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Resistance Analysis of Unsymmetrical Trimaran Model with Outboard Sidehulls Configuration

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Abstract: The application of multi-hull ship or trimaran vessel as a mode of transports in both river and sea environments have grown rapidly in recent years. Trimaran vessels are currently of interest for many new high speed ship projects due to the high levels of hydrodynamic efficiency that can be achieved, compared to the mono-hull and catamaran hull forms. The purpose of this study is to identify the possible effects of using an unsymmetrical trimaran ship model with configuration (S/L) 0.1–0.3 and R/L=0.1–0.2. Unsymmetrical trimaran ship model with main dimensions: L=2000mm, B=200 mm and T=45 mm. Experimental methods (towing tank) were performed in the study using speed variations at Froude number 0.1–0.6. The ship model was pulled by an electric motor whose speed could be varied and adjusted. The ship model resistance was measured precisely by using a load cell transducer. The comparison of ship resistance for each configuration with mono-hull was shown on the graph as a function of the total resistance coefficient and Froude number. The test results found that the effective drag reduction could be achieved up to 17% at Fr=0.35 with configuration S/L=0.1.
Keywords: trimaran model; unsymmetrical hull; ship resistance; stagger; drag reduction

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1 Introduction

Recently, ship resistance reduction has become the most popular talked about topic up for discussion and research by naval architects in a along time. The characteristics of resistance are principal aspects of the ship design spiral as they are strongly coupled with speed, operating cost and fuel consumption. The manufacture of modern hulls such as, multihull vessel is one of the methods for the reduction of resistance that occurs in the ship. The rapid transit for maritime transportation vehicles satisfying the paradox of high cruising speed at low resistance for use in the military, commercial, and recreational purposes, encourages many researchers to realize more practical solutions of such paradox. Practically, particular difficulties arise in the design of high speed maritime vehicles; in which a relatively large increase in their resistance naturally associates any speed increment. Such resistance increment, therefore, requires an increase in the vehicles propelling power, and consequently, the weight and size of the propulsion engine. As an unconventional solution of such difficulties, a few researchers devoted their efforts to investigate the hydrodynamic performance of the newly developed maritime vehicles, e.g., trimaran, by Hafez and El-Kot (2011, 2012). Application of multi-hull vessels as river and sea transportation modes continues to be developed. One of the reasons is the popularity of this ship is because of the availability of a wider deck that creates better stability compared to single-hull vessels. This research was already conducted by Seif and Amini (2004).

Trimaran concept has recently claimed significant advantages above monohulls and catamaran, Smith and Jones (2001), Lindstrom *et al*. (1995), Boote *et al*. (2004), Fach (2008). Trimarans are currently of interest for many new high speed ship projects due to the high levels of hydrodynamic efficiency that can be achieved compared to monohull and catamaran hull forms, by Mynard *et al*. (2008). The main hull and outriggers may be arranged so that the vehicle generated waves destructively interfere, producing smaller waves and thereby reducing the energy dissipated in overcoming the wave-making resistance, by Xu and Zou (2001). Trimarans share most of the characteristics of catamarans, but in few aspects, trimarans are more efficient than catamarans. Lyakhovitsky compared a trimaran with a mono-hull and a catamaran of same characteristics and showed that the trimaran was better in hydrodynamic performances compared to other alternatives, by Dubrovsky and Lyakhovitsky (2005). In addition, trimarans have some other advantages such as: extended deck, lower draft and better transverse stability compared with single body vessels, by Degiuli *et al*. (2005).

In process engineering, multi-hull vessel raises many technical challenges compared with conventional ship design. This is characterized by a more complex configuration and operating at higher speeds. In the multihull ship design, the designer uses experimental techniques (physical model test) and numerical modeling. In

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the multi-hull vessel, the problem of resistance is still widely discussed, partly because the component of resistance is more complex than that of the single-hull ships. Namely, the complexity of the interaction effects of viscous and wave resistance components in a multihull vessel are higher. The phenomenon of interaction of the components of this resistance is still a scientific discussion topic that continues to develop and grow. The two side hulls and main hull causes interference mutually. Different layouts of side hulls bring about different interferences. The wave loads of trimaran decreases when the three hulls make favorable interference. Therefore, it is very important to optimize a suitable layout of side hulls, by Xu and Zou (2011).

The purpose of this study is to identify the possible effects of using an unsymmetrical trimaran ship model with configuration (S/L) 0.1–0.3 and R/L=0.1–0.2. Unsymmetrical trimaran ship model with main dimensions: L=2 000 mm, B=200 mm and T=45 mm. In the study the ship model was pulled by an electric motor whose speed could be varied and adjusted. The ship model resistance was precisely measured by a load cell transducer. Comparing ship resistance, each configuration is shown in Fig. 4 as a function of the total resistance coefficient and Froude number. The experimental methods used load cell transducer with different speeds or Froude Numbers. Calibration of the resistance was used for this experimental methods. The ship model resistance measured by load cell transducer was calibrated to count the total resistance and frictional resistance. Thus, the ship resistance was then compared with Froude number in each configuration.

2 Experimental set-ups

Accurate ship resistance predictions are still difficult, Bertram (2000). Model tests are thus, far the best option, for providing resistance. This study was performed in a basin with calm water. The basin with a length of 20 m, width of 10 m, and water depth of 1.5 m.

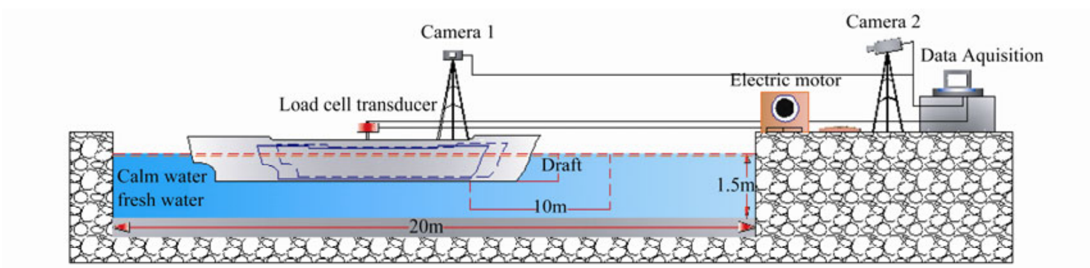

Fig. 1 Experimental set-up

Ship resistance was tested and measured according to Froude's law. Froude's law states that ship resistance can be devided into frictional resistance and residual components, with the residual resistance following his "law of comparison" (Froude similarity), Bertram (2000). The experiments were conducted for Froude number 0.1 up to 0.6.

Fig. 1 shows the experimental set-up in the basin. This set-up consists of ship models (trimaran and monohull), electric motor, data interface, camera, load cell transducer, AC voltage regulator and 10 kg load. The comparison of the total drags between trimarans with configuration S/L=0.1; S/L=0.2 and trimaran with configuration S/L=0.3 was analyzed. The model test was conducted in order to have the total resistance values of the ship model (R_T) at various velocity conditions (v).

During the model test experiments, ship model pulled by an electric motor designed for motor rotation to be used to pull the ship model with a constant speed and pull force was measured utilizing a load cell transducer. The load cell transducer was positioned at a point in the mid-ship and vertically above base line, allowing the model to move freely in the vertical plane. The total resistance was measured for each run over the test range of Froude numbers. In the resistance tests the ship model was pulled by a wire rope and the total longitudinal force acting on the model was measured for various speeds. Testing was done by recording the results of the string tension on the load cell with the data that could be read on the computer. The experimental data of the variation of the distance S/L=0.1–0.3 was the best configuration of ship resistance.

Table 1 The main dimension of test model

Parameter	Mainhull	Outriggers
L/m	2.0	0.08
B/m	0.20	0.10
T/m	0.045	0.045
H/m	0.14	0.14
C_b	0.5	0.54
C_p	0.68	0.64
C_m	0.73	0.85
Disp/kg	12.5	5.8

Fig. 2 and Fig. 3 are the hull configuration models of trimaran. Trimaran consists of three hulls in one configuration. Ship model configuration is classified into 5 types: S/L=0.1, 0.2, and 0.3 with R/L=0; S/L=0.3 with R/L=0.1 and S/L=0.3 with R/L=0.2.

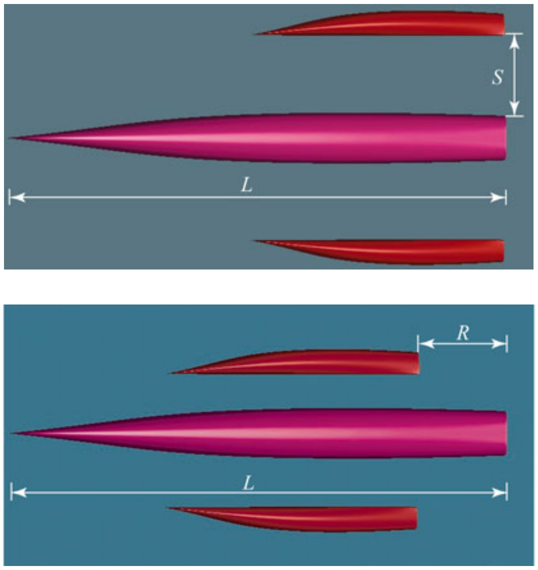

Fig. 2 Unsymmetrical trimaran with outboard sidehulls configuration

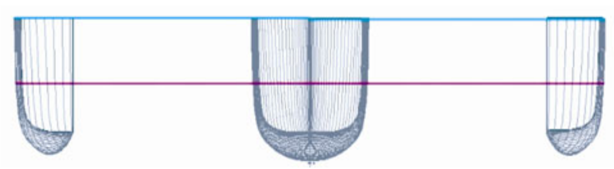

Fig. 3 Body plan of unsymmetrical trimaran

3 Test analyses

The theory of ship resistance has been elaborated by naval architects as a means of predicting ship performance from preliminary experiments with models. The resistance offered by a ship to movement through water may be categorized into two principal components: frictional resistance and residual resistance. The frictional resistance arises from frictional forces set up by the flow of water along the surface of the hull. While the residual resistance (mainly wave making resistance) is due to pressures developed in pushing the water aside, and arises from the form of the hull.

Total resistance coefficient can be defined as:

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

where C_T is total resistance coefficient, C_r is residual resistance coefficient, C_f is friction resistance coefficient and (1+k) is form factor.

From the experimental towing test results, for the models, the total resistance coefficient C_T have been calculated as:

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

where ρ is water density and S is the wetted area of ship hull.

Residuary resistance coefficient of the trimaran can be define as:

$$C_{R\ \text{Trimaran}} = C_{T\ \text{Trimaran}} - 2C_{f\ \text{Side}}\left(\frac{S_{\text{Side}}}{S_{\text{Total}}}\right) - 2C_{f\ \text{Main}}\left(\frac{S_{\text{Side}}}{S_{\text{Total}}}\right) \tag{3}$$

Froude number and Reynolds number are define as

$$Fr = \frac{V}{\sqrt{gL}} \tag{4}$$

$$Re = \frac{VL}{v} \tag{5}$$

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

Drag reduction (DR) was obtained by:

$$DR(\%) = \left|\frac{C_T - C_{TO}}{C_{TO}}\right| \times 100\% \tag{6}$$

C_T is total coefficient resistance of trimaran model. C_{TO} is total coefficient resistance of monohull model (monohull displacement identifies with trimaran displacement).

4 Results and discussion

Fig. 4 shows the relationship between total resistance coefficient and Froude number for the unsymmetrical trimaran model in each configuration (S/L=0.1, 0.2, and 0.3 with R/L=0; S/L=0.3 with R/L=0.1 and S/L=0.3 with R/L=0.2) and monohull. This indicates that each configuration has the same trendline, the values of C_T decrease with the increase of Fr up to Fr=0.2, and for Fr=0.3–0.5, C_T increases with increasing speed. At Fr>0.5, the C_T reduces. It appears that for the trimaran model, the value of C_T is relatively higher at Fr<0.2. When the Froude number further increased, Fr>0.3, at a certain range of values of C_T, a value smaller than the monohull ship model was found. On the other hand, it was found that the value of C_T depends on the position of configuration S/L. It appears that the ship model with configuration S/L=0.1 gives the smallest value of C_T. Here the total resistance was estimated as the sum of wave resistance and viscous resistance determined from a friction coefficient C_f according to ITTC 1957, a form factor based on the average flow speed along the hull surface, and a wetted surface which includes wavemaking and squat effects. Hull roughness effects, appendages, wind and seaway-induced resistance components were neglected.

The result shows that resistance hump occurs at Fr≈0.5. This result seems to agree with the numerical results of Hafez and EI-Kot (2011) and Wang and Lu (2011). It should be kept in mind that numerical results from Hafez and EI-Kot (2011) and Wang and Lu (2011) using symmetrical trimaran are not exactly the same as the experimental results from the present study using unsymmetrical trimaran. The occurrence of hump phenomenon was due to the wave breaking and influence transom, by Insel and Molland (1992). After pass the hump resistance, the wave breaking will shrink and even disappear, a procedure caused by the flat hull shape (slenderness) that is dominated by viscous resistance.

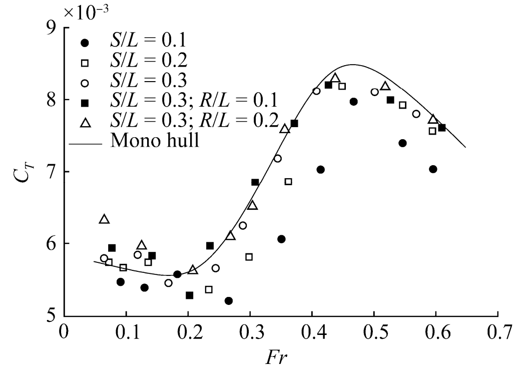

Fig. 4 Relationship between total resistance coefficient (C_T) and Froude number (*Fr*)

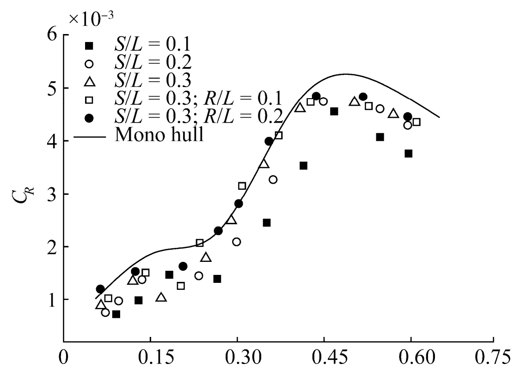

Fig. 5 Relationship between residuary resistances coefficient (C_R) and Froude Number (*Fr*)

Fig. 5 shows the relationship between residuary resistance coefficient and Froude number, each configuration has the same trendline, the values of C_R decreases with increasing *Fr* and configuration *S*/*L*=0.1 has the lowest residuary resistance coefficient as a function of wave resistance. This result agrees well with the experimental work of Zhang (2009) in a circulating water tunnel.

At the Froude number, *Fr*≈0.5, hump resistance occurred and configuration *S*/*L*=0.1 had the smallest value of C_R. In this configuration, the waves created by main hull did not interact with the side-hulls. This phenomenon could account for the reason of drag reduction. The wave field behind a ship consists of diagonal and transverse waves. Far behind the ship, the wave energy is contained nearly exclusively in the transverse waves. In this section a sector is filled about ±20 degrees around the backward extension of the midship line. In usual trimaran, the transverse wave systems generated by three hulls add up constructively over most of the breadth of the wave sector, because waves of equal size and phase are generated by three trimaran hulls. Transverse wave system contributes significantly to the amount of resistance produced. In unstaggered longitudinal configuration (*R*/*L*=0) the amount of resistance will be influenced by the strong wave pattern and the same phase. While the configuration of the *S*/*L*≠0, the system will be reduced due to the transverse wave interaction area of the smaller waves along side-hull.

For trimaran configuration when the three-bow hulls are aligned, as the speed increases, the rate of total drag growth will decrease, due to the length of interaction between the waves created by the main hull with outriggers decreases. Resistance decreases with increasing transverse distance where three hulls bow are aligned, but increasing transverse distance does not affect where three bodies stern are aligned, by Javanmardi and Seif (2008). What this means, is the resistance of the corresponding trimaran configuration is less than the non-interfered resistances; whereas a hump signifies a positive interference which is detrimental.

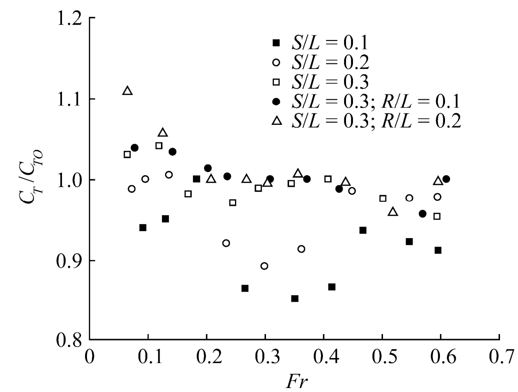

Fig. 6 Total resistance coefficient ratio between trimaran model and monohull model

Fig. 6 shows the total resistance coefficient ratio as a function of Froude number. The value of ratio indicates that drag reduction gradually occurred. If the ratio value is lower than 1, it indicates that resistance coefficient of the trimaran model is lower than mono-hull model. The best configuration is configuration *S*/*L*=0.1 because it has the smallest resistance ratio.

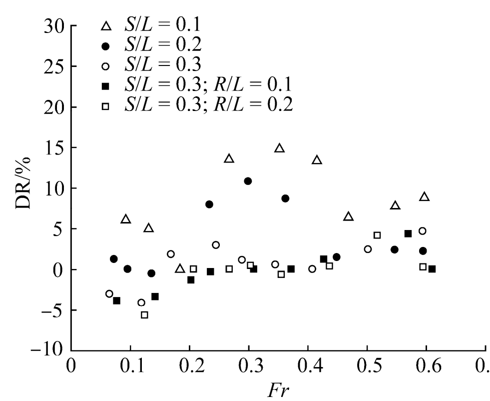

Fig. 7 Drag reduction ratio

Fig. 7 shows drag reduction that occurred. It is clear that drag reduction for configuration *S*/*L*=0.1 is greater than the other configuration. The drag reduction starts at Froude number about 0.075, the maximum drag reduction for this research is 17% at *Fr*=0.35.

5 Conclusions

This paper experimentally investigates the influence of hull stagger and clearance variation of the sidehull on the hydrodynamic interference of trimaran vessel. In consideration of the experimental model test results on Froude number 0.1–0.6, the conclusions can be drawn that the usual unsymmetrical trimaran with outboard sidehull configuration, had great influence on ship resistance. The test results found that the effective drag reduction could be achieved up to 17% at Fr=0.35 with configuration S/L=0.1. Study analysis for this case indicate the system will be reduced due to the transverse wave interaction area of the smaller waves along side-hulls.

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