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Experimental Analysis of Diamond Pentamaran Model with Symmetric and Asymmetric Hull Combinations

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Abstract: A new diamond pentamaran ship model with Wigley-hull form had been investigated with five main configurations of asymmetric and symmetrical-hull combinations along with three variants of hull separation. The model has been tested in calm water condition and constant Froude number ranging from 0.39-0.60. The total resistance coefficient of the symmetric configuration has a distinctive trend from the asymmetrics. Also, the total resistance coefficent characteristic of the model makes a slight distinction because of transverse distance variations on the same main configuration. Most of the configurations have negative value of the interference factor. The study expresses a specific approach of pentamaran resistance characteristic in the limited froude number range.

Key words: Pentamaran, asymmetric hull, diamond configuration, interference factor, Wigley-hull form

INTRODUCTION

Study of wave resistance is important and interesting subject ona ship theory. Wave resistance has two components: wave-breaking resistance and wave-making resistance. On the wave resistance point of view, if a ship is travel in a flawlesly calm water condition it experiences only the wave-making resistance. Michell was the first to treat the wave-making resistance of a moving ship at constant speed in unpeturbed water condition with infinite depth. This classical theory which is based on the assumption that the ship is thin the beam-to-length ratio is small has been well pursued by many researchers (Michell, 1898). Furthermore, thin-ship theory can also be used to determine the wave resistance for a multihull ship with a indistinguishable hull form.

The common arrangement of multihull from their number of hull is catamaran, trimaran, tetramaran and pentamaran respectively. The are many advatages of a multihull vessel than a conventional monohull: inherently larger deck area, higher safety and better seaworthiness, principally the transversal stability (Dubrovsky, 2010).

The number of studies on multihull ship have shown that they have a better characteristic than a monohull, typically over the high speed regime. Tuck and Lazauzkaz (1998) investigated the wave resistance for some model configurations of the monohull, catamaran, trimaran and quadramaran (Tuck, 1998). Weija did a research on high speed trimaran planing hullin order to investigate the characteristicof its resistance and hull form; ship model were tested to measure resistance, trim and heaving under different displacements and gravity center locations (Ma *et al*., 2013). Besides, Peng *et al*. (2004) confirmed the trimaran performances are highly dependent on outriggers longitudinal position but not too responsive to the transverse spacing. Additionally, acomparison between dihull and tetrahull was done by the result showed the tetrahull has lower total resistance for a short speed range at Fn 0.55 (Yeung and Wan, 2008).

Pentamaran, a multihull with five hulls has excellent stability its natural roll period is very tender and therefore extraordinary comfortable. Some investigations on pentamaran had been done by many researchers. Dudson discussed the hydrodynamic optimization of the central hull of a pentamaran for Sea Bridge in order to maximize the speed of the vessel with a pre-determined machinery package (Tahmassebpour, 2016). Showed that on a Froude number >0.8, the interference among the individual hull of the pentamaran was very small and the wave-making resistance could be reduced significantly (Seyedhosseini *et al*., 2016).

Although, there are many studies on multihull characteristic, yet there stillsome aspect to be explored and refined further. The investigation on multihull commonly focus on identifying the configuration which has the lowest resistance within a certain speed range (Muhyi and Jamaluddin, 2016). Work on the new configuration with its alternative combinations is well underway and is the objective of this study. The scope of this study focuses only on the ship resistance

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characteristic in the calm water condition where the only considered important of the drag component is viscous and wave-making resistance.

MATERIALS AND METHODS

Experimental setup

Ship model specifications: A pentamaran ship model had been tested with various configurations and hull separations. A multihull ship consists of mainhull and sidehulls (also called outer hull or outriggers) but in this pentamaran model, all hulls have similar characteristic the characteristic of the hull model is described in Table 1 without showing a distinction between the main hull and outrigger its lines plan of the Wigley-hull form is shown in Fig. 1. The subscript h refers only to the characteristic of the individual hull not the pentamaran model nor the ship configuration.

A geometry determination of multi hull is seemingly different with a mono hull. The proportion of its beam and Loa are mainly impacted by its configuration. The beam of a diamond pentamaran ship dependson the space beetwen main hull to inner outrigger along with the distance between inner outriggerto outer outrigger. In addition, the Loa has similar measurement but in a way of the ship horizontal axis. The geometry of the ship model with reference system is depicted in Fig. 2. The S_1 notation is the width between center length of main hull to inner outrigger also the S_2 is measured from the center length of inner outrigger to outer outrigger. Then, the notation of R_1 stands for the distance between midship of main hull to outer outrigger and the R_2 is measured from midship of outer outrigger to inner outrigger. In this testing model, S_1 and S_2 have identical length, thus the S symbol is applied replacing both of the symbol to express the distance of hull separation. Correspondingly, R notation is applied instead of R_1 and R_2 which have identical length to express the length of hull stagger in this ship model the R is equal to half of the hull's length. Each hull of the pentamaran model used in the experiment is distinguished by its hull form (either symmetrical or

Table 1: Main dimension of the hull model

Properties	Symbol	Symmetric hull	Asymmetric hull
Length (m)	Loa_h	1.800	1.800
Beam (m)	B_h	0.180	0.090
Height (m)	H	0.170	0.170
Draft (m)	T	0.075	0.075
Block coefficient	Cb	0.361	0.455
Waterplane-area coefficient	Cw	0.523	0.712
Prismatic coefficient	Cp	0.699	0.712
Midship-section coefficient	Cm	0.517	0.647
Displacement (kg)	Δ_h	7.400	4.700
Wetted surface area (m^2)	Sa_h	0.349	0.309

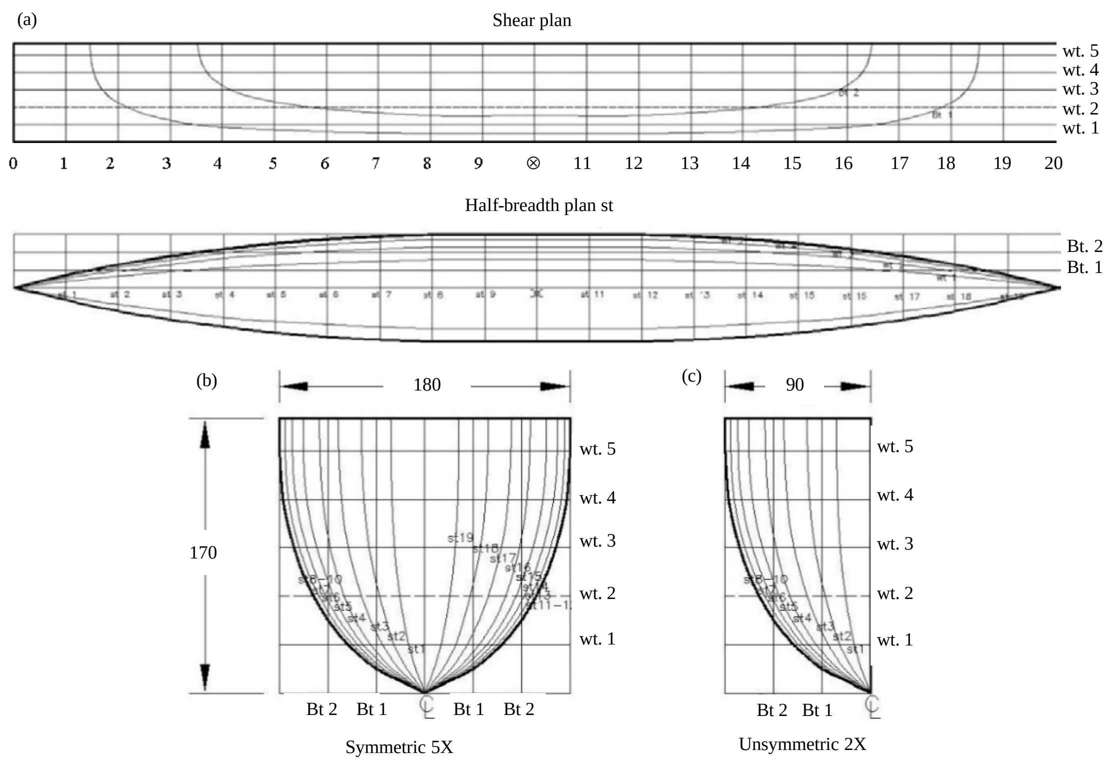

Fig. 1: Lines plan of the Wigley-hull formof the ship model

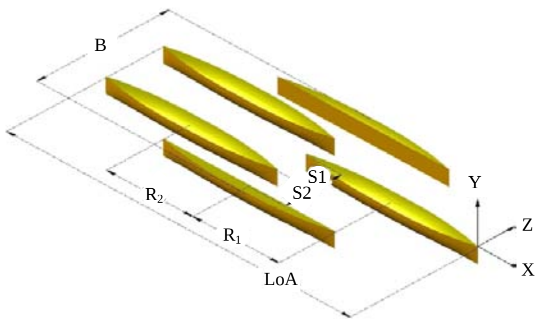

Fig. 2: The pentamaran modelgeometry and reference system

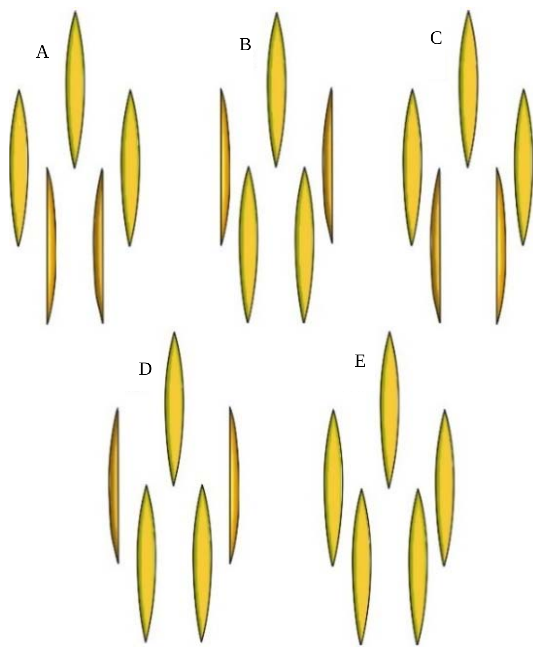

Fig. 3: Main configuration of the pentamaran model

asymmetrical) not its position (e.g., mainhull, sidehull). However, every center-hull used in all configurations was a symmetrical hull a pair of asymmetric hull along with another pair of symmetric were employed as outer-hulls. One of the configurations is a ship model with all symmetrical hull.

Every single configuration is represented by a simple marking to shorten and hence a simplification. There are five m ain configurations utilized in the current study (Fig. 3):

- A: inboard-inner asymmetric hull position
- B: inboard-outer asymmetric hull position
- C: outboard-inner asymmetric hull position
- D: outboard-outer asymmetric hull position
- E: symmetric hull position

Table 2: Hull separation of the model

Asymmetric hull position	Symbol	S/L ratio 1	2	3
Inboard-inner	A	0.08	0.11	0.14
Inboard-outer	B	0.08	0.11	0.14
Outboard-inner	C	0.08	0.11	0.14
Outboard-outer	D	0.08	0.11	0.14
-	E	0.08	0.11	0.14

Each and every main configuration has three variants of hull separation (transverse distance) the S/L ratio of the ship model is given in Table 2. However, the S had three variations no variant of horizontal distance had been involved meaning the beam of the ship model had been adjusted equivalently but the length remains constant the R/L ratio (hull stagger) is constantly 0.25.

Setup experiment: The pentamaran ship model had been towed in a water tank with 50 m long, 10 m wide and 2 m deep. The experimetal setup consisted some main apparatuses: a load cell transducer to measure the total drag of the towed ship model, one set of data acquisition system with Lab view software to translate and record the data from the load cell and two pairs of laser and receiver along with its data interface to account the model speed. Figure 4 illustrates the setup experiment.

The structure integritiy of the pentamaran model was kept tightly to avoid a bend in every ship axis there by composing some elbow steel bar in rigorous manner. Also, the experiment was performed in a calm water condition after every test performed there was a certain waiting time to retain the calm water condition. In addition, a constant Froude number had been ensured for every test performed the Fr is ranging from 0.39-0.6. Furthermore, each test had been carried out in multiple times to verify its accuracy.

Test analysis: The total resistance of a ship is influenced by many parts but dominated by wave and viscous resistance components. The wave resistance relates to Froude number and the viscous resistance relates to Reynold number. The components of the monohull total resistance are straight forward but not for a multi hull ship because the wave produced by its hulls interact with each other, consequently making it more intricate to examine.

A coefficient in the resistance value has a proportional magnitude either if the resistance is examined into its elements or not. The coefficient quantityis preferably used in the showing result because it represents acore of the resistance also comprehensible to compare and analyze (Yanuar *et al*., 2017). The total resistance coefficient is defined as:

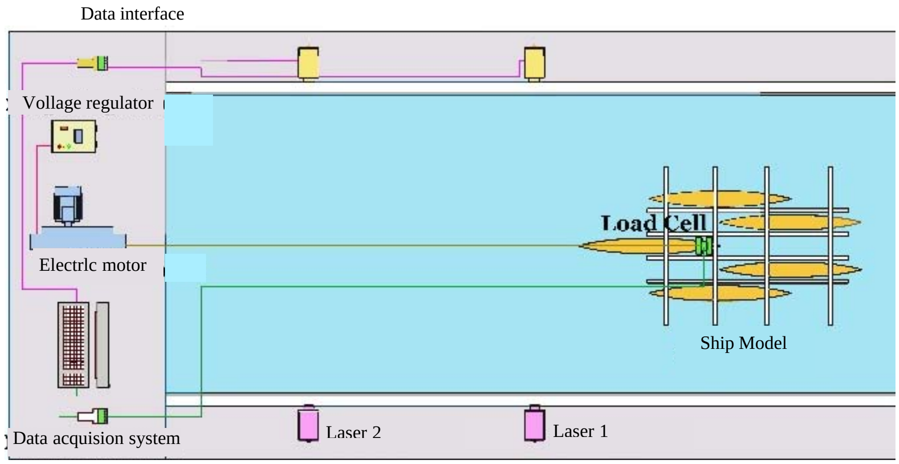

Fig. 4: Schematic of the experimental setup

$$C_t = \frac{R_t}{0.5\,\rho\,V^2 S} \quad (1)$$

Where:

ρ = The density of water
S = the wetted surface area
V = The velocity of the ship

Besides, Froude numbers is defined as:

$$Fn = \frac{V}{\sqrt{gL}} \quad (2)$$

Where:

g = The acceleration of gravity
L = The length of the ship

In this case, it is identical to twice of the hull's length. Attention needed to account wave interaction between each hull. The interaction could reduce the total resistance value of a multihull ship or expand it. The magnitude of the interaction between the hulls is defined as interference factor. In this investigation, speed and hull separation are used as a parameterto investigate the characteristic of it. The interference factor can be defined as:

$$IF = \frac{C_T^{(P)} - C_T^{(M)}}{C_T^{(M)}} \quad (3)$$

Where:

$C_T^{(P)}$ = The total resistance coefficient of the pentamaran ship model
$C_T^{(M)}$ = The sum of five individual total resistance coefficient of each hull it is a non-interference pentamaran

The amount of the multihull interference factor must be maintained at minimum or below zero if possible (Iglesias *et al*., 2012). An increment value over zero means a parasite effect where the multihull total resistance is larger than a monohull in similar characteristic in other word it means the pentamaran is not better than the non-interference pentamaran.

RESULTS AND DISCUSSION

Total resistance coefficient characteristic: Viscous and wave resistance are two major parts of the ship total resistance. The viscous resistance is dominated by friction resistance. Moreover, the wave resistance can be split into two component: wave-breaking resistance and wave-making resistance. In this study, the wave-breaking resistance is negligible because the ship model was tested in strictly-controlled calm water condition; the blockage effect from the tank is also neglected because the tank depth as well as its side wall are far enough from the ship model.

When a wave interacts with another wave, there will two possibities occured the wave combines with each other that will construct a bigger wave or the waves merge to be a weaker wave which possibly nullified each other. These constructive and destructive effect of the wave interference are known as hump and hollow phenomena, respectively. Because of its number of hulls, a multihull ship will experience these wave interference phenomena. Above that, the portion of wave-making resistance will expand over the skin friction resistance in high speed region and therefore a control on the wave interference issues cannot be completely disregard.

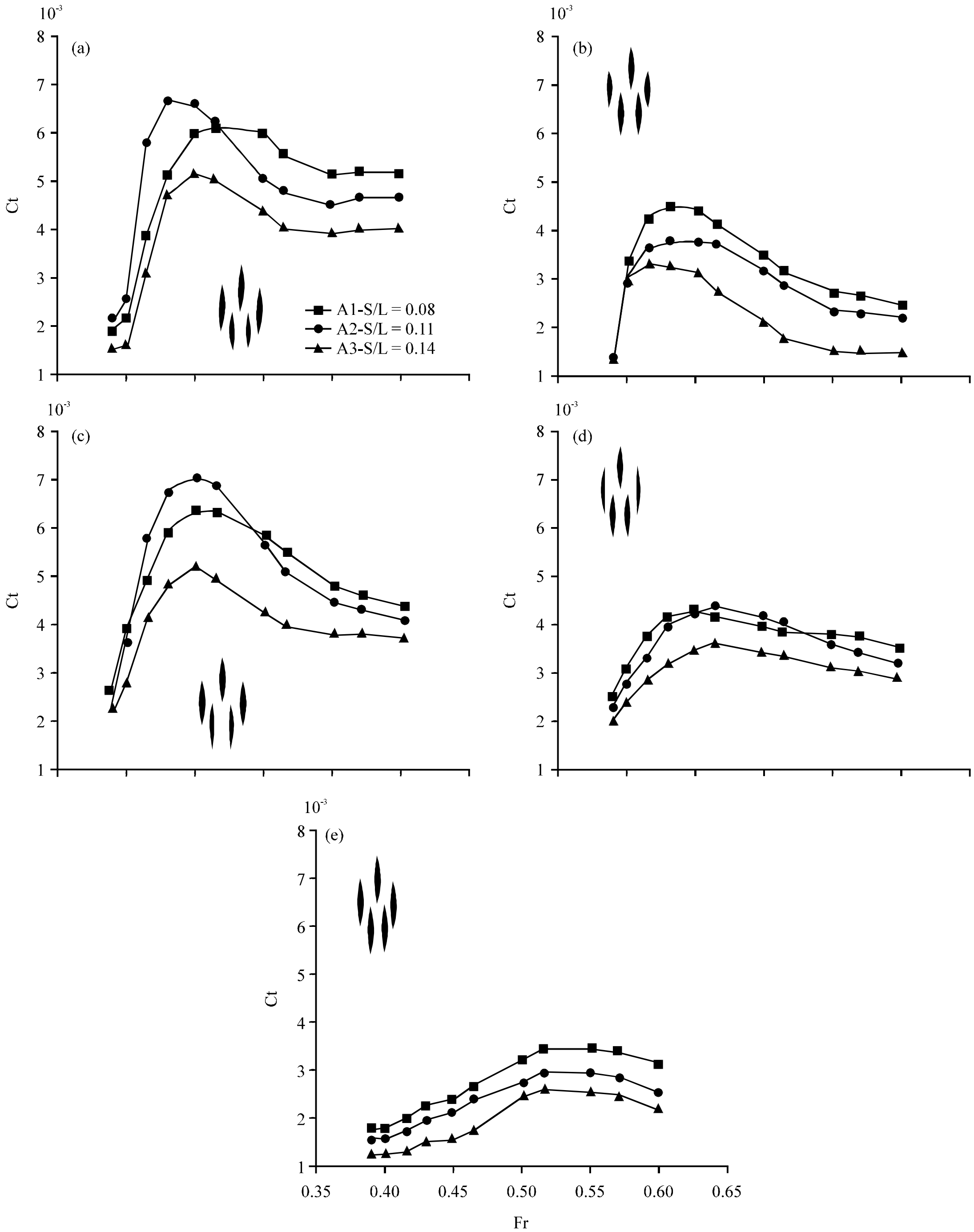

Fig. 5: a-e) Total resistance coefficient of the main configurations

The experiment test was done from medium to high velocity but the shown Froude number appears not too high (ranging from 0.39-0.60) because the ship length is proportioned twice the hull's length. As a function of Froude number, the diamond configuration cannot be straightly compared with a normal pentamaran configuration (e.g., transversely-lined pentamaran) even it has the same hull characteristic and speed because they tend to behave differently when travel in the same speed. Figure 5 depicts the total resistance coefficient of all the main configurations where each of them has three transverse distance variants. The curves start from Fr = 0.39 where all of them have favor to rise and made a peak when a hump phenomenon occured all of them except the symmetry configuration have a summit at slightly similar Froude number span and then they lean to dwindle gradually which signed a beginning of the hollow occurence. Because of the small Froude number scope in the study, there only one hollow and one hump phenomena that can be seen in the entire curves. These are very similar to the first trends by Yanuars *et al.* (2017) experimental result which have similar Froude number range. Further, this experiment shows a total resistance coefficient in a limited Froude number distance but it is able to clarify in more specific.

Generally, the S/L ratio affects the immensity of the wave interference phenomena but each main configuration vaguely made a similar trend. All the graphs show the wider hull separation has faintly low total resistance coefficient than the narrow when the Froude number tends to rise this tendency is also described by Iglesias (2012). Completely, the transverse distance effect can be disregarded because its total resistance coefficient only makes a very little difference on the same configuration (its magnitude times to the negative third).

The total resistance coefficient of the symmetry configuration is a bit lower than the others. This small magnitude of Ct is generated because the surface area of the symmetrical-hull configuration is larger than the asymmetric configuration (it has 5% more wetted surface area). Moreover, the trends of the symmetry configuration are more steady than the others yet after its steadily increment until Froude number reaches 0.5 it moves to lessen at a slow pace.

Interference factor: The interference factor curvesfor all asymmetric configurations are showed in Fig. 6. At the start of the Froude number range the curves are close together until they rise apartin each specific crest then they move on their own tendency.

Almost all configurations have a lower total resistance coefficient than the non-interfere hull the inferior value means a favorable design. The curves reveal there is not a single configuration with a lowest interference factor on the entire Froude number span whereas the inboard-outer asymmetric hull position with S/L = 0.14 (B3) is designated as the nethermost since the first quarter of the Froude number scope (Fr = 0.45).

Figure 7 portrays the interference factor for the symmetric configurations along with the configurations with S/L = 0.14 which have the most inferior IF value than the others on the same main configuration. From the graph it clearly confirms there is no optimum configuration on the explored Froude number. It plainly

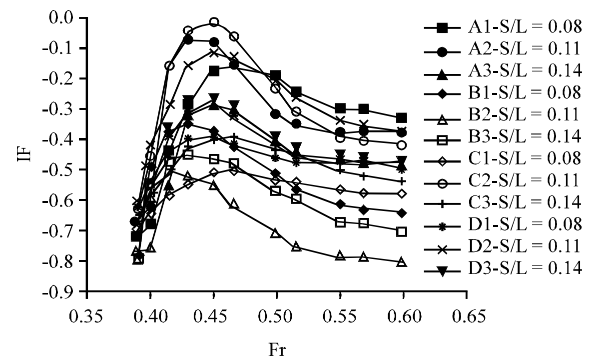

Fig. 6: Interference factor of the asymmetric configurations for each hull separation

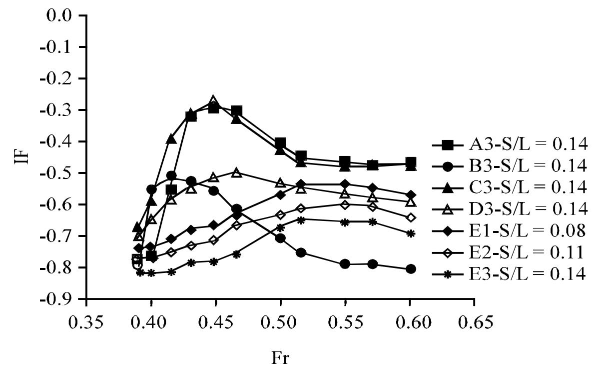

Fig. 7: Inteference factor of the symmetrics and configuration with S/L = 0.14

shows the wider transverse distance has lower interference factor than the other-investigated hull separation for the same configuration. Obviously for all configurations, the IF trend lines almost not different with the Ct trends because of the examined Froude number limitation yet they express in a detailed manner. Furthermore, the symmetric configuration have a steady-low interference effect trendmostly than the asymmetrics.

CONCLUSION

The experiment studied the effect of different symmetric and asymmetric hull combinations on diamond-shape pentamaran with Wigley-hull form model. The symmetric configuration has a dissimilar tendency compared with the asymmetrics it shows no hump phenomenon. In addition, the hull separation proves a very slightly change on the total reistance coefficient value on the same main configuration. On top of that, not a single configuration has an optimum characteristic on the whole Froude number regime. This investigation demonstrates the total resistance characteristic of the pentamaran model in more detail approach however the explored Froude number is limited. Furthermore, the variation of hull separation seems too tight.

Research on multihul ship should be investigated further especially for a new configuration and new view point analysis. This study is a potential data models for the numerical analysis and other evaluation.

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