A Study into the Selection of Mono- and Multi-Hull Vessel for Better Sea Transportation System

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Abstract: Intensive and continuous research into the development of monohull and multihull vessels (catamaran and trimaran) has been carried out at the Department of Naval Architecture of the Institute of Technology Sepuluh Nopember (ITS) at Surabaya – Indonesia. The work covers the aspects of resistance and powering, ship stability, layout arrangement and ship performance at sea which is better known as seakeeping. Three configurations of ship, namely mono-hull, twin-hull (catamaran), and three-hull (trimaran), were compared. In details, resistance and powering and seakeeping aspects were based on experimental and numerical investigations, ship stability evaluation was centred on the international maritime organization (IMO) criteria, and layout arrangement review was based on general ship design criteria. Final results show that the three types of vessel have demonstrated its own advantages, for example catamaran and trimaran has better transverse stability and monohull shows better seakeeping characteristics at higher speed. These results are also compared with other published data, which show very close agreement.

Keywords: Resistance and powering, stability, layout arrangement, seakeeping.

1 INTRODUCTION

During the last decade multihull ships have been very rapidly evolved into a dominant mode of sea transportation. Their particular area of proliferation is the short sea shipping where they show considerable superiority over competitive designs in attributes such as power requirements, economy, space availability and seakeeping. The rapid growth of the market has led to the need for an expanded range of multihull designs in terms of size, speed, and payload diversity (passengers, vehicles, containers). Various types of vessel are further developed in order to satisfy the design criteria. Among others, the concept of catamaran is preferred and becoming more popular (Sahoo et al, 2007). Pal and Doctors (Pal et al, 1995) developed a preliminary design method to provide accurate solution of catamaran passenger vessel. Meanwhile, trimaran hull form or vessel with three hulls has received considerable attention because it can provide even bigger deck area and shallower-draft (Utama et al, 2007; Subramanian et al, 2006). The form of trimaran is popularly used as warships because of its high quality of stability (Hebblewhite, 2008).

The calculation of power required by the catamarans needs an investigation into the resistance characteristics entirely in order to obtain the most by ship design (Molland, 2008). The resistance of catamaran can provide complex phenomena to ship designers particularly with the appearance of interaction between the demihull of catamaran. Therefore, it has been a basic need to obtain the breakdown and understanding of correct ship resistance components in order to obtain accurate calculation based on scaling transformation from model to the real ship.

A systematic investigation has been made by Insel and Molland (Insel, 1992; Utama et al, 2001) showing that there is a certain separation between 2 demihulls causing very small interaction or in practice it can be said that there is no interaction. The small interactions occur at separation to length ratio (S/L) of 0.4 and 0.5 and this provides an idea that a catamaran with similar displacement to comparable monohull could have smaller resistance and power of main engine.

Further investigation on the catamaran resistance is pioneered by Soeding (Söding, 1997) who found out that the reduction of ship resistance significantly when the demihull is varied longitudinally and this is known as staggered catamaran. Utama et al (Utama et al, 2008) applied NPL 5c model and found out that the reduction of resistance occurs when the catamaran was varied transversely (un-staggered) and longitudinally (staggered). If this is applied to a real ship, it has the potency to safe the use of fuel significantly.

The investigation was carried out both experimentally and numerically. The experimental work was conducted using towing tank and 3 ship models were applied, namely monohull, catamaran and trimaran and tested at various speed and separation to length (S/L) ratios. The numerical work was carried out using commercial ship design software (Maxsurf).

Physical models of the monohull, catamaran and trimaran are shown in Figures 1 to 3. The models were made from FRP (fibreglass reinforced plastics) in order to obtain appropriate displacement as scaled from full ship mode in accordance with Froude law of similarity. Principal particulars of the three ships are given in Tables 1 to 3.

The models were tested at speed equal to the speed of real vessel at open sea from about 5 to 10 knots and the Froude numbers are about 0.30 to 0.40. The catamaran and trimaran modes were tested at separation to length (S/L) ratios of 0.2, 0.3 and 0.4 following the works of Insel and Molland (Insel et al, 1992; Utama et al, 2001). Details of the results can be found in Utama et al (Utama et al, 1992).

2 MODEL DESCRIPTION AND TEST SET-UP

The models (mono, catamaran and trimaran) were produced according to a scale of 1 to 9. Their principal dimensions and mass properties are shown in Table 1. The model was statically and dynamically balanced to adjust the position of centre of gravity and radii of gyration as specified.

A series of model tests was conducted at the towing tank of Indonesian Hydrodynamic Laboratory (IHL). In this model tests, there were two series of tests, firstly the resistance tests where the model was towed by the carriage The model was connected to the load cell transducer at a point located amidships and vertically at 0.45T above base line, allowing the model to move freely in the vertical plane, and secondly the seakeeping tests where the model was free sailing by its self propulsion systems.

Table 1. Principal data of monohull, catamaran and trimaran

Dimension	Mono	Catamaran		Trimaran	
		Twin	Demi	Main	Side
LWL (M)	13.8	14.5	14.5	14.5	12.0
B (M)	2.88	7.66	1.86	2.00	1.15
D (M)	0.65	0.65	0.65	0.72	0.52
H(M)	1.30	1.30	1.30	1.44	1.24
Cb	0.50	0.38	0.382	0.384	0.39
DISP	11.8	11.8	5.90	6.96	2.42
TOTAL DISP	11.8	11.8		11.8	

a) Resistance Test Set-up.

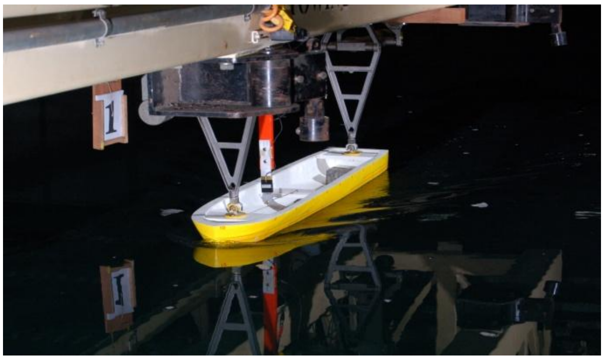
Figure 1a. Monohull model

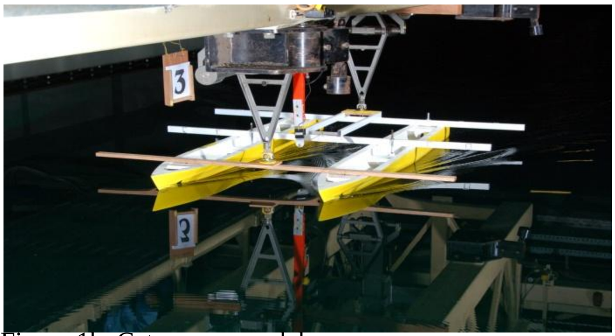
Figure 1b. Catamaran model

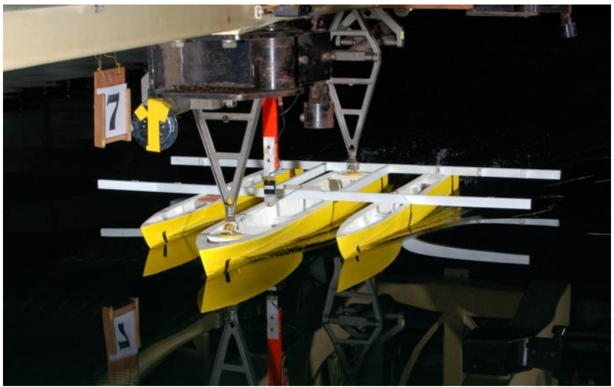
Figure 1c. Trimaran model

b) Seakeeping Test Set-up

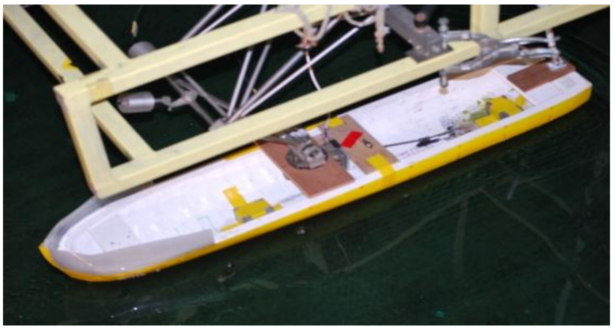

Figure 2a. Monohull model

Figure 2b. Catamaran model

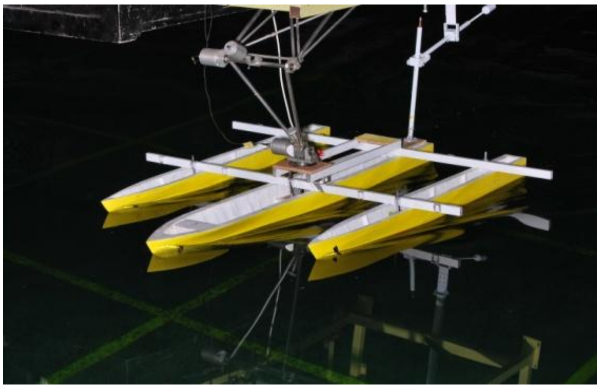

Figure 2c. Trimaran model

During the tests the model was fitted with a target frame and the model motions could be detected by camera tracking system which attached to the above of the towing carriage. The resistance and seakeeping test set-up are shown in Figure 1 and 2.

3 EXPERIMENTAL AND NUMERICAL RESULTS

The wider space area for activities on main deck is the main concern for the commercial sea transportation now. The space area on main deck for catamaran is mostly related to the separation length ratio (S/L). Therefore this ratio need to be investigated and discussed into the resistance performance to estimate the ship power and seakeeping qualities.

3.1. Resistance/ Powering

The most widely used estimation of catamaran resistance is the method proposed by Insel and Molland (Insel, 1992). In this case, catamaran hull consists of 2 isolated demihulls and creates wave and viscous resistance interference and formulated as follows:

$$C_T = (1 + \phi\, k)\sigma\, C_F + \tau\, C_W \qquad (1)$$

Where:
C_T is total resistance coefficient,
C_F is frictional resistance coefficient and obtained from ITTC-1957 correlation line,
C_W is wave resistance coefficient of isolated demihull,
(1+k) is form factor value of isolated demihull,
ϕ is used to estimate the change of pressure around demihull,
σ represents additional velocity between demihulls and calculated from the summation of local frictional resistance around wetted surface area.

In fact, the factors of ϕ and σ are difficult to measure hence for the practical purposes, the two factors can be combined to form viscous resistance interference factor β where $(1 + \phi\, k)\sigma = (1 + \beta\, k)$ hence:

$$C_T = (1 + \beta\, k)C_F + \tau\, C_W \qquad (2)$$

Where for monohull or demihull at isolation the value of β=1 and τ =1.

Empirical formulation to estimate the total resistance of trimaran is so far not known and depends highly on the experimental results (Doctors, 1991). This is attributed to the minimum publications of trimaran resistance both experimentally and numerically. Results of the experimental work were tabulated in Table 2, which described the correlation of resistance against speeds of ship.

The results from Maxsurf were shown in Table 3. Despite the software does not take resistance interaction between the hulls, the numerical study was taken at S/L=0.4 when there is presumably no significant interaction between demihulls (Insel, 1992; Utama et al, 1999).

Table 2. Results of monohull, catamaran and trimaran tests

Fr	Mono	Catamaran S/L			Trimaran S/L		
		0.2	0.3	0.4	0.2	0.3	0.4
0.25	1.07	1.82	1.66	1.66	1.92	1.83	1.66
0.26	1.74	2.14	1.85	2.06	2.14	2.43	2.05
0.29	2.24	2.44	2.24	2.35	2.76	2.70	2.30
0.31	2.88	2.85	2.68	2.95	3.72	3.49	2.62
0.33	3.71	3.46	3.57	3.55	4.33	4.23	2.80
0.35	5.00	4.47	3.95	3.77	4.96	4.80	3.01
0.36	6.06	4.84	4.35	4.34	5.58	5.40	3.38
0.39	7.26	5.15	4.79	4.66	6.15	5.85	3.58
0.40	7.67	5.81	5.59	5.51	7.23	6.81	3.81

Table 3. Results of monohull, catamaran and trimaran from Maxsurf

Fr	Monohull	Catamaran S/L=0.4	Trimaran S/L=0.4
0.26	1.06	1.20	1.34
0.28	1.18	1.32	1.47
0.29	1.30	1.44	1.62
0.32	1.66	1.68	1.91
0.34	1.85	1.82	2.06
0.35	1.99	1.94	2.21
0.37	2.10	2.08	2.39
0.38	2.20	2.24	2.57
0.39	2.31	2.40	2.78
0.41	2.88	2.56	3.00
0.44	4.54	3.16	3.66

3.2. Seakeeping

The requested random wave condition was adjusted prior to the actual model. This condition was done by measuring wave height at the neutral position of the model. The wave elevation was measured by means of a resistance wire type wave probe. The irregular waves were adjusted such that the spectral density distribution compares with the required theoretical energy distribution

When there is a linear relation between wave elevation and motions, accelerations or forces, this relation can be presented in the frequency domain with response functions or Response Amplitude Operators (RAOs). These RAOs give the ratio between the input wave amplitude and the output signal for each wave frequency and can be calculated using the spectral densities of the calibrated wave and the output signals according to [15]:

$$H_u = \frac{u_a(\omega_e)}{\zeta_a(\omega_e)} = \sqrt{\frac{S_{uu}(\omega_e)}{S_{\zeta\zeta}(\omega_e)}} \tag{3}$$

In which:

H_u = response function of a signal u

$U_a(\omega_e)$ = amplitude of frequency ω_e of signal u

$\zeta_a(\omega_e)$ = amplitude of frequency ω_e of wave elevation ζ

$S_{uu}(\omega_e)$ = spectral density of signal u

$S_{\zeta\zeta}(\omega_e)$ = spectral density of wave elevation ζ

Experimental investigation into seakeeping of the three ship modes was carried out under head sea condition, ship speed of 6.5 knots and sea state of 3 which indicates a condition known as sea breeze (Bhattacharyya, 1978; Faltinsen, 1990). The tests were focused on the motions of heave, pitch and surge. Roll motion was not investigated because of the equipment problem. The rolling apparatus did not work when the test was carried out. However, the roll motion is considered to be small in head seas (Jia, 2009). The results are shown in Figures 3 to 5.

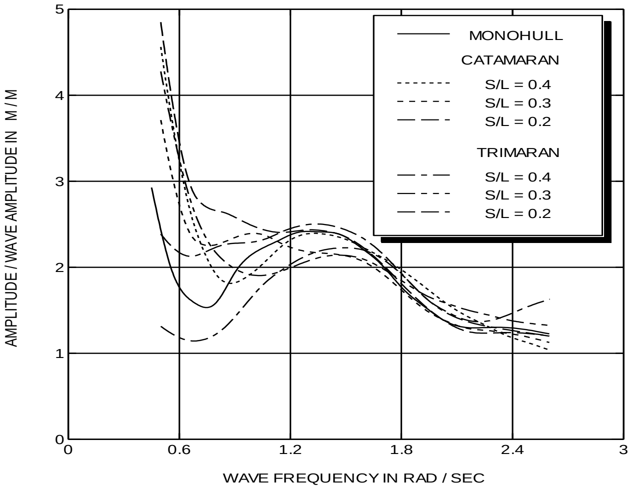

Figure 3. Response of heave motion

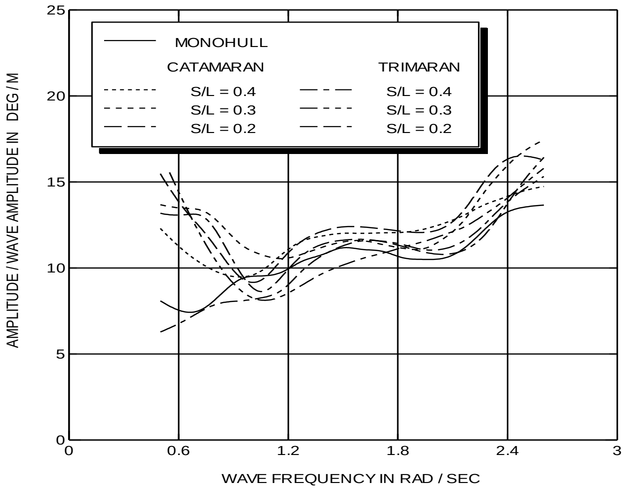

Figure 4. Response of pitch motion

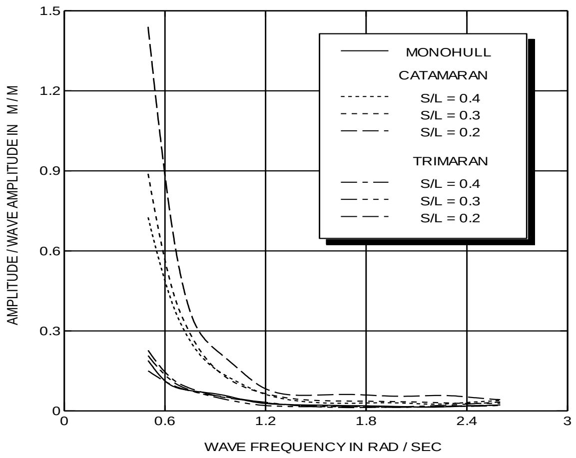

Figure 5. Response of surge motion

Table 4. Response of monohull

Ship Motion	Wave Directions				
	0^0	45^0	90^0	135^0	180^0
			Monohull		
Heave (m)	0.197	0.216	0.252	0.370	0.221
Roll (deg)	0.000	4.350	8.930	4.960	0.000
Pitch (deg)	2.480	2.290	1.260	2.060	2.330
			Catamaran S/L= 0.4		
Heave (m)	0.168	0.199	0.245	0.227	0.201
Roll (deg)	0.000	3.220	6.840	4.150	0.000
Pitch (deg)	2.030	1.950	1.600	1.660	1.530
			Trimaran S/L= 0.4		
Heave (m)	0.169	0.201	0.249	0.228	0.207
Roll (deg)	0.000	3.210	6.430	3.890	0.000
Pitch (deg)	2.036	1.954	1.610	1.667	1.534

Response of ship motion (heave, pitch and roll) using Maxsurf are shown in Table 4. The test was carried out at various wave directions and up to sea-state 3 where waves move in regular mode with wave height up to about 0.5-1.0m (Bhattacharyya, 1978; Faltinsen, 1990).

4 DISCUSSION

Experimental results shown in Table 2 and the Maxsurf results in Table 3 described the relation between speed and resistance at various configurations. Results of monohull configuration are presented in Tables 2 and 3 and further plotted in Figure 6. This indicates similar trend of resistance increase. However, Maxsurf shows a little increase compared to the experimental result and this also occurs at catamaran and trimaran configurations. This is attributed to the exclusion of resistance interference and wave breaking phenomenon by Maxsurf. The last term occurs at higher speed or Froude numbers and further discussion about this can be found in Hogben and Standing [19] and Utama et al [20]. Similar phenomena are also shown by catamaran with clearance S/L=0.4 (see Figure 7) and trimaran with clearance S/L=0.4 (see Figure 8) configurations. The catamaran form (Figure 7) shows lower resistance and the trimaran mode (Figure 8) indicates even lower resistance than the monohull mode of similar displacement. The reason for this, despite similar displacement, is because the catamaran and trimaran modes have slenderer hull-form than the monohull one. Thus, this has caused the resistance interaction and hence total resistance to decrease. By the use of Maxsurf, however, there is no indication of resistance decrease since the software or code does not take both resistance interaction and wave breaking phenomenon into consideration.

Among the catamaran and trimaran modes, it is clear that the total resistance decreases as the separation to length (S/L) ratio increases and this is caused by the decrease of resistance interaction following the increase of S/L ratios. This is in a good agreement with Utama (Utama et al, 2006) and Insel (Insel et al, 1992).

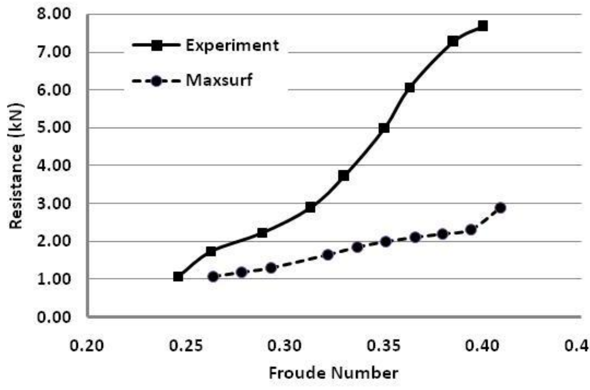

Figure 6: Plot of resistance of monohull type

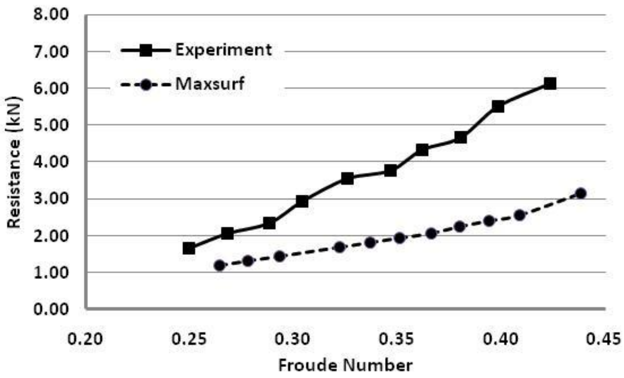

Figure 7: Plot of resistance of catamaran type

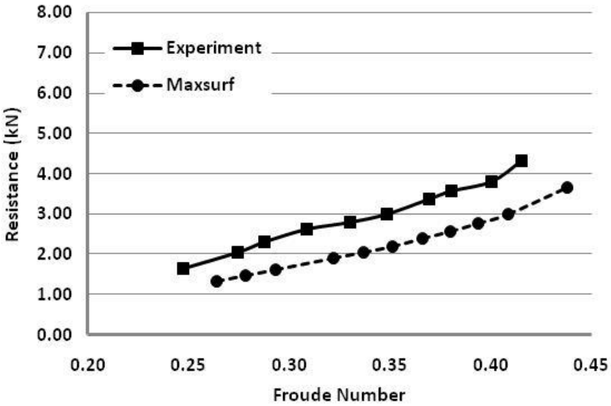

Figure 8: Plot of resistance of trimaran type

Results of ship motions experimentally presented in Figures 3 to 5, show that motion of catamaran and trimaran are slightly higher than the monohull's motion. However, the motion under numerical search using Maxsurf (Table 4) shows that the multihull modes have better characteristics, although the discrepancy is not significant. It can be said in general that the motion of multihulls are comparable with the motion of monohull. This fact is in a good agreement with the work done by Molland et al (Molland et al, 2000). Response of heave and pitch reach maximum values under following sea condition (0°). Waves coming from behind cause the vessel to move up and down more excessively. Meanwhile, roll motion arrives at maximum value under beam sea condition (90°). This has caused the vessel to move from one side to other side (known as roll) more extremely. Again, this is in good agreement with the results of Molland et al (Molland et al, 2000).

In addition, among the multihulls, the catamaran mode demonstrates slightly smaller heave and pitch responses compared to the trimaran. Conversely, the trimaran showed smaller roll response to the catamaran. This is because of the number of hulls, in which trimaran has more hulls and hence the total ship breadth. This further cause better or lower roll response, but higher heave and pitch responses, and this corresponds well with Rawson and Tupper (Rawson et al,1994)].

5 CONCLUSION

View of the experimental and numerical model analyses undertaken in research work, the folowing conclusion can be drawn:

- The catamaran and trimaran configurations provide lower total resistance than monohull one with equal displacement. The main and most significant factor is the geometry of ship hull and arrangement of ship wetted surface area.

- The trimaran mode demonstrates higher resistance or power effective at lower separation ratio (S/L=0.2 and 0.3). This is because the main hull of trimaran is bluff enough to cause higher flow interaction between the hulls hence causes higher resistance and power effective. In addition, the trimaran possesses three hulls, whilst the catamaran does have only two hence resistance and resistance interaction of the trimaran are consequently higher than those of the catamaran. However, at S/L=0.4 the interaction decreases significantly hence total resistance and power effective become much smaller.

- The multihull modes show almost similar motion characteristics as compared to the monohull. This is an indication (up to sea state 3), that catamaran and trimaran are as comfortable as the monohull. Furthermore, the effect of wave direction on ship motion is clear. Heave and pitch motions of both multihulls are more excessive under following sea condition, whilst roll motion is more extreme under quartering and beam sea conditions.

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