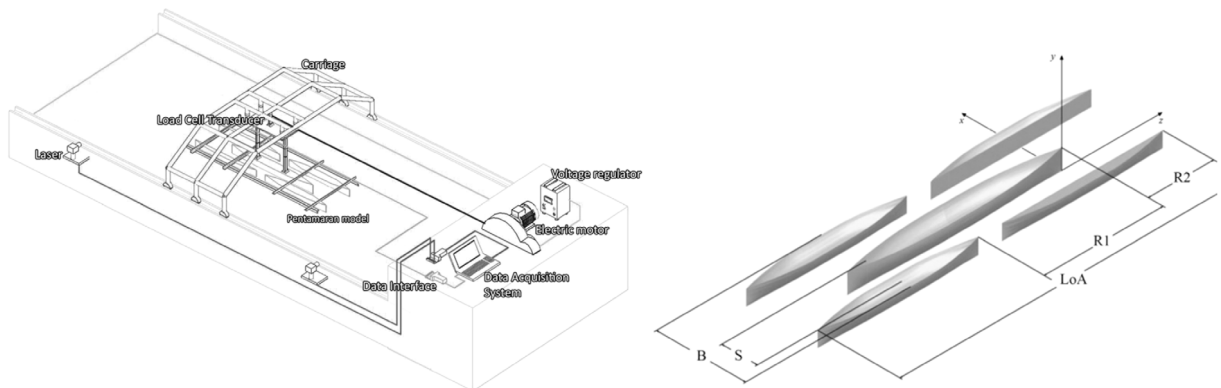


Fig. 2. Schematic drawing of the experimental setup (left), and basic geometry definition of the pentamaran model (right).

Fig. 2 (right) illustrates the ship model geometry and its reference. The notation of S stands for the distance between centre length of the main hull and the symmetrical side-hull. In this investigation, the longitudinal distance is consistent for each configuration. A pair of asymmetric outriggers were configured in a parallel arrangement. Fig. 3 shows the four main configurations, and the labelled name is defined in the followings:

- A. Rear position: asymmetric outboard
- B. Rear position: asymmetric inboard
- C. Front position: asymmetric outboard
- D. Front position: asymmetric inboard

Each configuration has the same variation of hull separation (S/L ratio) and is presented in Table 2.

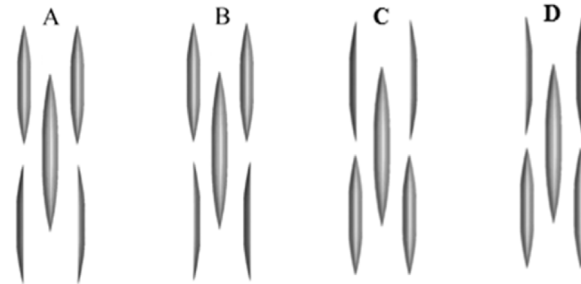
The total resistance of a vessel is most affected by both viscous and wave resistance. The viscous resistance is dominated by a portion of frictional drag which is influenced by the form factor of the hull. Further, the wave resistance can be divided into two parts: wave-breaking resistance and wave-induced resistance. On the high-speed range, the wave component of resistance is more significant than skin friction drag.

The total resistance coefficient is calculated from the obtained total resistance of the ship model as

$$C_T = \frac{R_T}{0.5S\rho U^2} \quad (1)$$

Table 2. Hull separations of the outriggers.

| Configuration | S/L Ratio | | |
|---------------|-----------|------|------|
| | 1 | 2 | 3 |
| A | 0.09 | 0.10 | 0.11 |
| B | 0.09 | 0.10 | 0.11 |
| C | 0.09 | 0.10 | 0.11 |
| D | 0.09 | 0.10 | 0.11 |

**Fig. 3.** Configurations of asymmetric outriggers.

Interference phenomena link directly to drag reduction of multihull vessel. The interference factor can be evaluated by comparing the resistance component of the multihull with the summed of all individual resistance as stated by Zaghi et al. [13]. Using only the total resistance attribute terminates other denominators like friction, wave, and additional components in the calculation process as well as the analysis step. The interference factor (IF) is extracted by:

$$IF = \frac{C_T^{(P)} - C_T^{(nonP)}}{C_T^{(nonP)}} \quad (2)$$

where $C_T^{(P)}$ is the total resistance coefficient of the pentamaran ship model and $C_T^{(M)}$ is the total resistance coefficient of non-interference multihull, or the sum of five each hull's total resistance. Souto-Iglesias et al. [14] convinced that the interference factor is best to be at a minimum value.

Hump and hollow are phenomena where it may appear at a certain speed of multihull vessel; it is a result of the interference of waves generated by each hull. A constructive wave-interference produces hump making an additional load in wave resistance, whereas a destructive wave-interference creates a hollow phenomenon which will possibly diminish the wave resistance. If hollow takes place, it will reduce the total resistance of the vessel that expresses a power consumption reduction. Hence, the optimal configuration of the multihull vessel is a configuration with the slightest Interference Factor (IF).

3. Results and discussions

Total resistance coefficient of all configurations as a function of Froude number is presented in Fig. 4. All hull separation and configuration variation showed a similar trendline. The smallest hull separation ($S/L = 0.09$) had the highest resistance on the investigated range of Froude number, whereas the most extensive hull separation ($S/L = 0.11$) signified an excellent sign of the lowest resistance trendline; Souto-Iglesias et al. [14] also reported this result.

The resistance coefficient trendlines created two peaks throughout the investigated Froude number. From the starting point of $Fn = 0.2$, there was a slight increase, and then a slight decrease before reaching $Fn = 0.4$. They then rose again, marking the highest peak approximately at $Fn = 0.6$. After that, they fell until the end of the examined Froude number. The result demonstrated a steady decrease of resistance at high Froude number range that showed a convergence result with Tuck and Lazauskas [4] and Yanuar [15]. Furthermore, not a single configuration showed the best resistance characteristic across the entire speed range at a similar value of hull separation. These results are alike compared to the asymmetric side-hull arrangements by Yanuar et al. [10].

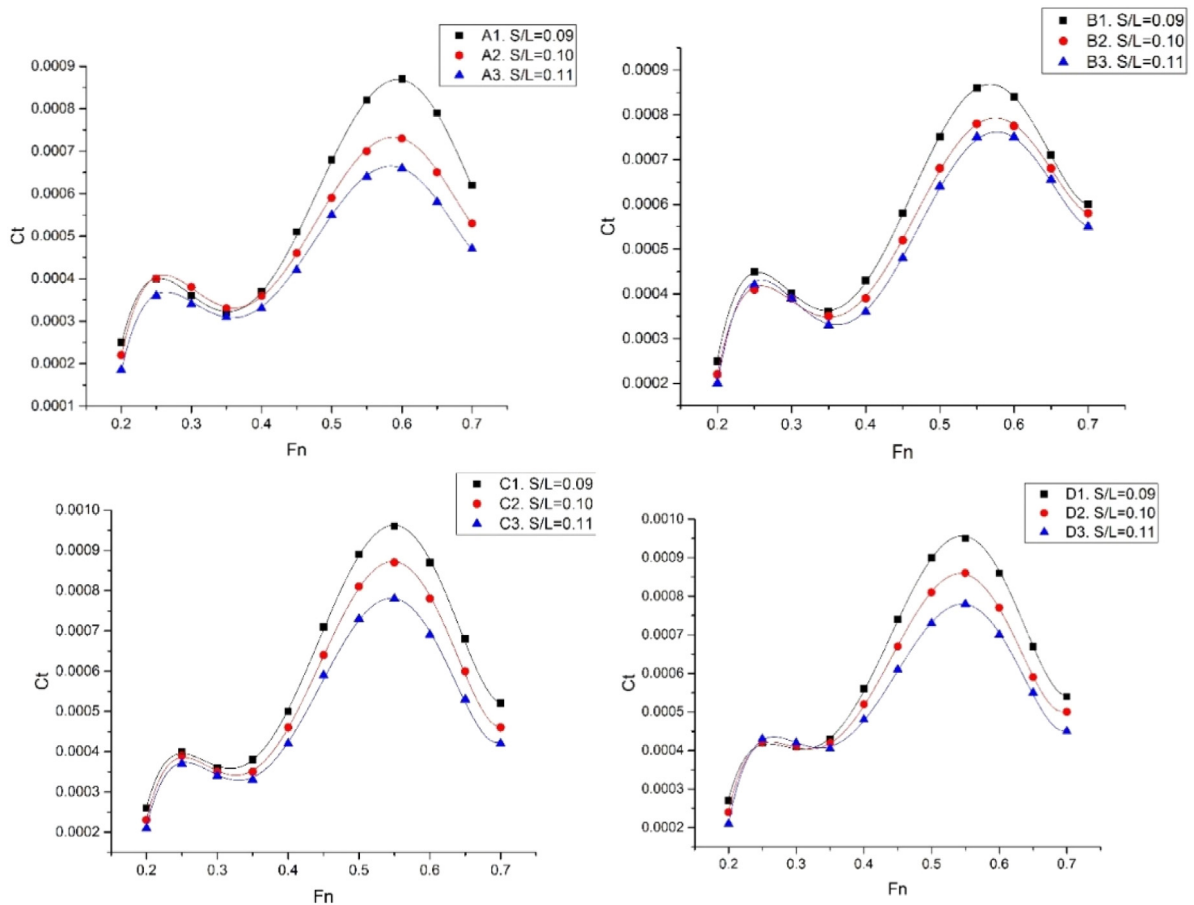


Fig. 4. Total resistance coefficient for all asymmetric-outriggers positions; Rear position: asymmetric outboard (A), asymmetric inboard (B) and Front position: asymmetric outboard (C), asymmetric inboard (D).

Meanwhile, configuration *C3* is the optimum configuration on the high-speed range, while configuration *A3* is also the optimum from low to medium Froude number range. Nevertheless, configuration *C3* generated the highest resistance magnitude on the second peak compared to the others.

Fig. 5 shows the interference factor of all configurations. A low magnitude on the interference factor indicates drag reduction of the vessel and a high one states an addition to the non-interference total drag. Negative interference is caused by a hollow phenomenon and the positive by a hump.

Configuration *A3* is the optimum compared to the others since it generated minimum magnitude from the starting Froude number to $Fn = 0.6$. However, on the subsequent range (Fn higher than 0.6), this configuration was outperformed by configuration *C3*. The lowest interference factor is achieved by configuration *C3* with -0.35 at $Fn = 0.7$. However, every configuration created a different characteristic, and each may produce a better characteristic in other range of Froude number.

4. Conclusion

This experiment investigated the effect of a variation of hull separation on several X-pentamaran model with asymmetric-hull configuration. On the investigated high-speed range, the lowest interference factor (-0.35) at $Fn = 0.7$ was produced by configuration *C* with *S/L* ratio of 0.11. A change in transverse distance produced a slight alteration of the resistance on the same configuration in which wave interference might take place. On top of that, no single configuration persistently outperformed the others throughout the entire range of Froude number. Furthermore, two configurations with the smallest hull separation showed the highest drag reduction performance

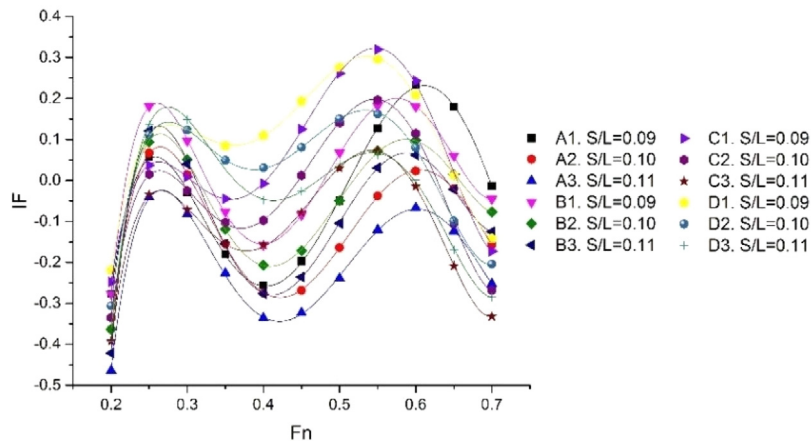


Fig. 5. Interference factor for all hull positions.

based on their Froude number range: configuration *A3* from $Fr = 0.2$ to $Fr = 0.6$ and configuration *C3* for the rest of the Froude number range.

The phenomena of interference resistance in pentamaran should be interrogated with various configurations and another type of experimental setup. Besides, we hope this examination will be helpful as a part of the original data set of multihull characteristics for computational analysis.

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References

- [1] Broglia R, Jacob B, Zaghi S, Stern F, Olivieri A. Experimental investigation of interference effects for high-speed catamarans. *Ocean Eng* 2014;76:75–85.
- [2] Hafez K, El-Kot AR. Comparative analysis of the separation variation influence on the hydrodynamic performance of a high speed trimaran. *J Mar Sci Appl* 2011;10:377–93.
- [3] Peng H, Qiu W, Hsiung CC. Measuring wave resistance of high-speed multi-hull ship with a small towing tank. In: 27th American towing tank conference, St. John's, Canada, 2004.
- [4] Tuck EO, Lazauskas L. Optimum spacing of a family of multihull. *Ship Technol Res* 1998;45:180–95.
- [5] Ikeda Y, Nakabayashi E. Concept design of a pentamaran type fast RORO ship. In: The fifth international forum on aluminium ships, Tokyo, Japan, 2005.
- [6] Peng H. Numerical computation of multi-hull ship resistance and motion (Doctoral thesis), Canada: Dalhousie University; 2001.
- [7] Dudson E, Gee N. Optimization of the sea keeping and performance of a 40 knot pentamaran container vessel. In: 6th international conference on fast sea transportation (FAST). Southampton, London: RINA; 2001.
- [8] Tarafder Md S, Ali MT Md, Nizam Md S. Numerical prediction of wave-making resistance of pentamaran in unbounded water using a surface panel method. *Procedia Eng* 2013;56:287–96.
- [9] Ackers BB, Michael TJ, Tredennick OW, Landen HC, Miller III ER, Sodowsky JP, Hadler JB. An investigations of the resistance characteristics of powered trimaran side-hull configurations. *SNAME Trans* 1997;105:349–73.
- [10] Yanuar Ibadurrahman, Karim S, Ichsan M. Experimental study of the interference resistance of pentamaran asymmetric side-hull configurations. *AIP Conf Proc* 2017;1826(1). <http://dx.doi.org/10.1063/1.4979241>.
- [11] Yu W, Chen Xj, Wu Gh, Liu J, Hearn GE. A fast numerical method for trimaran wave resistance prediction. *Ocean Eng* 2015;107:70–84.
- [12] Muscat-Fenech CMDM, La Rosa AMG. Resistance analysis for trimaran. *Int J Mech Aerosp Ind Mechatron Manuf Eng* 2014;8(1).
- [13] Zaghi S, Broglia R, Di Mascio A. Analysis of the interference effects for high-speed catamarans by model tests and numerical simulations. *Ocean Eng* 2011;38:2110–22.
- [14] Souto-Iglesias A, Fernandez-Gutierrez D, Pierez-Rojas L. Experimental assessment of interference resistance for a Series 60 catamaran in free and fixed trim-sinkage conditions. *Ocean Eng* 2012;53:38–47.
- [15] Yanuar Ibadurrahman. An investigation of the pentamaran resistance characteristic with variance in hull combination and configuration. *Energy Procedia* 2019;156:469–74. <http://dx.doi.org/10.1016/j.egypro.2018.11.080>.