Energy Efficiency of High Speed Tetramaran Ship Model with Minimum Resistance Configuration

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***Abstract*—Globalization is keep growing in this era. This fact leads to the increase of demand in every country which needs a larger supply. Ship still the best choice to transport goods from one country to another. But the problem arises how to reduce the resistance of ship in order the shipping can be done efficiently in aspects of operating cost which is fuel consumption. There are many ways to reduce the resistance of the ship. Multihull is one of them that has been a practical answer to this problem. Therefore, it needs more comparison among any multihull ship. The purpose of this experiment is to analyse the resistance of a tetramaran ship with stagger and unstagger configuration, the dimension of each hull are L: 2 m, B: 0.2 m, T: 0.045 m. A towing test was performed within the range of Fn between 0.1-0.6. This configuration will be pulled by steel wire rope. It was connected to electric motor which the rotation was controlled by voltage regulator. The force results to pull the ships model will be gathered by load cell transducer and will be calculated into total resistance. The analysis will be done according to the graph between Fn and C_T, C_R, C_T/C_{TO}, and drag reduction comparison value. The best result was achieved by S/L-R/L 0.2-0.5 configuration, with 28% of drag reduction around Fn 0.3.**

***Index Terms*—drag reduction, resistance, staggered, tetramaran, unstaggered, wave interference**

I. INTRODUCTION

Your goal is to simulate the usual appearance of papers in the. We are requesting that you follow these guidelines as closely as possible. The world is in a globalization era and it will keep growing every year. Every country will try to expand their market in order to achieve great economic development. Nowadays, Asia is starting to challenge the west countries not only because of the high market but also for cheap labor. This fact somehow affect shipping industry in positive way, which is Asia will need a lot of container and cargo ship to provide all the economic activity. In the end, it is our job to design a ship that use less energy and eco-friendly. In order to achieve that goal, many researchers working on a drag reduction topic, so they can reduce the resistance of a ship that leads to cheaper operational cost and efficiently energy usage.

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The results of their research can be used on many functions, such as for industry, military, and leisure activities. Every function has its own operational characteristic and basically become the constraint when it operates. For example, when we are taking a vacation and would like to travel from one island to another, we need a stable and fast ship. But we know that as the ship speed increase so does the resistance. This fact encourages many researchers to find a solution, which is by using a multihull ship.

In Reference [1], there are some advantages about using the multihull ship, which is they could have same displacement with lower draft and have a broader deck than single hull ship. This means that multihull ship has better stability than the single hull ship. On the other hand, speed is the essential consideration when we built a ship. This leads many researchers to keep continuing their work about multihull research since 1998 by Tuck, E.O. [2]. He used thin-ship theory to get a minimum wave-making on multihull configurations.

It is common perception that conventional monohull ship will experiencing a significant increase of wave resistance around Fn 0.37 and first hump around Fn 0.5, by Yeung and Ronald [3]. Based on this fact, multihull ship starts to become widely used. Nowadays, many catamarans are used for ferries and trimaran for warship. This is a proof that multihull ship is become a practical solution even though it is used with certain constraint. Therefore, we need hydrodynamic characteristic comparison for multihull ships, which one of them is tetramaran configuration.

In Reference [4], it stated that big wave on a ship is started at Fn 0.55. They accomplished to calculate a pressure distribution design for a weak wave resistance and followed by computation on a flat plate ship.

In Reference [5], it had compared two numerical methods to predict calm water resistance on a high speed sealift trimaran. This experiment used six configurations and one of them succeeds to reduce total resistance as much as 0.029 at 40 knot. The total resistance reduction would be difference on a prototype scale because of the Reynold number difference.

In Reference [6], it investigated the effect of stagger variation from trimaran outrigger to hydrodynamic interference. This stagger variation is applied on three

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types of hull which is Wigley, AMERC-09, and NPL-4a. Using one of the module on Maxsurf, trimaran resistance could be calculated based on Slender Body Method. The inboard separation variation shows a good hydrodynamic performance at Fn less than 0.5 and a bad interference effect. In Reference [7] quadramaran hull separations with greater S/L ratios have the least resistance in each configuration at high speeds. Development of ship with four outriggers or pentamaran has been researched by Yanuar, Gunawan, Waskito, and Jamaluddin [8], and Yanuar, Ibadurrahman, Waskito, Karim, and Ichsan [9]. They concluded that the characteristics of resistance much influences by wave interferences existence.

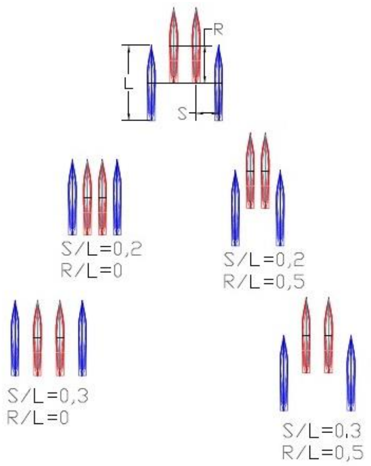

Figure 1. Tetramaran configuration

This research used tetramaran ship model which each hull dimensions are L = 2 m, B = 0.2 m and T = 0.045 m in 4 configuration as in Fig. 1. This configuration will be pulled by a steel wire rope that connected to electric motor which the rotation was controlled by a voltage regulator. The force results to pull the ships model will be gathered by a load cell transducer which is located on midship of the model. The data will be calibrated into the total resistance of the ship model. At the end, the total resistance coefficient value will be compared with Froude number for each configuration.

II. Methodology

According to Reference [10], Model tests are still the most important part to predict the total resistance of a ship, which will be used to calculate power requirements for the ship. This study was performed in a calm water basin which dimensions are length of 20 m, width of 10 m, and water depth of 4 m.

Fig. 1 shows each configuration that will be towed to predict the total resistance. Not all configurations will perform well from the total resistance point of view, there will be one configuration that performs poor and the other one that perform well in some Fn range.

Fig. 2 shows isometric view of tetramaran configuration. Each hull was arranged in separation and staggered distance variations.

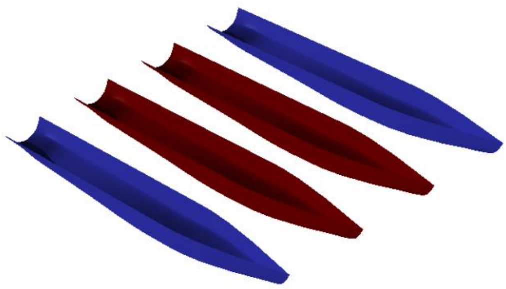

Figure 2. Isometric view of Tetramaran

Table I shows specification of each hull tetramaran model. All four hulls are identical.

TABLE I. Specification of Each Hull Model

Parameter	Mainhull	Unit
L	2.0	m
B	0.20	m
T	0.045	m
H	0.14	m
Cb	0.542	-
Cp	0.732	-
S	0.384	m^2
Disp.	12.5	kg

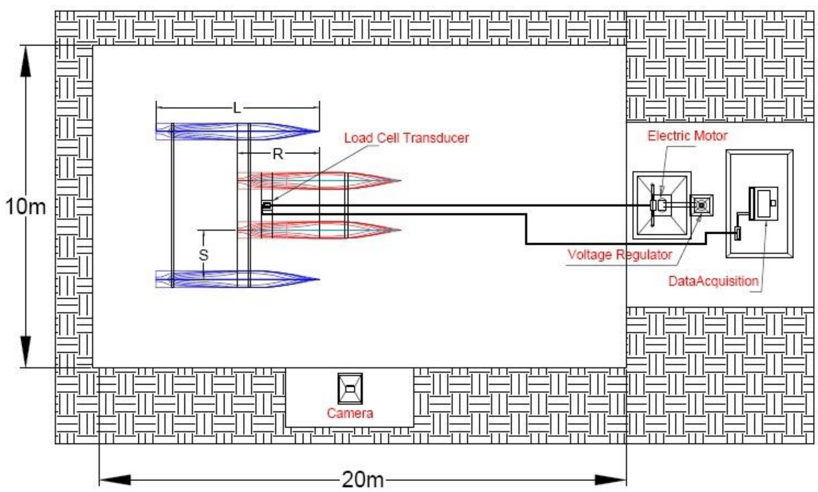

Figure 3. Experimental set-up

Froude's Law is the basis for our ship model resistance calculation. The experiment will be done in 0.1-0.6 range of Froude number. Froude divided the total resistance into two component, which is frictional resistance and residual resistance by Bertram [10].

Fig. 3 shows the experimental setup from the top view of the basin. Ship models (tetramaran and monohull), load cell transducer, data interface, camera, electric motor, AC voltage regulator and 50 kg of load will be used in the experiment. The comparison between S/L 0.2 and S/L 0.3 with R/L 0 and R/L 0.5 will be analyzed.

In this experiment, the ship model will be towed by an electric motor connected to a roller with a pulley. Wire rope will be connected to the roller and on the other end will be connected to load cell transducer that located on the midship of the model. Using AC voltage regulator, the electric motor rotation can be controlled, therefore, Froude number variation can be achieved. The load cell transducer will calculate the wire tension for each configuration for several Froude number through a data acquisition that connected to a laptop.

III. Test Analysis

International Towing Tank Conference as international standard classified ship resistance in calm water in two components. The first one is frictional resistance that mainly effected by the form of the hull and viscosity of the water. The second one is residual resistance due to the normal stress component that leads into wave-making and viscous pressure resistance. The aim of this study is to get the best configuration which has the largest drag reduction as in (1). It can be calculated as follows,

$$DR(\%) = \left| \frac{C_T - C_{TO}}{C_{TO}} \right| x100\% \tag{1}$$

C_T is total resistance coefficient of tetramaran model and C_{TO} is total resistance coefficient of monohull with same displacement.

From the experiment, the total resistance value can be gathered for each configuration. Then, using (2), the total resistance coefficient can be calculated,

$$C_T = \frac{R_T}{0.5 \rho S V^2} \tag{2}$$

where, ρ is water density, S is the wetted surface area of the model and V is the model speed.

According to ITTC 1957, total resistance coefficient can be divided using (3) into

$$C_T = C_r + (1+k)C_f \tag{3}$$

where, C_r is residual resistance coefficient, C_f is friction resistance coefficient and (1+k) is form factor. By calculating the friction resistance coefficient as in (4), then the residual resistance coefficient can be obtained. The friction resistance coefficient equation obtained as follows:

$$C_F = \frac{0.075}{(\log_{10} \mathrm{Re} - 2)^2} \tag{4}$$

After that, the plots where the x-axis is Fn and the y-axis are DR, C_T/C_{To}, C_T , and Cr can be shown.

Froude number and Reynolds number are defined as follows:

$$Fr = \frac{V}{\sqrt{gL}} \tag{5}$$

where, V is the speed of the model, L is the length, g is the gravity acceleration and ν is the kinematic viscosity of water.

IV. Result and Discussion

Fig. 4 shows the relationship between total resistance coefficient and Froude number for all tetramaran configuration (S/L-R/L 0.2-0, 0.3-0, 0.2-0.5, and 0.3-0.5) and monohull with the same displacement as the tetramaran. It appears there is some trendline similarity between stagger and unstagger configuration. This similarity can be seen around Fn 0.3 and Fn 0.5, where the hump occurs. Overall, the C_T values of tetramaran model are higher than the monohull. Only some of them show a positive effect, which is occurs around Fn 0.07, Fn 0.29, and Fn more than 0.55. But, it only happens in 2 configurations (S/L-R/L 0.2-0.5 and 0.3-0.5). On the other hand, the other configurations show a detrimental effect, especially at Fn 0.45 that has the highest values of C_T.

The tetramaran unstagger configuration indicates that the C_T values are enormously depended on the position of the outer hull. Actually, the C_T value of unstagger configuration is better than the stagger at Fn less than 0.3. But, as the speed increase, the C_T values rises significantly. The contrary result happens with the stagger configuration. Although its C_T values appear to be higher than the monohull but there is a phenomenon that make the C_T values is smaller at Fn 0.3 and Fn more than 0.55. This phenomenon is called destructive wave interference.

From the basic wave theory, there would be two type of wave interference, constructive and destructive. A constructive interference will occur when there are two waves travel in same phase. Conversely, the destructive interference will occur when the two waves are out of phase. This is the reason why such configuration has a smaller or higher value of C_T at certain range of Fn.

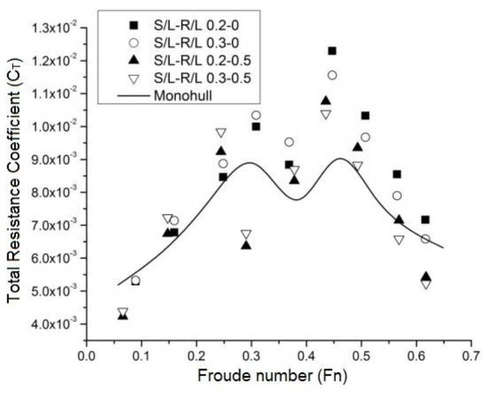

Figure 4. Relationship between total resistance coefficient (C_T) and Froude number (Fn)

Fig. 5 shows the relationship between residuary resistance coefficient and Froude number. Each configuration shows the same trendline with Fig. 4, which is possible because it is calculated by reducing C_T values with friction coefficient.

The first hump resistance occurs around Fn 0.25 and the second hump around Fn 0.45 for all configurations. And not only S/L-R/L 0.2-0.5 configuration has smallest value of C_R at Fn 0.3, but also S/L-R/L 0.3-0.5 configuration at Fn more than 0.6. Both configurations perform well because cancellation wave interference occurs at certain speed. On the other hand, when the wetted surface area is increased then the skin friction drag is also increased. The boundary layer on each hull being affected by the wave interaction and as a result, the higher coefficient values occur. It is the reason why generally the tetramaran coefficient value seems higher than the monohull.

There are two types of wave system that occurs due to ship movement which is transverse wave system and divergence wave system. The dominant portion of wave resistance will be associated with transverse waves system according to Newman [11]. Since the appendages, wind resistance, and hull roughness effect being neglected then residuary resistance coefficient above could be similar with wave resistance coefficient.

For the unstagger configuration, the coefficient values reach its first hump and second hump after the stagger configuration does. This indicates that there is a wave phase changing using stagger configuration. When the four hulls are aligned, the transverse wave system occurs will amplify one another which are detrimental. But for the stagger configuration, the transverse wave system will be interacted each other and make a useful wave cancellation at certain speed.

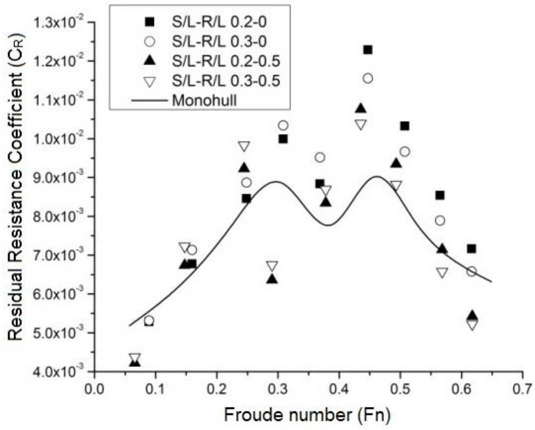

Figure 5. Relationship between residuary resistance coefficient (C_R) and Froude number (Fn)

Fig. 6 indicates the ratio of total resistance coefficient for each Froude number. When the ratio values are larger than 1, it means there is no drag reduction occurs. Otherwise, there is a drag reduction phenomenon happens in certain speed. The S/L-R/L 0.2-0.5 and S/L-R/L 0.3-0.5 configuration perform well at some ranges which is Fn less than 0.1, Fn around 0.3, and Fn more than 0.6.

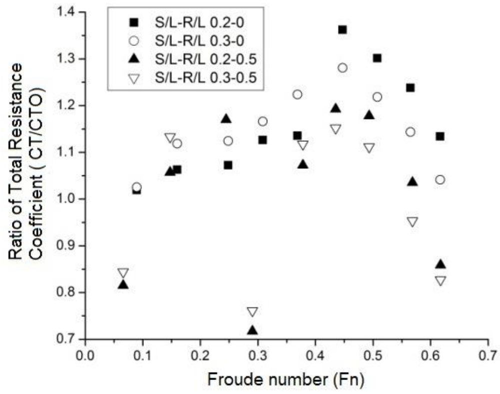

Figure 6. Total resistance coefficient ratio between tetramaran model and monohull model

Fig. 7 shows drag percentage comparison between tetramaran and monohull. When the value is positive then there is an increasing in drag. But when the values show negative value, it indicates that there is drag reduction occurs. It can be concluded that the maximum drag reduction occurs at Fn around 0.3 as large as ± 20% for both configurations.

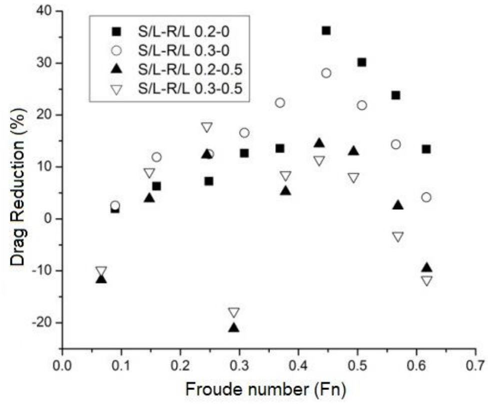

Figure 7. Drag Reduction comparison

V. Conclusion

This experiment basically analyses the resistance of tetramaran ship. It was found that stagger configuration shows good performance for certain Fn. Otherwise, the unstagger configuration perform poorly because it has the largest coefficient values. The best result is achieved by S/L-R/L 0.2-0.5 configuration with 28% of drag reduction at Fn 0.3.

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