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Hydrodynamic Performance of a 2,500-ton Class Trimaran

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Abstract

This paper describes the powering, seakeeping and maneuvering performances for a 2,500-ton class trimaran. Influence of the side-hull forms and location of those in longitudinal and transverse direction to resistance performance was systematically investigated by a series of model tests and numerical calculations. It was found that the longitudinal location of side-hulls was the most influential design parameter to the resistance performance of the trimaran and the optimum location of side-hull depends on ship speeds. When the side-hull stem is located near the primary wave hollow generated by the main hull, the trimaran shows the best resistance performance. Powering performance of the trimaran is superior to those of similar mono-hull ships. Seakeeping model tests for the trimaran were executed and the results were compared with the theoretical results of a similar mono-hull ship. Generally speaking, seakeeping performance of the trimaran is superior to that of a mono-hull ship. In particular, pitching and rolling performance of the trimaran is excellent, which is due to the increased length and breadth. Maneuvering model tests using a HPMM equipment were executed to evaluate the maneuvering performance of the trimaran. Maneuvering simulation was performed using the maneuvering coefficients from the model tests. The results show that the control ability of heading angle and the direction keeping stability of the trimaran is excellent, even though the turning performance is rather worse compared to those of a similar mono-hull ship.

Keywords: trimaran, resistance, seakeeping, maneuvering, hydrodynamic performance

1 Introduction

The demand for high-speed ships has been increased during the last decade. Many different types of ship concepts and hull forms have been considered to meet the demand. Among them, a trimaran, which consists of a slender main hull and two very fine side-hulls, is one of the most interesting hull forms.

Trimarans have several advantages over other hull forms, such as low resistance at high speeds, easy arrangement on wider deck, superior seakeeping performance in waves, high survivability in damaged condition and reduction of thermal signature and radar cross-section area, etc. On the other hand, trimarans have several disadvantages, such as increase of hull weight, difficult handling

Table 1: Principal particulars of a 2,500-ton class trimaran

Item(unit)	Main Hull	Side-Hull	Trimaran
$Displ.(ton)$	2,324	176	2,500
$L_{PP}(m)$	120.0	45.0	120.0
$Breadth(m)$	9.0	1.8	30.0
$Depth(m)$	12.0		12.0
$Draft(m)$	4.2	2.5	4.2
C_B	0.50	0.423	
C_{WP}	0.7745	0.9	
C_M	0.8468	0.5	
$LCB(\%)$	-2.48	0.0	
$V(Crusing)$	18 knots(F_n=0.27)		
$V(Max.)$	30 knots(F_n=0.45)		
$Propulsion$	Twin propllers, D_P=3.0m		

in harbor, etc. The feasibility studies and the application examples on a trimaran were introduced in recent FAST symposia. In particular, design and construction of "RV Triton" in U.K. encourage the possibility of the use of trimarans for future warship.

This paper presents the results of studies investigating the powering, seakeeping and maneuvering performance of a 2,500-ton class trimaran. A series of resistance tests and numerical calculations were carried out to investigate the influences of side-hull form and the location of side-hull on the resistance characteristics of the trimaran. And the propulsion test was conducted to investigate the propulsion efficiency, and the powering performance was compared with that of the similar mono-hull ships. Furthermore, seakeeping and maneuvering performances of the trimaran have been investigated through the experiment and numerical calculation.

2 Principal dimensions and hull form design

2.1 Principal dimensions

Hull forms should be designed to satisfy the whole hydrodynamic performance at a design speed, where the resistance performance is very important. In particular the main hull and side-hull should be optimized at the same time to ensure the excellent resistance performance for the trimaran. The key parameters for trimaran design are main hull length to beam ratios, side hull length and location. The principal particulars of a 2,500-ton class trimaran are shown in Table 1, which are decided from the concept design referring to the design requirement and those of 'RV Triton'

2.2 Hull form

The wave resistance of the main hull affects dominantly on the resistance performance of the trimaran. Therefore, it is very important to find out the hull form with excellent resistance performance for the design of main hull form at initial design stage. A displacement type hull, which was recently developed as a high-speed hull in KRISO, was selected as a parent ship of the main hull. Three kinds of side-hulls(inboard, symmetry and outboard type) with wedge shape were de-

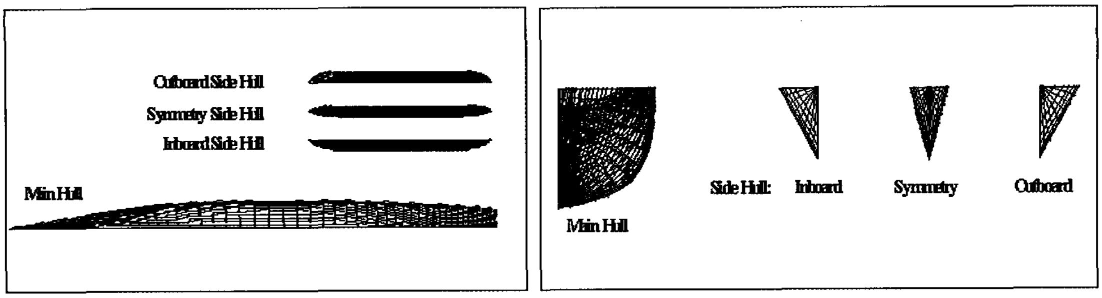


Figure 1: Drawing of a 2,500ton class trimaran(main-hull and three kinds of side-hull forms)

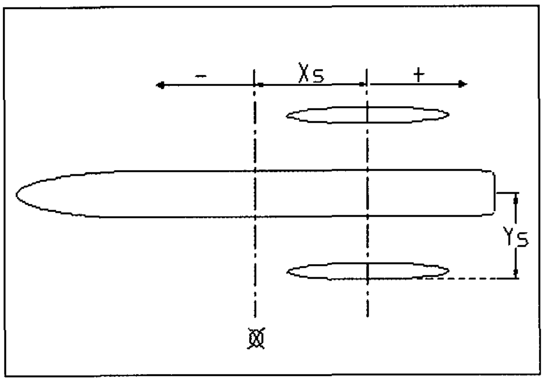


Figure 2: Definition of side-hull location

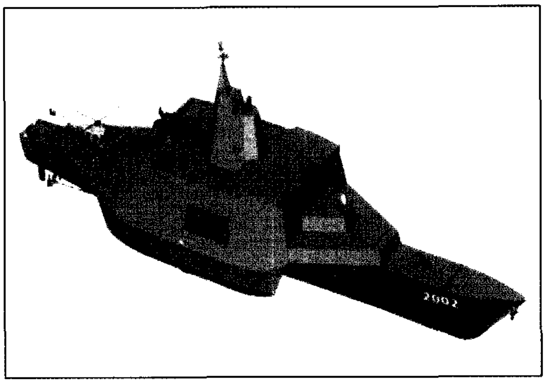


Figure 3: Graphic design model of the trimaran

signed referring to Ackers(1997). Figures 1, 2 and 3 show the drawings of main hull, three kinds of side-hull and the definition of the side-hull location and the graphic model of the trimaran, respectively.

3 Powering performance

To figure out the resistance characteristics of the trimaran, the following 3 items were investigated for the side-hull.

- Cross section shapes: 3 ea
- Longitudinal locations: 5 ea
- Transverse locations of the side-hull

From the above results, the optimum location of the side-hull shall be discussed and the powering performance for the trimaran shall be compared with similar mono-hull ships.

3.1 Model test and analysis method

A 1/16.667-scale trimaran and twin propellers were used for the model tests. Appendages are twin shafts, struts and rudders.

A series of resistance tests were conducted to figure out the influences of side-hull forms and

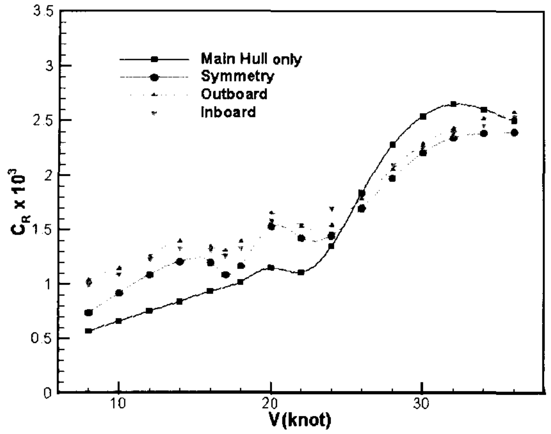


Figure 4: C_R curves for three side-hull forms

locations on the resistance characteristics of the trimaran. And propulsion tests were conducted to investigate the propulsion efficiency of the trimaran.

Based on the Froude's assumption and 1957 ITTC model-ship correlation line, full-scale values were predicted from the resistance tests. The scale effect correction was carried out based on the 1978 ITTC performance prediction method.

3.2 Numerical computation

The numerical method tocalculate the wave resistance was developed by Kim et al(1999), which adopted a first order panel method.

For the free surface treatment the well-known Dawson's approach is adopted in the present method. To enforce the radiation condition the present method employs Dawson's 4-point upwind-difference operator in a longitudinal direction. For a transverse direction 3-point central-difference operator is used. Furthermore, the collocation points are shifted upstream in order to smooth out the source strengths and to prevent the upstream waves at high speeds. The shifted distance is usually about 10%~30% of panel length.

To take into account the transom stern effect, the Cheng's method based on dry transom assumption is used in the present approach.

3.3 Effects of side-hull form

Three kinds of side-hull form(inboard, symmetry and outboard types) were tested to find out the influence on the resistance performance.

Model tests and numerical calculations were carried out at the side-hull location of X_S/L_{PP}=0.3 in length and Y_S/L_{PP}=0.125 in beam.

The outboard and inboard type side-hulls generates significant stem wave spray during model tests. However, the symmetry type side-hull shows moderate stem wave system.

Figure 4 shows the residuary resistance coefficient(C_R) curves obtained from the model tests. On the other hand, Figures 5 and 6 show the calculated wave resistance coefficient(C_W) curves together with C_R values at 18 knots and 30 knots, respectively, which show very good agreement in qualitative characteristics. From the above results, it is found that the symmetry shape has the most favorable resistance characteristic among three side-hull forms.

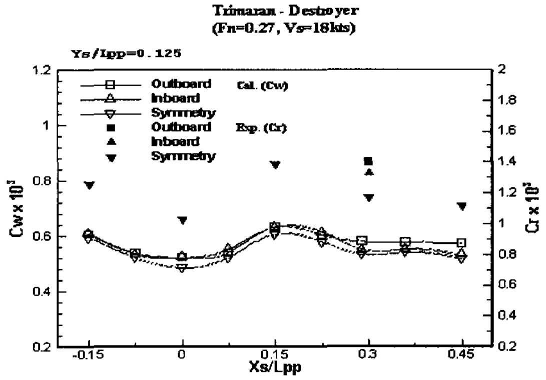


Figure 5: C_R & C_W curves at 18 knots(F_n=0.27)

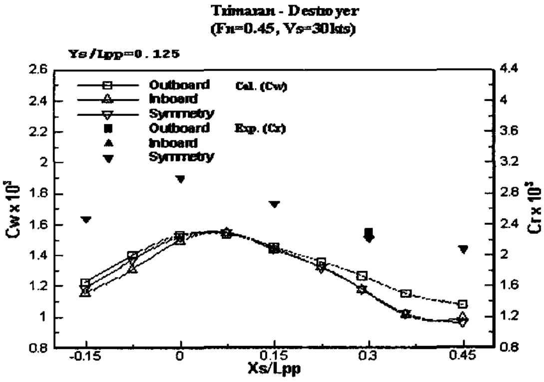


Figure 6: C_R & C_W curves at 30 knots(F_n=0.45)

3.4 Effects of side-hull location in longitudinal direction

Longitudinal location of a side-hull was investigated to figure out the influence on the resistance performance of the trimaran. Model tests and numerical calculations were carried out for the side-hull location of X_S/L_{PP}=-0.15, 0.0, 0.15, 0.30 & 0.45 in length and Y_S/L_{PP}=0.125 in beam.

Figures 5 and 6 show very good agreement between the calculation and the experiment at 18 knots and 30 knots. It is almost possible to select the optimum longitudinal location by numerical calculation.

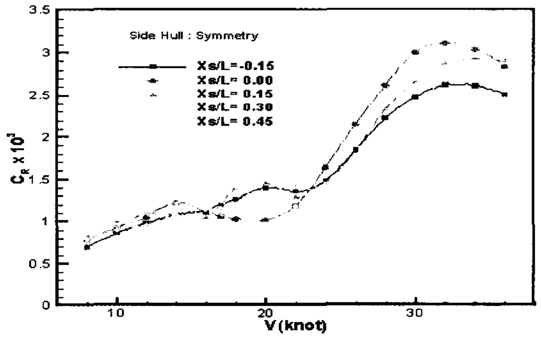


Figure 7: C_R curves for side-hull locations in length

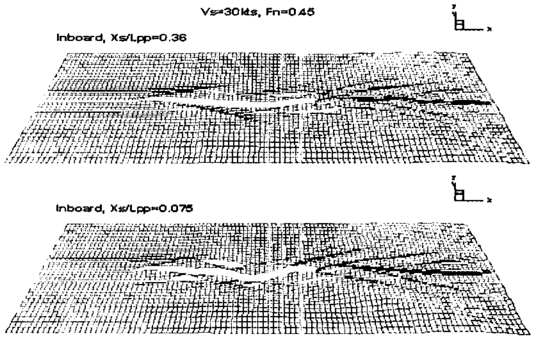


Figure 8: Comparison of wave patterns

Figure 7 shows the C_R curves obtained from model tests. The differences were caused by the wave interference according to the longitudinal locations of side-hull.

Figure 8 shows the comparison of calculated wave patterns for the side-hull locations X_S/L_{PP} =0.36 and 0.075, which shows big difference in wave system. It can be found from the wave system that the former shows favorable wave interference but the latter shows nearly the worst case.

From the above results, it is found that the optimum longitudinal location is related with the ship's speed. And the trimaran shows a favorable resistance performance when the side-hull moves toward the stern of main hull at high speeds. However, it is supposed that the optimum longitudinal location is near X_S/L_{PP}=0.3 considering other constraint conditions.

3.5 Effects of side-hull location in transverse direction

Numerical calculations were carried out to investigate the effect of the side-hull's transverse location on the wave resistance characteristics of the trimaran. The trimaran with symmetry type side-hull was used for the calculation.

Figure 9 shows the calculation results for the transverse locations of Y_S/L_{PP}=0.125~0.225 while the longitudinal location is fixed as X_S/L_{PP}=0.15 at 30 knots.

Figure 10 shows the calculated wave height in transverse direction for the main hull only at main hull center X_S=0.0. Hereafter, in the figures h, x and L means wave height, X_S and L_{PP} at each. From these two figures it seems that the wave resistance is related with the encountering wave height of the side-hull. However, the maximum difference of the wave resistance coefficient C_W due to the different transverse locations is less than 10% of that due to the longitudinal locations.

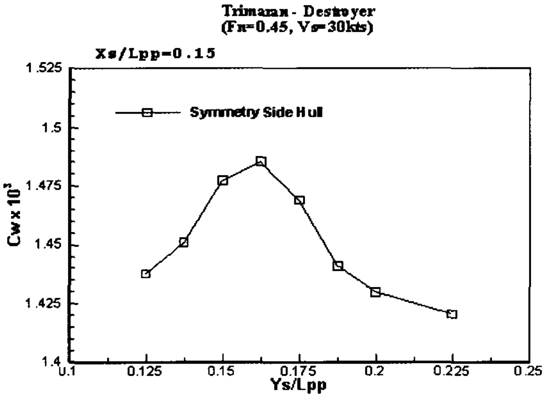


Figure 9: Calculated C_W curve according to the transverse locations of side-hull(30 knots)

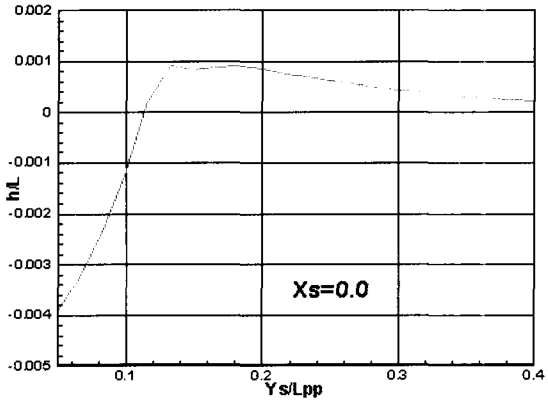


Figure 10: Wave height generated by main hull in transverse direction(30 knots)

3.6 Discussion on the optimum location of side-hull

The present topic is to find out the easy way to predict the optimum location of side-hull at initial design stage. The resistance characteristics of trimaran are highly affected by the wave interference between the main hull and the side-hull. Therefore, the optimum location of side-hull is supposed to be the place where the waves generated by the main hull and the side-hull cancel out each other.

Figure 11 shows the wave profile generated by main hull at 30 knots(F_n=0.45) and five locations of side-hull at the transverse location of Y_S/L_{PP}=0.125. This relative location seems to show a close relation with the wave resistance as shown in Figure 6. Therefore, it can be said

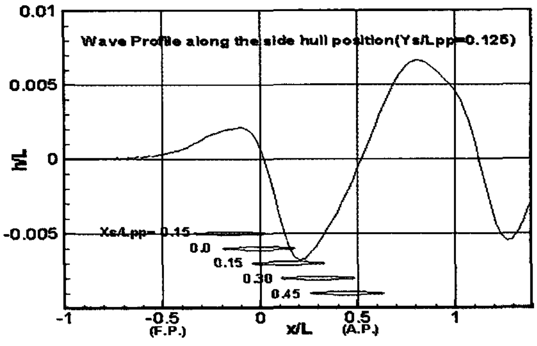


Figure 11: Relation between wave profile and side-hull location(30 knots)

carefully that the trimaran has favorable resistance performance when the side-hull stem is located near the primary wave hollow generated by the main hull.

3.7 Comparison of powering performance

Figures 12 and 13 show the comparison of C_R curves and Admiralty coefficients(Cadm) for the trimaran and the similar mono-hull ships, respectively. The propulsion efficiency oftrimaran is almost same as the others. The trimaran shows good powering performance in most speed range though the wetted surface area is increased by 28% comparing to the others.

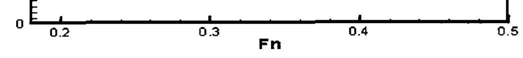


Figure 12: Comparison of C_R curves

Figure 13: Comparison of Admiralty coefficients

4 Seakeeping performance

4.1 Model test condition

Model tests for seakeeping performance were conducted with a 1/32-scale model of the trimaran. The height of freeboard was designed to be 7.8 meters. The center of side-hull is located at $0.05^* L_{PP}$ backward from the center of main-hull in longitudinal direction. The wet deck between main-hull and side-hulls was made of acrylic plate to observe the flow under it. The distance from the still water to the wet deck is 4 meters.

The ship condition for the seakeeping model test is shown in Table 2 and the radius of gyration was estimated from the weight distribution according to the general arrangement, where * means the measured value from model test.

Model tests were conducted according to the test conditions shown in Table 3, but the ship speed in beam sea was set to zero. Measuring items and methods are shown in Table 4, and slamming phenomenon on the wet deck was observed by eye. Figure 14 briefly shows the measuring system and model test equipment. The irregular head and beam waves corresponding to each sea state were generated based on the ITTC(1981) wave spectrum.

Table 2: Ship condition for seakeeping model test

Item	Trimaran
LCG	-3.188m
KG	6.054m
Transverse Metacenter (GMT)	10.25m 9.89m*
Roll Natural Period	5.00m*
Gyradius of Roll (kxx)	6.176m 7.04m*
Gyradius of Pitch (kyy)	27.20m 27.52m*

Table 3: Regular head wave for model test

Spectrum I.D.	Sea state	Significant wave height(m)	Model period (sec)	Ship speed ($knot$)
SP1	4	1.88	8.8	12, 18, 25
SP2	5	3.25	9.7	8, 12, 18
SP3	6	5.00	12.4	4, 8, 12, 18

Table 4: Measuring items in head sea

Measuring items	Measuring location	Measuring device
Wave	7m forward from mid-ship	Wave prove
Heave	Center of gravity	Potentiometer
Pitch	Center of gravity	Potentiometer
Added Resistance	Center of gravity	Load cell
Vertical accel. at bridge	Bridge	Accelerometer
RBM 1	$F.P.$	Wave prove
RBM 2	0.15 L_{PP} from $F.P.$ to $A.P.$	Wave prove
Deck wetness	Bulwark top	Eye

4.2 Evaluation of seakeeping performance

Seakeeping performances of the trimaran were compared with the theoretical analysis results of a similar mono-hull ship whose displacement is 2,150 tons. Computer program(Yang et al 1979) based on strip method was used for the theoretical analysis.

ITTC wave spectrum was adopted for the description of irregular sea waves for the model tests and the theoretical analysis. U.S. navy criterion was used to evaluate the seakeeping performance.

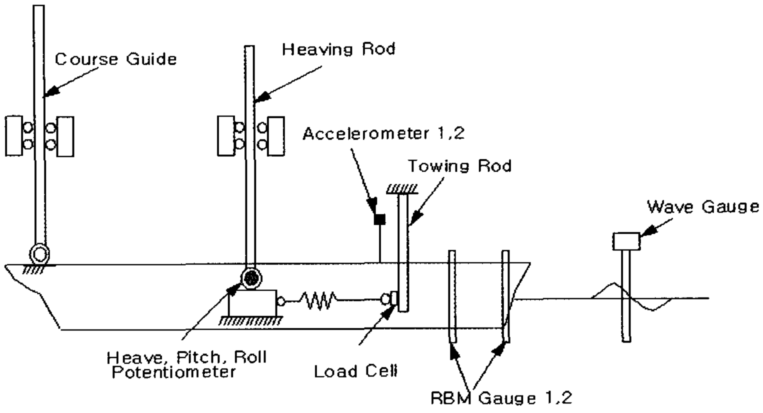


Figure 14: Seakeeping test arrangement

4.3 Seakeeping performance in head sea

Figures 15 & 16 show heave and pitch responses according to the ship speed. Hereafter, in the figures ss# means sea state number. It can be found that the trimaran has better performance in heave and pitch motion than the similar mono-hull ship. Figure 17 shows the root mean square (RMS) values of vertical acceleration at the bridge. The trimaran's values are lower than the mono-hull ship in low and middle speed range, but the values are crossed in high-speed range. However, both ships do not exceed the criterion till sea state 6. Figure 18 shows the added resistance at different sea states. The added resistance of trimaran is mainly affected by the relative motion rather than wave reflection, due to its slenderness. The added horse power of trimaran at 18 knots is estimated as much as 5.8%, 34.9% and 78.7% of horse power in still water for sea states 4, 5 and 6, respectively.

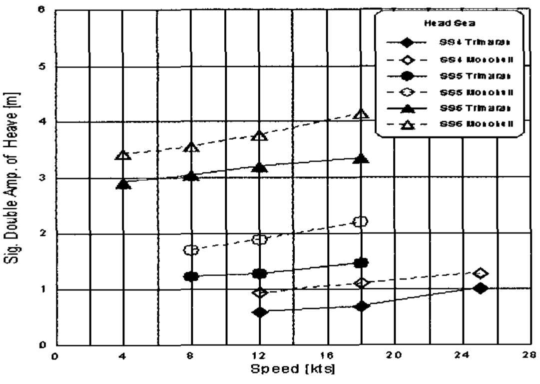


Figure 15: Significant double amplitude of heave

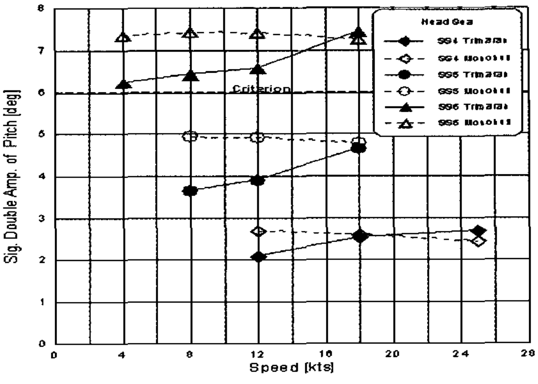
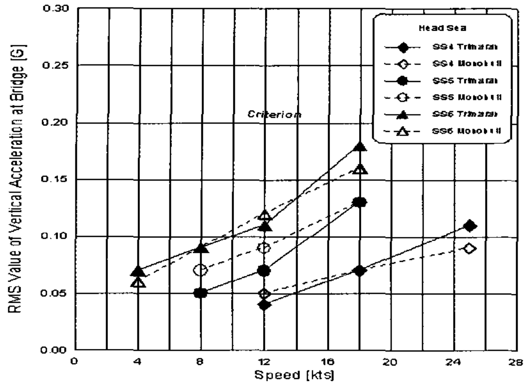


Figure 16: Significant double amplitude of pitch

Figure 19 shows the RMS value of relative bow motion (RBM), which of the trimaran is nearly same as the mono-hull ship in sea state 4 & 5. However, the value of the trimaran is about 0.3 meters higher than that of the mono-hull ship at sea state 6.



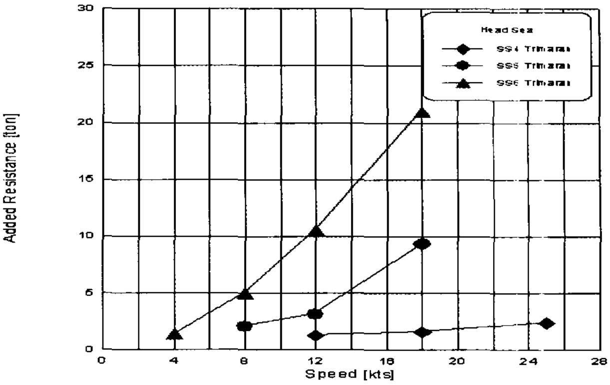


Figure 17: RMS value of vertical accel. at bridge

Figure 18: Added resistance

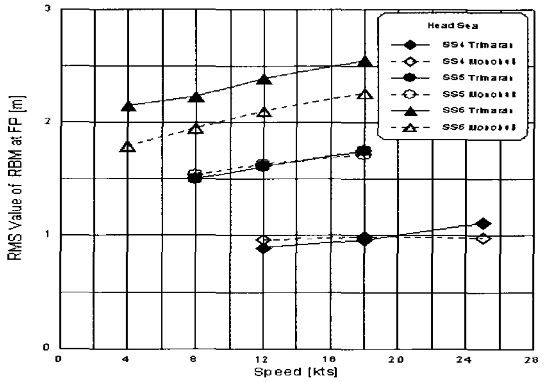


Figure 19: RMS value of RBM at *F.P.*(head sea)

4.4 Seakeeping performance in beam sea

Figure 20 shows the significant double amplitude of heave motion in beam sea condition. The mono-hull ship has almost the same values as the significant wave heights, but the trimaran has 0.5~0.6m lower values. The heave motion of the trimaran is rather small in short beam waves, due to its large breadth.

Figure 21 shows the significant double amplitude of roll motion in beam sea condition. Roll natural period is about 8.2 seconds for the mono-hull ship and about 5 seconds for the trimaran. The roll motion response of the trimaran is less than the mono-hull ship, because the wave energy density near the roll natural period of the former is much less than the latter. And the large breadth of the trimaran contributes to the reduction of roll motion, too. However, it exceeds the criterion in the wave conditions above sea state 5.

Figure 22 shows the averaged zero-crossing roll period. That of the trimaran is about 7 seconds, which is 1.3 seconds shorter than that of the mono-hull ship.

Figures 23 & 24 shows the root mean square (RMS) values of vertical and lateral acceleration at the bridge, respectively, which of the trimaran are less than those of the mono-hull ship. The water contact under the wet deck between the main-hull and side-hulls was observed at the range

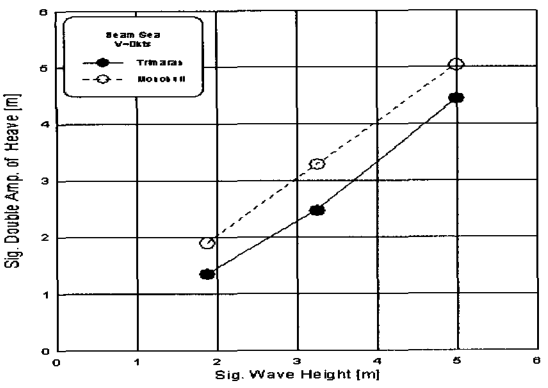


Figure 20: Significant double amplitude of heave

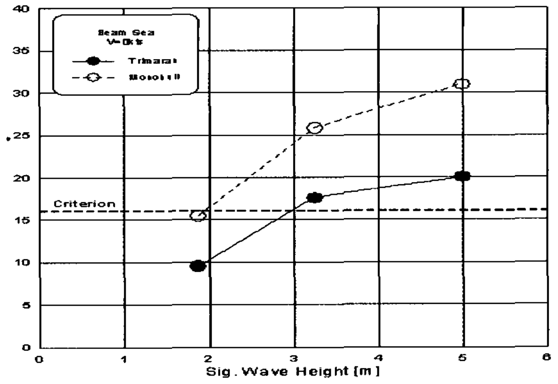


Figure 21: Significant double amplitude of roll

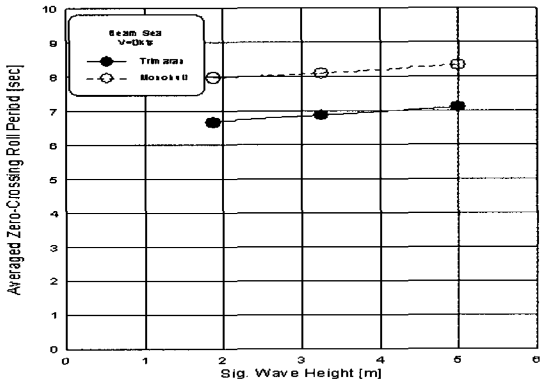


Figure 22: Averaged zero-crossing roll period

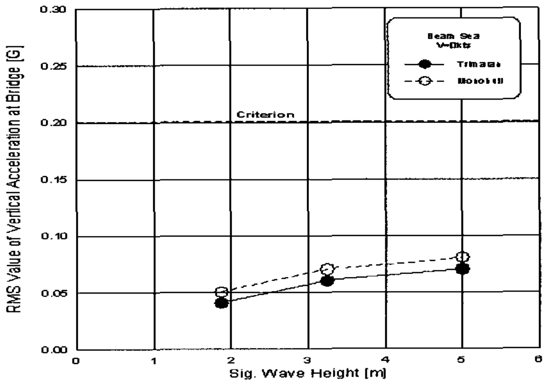


Figure 23: RMS value of vertical accel. at bridge

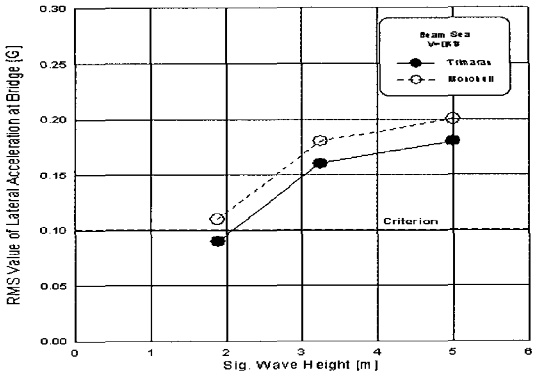


Figure 24: RMS value of lateral acceleration at bridge

over 18 knots at sea state 4 and 5, and over 12 knots at sea state 6. This phenomenon was due to the stem wave of side-hull and pitching motion. However, the water impact is considered as week as negligible. Therefore, It can be seen that the clearance of 4 meters from water surface is sufficient to avoid severe water impact. And the number of deck- wetness on the upper deck was not so much.

5 Maneuvering performance

5.1 HPMM Tests

HPMM tests were conducted at 17 knots with a 1/16.667 scale model of the trimaran. Details of HPMM system, test procedure and analysis method and test results are described in the reference(Kim et al 1988, Kang et al 2000).

Table 5: Predicted maneuvering characteristics of the trimaran

Turning Circle Test	35^o rudder angle	
	Advance	$3.56L$
	Tactical Diameter	$5.01L$
Zig-Zag Test	$10^o/10^o$	
	1st overshoot angle	2.1^o
	2nd overshoot angle	2.3^o
	$20^o/20^o$	
	1st overshoot angle	6.0^o
Initial Turning Test	10^o Rudder angle	
	Path Length	$1.93L$
Spiral Test	Width of Loop	0.0^o
	Height of Loop	$0.0^o/sec$

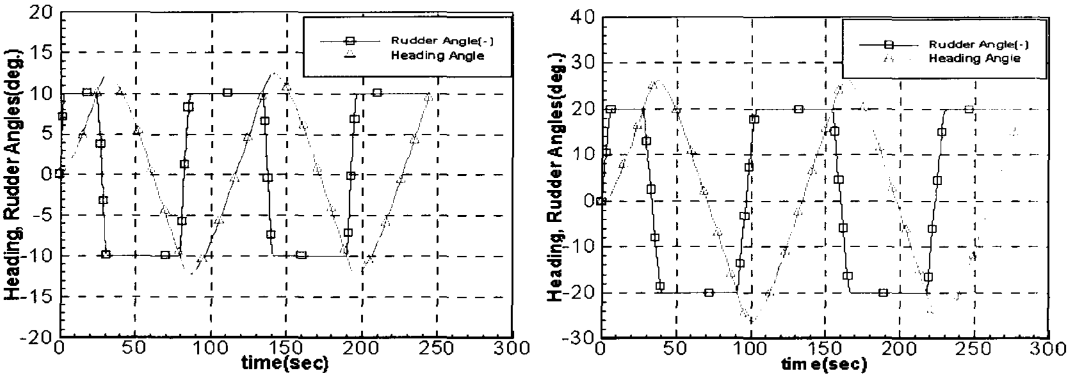


Figure 25: Time history of zig-zag test

5.2 Maneuvering simulation

With the hydrodynamic coefficients obtained from the HPMM test, computer simulation of the maneuvers for the trimaran has been made at cruising speed 18 knots. Equations for the maneuvering simulation are described in the reference(Kang et al 2000). The simulation results are summarized in Table 5.

Figure 25 shows the time histories of rudder and heading angle changes for $10^o/10^o$ and $20^o/20^o$ zig-zag maneuvers respectively. Figure 26 shows the turning trajectory of the trimaran at rudder angle of 35^o. Figure 27 shows spiral maneuver characteristics. It can be seen from the simulation results that the trimaran has excellent course stability, but has a little poor turning ability.

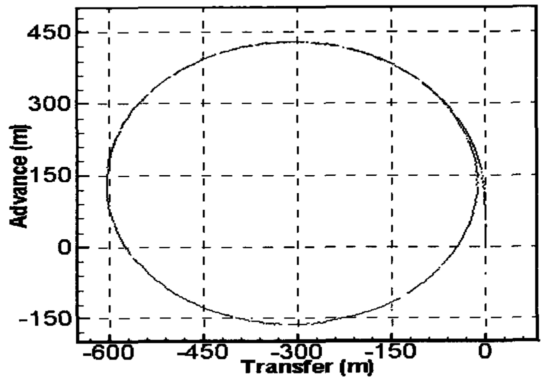


Figure 26: Turning trajectory of 35^o rudder turn

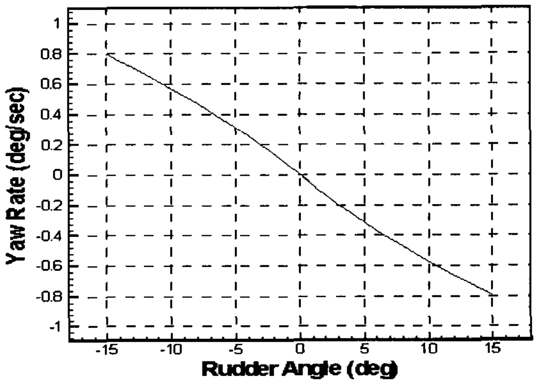


Figure 27: Spiral maneuver characteristics

6 Concluding remarks

A 2,500-ton class trimaran was designed and hydrodynamic performance was investigated. The results are summarized as follows.

6.1 Powering performance

- The symmetry side-hull form shows the best performance on wave resistance among three kinds of side-hull forms.
- The longitudinal location of the side-hull has larger influence on the wave resistance of the trimaran while the side-hull form and transverse location has smaller influence.
- The optimum location of the side-hull is changing according to the ship's speed.(The optimum location moves to the stem as the speed of the trimaran is increased.)
- The trimaran shows favorable resistance performance where the side-hull stem is located near the primary wave hollow generated by the main hull.

- The trimaran is superior to the similar mono-hull ships in powering performance except the low speed range, in spite of the fact that the wetted surface area is increased by 28%.

6.2 Seakeeping performance

- The trimaran shows better seakeeping performance than a similar mono-hull ship.
- Larger hull length and breadth of the trimaran results in better pitching and rolling motion characteristics.
- A roll reduction device is needed to improve the roll motion and lateral acceleration at sea condition over sea state 5.
- Favorable slamming phenomenon was observed under the wet deck within the test conditions.

6.3 Maneuvering performance

- The trimaran is evaluated to have excellent course stability, but a little poor turning performance.

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