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Article

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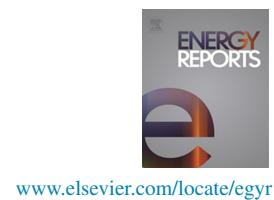
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The influences of diversity hull shapes and outriggers arrangement in pentamaran systems

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Abstract

The wave flow pattern builds up along the hull and expansion flow behind the hull is absorbing the energy from the ship as a resistance. The ship's resistance and the behaviour of its components are significant in estimating the propulsion of the ship, which positively influences fuel consumption. The aim of this work was investigating the influence of two hull forms and its outriggers arrangement in pentamaran systems. The investigating was in wave resistance, interference, and far-field wave spectrum. This study focused on warp-chine and Wigley hull shapes by comparing a computation which was based on Michell's thin ship theory and various tests in clearance and stagger of side hulls. The results of this study founded the resistance coefficients based on Michell's approach agreed with towing test results at $F_n > 0.5$. Besides, wave resistance for warp-chine configurations was established to be much better than Wigley except at $F_n < 0.5$. High coefficient reduction for warp-chine hulls was generated with a setting where the main hull to side hull on a formation as an arrow trimaran near to Kelvin angle. As for Wigley, the high reduction was produced by a configuration where the front-side hull and the stern-side hull were in line. Then, captured wave patterns of the towing test exhibited a fit visual with the computation, in which Wigley hulls produced a more significant wave than warp-chine hulls.

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Keywords: Pentamaran; Warp-chine; Wigley; Wave resistance; Interference; Far-field wave spectrum

1. Introduction

An optimum hull form is expected to result in minimum total resistance. In a Multihull ship, the shape, position, and side displacement of its hulls are critical in achieving expected seakeeping, friction resistance and stability. In general, wave resistance and interference represent the distribution of wave energy of a ship at various wave angles. Therefore, it takes an appropriate placement and suitable hull shape(s) to prevent the wave or to minimise any substantial interference. A slender hull has been recognised to produce the lowest ship power [1]. If it applies

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Nomenclature

$A(\theta)$	amplitude
$A_j(\theta)$	amplitude for multihull with j numbered of hull
R_w	wave resistance
C_F	friction coefficient
C_w	wave coefficient
C_v	viscous coefficient
$F(\theta)$	interference between the hulls
k_0	$=g/U^2$, basic wave number
$k(\theta)$	$=k_0 \sec^2 \theta$, wave number at angle θ
R_F	friction resistance
R_T	total resistance
S	wetted surface area
U	ship velocity
ρ	water density
θ	angle propagating wave
σ_j	total displacement fraction of multihull
$\zeta(x,y)$	wave pattern of ship at angles θ to x-axis direction of ship motion

to a large monohull ship, it will affect ship stability, suggesting Multihull as the solution [2]. Practically, optimising the factors can be conducted by adequately selecting the shapes and placement of the hulls. Currently, warp-chine has been considered as a hull shape with the lowest resistance and the best capability to function in high speed. Besides, Wigley is another commonly used hull form for Multihull ships.

In the literature, numerous towing tests had been conducted on pentamaran (five hulls) configurations [3–6] while numerical studies had investigated optimum distance and expected wave resistance as well as the interference of Multihull configurations [7,8]. This research, therefore, aimed at investigating the hydrodynamic characteristics of pentamaran hulls in Wigley and warp-chine forms by using “Michlet 9.32” tool, which was based on Michell’s thin-ship theory, and validating the results with towing tests. Factors under investigations included wave resistance, interference, and far-field wave patterns at different speeds.

2. Towing test

2.1. Model test

The test model was conducted in calm water [9] using a towing tank available in the Sepuluh November Institute of Technology (ITS), Indonesia. [Table 1](#) and [Figs. 1–2](#) describe the body plan of pentamaran ship models with Wigley and warp-chine hull forms. The main hull used warp-chine, as the shape that has been suggested by Savitsky and Koebel [10] and alongside four outriggers in a common V form. In a pentamaran with Wigley hull form, the main hull and four outriggers have an identical shape.

Table 1. Dimensional characteristics of pentamaran.

Main Dimension	Wigley		Warp-chine	
	Main hull	Outrigger	Main hull	Outrigger
Total length (LOA) m	1.800	0.500	1.500	0.414
Breadth (B) m	0.180	0.050	0.150	0.030
Height (H) m	0.170	0.116	0.090	0.078
Draft (T) m	0.080	0.030	0.024	0.012
Wetted surface (S) m ²	0.368	0.033	0.177	0.015
Total Displacement (Kg)		11.12		2.313

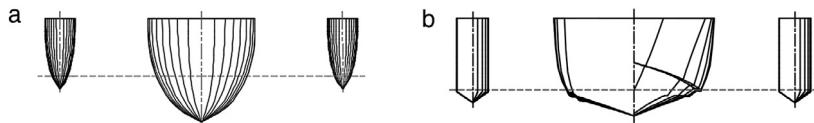


Fig. 1. The body plan of pentamaran (a) Wigley hull; (b) warp-chine hull.

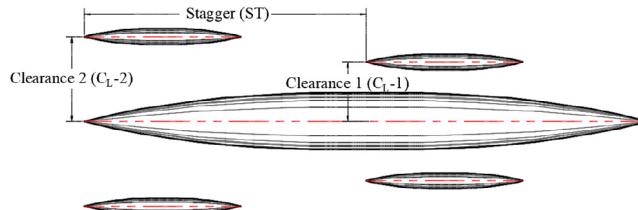


Fig. 2. Set-up pentamaran configuration.

Table 2. Pentamaran configurations.

Configuration	Stagger (S/L) (m)	Clearance 1 (C _{L1} /Bmh) (m)	Clearance 2 (C _{L2} /Bmh) (m)
CH/WI -A	0.36	1.20	1.20
CH/WI -B	0.36	1.05	1.50
CH/WI -C	0.42	1.20	1.20
CH/WI -D	0.42	1.05	1.50
CH/WI -E	0.50	1.20	1.20
CH/WI -F	0.50	1.05	1.50

2.2. Test configurations

Towing tank used in this study had $50 \times 3 \times 2$ m dimensions (length \times width \times deep). Model tests were conducted on twelve different sets of arrangements at the range of Froude number (F_n) 0.4–0.7. For a more convenient explanation, pentamaran with warp-chine hull was indicated as CH and Wigley hull as WI (Table 2).

The test was conducted to discover total resistance (R_T) and determine form factor ($1 + k$) in low speeds at $0.12 < F_n < 0.2$, and $(1 + k) * R_F$ to calculate the viscous resistance (R_F). Then, wave resistance (R_W) was obtained by the following:

$$R_W = R_T - (1 + k)R_F \quad (1)$$

where friction resistance (R_F) was determined from friction coefficient C_F following a formula suggested by ITTC-1957

$$C_F = 0.075/(\log 10 Re - 2)^2, R_F = 0.5 \rho U^2 S C_F \quad (2)$$

Then, the total resistance coefficient (C_T) and wave coefficient (C_W) were expressed as

$$C_T = R_T/0.5 \rho U^2 S, C_W = R_W/0.5 \rho U^2 S \quad (3)$$

3. Michell's thin-ship approach

In the literature, Michell's thin-ship theory had been applied to Multihull for determining wave resistance (R_W) as the energy left in a wave system, which indicated free-wave spectrum integration to a propagation angle (θ).

$$R_W = \frac{2}{\pi} \rho U^2 k_0^4 \int_{-\pi/2}^{\pi/2} d\theta \sec^2 \theta \left| \iint_W dx dz Y(x, z) e^{ik_0 x \sec \theta + ik_0 z \sec^2 \theta} \right|^2 \quad (4)$$

And it was related to the complex wave amplitude function $A(\theta)$, which was also stated as a free-wave spectrum.

$$A(\theta) = -\frac{2i}{\pi} k_0^2 \sec^4 \theta \iint Y(x, z) e^{ik_0 z \sec^2 \theta + ik_0 x \sec \theta} dx dz \quad (5)$$

Then, total wave pattern, $z = \zeta(x, y)$, of Multihull with N hulls resulted in the complex amplitude of each hull (j):

$$\zeta(x, y) = \int_{-\pi/2}^{\pi/2} e^{-ik(\theta)[x \cos \theta + y \sin \theta]} \sum_{j=1}^N A_j e^{ik(\theta)[x_j \cos \theta + y_j \sin \theta]} d\theta \quad (6)$$

where $A_j(\theta) = \sigma_j A_0(\theta)$, in which $A_0(\theta)$ was determined from wave interference, $F(\theta)$, as a factor of wave-making for each hull and a function of the arrangement pattern (x_j, y_j) and σ_j .

$$F(\theta) = \sum_{j=1}^N \sigma_j e^{ik(\theta)[x_j \cos \theta + y_j \sin \theta]} \quad (7)$$

4. Comparative investigation

The comparative results of the towing tests and the “Michlet” tool [11] are provided in Figs. 3–4 and Tables 3 and 4. And Fig. 5 provide the wave pattern.

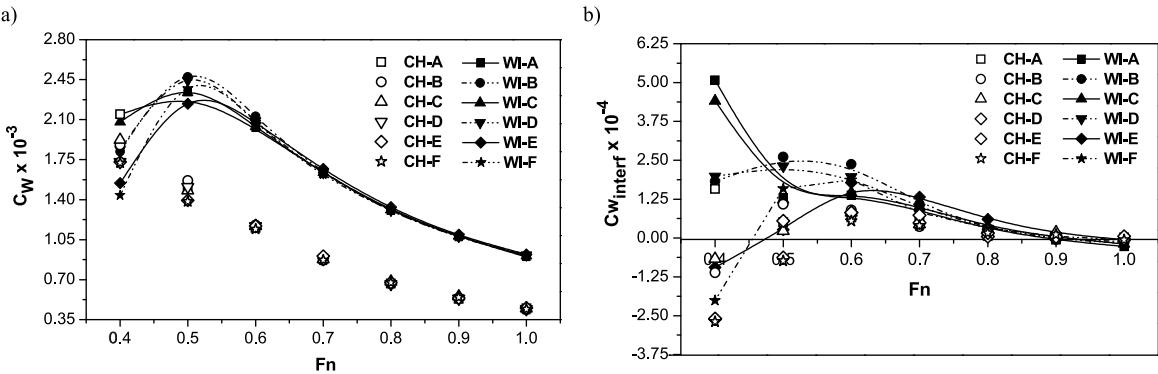


Fig. 3. Michlet calculation on warp-chine (CH) and Wigley (WI): (a) Wave resistance coeff. (C_w); (b) Wave interference coeff. ($C_{w\text{ interf}}$).

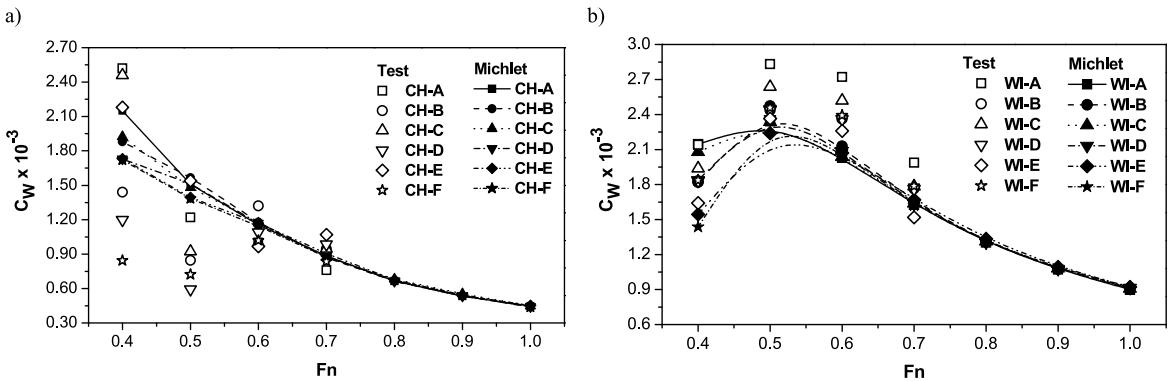


Fig. 4. Comparison of wave resistance coefficients (C_w) between towing tests and Michlet tool for (a) Warp-chine (CH) and (b) Wigley (WI).

The analysis results for all configurations are provided in Figs. 3–4. Fig. 3(a) exhibits a significant difference in plot trend of wave resistance coefficients for the warp-chine hull, which in fact, lower than those of Wigley-hull at a 36.7% average deviation for both of all configurations. Warp chine produced its peak at $Fn = 0.4$ and continued to decrease, while Wigley provided its peak at $Fn = 0.5$ and decreased afterwards. Fig. 3(b) shows the differences in wave resistance interference of all models. Warp-chine (CH-hull) has a negative interference tendency at $Fn \leq 0.5$ and becomes positive afterwards, while Wigley (WI-hull) has a high interference at $Fn = 0.4$ and continued to decrease in parallel with speed increases. Deviations for wave resistance interference are found to have a 58.3% average for both hulls. The results of the comparison between wave resistance coefficients (C_w) in towing tests and “Michlet” tool are provided in Fig. 4(a) and Table 3 for CH-hull, and Fig. 4(b) as well as Table 4 for WI-hull. A

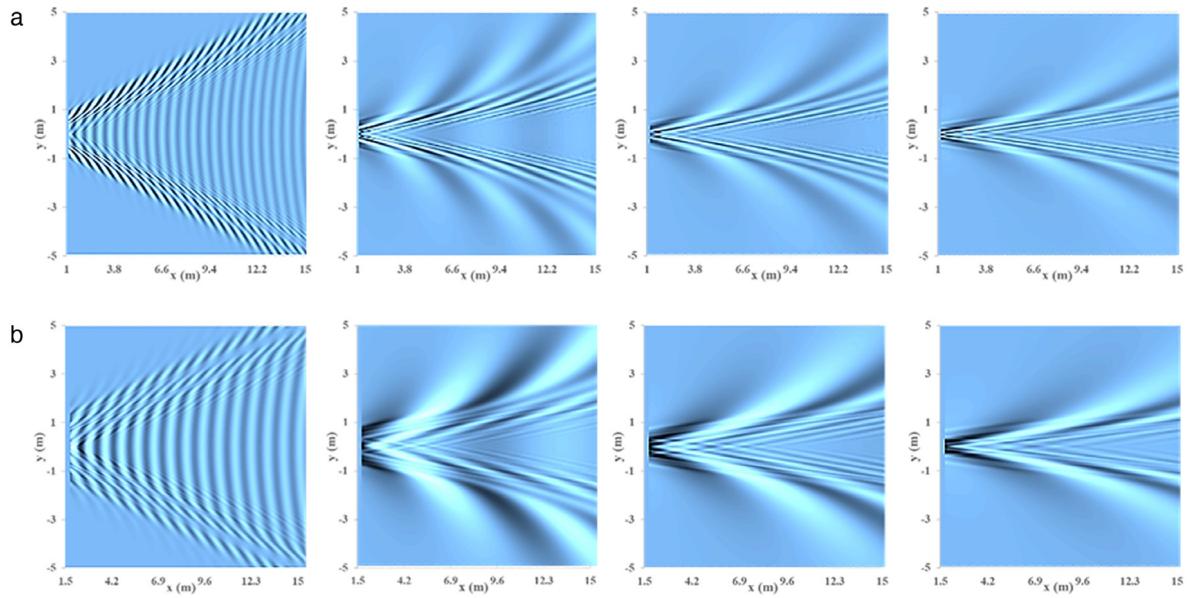


Fig. 5. Far-field wave pattern of pentamaran (a) CH-hull, (b) WI-hull, at Fn: 0.2, 0.6, 0.8, 1.0 (left to right).

Table 3. Wave resistance in average percentage for CH-hull [5].

Stagger	Test	Michlet	Clearance	Test	Michlet
CH-A to B	15.137	-1.739	$C_L1 = C_L2$	CH-A to C	0.985
CH-C to D	19.766	1.193		CH-C to E	4.521
CH-E to F	21.663	2.037	$C_L1 \neq C_L2$	CH-B to D	6.386
				CH-D to F	6.778

Table 4. Wave resistance in average percentage for WI-hull.

Stagger	Test	Michlet	Clearance	Test	Michlet
WI-A to B	13.269	0.918	$C_L1 = C_L2$	WI-A to C	8.313
WI-C to D	5.461	1.101		WI-C to E	0.059
WI-E to F	-8.865	0.196	$C_L1 \neq C_L2$	CH-B to D	12.30
				CH-D to F	-0.99

decreasing resistance is expressed as a positive value in the average percentage and an increasing resistance as a negative value. The total of the average deviation of comparing wave resistance coefficients between towing test and “Michlet” tool was 11.8% (CH-hull) and 8.25% (WI-hull).

The wave pattern (Fig. 5), $z = \zeta(x, y)$, in far-field for CH-hull (a) and WI-hull (b), respectively. At low speed ($Fn = 0.2$), CH-hull exhibited a larger transverse, but WI-hull had a broader and thicker diverging wave pattern than CH-hull. At $Fn = 0.6$ –1.0, WI-hull showed thicker dark blue colour than CH-hull, indicating a deeper basin, and dominated by a blue–white colour, indicating a high peak. The wave pattern of CH-hull has been discussed by Sulistyawati et al. [6].

5. Conclusion

Results of analyses in this study are expected to deliver a useful reference for ship planning literature, particularly related to hull shape and the configuration of outriggers in pentamaran models in conjunction with desirable ship speed. All CH-hull configurations appeared to generate lower waves and produce less interference than any WI-hull configurations. Besides, the comparison between the results of towing tests and computational calculations indicated

a change in stagger (S/L) delivered more influence on the decrease of wave resistance than clearance (CL/Bmh). In $C_L1 \neq C_L2$ position, all CH configurations achieved a more significant reduction in resistance and interference than in $C_L1 = C_L2$ position. Meanwhile, arrangements for WI-hull in $C_L1 = C_L2$ position delivered more decrease in both resistance and interference than $C_L1 \neq C_L2$.

In general, this study delivered investigation results on hydrodynamic characteristics of the wave resistance of two different pentamaran hull shapes and their outrigger configurations. However, a separate analysis or method is needed to validate and sustain the results of this study. In practices, economic considerations for a ship being designed sharply depend on its hydrodynamic aspects. Therefore, further researches need to conduct more analyses on other hydrodynamic elements, e.g. wave load of the seakeeping in different configurations.

Acknowledgments

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