11th International Conference on Marine Technology
MARTEC 2018

COMPARATIVE ANALYSIS OF DIVERSITY HULLFORM INFLUENCE ON RESISTANCE ASSESSMENT OF A PENTAMARAN

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ABSTRACT

This paper investigates the effect of diversity hullform and their positions to wave resistance, far-field wave patterns, and wave interference of a pentamaran. The investigations were conducted for some of the model configurations with comparison an experimental and calculation based on Michell approximation. This study of pentamaran used two models with hull represents a hard chine recommended from model of Savitsky and Wigley. Where the pentamaran which each side consist of two side hulls located on portside and starboard as arrow as a trimaran. A series of tests were carried out on clearance of front-side hull: 1.05B-1.2B; clearance of after-side hull: 1.2B-1.5B; and stagger 0.35L, 0.42L and 0.5L in the whole speed range corresponding to Fn 0.4-1.0. The longitudinal positions (stagger) selected are measured as a percentage of main-hull length and transverse positions (clearance) as a percentage of main-hull width. The experimental study attempts to analysis of the resistance characteristics of diversity hullform and application of design tool based on "Michell" for determination of wave resistance, far-field wave patterns, and wave interference of a pentamaran.

Keywords: *pentamaran, wave resistance, wave pattern, wave interference*

1.0 INTRODUCTION

It has been recognized that the resistance problem of multihull is complicated due to the interference effects between hulls components other than the resistance factors from the shape of hulls and waves flow due to their movement. The addition of the wetted surface area of multihull will automatically increasing the frictional resistance, however the wave resistance can be lowered by the appropriate shape and the proper placement of outriggers. The Shape of hull largely determines speed of a ship, which influence on fuel consumption and behavior in a seaway.

The using of slender hull was a one of solutions to increase the speed and problem solving of existing multihull vessels. The "slender" was used on multihull ships generally a Wigley form. Another form also commonly used on multihull ships with the aim of minimum and highspeed resistance was a warp-chine form. Research of [1] and [2] had proved chine hullform successful reduce resistance and had good propulsive efficiency than Wigley hullfrom.

At the end of the 1920s, Wigley and Weinblum had discovered Michell's integral of the linear theory of ship wave resistance. [3] developed a computation based on

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"Michell" thin ship wave resistance theory and compared it with experiments of [4]. Furthermore Tuck [5, 6] delivered the slender-ship approximation as a generalization of the thin-ship of Michell theory. Here with design tool based on Michell integral as "Michlet" to investigations the hydrodynamic characteristics on wave resistance, far-field wave patterns, and wave interference with diversity hull: warp-chine, which its hull not pure thin and Wigley on several configurations of clearance and stagger. This tool delivered great accurate results and fine detail on inexpensive desktop computers in just a few minutes.

2.0 MODEL CHARACTERISTIC

The pentamaran as trimaran formation was composed main hull and four outriggers, with 2 hulls model to be analyzed i.e. hard chine and Wigley. The hull plan of pentamaran warp-chine is shown in Figure 1 and Wigley in Figure 2, and the dimensional parameters are given in Table 1.

Table 1: Principal characteristics of model pentamaran

Main Dimension	Warp-chine hullform		Wigley hullform	
	Main hull	Side hull	Main hull	Side hull
LOA (m)	1.500	0.414	1.800	0.500
B (m)	0.150	0.030	0.180	0.050
T (m)	0.024	0.012	0.080	0.030
H (m)	0.090	0.078	0.170	0.116
WSA (m^2)	0.491	0.041	0.368	0.033
∇ (m^3)	0.009	3.210x10^{-4}	81.772	1.775
Deadrise β (deg)	20	35	-	-

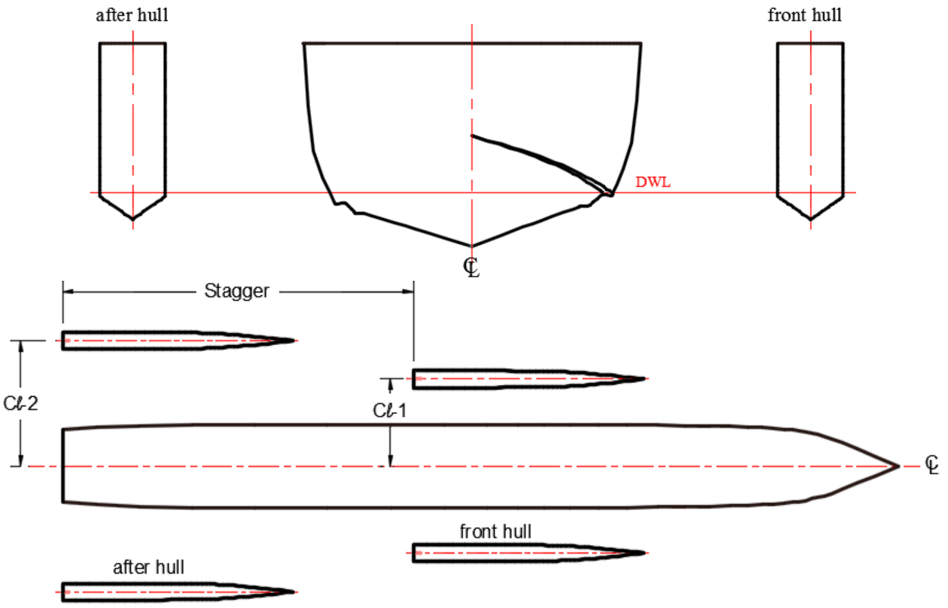

Figure 1: Pentamaran warp-chine hullform

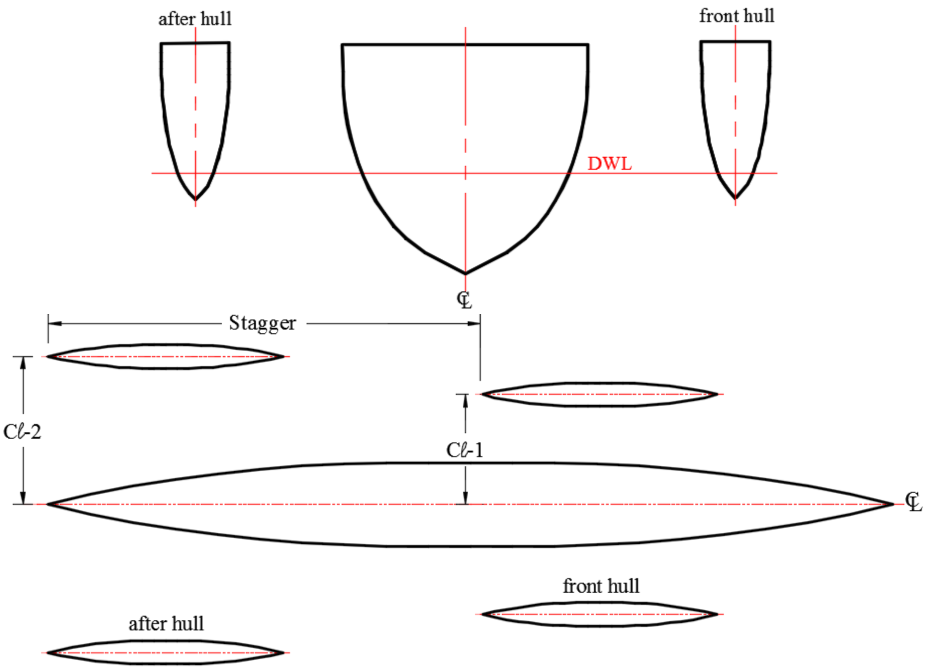

Figure 2: Pentamaran Wigley hullform

The stagger (ST) express the longitudinal position between side hulls as the distance from the transom section of after hull to the transom section of front hull. The transversal position, clearance 1 (Cl-1) express as the distance from the centerline of front hull to the centerline plane of the main hull; clearance 2 (Cl-2) express as the distance from the centerline of after hull to the centerline of the main hull. The stagger as a percentage of Lwl of main-hull and the clearance as a percentage of breadth molded of main-hull.

3.0 EXPERIMENTAL TEST

3.1 Model configuration

[7] to [11] had proved the interference effects with certain combinations of stagger, separation and speeds can significantly reduce the total wave resistance. Here the tests performed on pentamaran to prove the statement of them which it’s carried out on clearance 1 (Cl_1): 1.05 Bml, 1.2Bml; clearance 2 (Cl_2): 1.2Bml, 1.5 Bml; stagger: 0.35L, 0.42L, 0.5L. Twelve configurations of pentamaran were tested which consist of warp-chine hulls expressed as initials C1-C6 and Wigley hulls as initials W1-W6 had shown in Table 2, in speed range corresponding to Fn 0.4 - 1.0.

Table 2: Model test and configurations

Configuration	Stagger (m)	Cℓ -1 (m)	Cℓ -2 (m)
C1/ W1	0.36Lwl	1.20Bml	1.20Bml
C2/ W2	0.36Lwl	1.05Bml	1.50Bml
C3/ W3	0.42Lwl	1.20Bml	1.20Bml
C4/ W4	0.42Lwl	1.05Bml	1.50Bml
C5/ W5	0.50Lwl	1.20Bml	1.20Bml
C6/ W6	0.50Lwl	1.05Bml	1.50Bml

3.2 Towing tests

The configurations models were tested in the Institut Teknologi Sepuluh Nopember towing tank which dimensions are 50 m x 3 m x 2 m. In this towing installed 3 cameras on the front of hull, after stern and between mainhull-sidehull. The hydrodynamic resistance performances in calm water were using ITTC 1957 line and zero correlation allowance. The towing tests setup were performed as shown in Figure 3.

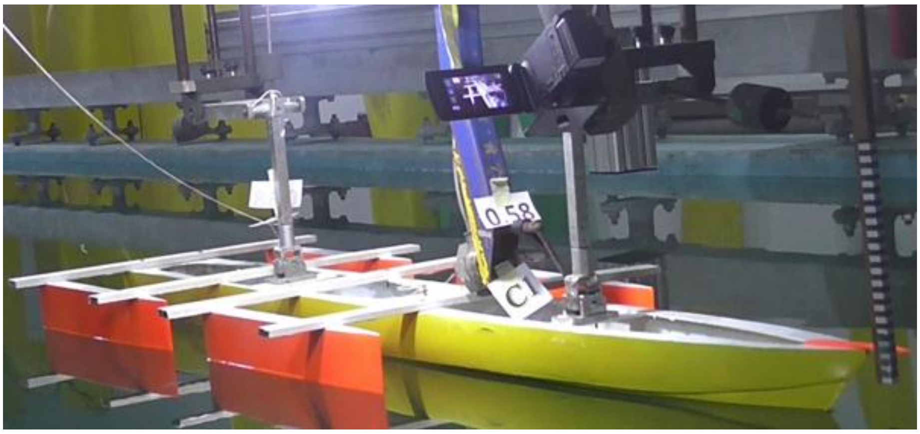

Figure 3: Towing tests setup

3.2 Resistance assessment

[6] represent that Michell's thin-ship theory can be applied to multihull, that the relative interaction error between hulls was proportional to the beam-to-length ratio. The wave resistance (Rw) based on Michell’s theory by integration of the free-wave spectrum as the energy left in the wave system is

$$Rw = \frac{2}{\pi}\rho U^2 k_o^4 \int_{-\pi/2}^{\pi/2} d\theta \sec^2\theta \left| \iint_W dxdz\, Y(x,z) e^{ik_0 x \sec\theta + ik_0 z \sec^2\theta} \right|^2 \tag{1}$$

where y = ±Y (x, y), the hull surface which the (x, z) integral as the centerline W of the ship; ρ, the water density; U, the ship speed; k0= g/U^2, the wavenumber and g is gravity. The integral in bar equation (5) is the complex amplitude function A(θ) called the free wave spectrum.

$$A(\theta) = -\frac{2i}{\pi} k_0^2 \sec^4\theta \iint Y(x,y) \exp(k_0 z \sec^2\theta + ik_0 x \sec\theta)\, dxdz \tag{2}$$

The free-surface wave pattern z = ζ(x,y) of a multihull with N hulls generates amplitude on each hull (j), so the total far field waves:

$$\varsigma(x,y) = \sum_{j=1}^{N} R_W \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} A_j(\theta) e^{-ik(\theta)[(x-xj)\cos\theta + (y-yj)\sin\theta]} d\theta \tag{3}$$

$$= R_W \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} e^{-ik(\theta)[x\cos\theta + y\sin\theta]} \sum_{j=1}^{N} A_j\, e^{ik(\theta)[x_j\cos\theta + y_j\sin\theta]} d\theta \tag{4}$$

here $k(\theta) = k0 \sec^2 \theta$; $Aj\ (\theta) = \sigma j\ Ao(\theta)$ which σj, a fraction of the multihull total displacement. Then the combined wave amplitude is

$$A(\theta) = A_0(\theta)\ F(\theta) \tag{5}$$

$F(\theta)$, wave interference is an factor of wave-making of each hulls which determined by value of $A_0(\theta)$.

$$F(\theta) = \int_{j=1}^{N} \sigma j\, e^{ik(\theta)[xj\cos\theta + yj\sin\theta]} \tag{6}$$

The far-field free-wave patterns on the sectoral patch of aft of ship be illustrated in Figure 10 at Fn 1.0. The color indicates value of Z (x, y) the deepest troughs with dark blue and the highest crests with nearly white.

The experimental is determining the total resistance (R_T) and form factor with a Prohaska method to estimate the viscous component, which the wave resistance (R_W) is obtained via the Hughes [12]

$$R_T = R_W + (1 + k)R_F \tag{7}$$

$$R_F = {}^{1}\!/_{2}\,\rho V^2 S C_F \tag{8}$$

where k, the form factor is obtained with Prohaska's method; RF, the friction resistance; C_F follow the ITTC 1957 formula:

$$C_F = {}^{0.075}\!/_{(logRe - 2)^2} \tag{9}$$

and the total resistance coefficient (C_T); wave coefficient (C_W)

$$C_T = {}^{R_T}\!/_{0.5\rho V^2 S} \tag{10}$$

$$C_W = {}^{R_W}\!/_{0.5\rho V^2 S} \tag{11}$$

The interference resistance of multihull can be calculate by:

$$\Delta R_T = R_{Tpenta} - (R_{Tmain} + 4R_{T_{side}}) \tag{12}$$

4.0 RESULTS

Comparative analysis on multihull between experimental and computation based on Michell's theory has been exposed by [3], where the model and configuration had a significant impact on the hydrodynamic performance of of the multihull. This analysis research had been also performed based on Michell's theories with the computational tool "Michlet" on the configuration variations of Wigley and warp-chine were shown in Figures 4 to 7.

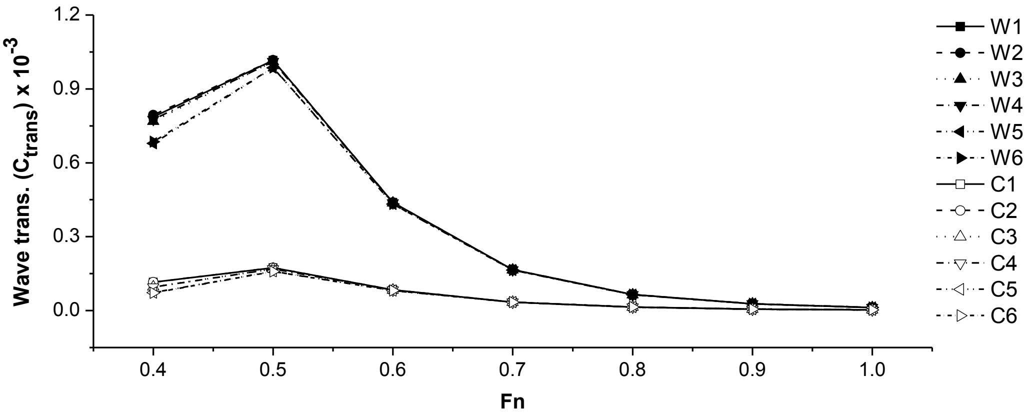

Figure 4: Comparison of transversal wave coefficients for all configurations of Wigley and warp-chine

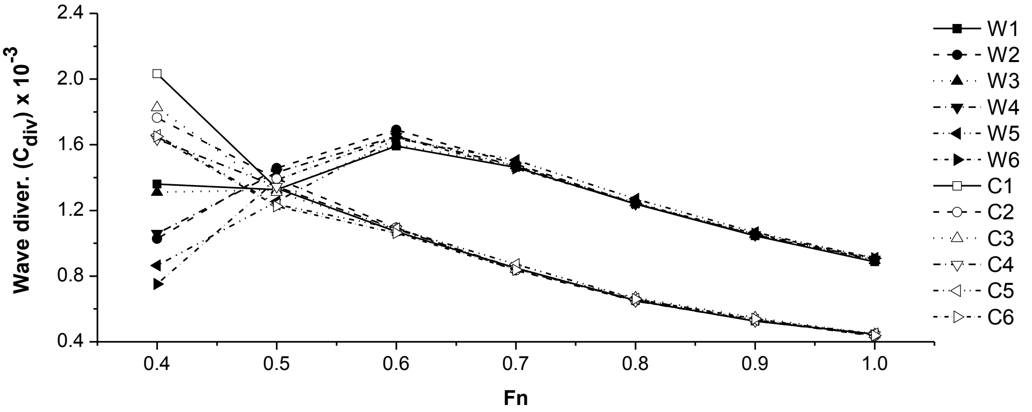

Figure 5: Comparison of divergent wave coefficients for all configurations of Wigley and warp-chine

In Figure 4 the trend of the transversal wave coefficients for all configurations showed basically consistent. The warp-chine models get higher reduction than Wigley with the largest deviation until 82.8% at a range of Fn 0.5. Figure 5 for the divergent wave coefficients and Figure 6 for wave resistance coefficient, had the similarity trend which the warp chine model had a continuously declining trend, while the Wigley model had a hump at Fn 0.5 and subsequently decreased. The deviation between the two models to 24.13% with the warp-chine model was still consistent with the lower values. Negative Interference (Figure 7) had tendency occur to warp-chine model at Fn <0.5, and with increasing Fn the interference of both models Wigley and warp chine had up and then tended to fall at Fn> 0.6.

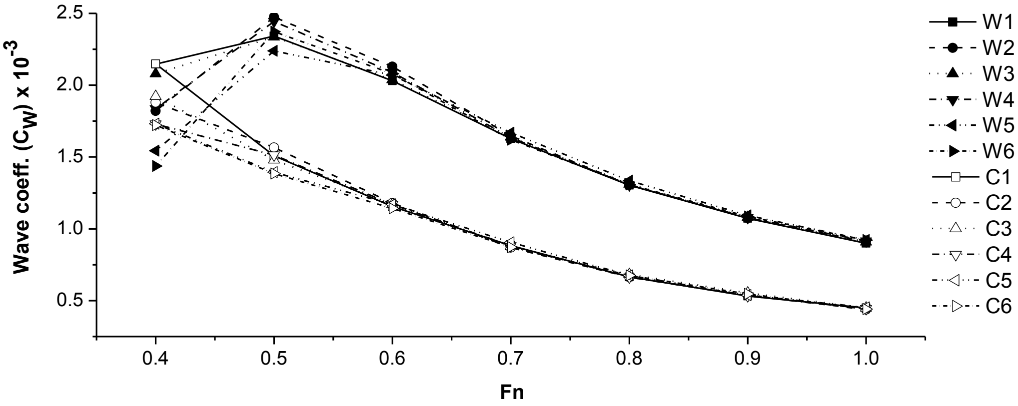

Figure 6: Comparison of wave resistance coefficients for all configurations of Wigley and warp-chine

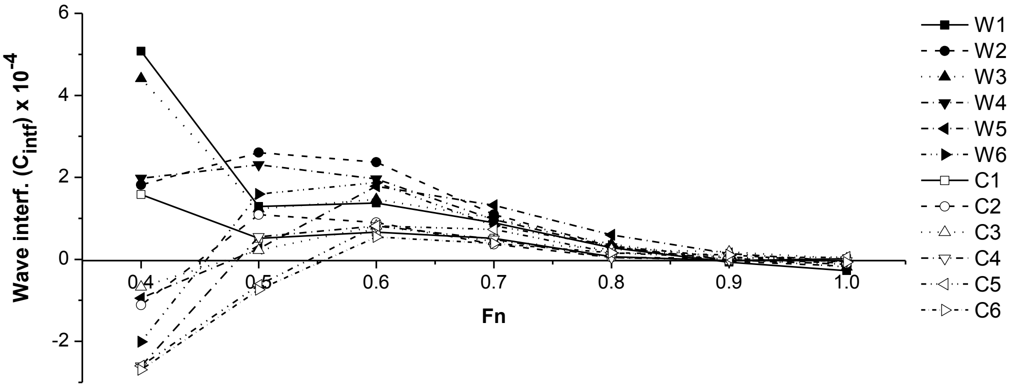

Figure 7: Comparison of wave interference coefficients for all configurations of Wigley and warp-chine

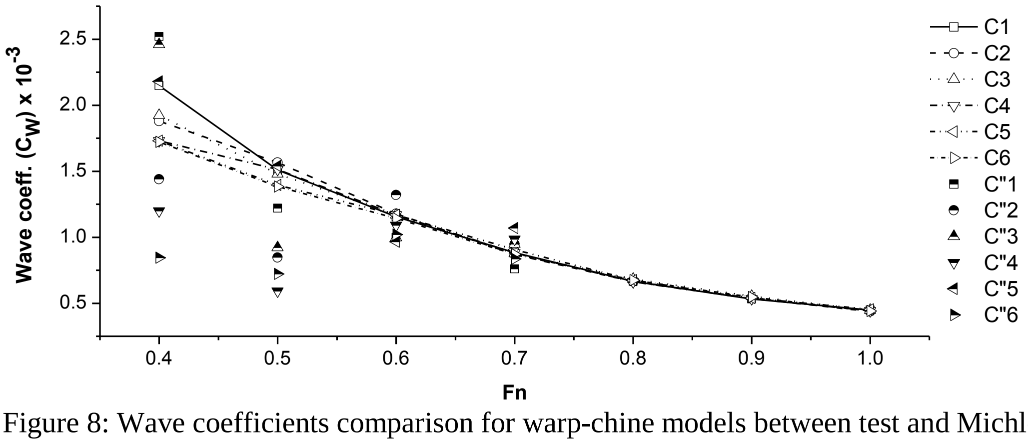

Figure 8: Wave coefficients comparison for warp-chine models between test and Michlet

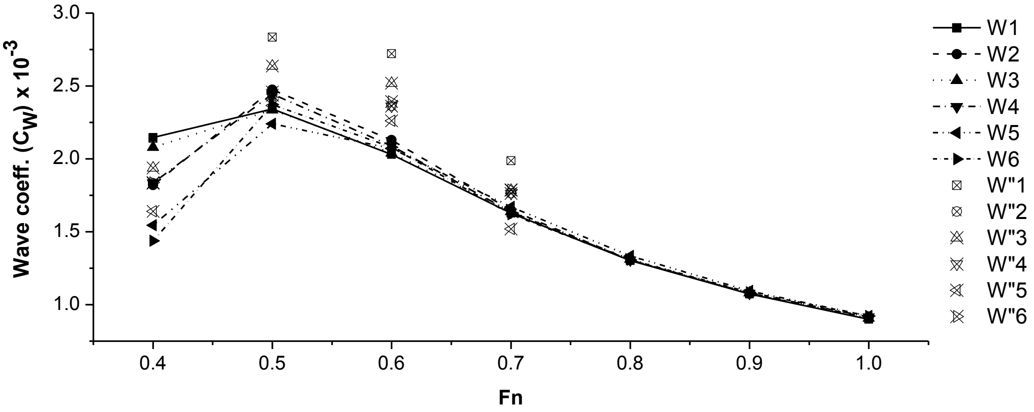

Figure 9: Wave coefficients comparison for Wigley models between test and Michlet

Comparisons of results obtained from calculations by “Michlet” and experimental were not satisfactory especially at Fn below 0.6 as shown in Figure 8 and 9. The addition of a sign (") on both symbol models of Wigley (W) and warp-chine (C) as experimental models. The deviation in average of the wave resistance between two methods for Wigley by 8.25% and warp-chine by 11.8%.

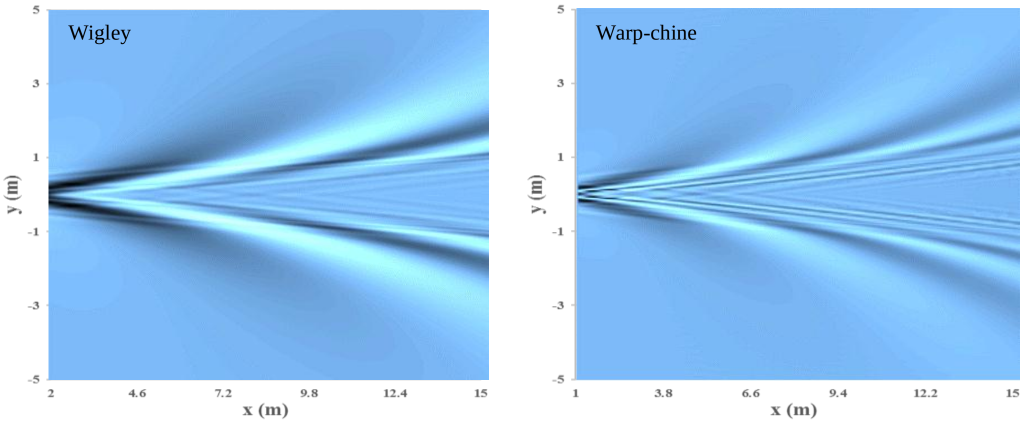

Figure 10: Comparison of far-field wave pattern characteristic of warp-chine (a) and Wigley (b) at Fn 1.0

5.0 CONCLUSION

The experiment tes and computation based on Michell approximation on pentamaran with Wigley and warp-chine had been performed that overall of the resistance components results showed Michell’s theory agreement with the experiments especially at Fn greater than 0.5. The results of configurations of warp-chine much better than Wigley, except for the divergent resistance at Fn 0.4. Increasing stagger S/L of all models has decreased interference at Fn> 0.5, it’s accordance with test by [10] that the interference between hull can be decreased resistance on the proper stagger. Further research is enabling simulation technology to optimize the confinement configuration and apply multi-variation warp-chine that has been done by other researchers.

ACKNOWLEDGEMENTS

This research has been financially supported by Universitas Indonesia of funding Hibah PITTA 2018. The authors gratefully acknowledge use of the services and facilities of ITS Surabaya towing laboratory.

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