Demihull dénouement

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Utama, Jamaluddin and Aryawan reveal some staggering facts about catamaran hull design.

Who should read this paper?

Anyone with an interest in the design or operation of catamaran vessels will derive from this paper a better understanding of the implications of demihull design and spacing on overall efficiency, as well as the challenges that remain in designing a catamaran with small resistance.

Why is it important?

'Catamaran,' from Tamil *kattu* "to tie" and *maram* "wood, tree," is a type of boat consisting of two hulls joined by a frame. The catamaran is commonly believed to be an invention of fishermen on the southern coast of Tamil Nadu, India, as early as the 5th century AD. In modern shipbuilding, the catamaran design offers many potential advantages – most notably speed, stability and carrying capacity. However, drag (resistance) and interactive forces between the demihulls remain as significant design challenges. Not only do the size and shape of the demihulls have an impact on drag (resistance), their position relative to each other has a bearing on the interplay of forces (interference) and, consequently, the global structure of the vessel.

In this paper, the authors report on the results of rigorous testing of the drag characteristics and interference effects between laterally separated and longitudinally staggered demihull configurations for both symmetrical and asymmetrical hull cross-sections. The authors recognize that, while a longitudinally staggered hull design is not immediately practical, their experimental results indicate that as hull separation and stagger are increased, resistance decreases. Furthermore, asymmetrical hulls are found to be less influenced by the interference between hulls than are symmetrical hulls.

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EXPERIMENTAL INVESTIGATION INTO THE DRAG INTERFERENCE OF SYMMETRICAL AND ASYMMETRICAL STAGGERED AND UNSTAGGERED CATAMARANS

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ABSTRACT

One of the design challenges faced by naval architects is the accurate prediction of hull resistance characteristics in order to predict precisely the power requirements. Even though a considerable amount of research has been carried out in this area, there remains a degree of uncertainty in the prediction of calm-water resistance of catamaran hull forms. This paper attempts to report on an experimental investigation into a systematic series of slender catamaran hulls. The model hull forms comprise a conventional catamaran along with laterally separated and longitudinally staggered (longitudinal shift between demihulls) demihull (hulls which make up the catamaran) configurations for both symmetrical and asymmetrical hulls. A series of tests on the models were conducted at the Towing Tank of the Indonesia Hydrodynamic Laboratory over a speed range corresponding to Froude number up to 0.7. Experimental results are presented in tabular and graphical forms. The drag characteristics and interference effects are discussed and compared with recently published information. Results presented in this paper offer practical information and considerable promise and it is envisaged that further work will be carried out in order to gain further understanding.

KEY WORDS

Experiment; Drag; Interferences; Catamaran; Hull separation; Hull stagger

NOMENCLATURE

L_{WL}	=	Length on waterline (m)
L_{BP}	=	Length between perpendiculars
b	=	Breadth of demihull (m)
B	=	Breadth of catamaran (m)
T	=	Draught (m)
s/L	=	Lateral separation (clearance) ratio, between demihull centrelines
R/L	=	Longitudinal stagger ratio, between demihull transoms
V	=	Ship speed (m sec^{-1})
Fr	=	Froude number
Re	=	Reynolds number
R_T	=	Total resistance (N)
Cb	=	Block coefficient
C_T	=	Total resistance coefficient
C_F	=	Frictional resistance coefficient
IF	=	Total interference factor
$IF_{separation}$	=	Separated catamaran interference factor
$IF_{stagger}$	=	Staggered catamaran interference factor
WSA or S	=	Wetted surface area (static condition) (m^2)
ρ	=	Density of water (kg m^{-3})

INTRODUCTION

During the last decade catamaran ships have 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 space availability and seakeeping quality.

Resistance characteristics are principal aspects of the catamaran design spiral as they are strongly coupled with speed and fuel economy and, consequently, the operating and cost efficiencies of the vessel.

A considerable amount of research has been carried out to determine the resistance interference effects of demihulls (hulls which make up the catamaran) in proximity of one hull on the other, including experimental work in a towing tank [Insel and Molland, 1992; Molland et al., 1996]; in wind tunnels [Utama, 1999; Armstrong, 2003]; and theoretical work from Sahoo et al. [2007] and Muller-Graf et al. [2002]; but all of these investigations have focused on the effects of various lateral separations (clearance). Little work has been carried out regarding the staggered (longitudinal shift between demihulls) demihull configuration, other than the investigations undertaken by Soding [1997], Sahoo et al. [2006] and Caprio and Pensa [2007]. While the staggered catamaran hull form is not immediately practical, it is of great interest to understand the wave field interaction between the demihulls.

This paper constitutes a resistance analysis of symmetric and asymmetric displacement of catamaran hull forms with the effects of various lateral separation (clearance) and longitudinal stagger on the drag characteristics.

The paper by Insel and Molland [1992] summarizes a calm-water-resistance investigation into high-speed semi-displacement catamarans, with symmetrical hull forms based on experimental work carried out at the University of Southampton. Two interference effects contributing to the total resistance effect were established; these are viscous interference, caused by asymmetric flow around the demihulls which affects the boundary layer formation, and the wave interference, due to the interaction of the wave systems produced by each demihull. They proposed that the total resistance of a catamaran could be expressed by the equation:

$$(C_T)_{CAT} = (1 + \phi k)\sigma C_F + \tau C_W \qquad (1)$$

The factor ø has been introduced to take account of the pressure-field change around the demihulls and σ takes account of the velocity augmentation between the hulls and would be calculated from an integration of the local frictional resistance over the wetted surface, while (1+k) is the form factor for the demihull in isolation. For practical purposes, *ø* and σ can be combined into a viscous interference factor β where *(1+øk) σ= (1+βk)*. Hence

$$(C_T)_{CAT} = (1 + \beta k) C_F + \tau C_W \qquad (2)$$

For a catamaran, τ can be calculated from the equation:

$$\tau = \frac{C_{WCAT}}{C_{WDEMI}} = \frac{[C_T - (1 + \beta k) C_F]_{CAT}}{[C_T - (1 + k) C_F]_{DEMI}} \qquad (3)$$

Where $\beta = 1$ and $\tau = 1$ for monohull.

DESCRIPTION OF MODELS

A catamaran comprises two demihulls, usually with each demihull having the same waterline length *L* and hull width *b*. The demihulls are usually positioned abreast of each other, with a distance between the centrelines *S*, Figures 1a and 1b, and *B* is the overall beam of the catamaran, as illustrated in Figures 2a and 2b, for body plans of symmetrical and asymmetrical catamarans, respectively.

The two tested models, symmetrical and asymmetrical catamaran, were built from fibreglass materials. The main particulars of both models are presented in Table 1.

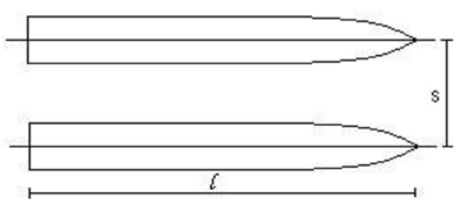

Figure 1a: Symmetrical catamaran.

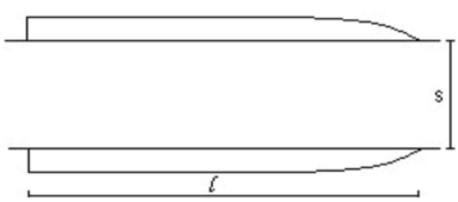

Figure 1b: Asymmetrical catamaran.

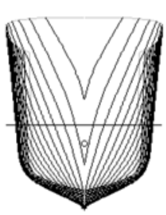

Figure 2a: Symmetrical catamaran.

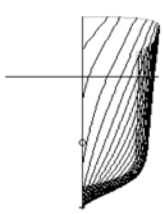

Figure 2b: Asymmetrical catamaran.

Parameter	Demihull		Catamaran		Unit
	Asym.	Sym.	Asym.	Sym.	
L_{WL}	1.405	1.372	1.405	1.372	m
b	0.066	0.132	-	-	m
T	0.126	0.078	0.126	0.078	m
WSA	0.356	0.256	0.712	0.512	m^2
Volume	0.007	0.007	0.014	0.014	m^3
Displac.	7.023	7.023	14.044	14.044	kg

Table 1: Main dimension of demihull and catamaran.

The asymmetrical demihull is arranged such that the hull width is a half of the symmetrical hull with the flat sides facing inwards. The displacement for both symmetrical and asymmetrical demihull is kept constant; consequently, each hull has a different draught (T) and Wetted Surface Area (WSA).

EXPERIMENTAL INVESTIGATION

A series of model tests was conducted at the towing tank of Indonesian Hydrodynamic Laboratory. The towing tank has a length of 240 m and width of 11 m, with a constant water depth of 5.5 m. Views of model testing are shown in Photos 1 and 2.

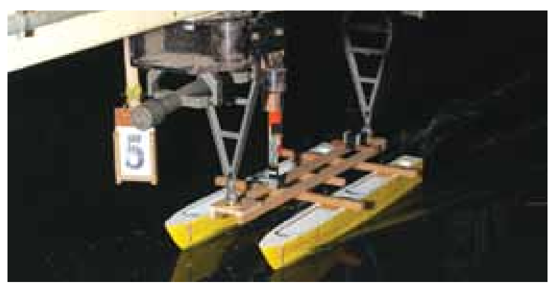

Photo 1: Model test of symmetrical catamaran.

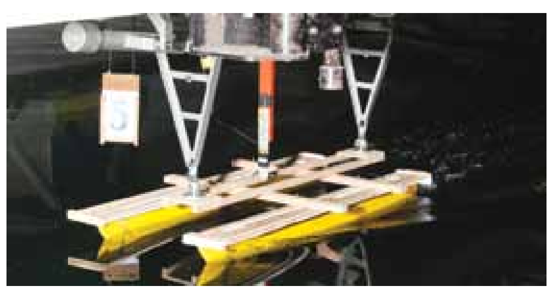

Photo 2: Model test of asymmetrical catamaran.

The experiments were conducted for Froude number up to 0.7 with three separation hull distances (clearances) and four longitudinally hull staggers, including the single demihull cases for both symmetrical and asymmetrical hull forms.

The test conditions for both hull forms are outlined in Table 2, where (s/L) values dictate the lateral separation ratio, between demihull centrelines, and the stagger (R/L) values represent the longitudinal stagger ratio, between demihull transoms.

Model Description	Separation (s/L)	Stagger (R/L)
Demihull	-	-
Catamaran	0.2	0.0, 0.2, 0.3, 0.4
Catamaran	0.3	0.0
Catamaran	0.4	0.0, 0.2, 0.3, 0.4

Table 2: Tested separation and stagger conditions.

The models were fitted with turbulence stimulation comprising sand grain strips of 0.5 mm diameter and 10 mm width. The strips were situated (leading edge) about 5% L_{BP} aft of the bow [ITTC, 2002].

The model was connected to the load cell transducer at a point located amidships and vertically at 0.45 T above base line, allowing the model to move freely in the vertical plane. Total resistance was measured for each run over the test range of Froude numbers.

RESULTS AND DISCUSSION

Catamarans and demihulls of both the models have been tested at Froude up to 0.7. A comparison of the symmetrical and asymmetrical, staggered and unstaggered catamarans was made to evaluate the drag characteristics; see Tables 3-5.

From the experimental towing test results, for the models, the total resistance coefficient, C_T, and the total interference factors (*IF separation*, IF *stagger*) have been calculated. The total resistance coefficient is defined as:

$$C_T = \frac{R_T}{0.5\rho(WSA)V^2} \quad (4)$$

where WSA is the wetted area of both hulls in the case of the catamaran.

Form Factors

The viscous resistance component, composed of the flat plate frictional resistance and form drag including the earlier mentioned viscous (body) interference, is still very difficult to estimate accurately. While flat plate resistance in isolation can be estimated with a reasonable precision using ITTC-57 extrapolation line, the form drag (viscous pressure), caused by the boundary layer activity and the body interference effect, requires a series of model test data.

Bertram [2000] recommended to determine the form factor “k” by utilizing experimental data at very low speed or low Froude numbers (*Fr* < 0.2), where Cw must become negligible. Prohaska’s method [ITTC, 2002] allows the form factor to be calculated by assuming that, at low speed, the total resistance is described as:

$$C_T = (1+k)\,C_F + a\,Fr^n \quad (5)$$

At low speed, Fr <0.2 is assumed to be a function of Fr^4, the straight line plot of C_T/C_F versus Fr^4/C_F, and will intersect the ordinate (Fr=0) at (1+k), enabling the form factor to be determined as shown in Tables 3 and 4, which show the raw resistance measured for both types of hull form including catamaran and demihull configuration at different separation and staggered ratios.

Table 5 shows the test results of viscous form factor for demihull (monohull) and catamaran. The viscous form factors of demihull are lower than that of catamaran with hull separation of s/L = 0.2 to s/L = 0.4. This explains the

Resistance (N)	*Fr*	*Re*	C_T	C_F
Demihull				
0.03167	0.0476	2.78E+05	0.00810	0.00633
0.10428	0.0936	5.45E+05	0.00691	0.00537
0.41977	0.1874	1.09E+06	0.00694	0.00460
s/L= 0.2				
0.07201	0.0477	2.78E+05	0.00902	0.00632
0.23358	0.0929	5.41E+05	0.00772	0.00538
0.89902	0.1876	1.09E+06	0.00729	0.00460
s/L=0.2, R/L=0.2				
0.07230	0.0477	2.78E+05	0.00905	0.00632
0.23377	0.0929	5.41E+05	0.00773	0.00538
0.90242	0.1873	1.09E+06	0.00735	0.00460
s/L=0.2, R/L=0.3				
0.07248	0.0478	2.79E+05	0.00905	0.00632
0.23426	0.0929	5.42E+05	0.00774	0.00538
0.94711	0.1875	1.09E+06	0.00769	0.00460
s/L=0.2, R/L=0.4				
0.07220	0.0477	2.78E+05	0.00907	0.00632
0.23456	0.0929	5.42E+05	0.00775	0.00538
0.97517	0.1876	1.09E+06	0.00791	0.00460
s/L=0.3				
0.07115	0.0476	2.78E+05	0.00895	0.00632
0.23307	0.0934	5.44E+05	0.00763	0.00537
0.84126	0.1877	1.09E+06	0.00682	0.00460
s/L=0.4				
0.06977	0.0472	2.75E+05	0.00894	0.00634
0.23186	0.0933	5.44E+05	0.00760	0.00537
0.83515	0.1876	1.09E+06	0.00677	0.00460
S/L=0.4, R/L=0.2				
0.07206	0.0477	2.78E+05	0.00904	0.00632
0.23357	0.0929	5.42E+05	0.00772	0.00538
0.85025	0.1877	1.09E+06	0.00689	0.00460
S/L=0.4, R/L=0.3				
0.07207	0.0477	2.78E+05	0.00904	0.00632
0.23411	0.0931	5.42E+05	0.00772	0.00538
0.84940	0.1875	1.09E+06	0.00690	0.00460
S/L=0.4, R/L=0.4				
0.07207	0.0477	2.78E+05	0.00904	0.00632
0.23404	0.0931	5.43E+05	0.00771	0.00538
0.84891	0.1876	1.09E+06	0.00688	0.00460

Table 3: Resistance measured for symmetrical catamaran.

Resistance (N)	*Fr*	*Re*	C_T	C_F
Demihull				
0.04126	0.0457	2.76E+05	0.00804	0.00633
0.14412	0.0929	5.61E+05	0.00680	0.00534
0.57006	0.1853	1.12E+06	0.00676	0.00458
s/L=0.2				
0.08392	0.0450	2.72E+05	0.00844	0.00636
0.30127	0.0929	5.61E+05	0.00711	0.00534
1.17750	0.1857	1.12E+06	0.00695	0.00457
s/L=0.2, R/L=0.2				
0.08953	0.0466	2.81E+05	0.00841	0.00631
0.30363	0.0929	5.61E+05	0.00716	0.00534
1.23674	0.1854	1.12E+06	0.00733	0.00458
s/L=0.2, R/L=0.3				
0.08957	0.0465	2.81E+05	0.00842	0.00631
0.30313	0.0929	5.61E+05	0.00716	0.00534
1.25491	0.1853	1.12E+06	0.00744	0.00458
s/L=0.2, R/L=0.4				
0.08957	0.0466	2.81E+05	0.00842	0.00631
0.30323	0.0929	5.61E+05	0.00716	0.00534
1.28367	0.1852	1.12E+06	0.00762	0.00458
s/L=0.3				
0.08254	0.0450	2.72E+05	0.00830	0.00636
0.29744	0.0929	5.61E+05	0.00702	0.00534
1.15641	0.1857	1.12E+06	0.00683	0.00457
s/L=0.4				
0.08252	0.0450	2.72E+05	0.00830	0.00636
0.29628	0.0930	5.61E+05	0.00698	0.00534
1.14593	0.1856	1.12E+06	0.00678	0.00457
s/L=0.4, R/L=0.2				
0.08623	0.0460	2.78E+05	0.00829	0.00632
0.29912	0.0930	5.61E+05	0.00705	0.00534
1.20583	0.1854	1.12E+06	0.00714	0.00457
s/L=0.4, R/L=0.3				
0.08632	0.0460	2.78E+05	0.00830	0.00632
0.29913	0.0929	5.61E+05	0.00705	0.00534
1.21007	0.1851	1.12E+06	0.00719	0.00458
s/L=0.4, R/L=0.4				
0.08620	0.0460	2.78E+05	0.00829	0.00632
0.29872	0.0929	5.61E+05	0.00705	0.00534
1.20967	0.1851	1.12E+06	0.00719	0.00458

Table 4: Resistance measured for asymmetrical catamaran.

Hull Form	Monohull (1+k)	s/L= 0.2	s/L= 0.3	s/L= 0.4
		(1+βk)	(1+βk)	(1+βk)
Sym.Cat.	1.277	1.426	1.415	1.410
R/L=0.2	-	1.430	-	1.430
R/L=0.3	-	1.430	-	1.430
R/L=0.4	-	1.430	-	1.429
Asym.Cat.	1.266	1.324	1.305	1.302
R/L=0.2	-	1.330	-	1.310
R/L=0.3	-	1.330	-	1.310
R/L=0.4	-	1.329	-	1.309

Table 5: Experimental viscous form factor values.

occurrence of viscous interferences on catamaran hull. The interference phenomena are generated by variation of velocity field and pressure around demihulls, change of form factor value.

The symmetrical and asymmetrical catamaran configurations were found to have approximately 10% and 5% greater form factor than the demihull (monohull). The results also show that the higher the hull separation and stagger, the lower the form factor. The effect of the hull separation is higher than that of the hull staggers.

It should be noted that the ITTC-57 correlation line is an empirical fit and that some form effect is included. This is unfortunate since the friction is calculated empirically based on the friction of a flat plate and is then modified, in a semi-empirical manner, to obtain the viscous resistance component; the relative magnitude of this component can lead to a lack of precision in the final result.

It would also appear that the transom has a significant, if not yet fully understood, effect on resistance. It will be shown that the findings for monohulls are pertinent to catamarans, which have the added complications of wave and viscous interactions between the demihulls.

Form factors for all the demihull spacing tested were found to be considerably higher than those of the monohulls suggesting that viscous interaction effects were present. It is unclear whether the viscous resistance increase is due primarily to modifications of the boundary layer and velocity augment between the demihulls or to additional spray associated with constructive interference of the two wave systems, particularly in the vicinity of the transom. These interaction effects may be investigated and studied further using wind tunnel models.

Unstaggered Catamarans

The total resistance coefficients (C_T) are strongly affected by the change of hull separation (s/L) for both symmetrical and asymmetrical catamarans as shown in Figures 3 and 4. The interaction effects due to separation on the symmetrical catamaran are quite stronger, Figure 3, while these effects are less strong on the asymmetrical catamaran, Figure 4.

In general, the C_T values of the symmetrical catamaran are higher than that of the asymmetrical catamaran, especially being much higher at Fr 0.4-0.6. It is also shown that the smaller the separation (s/L), the higher the resistance and the critical Froude number. This is attributed to the more intensive wave and viscous interaction between the hulls [Caprio and Pensa, 2007].

It is noted that Figures 3 and 4 show that the smaller the separation (s/L), the higher the resistances, particularly for symmetrical hull. This is attributed to the more intensive wave and viscous interaction between the hulls.

For the large hull, separation (s/L = 0.3-0.4) is

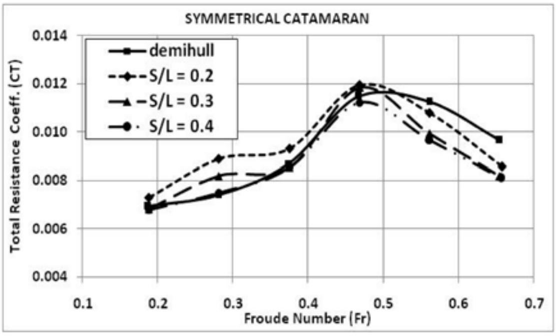

Figure 3: C_T values of symmetrical catamaran.

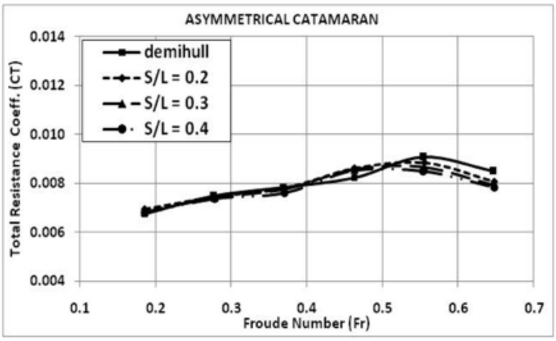

Figure 4: C_T values of asymmetrical catamaran.

practically equal or slightly lower (for Fr = 0.35-0.50) to double the demihull resistance, indicating that for this separation distance, the interaction effect has already vanished [Jamaluddin et al., 2010]. For Fr > 0.5, the resistance of catamaran hulls is significantly lower than that of the double of the demihull for the given hull separation. The reason for this is that the wave interference contributed a favourable effect.

Staggered Catamarans

Experimental data results as plotted in Figures 5 to 8 show the resistance characteristics on change of longitudinal stagger. The effects of longitudinal stagger configuration clearly show that between Fr values of 0.4 and 0.55, favourable interference does take place.

The catamaran with the maximum stagger shows a considerable reduction in resistance.

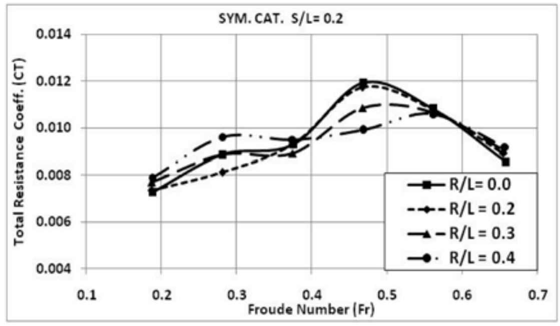

Figure 5: C_T values of staggered symmetrical catamaran, s/L=0.2.

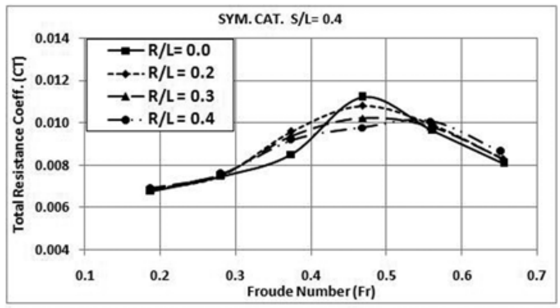

Figure 6: C_T values of staggered symmetrical catamaran, s/L=0.4.

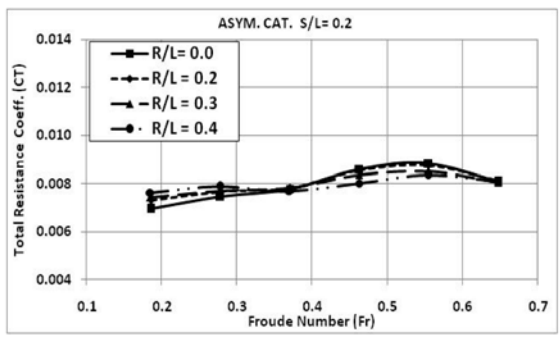

Figure 7: C_T values of staggered asymmetrical catamaran, s/L=0.2.

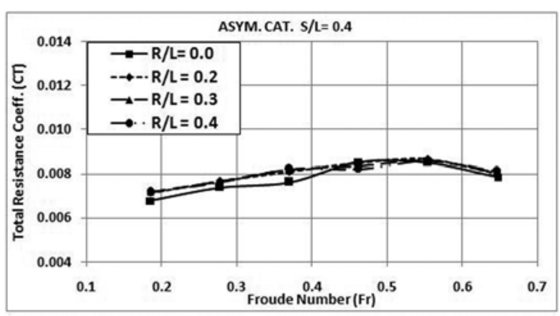

Figure 8: C_T values of staggered asymmetrical catamaran, s/L=0.4.

At the higher Froude numbers > 0.55, changes in hull stagger tend to have a relatively small effect. On the other hand, for Fr<0.4, the effects of longitudinal stagger configuration show an unfavourable interference. The reason for this may be caused by the wave interference between the hulls [Molland et al., 2000; Wang and Lu, 2011].

Figures 5 and 6 show the experimental results of the stagger symmetrical catamaran for R/L = 0.2 and 0.4. The results display a large change on resistance for s/L = 0.2 compared to s/L = 0.4 at the range of Fr 0.4-0.55. This trend is also followed by the asymmetrical catamaran, as shown in Figures 7 and 8. However, the resistance of asymmetrical catamaran is lower than that of the symmetrical one.

Interference Phenomena

The interference phenomena are generated by variation of velocity field around demihulls, change of form factor value and superimposition of wave patterns [Insel and Molland, 1991].

In addition to this breakdown, the interference factors have to be evaluated considering the viscous and the wave components separately. These procedures are of great scientific interest, but they need to measure directly both the resistance components. In the case of catamarans, these methodologies are really complex and the obtained data may not be reliable, especially for the viscous component.

For this reason, in the current work, in order to evaluate the interference phenomena, the ratio *IF separation* has been chosen:

$$IF_{separation} = \frac{C_{TCAT}}{C_{TDH}} = \frac{R_{TCAT}}{2R_{TDH}} \qquad (6)$$

where C_{TCAT} and C_{TDH} are for the catamaran and demihull, respectively.

And the ratio *IF stagger* is written as:

$$IF_{stagger} = \frac{C_{TCAT\,stagger}}{C_{TCAT}} \qquad (7)$$

Since the *IF* factor is calculated with the total resistance, it depends on viscous resistance. So the *IF* factor changes if different ship scales are considered.

Experimental results of interference phenomena for separation and stagger effects are presented in Figures 9 and 10 and Figures 11 to 14, respectively.

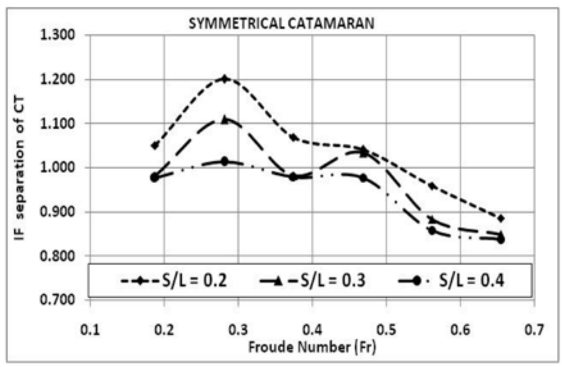

Figure 9: C_T values of *IF separation* symmetrical catamaran.

Figures 9 and 10 show the interference factor ($IF_{separation}$) by the change of hull separation (s/L). The interference effects due to separation on the symmetrical catamaran are stronger than that of the asymmetrical catamarans.

The interference factors for stagger (*IF stagger*) are presented in Figures 11 to 14. There is a significant change in interference factor for S/L = 0.2 compared to S/L = 0.4 at the range

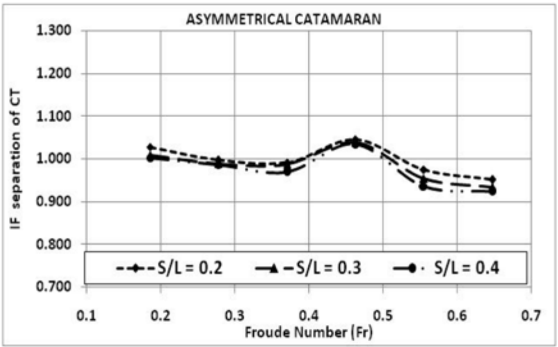

Figure 10: C_T values of *IF separation* asymmetrical catamaran.

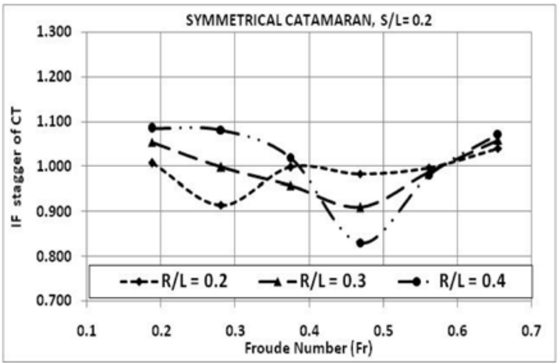

Figure 11: C_T values of *IF stagger* symmetrical catamaran, s/L=0.2.

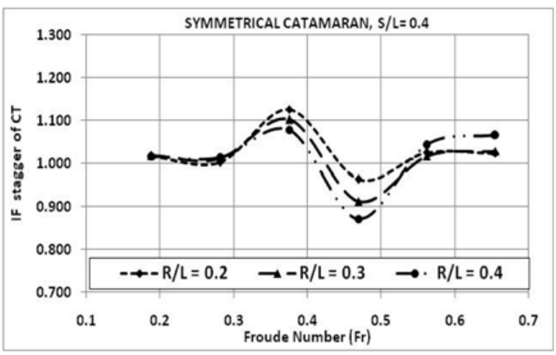

Figure 12: C_T values of *IF stagger* symmetrical catamaran, s/L=0.4.

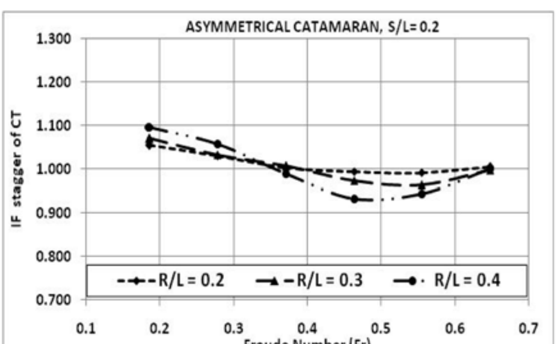

Figure 13: C_T values of *IF stagger* asymmetrical catamaran, s/L=0.2.

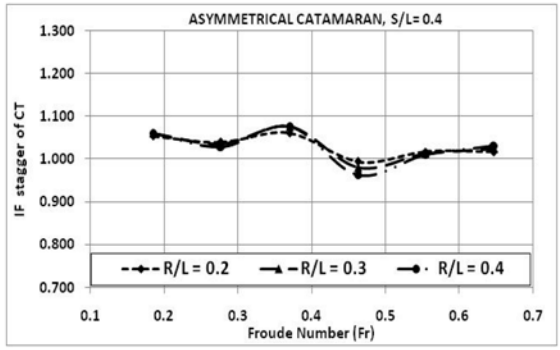

Figure 14: C_T values of *IF stagger* asymmetrical catamaran, s/L=0.4.

of Fr 0.4-0.55, particularly for the symmetrical hull. For this range of Froude numbers, the interference factor (*IF stagger*) is smaller than the one for both hull forms. This indicated that the configuration of the staggered catamaran produced smaller resistance compared to the unstaggered catamaran. It is attributed to bigger wave interference at unstaggered formation [Molland et al., 2000; Utama et al., 2008; Utama et al., 2010].

It is not possible to identify a law describing the dependence of *IF* for hull separation and stagger [Caprio and Pensa, 2007]. The viscous phenomena probably have strong influences on the *IF* values. These phenomena have occurred for various separation and stagger configurations for both symmetrical and asymmetrical hulls. For Fr> 0.65 the *IF stagger* curves converge to unity.

CONCLUSION

The following conclusions can be drawn based on experimental work:

- It has been highlighted that there is a great influence on catamaran resistance due to separation and stagger.
- The resulting values of (1+k) and (1+βk)

for various configurations provide a broad indication of changes in viscous resistance and viscous interference due to the change in hull separation and stagger.

- The general trend in all cases is that as the hull separation and stagger are increased, the resistance decreases.

- The resistance and interference factors are significantly affected on the symmetrical hull compared to the asymmetrical one.

- Asymmetrical hulls are found to be less influenced by the interferences due to separation and stagger changes.

Results presented give practical data and a series of tests in a wind tunnel will be carried out for development of the research and to gain further understanding of the interference components of resistances of symmetrical and asymmetrical staggered and unstaggered catamarans.

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