Experimental Investigation into the Resistance Components of Displacement Trimaran at Various Lateral Spacings

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Abstract— *An investigation into the breakdown of resistance components of a displacement trimaran was carried out experimentally using a towing tank. A trimaran model consisting of one main-hull with length of 1.2m and two symmetric side-hulls with length of 0.5m was tested at various configurations between Froude numbers of 0.15 and 0.27 at various lateral spacing (S/L) between 0.2 and 0.5. The experimental investigation was conducted using a towing tank belongs to Institute of Technology Sepuluh Nopember (ITS) at Surabaya. Individual test on each part of trimaran hull was also carried out in order to clarify the interference phenomena between the hulls more clearly. Overall results indicated that the wider the hull separation, the smaller the interference between the hulls. The widest separation (S/L=0.5) indicated that there is nointerference between the hulls and this is in good agremeent with individual test of each hull when interference is neglected.*

Keywords— trimaran, resistance, tank test, CFD, separation, interference

I. INTRODUCTION

The increase use of vessels for carrying cargoes and passengers in order to decrease the use of energy has developed intensively since the last 4 decades. Various hull form and configuration has been developed and these include the development of mono- and multi-hull types of vessel. Among those vessels, the use of multihulls (catamaran and trimaran) have received considerable attention due to its better transverse stability and providing wider deck are compared to the monohulls such as reported by byInsel and Molland (1992), Utama (1999), and Jamaluddin (2012). Multihull ships show unique resistance characteristics such as outlined by Turner and Taplin (1968) describing the powering of large size catamaran; Larssonand Baba (1996) discussing the breakdown of resistance into its components; Pien (1976), Miyazawa (1979), and Liu and Wang (1979) explaining the determination of estimation of resistance interference of a catamaran, Insel and Molland (1992) introducing the breakdown of catamaran resistance and proposed a mathematical formulation on the prediction of its resistance; Utama (1999) expressing the estimation of catamaran viscous resistance using experimental approach; and Utama et al (2008) discussing the resistance estimation of river catamaran and trimaran using experimental technique.

Trimaran, in particular, is a kind of multihull type of vessels comprising one main-hull placed inside and two side-hulls with lower length compared to the main-hull. Several work indicated that trimaran can offer lower resistance at higher speeds compared to monohulls (Maynard et al, 2008) and even to catamaran (Murdijanto et al, 2011).Meanwhile, Pei-yong et al (2002) did a study into the wave-making resistance and wave resistance interference of trimaran experimentally, and Muscat-Fenech and La Rosa (2014) investigated the resistance of trimaran at various configurations of separation and draught. Both discovered interesting phenomenon related to wave resistance and wave resistance intereference as well as the way to reduce total ship resistance.

Overall, the work into the improvement of hull-form, including trimaran, have been carried out intensively worlwide in order to increase the speed in one hand, and reduce the energy consumption in the other hand (Molland et al, 2014). The work especially explained that trimaran hull form has interesting phenomena, in term of resistance characteristics, compared to monohulls and even to catamarans. The resistance of catamaran, in one hand, has been formulated well such as the work done by Insel and Molland (1992) and followed by other work to enrich and improve the formulation such as the work done by Utama and Molland (2001), Sahoo (2007), and Jamaluddin et al (2012a, 2012b). The resistance of trimaran, in the other hand, cannot be formulated yet such as the the mathematical expression of catamaran because the number of its configuration can be hundreds. The current work is attempted to provide such detail information on trimaran resistance based on certain configuration of separation. In this case, the position of the two side-hulls is made parallel and in one line with the main hull.

1.1 Resistance of Monohull

William Froude is known as the pioneer on the prediction of ship resistance using a model which is far smaller than the real ship (Date and Turnock, 1999). Froude (1868) described that the total ship resistance consists of frictional resistance and residuary resistance, which is dominated by wave resistance. Froude's expression is formulated as:

$$C_T = C_F + C_R \tag{1}$$

Where C_T is total resistance coefficient, C_F is frictional resistance coefficient, and C_R is residuary resistance coefficient.

The approach of William Froude was improved by Hughes (1954) and Granville (1956), which introduced the term of form factor in order to take into account three-dimensional effect of the ship hull form. The total resistance is later grouped into 3 (three) main components, namely (1) *frictional resistance*, which is a tangential force created as a reaction between the molecules of water and the skin hull of ship and later known as resistance of surface area with comparable area and length with the ship model, (2) formor pressure resistance arises because of the shape of object and depends on the longitudinal section of the body and part of its component is popularly known as form factor (1+k), and (3) wave resistance is a form of drag that affects surface watercraft, such as boats and ships, and reflects the energy required to push the water out of the way of the hull and this energy goes into creating the wave.

The description is formulated mathematically as:

$$C_T = (1+k)\, C_F + C_W = C_V + C_W \tag{2}$$

Where C_W is wave resistance coefficient, (1+k) is form factor, and $(1+k)\ C_F$ is viscous resistance coefficient which later expressed as $(1+C_V)$.

The value of C_F may be estimated using ITTC-1957 correlation line:

$$C_F = \frac{0.075}{(\log(\mathrm{Re}) - 2)^2} \tag{3}$$

Furthermore, international standard by ITTC (1978), practically classified the total ship resistance into 2 (two) main components, namely viscous resistance as a function of Reynolds (Re) number and wave resistance as a function of Froude number (Fr) and the correlation between the 2 (two) components is formulated as:

$$R_{T(Fr,\ Re)} = R_{W(Fr)} + R_{V(Re)} = R_{W(Fr)} + (1+k)_{(Fr)}\ R_{F(Re)} \tag{4}$$

Later the resistance components are broken down into further details and including spray, wave breaking, transom drag, induced drag, etc such as described by (Couser et al, 1997).

1.2 Resistance of Trimaran

Resistance of a trimaran can be calculated from the resistance of each individual hull (mainhull and sidehulls). However, when the three hulls are combined together and forming a trimaran, its total resistance is higher than the summation of individual resistance. The difference is attributed to resistance interference or interaction. Certain formulation to calculate the total resistance and its interference is not avaiable yet, but simple formulation by Pien (1976) andJamaluddin (2012) may be used and expressed as:

$$IF = \frac{R_{T2}}{R_{T1}} \tag{5}$$

Where IF is interference factor, R_{T2} is total resistance of trimaran configuration, and R_{T1} is total resistance of individual hull forming a catamaran.

II. METHODOLOGY

The investigation was conducted experimentally using a ship model and tested at ITS towing tankwith particulars: length (L) of 50m, Breadth (B) of 3m, depth (H) of 2m, maximum draft (T) of 1.8m and maximum speed of carriage is 4.0 m/s. The particulars, body plan and trimaran configuration, and setting of the model are shown in Table 1, Figures 1 and 2 and Figures

3 to 6, respectively. The test was conducted at various speed (and Froude numbers) and space to length ratios or clearances (S/L) as shown in Table 2:

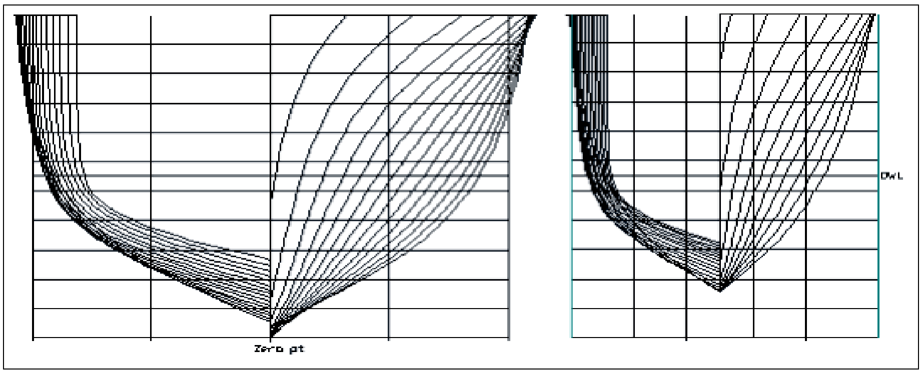

FIGURE 1. BODY PLAN OF MODEL: MAINHULL (A) AND SIDEHULL (B)

TABLE 1
PRINCIPLE PARTICULARS OF TRIMARAN VESSEL AND MODEL

Particular		Trimaran vessel	Model
$LOA_{Mainhull}$	m	74.140	1.2525
$LPP_{Mainhull}$	m	72.090	1.2178
$LOA_{Sidehull}$	m	62.639	1.0582
$LPP_{Sidehull}$	m	60.177	1.0166
$B_{Mainhull}$	m	9.901	0.1675
$B_{Sidehull}$	m	5.710	0.0965
B (S/L = 0.2)	m	34.550	0.5836
B (S/L = 0.3)	m	48.980	0.8274
B (S/L = 0.4)	m	63.380	1.0707
B (S/L = 0.5)	m	77.940	1.3166
H	m	7.160	0.1210
T	m	3.951	0.0667
WSA	m^2	1367.93	0.3904
Displacement	ton	1440.00	0.006942

TABLE 2
CONFIGURATION AND VARIOUS SPEED OF TEST

Froude Numbers (Fr)	Type of ship	Clearance (S/L)
0.15, 0.17, 0.19, 0.21, 0.23, 0.25, 0.27	Trimaran	0.2, 0.3, 0.4, 0.5

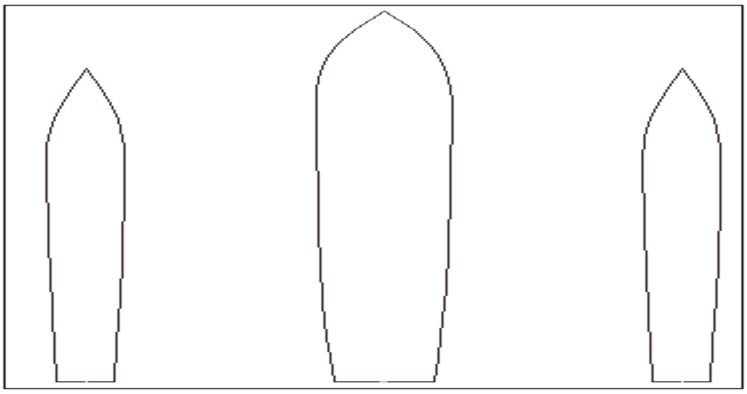

FIGURE 3. TRIMARAN CONFIGURATION

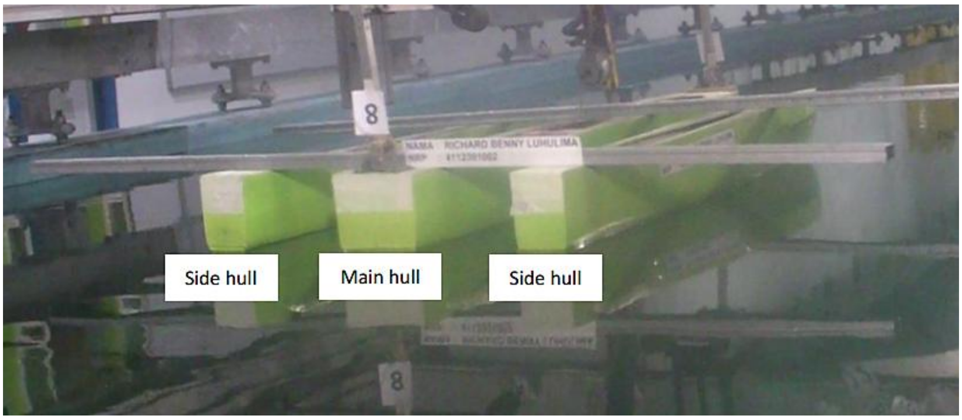

FIGURE 3. SETTING OF TRIMARAN MODEL S/L=0.2

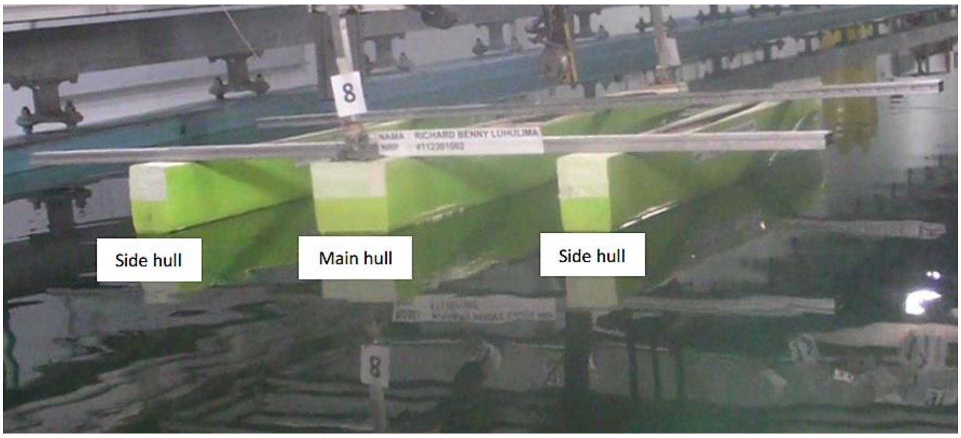

FIGURE 4. SETTING OF TRIMARAN MODEL S/L=0.3

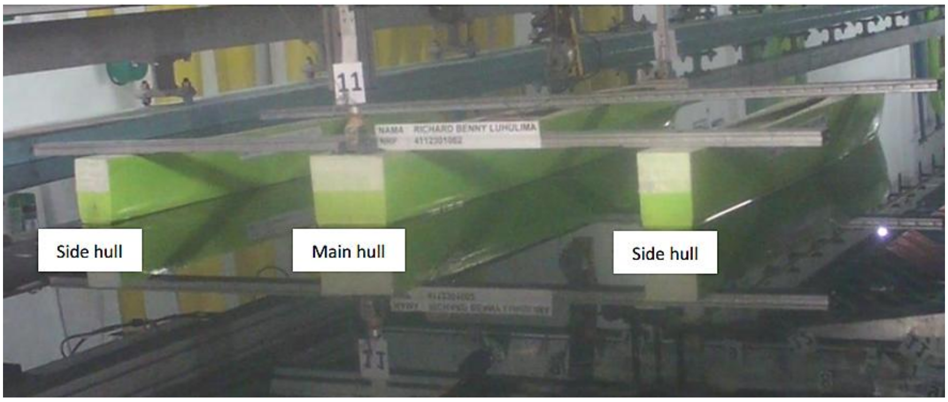

FIGURE 5. SETTING OF TRIMARAN MODEL S/L=0.4

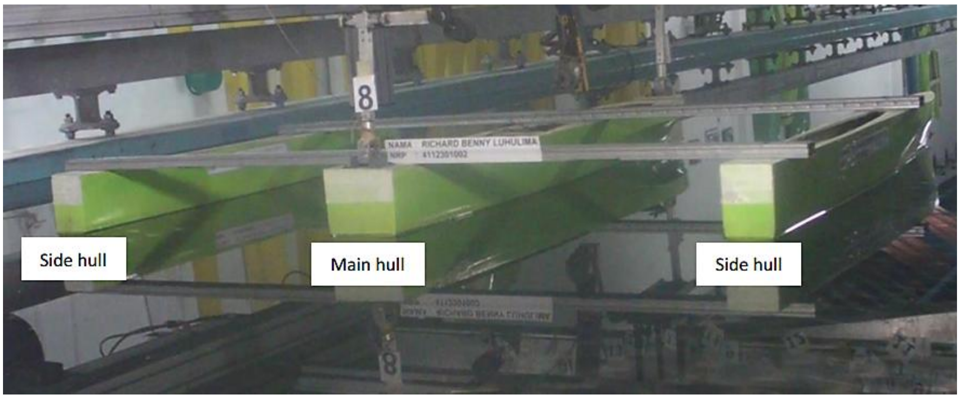

FIGURE 6. SETTING OF TRIMARAN MODEL S/L=0.5

According to the international towing tank conference (ITTC) standard, calibration of the load cell must be carried out in order to make sure that the load cell provides the real and correct results of measurement (ITTC, 1978). The calibration test was conducted as follows. A load cell of 2 kg is measured and calibrated and the results is analysed through computer data analysis system. The accepted error is less than 5% (ITTC, 1978). If the record in computer shows the error of measurement is less than 5% thus the load cell can be used for the tank test experiment. If not, calibration process must be repeated. Blockage correction was also conducted according to (Utama, 1999) and it was find out that there was no effect of the cross-sectional size of the tank and distance from sidehull of the widest spacing (S/L=0.5) on the total resistance.

III. RESULTS

3.1 Total, Viscous, and Wave Resistance Coefficients

The recommended method to obtain the values of '1+k' can be done by carrying out a low speed test where C_W closes to zero hence hence Equation (2) can be simplified into $(1+k)=C_T/C_F$. In this case, the method of Prohaska (ITTC 1978, 2002; Bertram 2000) may be used:

$$C_T = (1+k)\, C_F + a\, Fr^n \tag{6}$$

It is assumed that $C_W = aFr^n$for low speed test (generally $Fr< 0.2$), and *form factor (1+k)* can be calculated through *straight-line plot* between C_T/C_FdanFr^4/C_F coincides at Fr=0, and the values of $n = 4 – 6$ and generally used as n=4 (Molland et al, 2011) as shown in Figure 7.

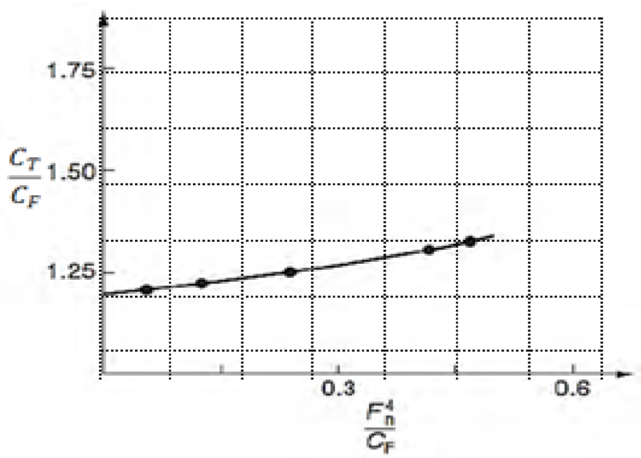

FIGURE 7. PROHASKA METHOD TO ESTIMATE FORM FACTOR (1+K) (MOLLAND ET AL, 2011)

The results of form factor estimation were tabulated in Table 3 indicating form factor of individual trimaran (1+k) and trimaran at various spacing (1+βk). These were then recalculated using Equation (2) to give total resistance (C_T), viscous resistance (C_V), and wave resistance (C_W), respectively.

TABLE 3
VISCOUS FORM FACTOR FROM TANK TEST RESULTS

1+k	1+βk			
Trimaran Hull	*Trimaran Hull Clearances (S/L)*			
	0.2	0.3	0.4	0.5
1.274	1.287	1.285	1.279	1.277

The results of experimental investigation were summarized in Tables 4 to 6 and figured out in details in Figures 8 to 10 showing the magnitude of each resistance components at various speeds (Froude numbers) and separation to length ratio (S/L).

TABLE 4
TOTAL RESISTANCE COEFFICIENT ESTIMATION

Fr	Total Resistance Coefficient				
	Trimaran Hull ($x\ 10^{-3}$)	S/L = 0.2 ($x\ 10^{-3}$)	S/L = 0.3 ($x\ 10^{-3}$)	S/L = 0.4 ($x\ 10^{-3}$)	S/L = 0.5 ($x\ 10^{-3}$)
0.15	4.207	4.257	4.248	4.228	4.218
0.17	4.358	5.169	5.108	4.779	4.367
0.19	4.623	5.375	5.246	5.025	4.697
0.21	5.135	5.862	5.605	5.456	5.162
0.23	5.708	6.557	6.288	5.977	5.777
0.25	5.88	6.681	6.581	6.312	6.058
0.27	5.865	6.792	6.728	6.346	6.092

TABLE 5
VISCOUS RESISTANCE COEFFICIENT ESTIMATION

Fr	Viscous Resistance Coefficient				
	Trimaran Hull ($x\ 10^{-3}$)	S/L = 0.2 ($x\ 10^{-3}$)	S/L = 0.3 ($x\ 10^{-3}$)	S/L = 0.4 ($x\ 10^{-3}$)	S/L = 0.5 ($x\ 10^{-3}$)
0.15	3.301	3.307	3.306	3.305	3.303
0.17	3.26	3.263	3.262	3.261	3.26
0.19	3.208	3.213	3.211	3.21	3.209
0.21	3.178	3.182	3.18	3.179	3.178
0.23	3.151	3.158	3.156	3.154	3.152
0.25	3.136	3.142	3.14	3.139	3.137
0.27	3.104	3.11	3.108	3.108	3.106

TABLE 6
WAVE RESISTANCE COEFFICIENT ESTIMATION

Fr	Wave Resistance Coefficient				
	Trimaran Hull ($x\ 10^{-3}$)	S/L = 0.2 ($x\ 10^{-3}$)	S/L = 0.3 ($x\ 10^{-3}$)	S/L = 0.4 ($x\ 10^{-3}$)	S/L = 0.5 ($x\ 10^{-3}$)
0.15	0.906	0.95	0.942	0.922	0.915
0.17	1.098	1.906	1.846	1.518	1.107
0.19	1.416	2.163	2.035	1.815	1.488
0.21	1.958	2.68	2.425	2.278	1.984
0.23	2.557	3.399	3.132	2.823	2.625
0.25	2.744	3.539	3.441	3.173	2.921
0.27	2.761	3.681	3.62	3.238	2.985

It is apparent that as the spacing (S/L) increases, the resistance interference decreases and this is in good agreement with the work done by Insel and Molland (1992), Utama (1999), and Jamaluddin (2012). It was shown that the total, viscous and wave resistances at the highest spacing (S/L=0.5) is nearly the same as the total resistance of individual trimaran when the interference is not taken into consideration. It is an indication that the interference tendsto be zero or unity at the widest spacing and this can be found in Tables 7 to 9. This fact agrees well with the work done by Couser et al (1997) and Utama (1999).

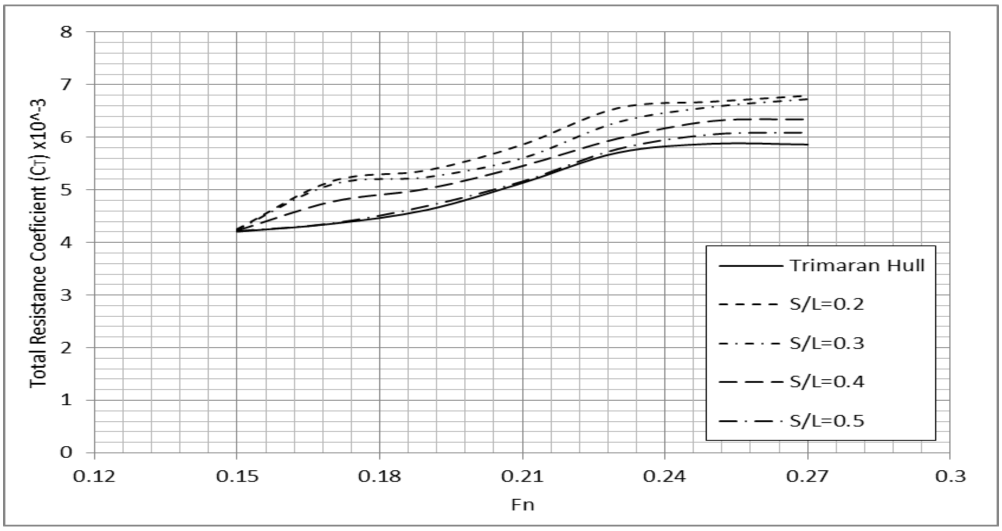

FIGURE 8. TOTAL RESISTANCE COEFFICIENT OF TRIMARAN

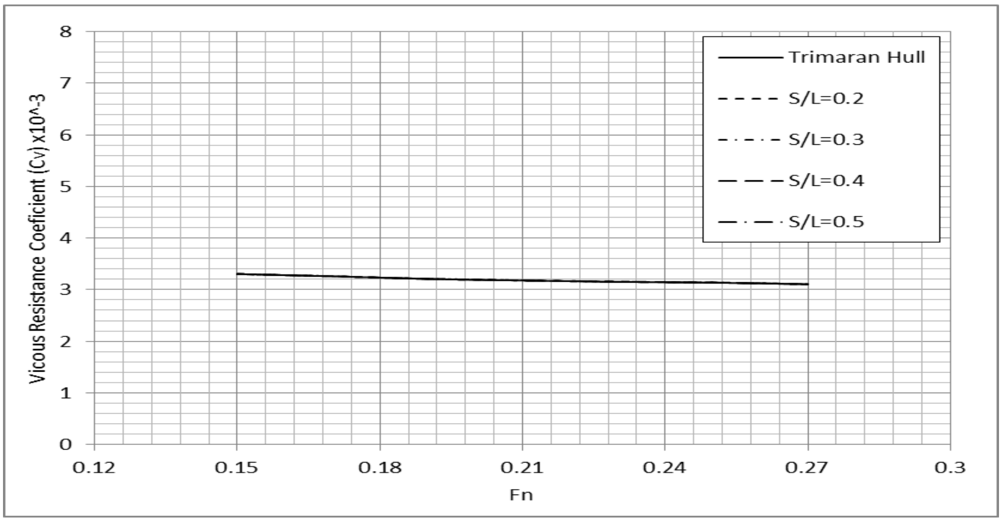

FIGURE 9. VISCOUS RESISTANCE COEFFICIENT OF TRIMARAN

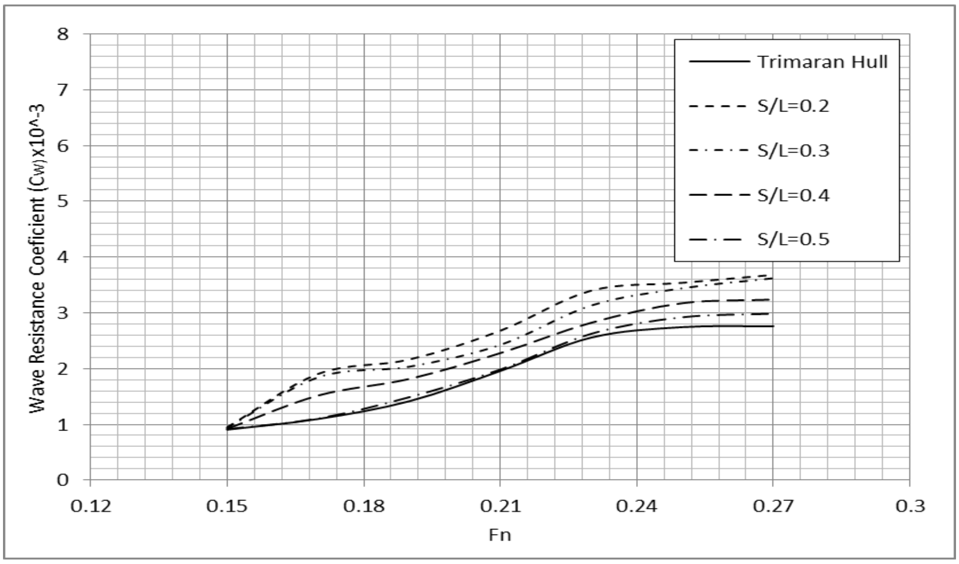

FIGURE 10. WAVE RESISTANCE COEFFICIENT OF TRIMARAN

If investigated more closely, it is obvious that the total resistance interference was about 2%, whilst the viscous resistance interference and wave resistance intereference were about 0.1% and 4%, respectively. It is an indication that wave resistance interference is predominant than viscous resistance interference, which is tend to be zero or very small because the hull of catamaran is quite slender (L/B mainhull ≈ 8 and L/B sidehull ≈ 8). In addition, the interference tends to increase as the speed increases and this is attributed to more intensive (especially wave) interference created at higher speed.

TABLE 7
TOTAL RESISTANCE INTERFERENCE EXPERIMENT

Fr	Total Resistance IF			
	S/L = 0.2 (x 10^{-3})	S/L = 0.3 (x 10^{-3})	S/L = 0.4 (x 10^{-3})	S/L = 0.5 (x 10^{-3})
0.15	1.012	1.010	1.005	1.003
0.17	1.186	1.172	1.097	1.002
0.19	1.163	1.135	1.087	1.016
0.21	1.142	1.092	1.063	1.005
0.23	1.149	1.102	1.047	1.012
0.25	1.136	1.119	1.073	1.030
0.27	1.158	1.147	1.082	1.039

TABLE 8
VISCOUS RESISTANCE INTERFERENCE

Fr	Total Resistance IF			
	S/L = 0.2 (x 10^{-3})	S/L = 0.3 (x 10^{-3})	S/L = 0.4 (x 10^{-3})	S/L = 0.5 (x 10^{-3})
0.15	1.002	1.002	1.001	1.001
0.17	1.001	1.001	1.000	1.000
0.19	1.002	1.001	1.001	1.000
0.21	1.001	1.001	1.000	1.000
0.23	1.002	1.002	1.001	1.000
0.25	1.002	1.001	1.001	1.000
0.27	1.002	1.001	1.001	1.001

TABLE 9
WAVE RESISTANCE INTERFERENCE

Fr	Total Resistance IF			
	S/L = 0.2 (x 10^{-3})	S/L = 0.3 (x 10^{-3})	S/L = 0.4 (x 10^{-3})	S/L = 0.5 (x 10^{-3})
0.15	1.049	1.040	1.018	1.010
0.17	1.736	1.681	1.383	1.008
0.19	1.528	1.437	1.282	1.051
0.21	1.369	1.239	1.163	1.013
0.23	1.329	1.225	1.104	1.027
0.25	1.290	1.254	1.156	1.065
0.27	1.333	1.311	1.173	1.081

IV. CONCLUSION

The present study has demonstrated the use of experimental method into the breakdown and analysis of trimaran resistance quite successfully. It is clear that the resistance interference decreases as the spacing or separation between the hull increases. The resistance interference is dominated by wave resistance interference (and not by viscous resistance interference). This is due to the slenderness of the hull in one hand, and the creation of more excessive wave (and hence the wave interference) at higher speeds. The wave resistance interference contributed about 4% effect on the total resistance, whilst the viscous resistance interference is only about 0.1%.

The overall results showed that the widest separation can give almost the same resistance and hence power requirement. This is a good indication that trimaran configuration can give lower resistance than monohull of similar displacement in order to reduce the use of fossil fuels and hence to decrease the effect of toxic gases into the atmosphere.

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