The 6th International Workshop on Ship Hydrodynamics, IWSH'2010
January 9-12, 2010, Harbin, China

A Feasibility Study on a New Trimaran PCC in Medium Speed

-Performance in Still Water and Strong Wind-

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Abstract: In the present paper, a new trimaran PCC is proposed and a feasibility study on the ship is carried out. In this study, first, the effective horse power (EHP)/car of the PCC running in still water is predicted. By comparing the predicted EHP/car with that of a conventional mono-hull PCC, it is found that the trimaran PCC is superior to the conventional mono-hull PCC at rather higher speed. As ship speed increases, the reduction of the resistance of the trimaran is bigger. It is also found that at common service speed of PCCs, the EHP/car of a small PCC is lower than that of the conventional PCC. Secondly, the optimal L/B of a main-hull of the trimaran PCC in still water is determined. The optimal L/B of the main-hull varies with ship speed and size because the wave resistance decreases but the frictional resistance increases as L/B of the hull increases. As ship size increases, the optimal L/B of the main-hull of the trimaran PCC decreases. Finally, the increase of the resistance of PCCs running in strong wind is predicted. The results show that drift angle and speed reduction of the trimaran PCC is much smaller than the conventional mono-hull PCC because of large side force created by three demi-hulls.
Keywords: Trimaran; PCC; EHP; Drift angle; Speed Reduction

1 Introduction

A Pure Car Career (PCC) needs huge parking space but smaller displacement since a car is comparatively light for its volume. As a result, a PCC has huge structure above waterline and shallow draft. These features cause lack of stability and serious speed reduction induced by oblique sailing caused by strong winds.

To overcome these technical issues, one of the authors has proposed a new trimaran PCC[1]. The trimaran needs little ballast water because of large stability created by two side hulls.

In the present study, an effective horse power of the trimaran PCC with various length/breadth ratio of a main-hull is predicted in still water. Moreover, steady cruising performances of the trimaran PCC in strong wind condition are predicted.

2 Concept of a New Trimaran PCC

Schematic view of the proposed trimaran PCC is shown in Fig.1. The ship has longer side-hulls compared with existing and planned high speed trimarans. This is because the proposed PCC is not a fast ship, but a medium speed ship. Its side-hulls are used to increase stability. As shown in Fig.1 the trimaran PCC can efficiently carry cars on very wide decks above the bulkhead deck, as a result, the ship's height is much lower than a conventional mono-hull PCC.

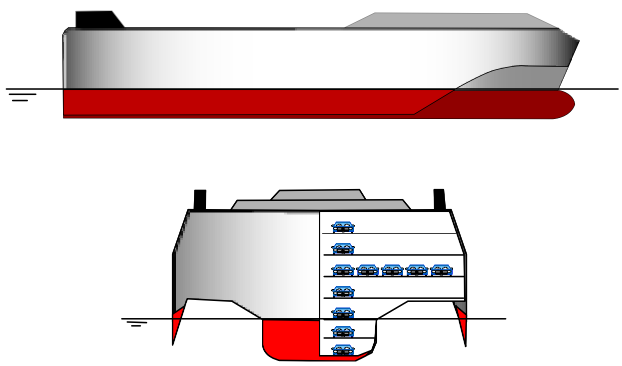

Fig.1 Proposed trimaran type PCC.

3 Reductions of Displacement

In this section, reductions of displacement of the proposed trimaran PCC from that of an existing mono-hull PCC with the same capacity of cars are evaluated.

For this evaluation, a prediction method of lightweight of ships is developed for a mono-hull and a trimaran as

Received date:
Foundation item:
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follows. At first, hull surface area is calculated for hull below and above bulkhead deck, respectively. On the basis of the area, the weight of hulls is approximately predicted. The weight of multiple decks is also included. The weight of equipments of a ship is assumed to be 20% of the total hull weight.

Deadweight includes weights of cars, fuel and ballast water. The weight of ballast water is assumed to be 75% of the weight of cars for a mono-hull PCC and 25% for a trimaran PCC. The reduction of weight of ballast water is caused by larger stability of the trimaran.

The Flowchart of the computer program for the prediction of size, numbers of decks and displacement are shown in Fig.2. Here, NC(1) ; number of cars, B_m ; breadth of the main-hull, B ; maximum breadth of the ship, D_{hull} ; depth of hull below bulkhead deck, t ; thickness of steel plate of hull, Nc(2) ; capacity of cars, LW ; light weight, DW ; dead weight, Δ; full load displacement, d ; draft and Z ; modulus of section.

As input data, number of cars, NC(1) is given. To determine the shape of the trimaran, the L_{PP}, B_m, B, D_{hull}, and t are changed systematically. Using these data, capacity of cars, light weight, dead weight and full load displacement are calculated. Then if calculated capacity of cars coincides with the number of cars input as an initial value, and draft and modulus of section are sufficient, the results are shown as the final output.

In the calculations, following assumptions for the trimaran are made.

1) Prismatic coefficient of the main-hull is 0.6.
2) The length/breadth ratio of the side-hull is 20.
3) Length of side-hulls is 70% of Lpp.
4) Depth of side-hull below bulkhead deck is 70% of that of main-hull.
5) The displacement of a side-hull is 2.5% of total full load displacement of the ship.
6) Midship coefficient of the main-hull is 0.975.

For mono-hulls, Lpp/B and Cp are assumed to be 6 and 0.6 respectively.

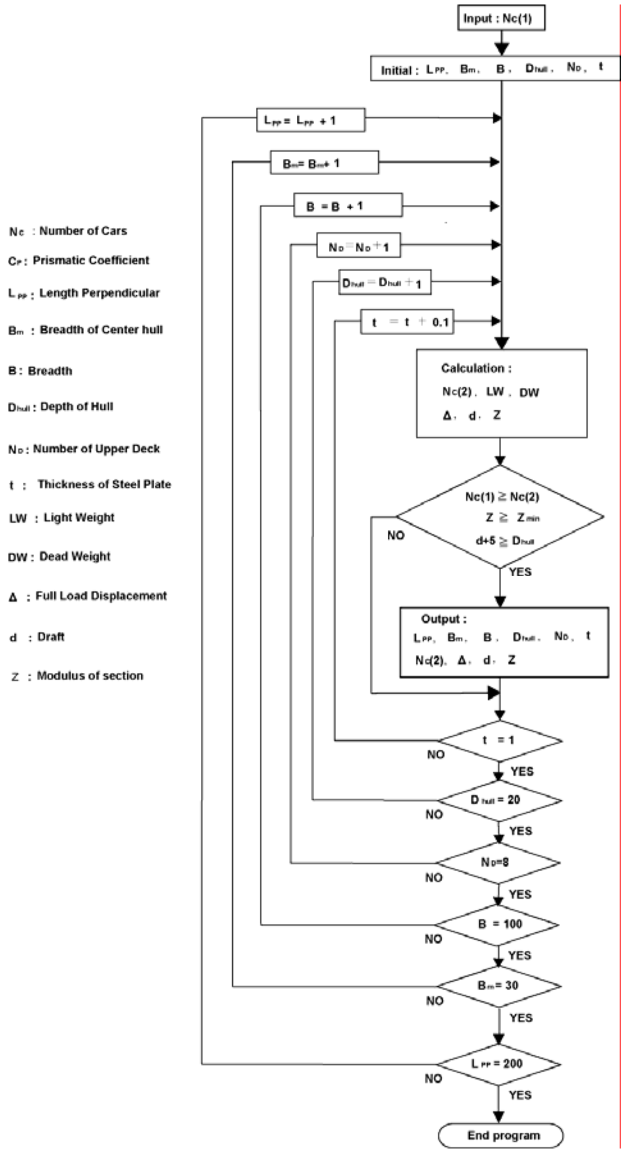

Fig.2 Flowchart to decide principal particulars of a ship.

In Fig.3, obtained light weight (a), dead weight (b), and full load displacement (c) are shown for a mono-hull PCC and a trimaran. These ships are selected ones from the calculated results. The results of the lightweight (a), a trimaran is lighter than a mono-hull with the same capacity of cars because the steel plate of a trimaran is thinner than that of a mono-hull. The middle figure (b) shows that dead weight of a trimaran is lighter than a mono-hull because of large reduction of ballast water. The lower figure (c) demonstrates that full load displacement of a trimaran is lighter than that of a mono-hull in capacity of cars above 2000.

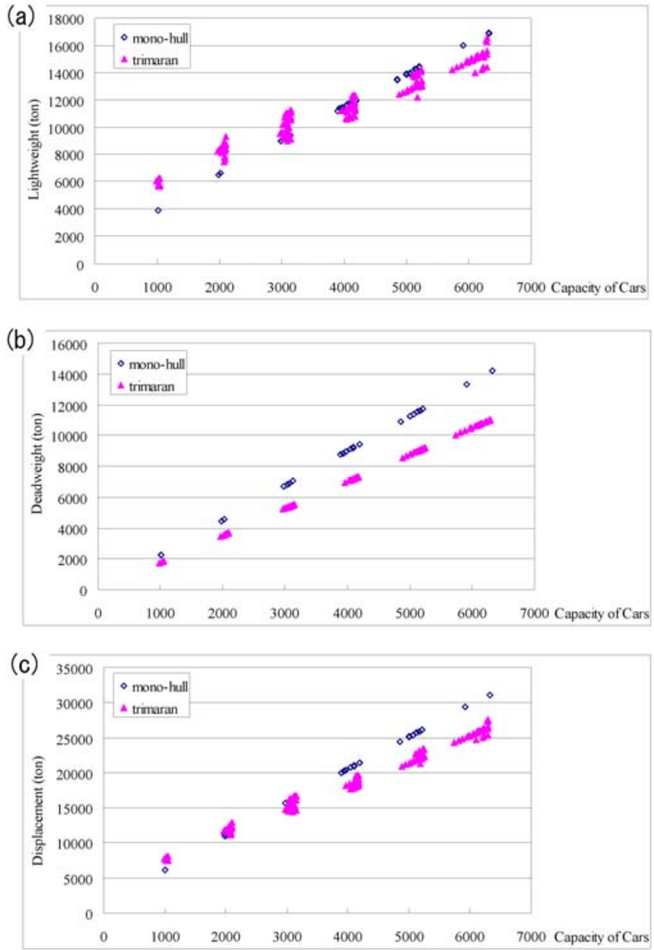

Fig.3 Comparison of light weight (a), dead weight (b) and full load displacement (c) between a mono-hull PCC and a trimaran one.

4 Reduction of Resistance of a New Trimaran PCC

Evaluation of resistance of the proposed trimaran PCC is carried out. For the comparison, the resistance of a mono-hull is also calculated.

Frictional resistance is calculated by using Shoenherr's formula, and residual resistance is calculated for a mono-hull and the main-hull of a trimaran by using Taylor chart. Since the side-hulls are very slender (L/B=20), the wave resistance of them is ignored. Using the predicted resistance of ships, effective horse powers (EHP) of the ships are calculated.

As an example of the predicted EHP, the results for a smaller PCC with 1000 car capacity is shown in Fig.4 in terms of EHP per a car. We can see that EHP of a trimaran is lower than that of a mono-hull in the speed region above 18 knots, and the reduction of EHP rapidly increases with advanced speed.

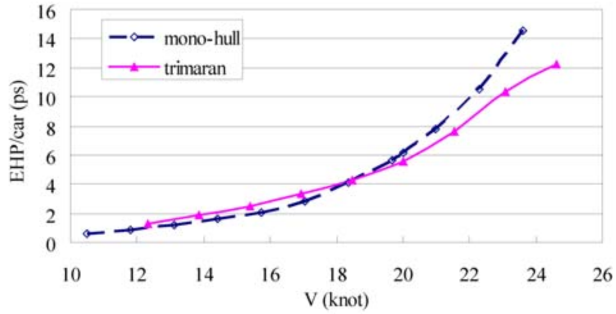

Fig.4 Calculated EHP/car of 1000 car capacity PCCs

The EHP/car of a trimaran significantly depends on L/B of the main hull or capacity of cars. The predicted result of the EHP/car at speeds of 20, 24 and 28 knots are shown in Figs.5-7.

In Fig.5, at 20 knots, the same speed as an existing mono-hull PCC, the EHP/car of a trimaran is lower than that of a mono-hull in capacity of cars, 1000~2000, the EHP/car of a trimaran and a mono-hull is almost same for ships above 3000 capacity of cars. The reduction of the EHP/car appears more remarkably as speed increases as shown in Figs.6-7.

In Fig.8, the length/breadth ratios (L/B) of the main-hull of a trimaran and a mono-hull at 20 knots are shown. The calculated results suggest that for larger trimaran PCCs like 6000 capacity of cars, smaller L/B is better in respect of resistance in still water, on the other hand, larger L/B is better for a smaller trimaran like 1000 cars.

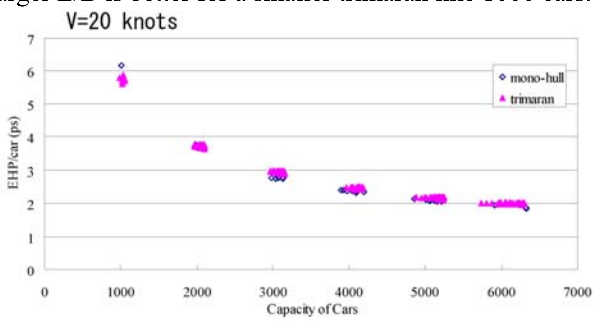

Fig.5 Calculated EHP/car of ships with 1000~6000 capacity of cars at 20 knots.

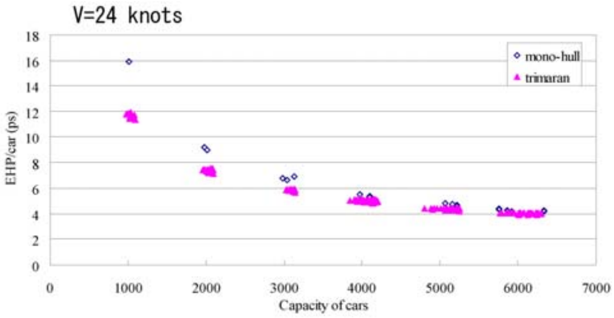

Fig.6 Calculated EHP/car of ships with 1000~6000 capacity of cars at 24 knots.

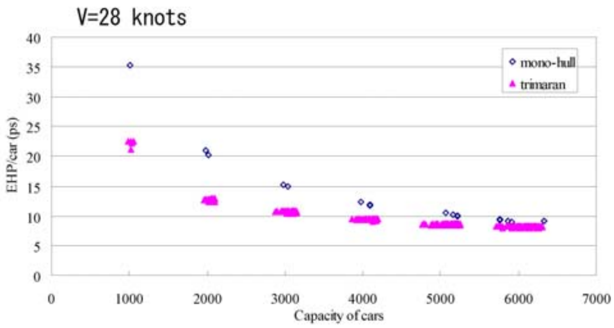

Fig.7 Calculated EHP/car of ships with 1000~6000 capacity of cars at 28 knots.

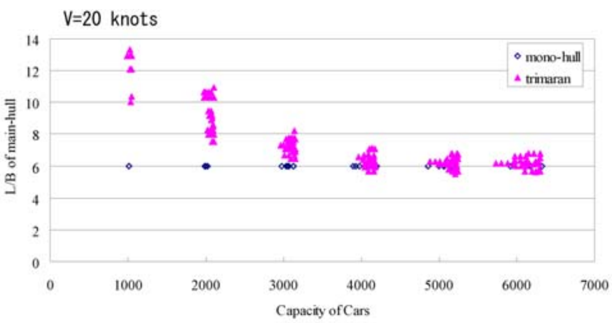

Fig.8 The length/breadth ratio of main-hull of trimaran PCC and that of mono-hull at 20 knots.

5 Reduction of Resistance in Strong Wind

In this section, the prediction of steady cruising performances of a trimaran PCC and a mono-hull PCC under strong wind are carried out.

5.1 Ship Motion Equation

The coordination is represented in Fig.9. Steady navigating will persist when there are no rates of change of the ship motion parameters the longitudinal, lateral and yaw velocities with respect to the center of gravity of the ship $u, v, \dot{r}$. The conditions of steady cruising reduce the terms to the three mathematical equations as follows:

$$X = 0, \qquad Y = 0, \qquad N = 0$$

Here, X, Y and N are the longitudinal and lateral forces, and yaw moment as defined in Fig.9. These equations will be solved for the steady advance speed of a ship, drift and rudder angles, V, β and δ, respectively, for different wind speeds, U_W, and direction, χ.

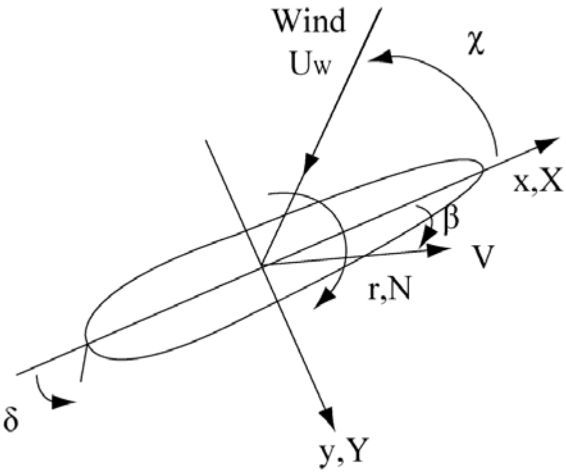

Fig.9 Coordinate systems and definitions of forces and moment.

5.2 External Loads Experienced on Ship

The external forces shown in the left hand side of the equation (1) are assumed as follows:

$$\begin{aligned} X &= X_H + X_P + X_R + X_A \\ Y &= Y_H + Y_R + Y_A \\ N &= N_H + N_R + N_A \end{aligned} \qquad (2)$$

In the equation (2), the subscript “H” symbolize ship hull, “P” propeller, “R” rudder and “A” wind.

5.2.1 Hull Hydrodynamic Loads

The longitudinal and lateral forces, and yaw moment acting on hulls are expressed as follows:

$$\begin{aligned} X_H &= X_{H0} \cos^2 \beta \\ Y_H' &= Y_\beta' \beta \\ N_H' &= N_\beta' \beta \end{aligned} \qquad (3)$$

The superscript ’ refers to non-dimensional quantities as follows:

$$\begin{aligned} Y_H' &= Y_H / \tfrac{\rho}{2} L_{PP} d V^2 \\ N_H' &= N_H / \tfrac{\rho}{2} L_{PP}^2 d V^2 \end{aligned} \qquad (4)$$

The lateral force and yaw moment coefficients are estimated by following approximate formula proposed by Kijima et al.[2]:

$$Y'_\beta = \frac{1}{2}\pi k + 1.4 C_B B/L$$
$$N'_\beta = k \qquad (5)$$
$$where \qquad k = 2d/L$$

5.2.2 Propeller and Rudder Loads

The propeller thrust is assumed to be constant. The rudder forces and moments are calculated by the formulae proposed by Kijima et al. as follows[2]:

$$X_R = -F_N \sin\delta$$
$$Y_R = -F_N \cos\delta \qquad (6)$$
$$N_R = -x_R F_N \cos\delta$$

The normal rudder force F_N is defined in terms of the rudder aspect ratio and the effective speed of water flow over rudder.

5.2.3 Wind Loads

The longitudinal force, lateral force and yaw moment coefficients are defined in non-dimensional forms as follows:

$$C_X = X_A \Big/ \left(\frac{1}{2}\rho_A U^2 A_F\right)$$
$$C_Y = Y_A \Big/ \left(\frac{1}{2}\rho_A U^2 A_L\right) \qquad (7)$$
$$C_N = N_A \Big/ \left(\frac{1}{2}\rho_A U^2 A_L L_{OA}\right)$$

Here, ρ_A ; density of air, U ; the relative wind velocity, L_{OA} ; length overall, A_F ; the frontal projected area, A_L ; the lateral projected area.

The wind force and moment coefficients of a trimaran PCC are measured by a wind tunnel experiment using a model ship, and the wind load coefficients of a mono-hull PCC is estimated by using formula proposed by Fujiwara et al.[3].

5.3 Calculated Condition

For the prediction, 6000 car capacity PCCs in mono-hull and trimaran types are selected as shown in Table 1, and shapes of both PCC are shown in Fig.9.

Table 1 Principal particulars of the trimaran PCC and the mono-hull PCC

	mono-hull	trimaran
L_{OA}(m)	198	185
L_{PP}(m)	192	180
B(m)	32	30
d(m)	8.44	7.56
L_{side}(m)		126
B_{side}(m)		6.3
d_{side}(m)		1.56
A_F(m^2)	927	1090
A_L(m^2)	5700	3338

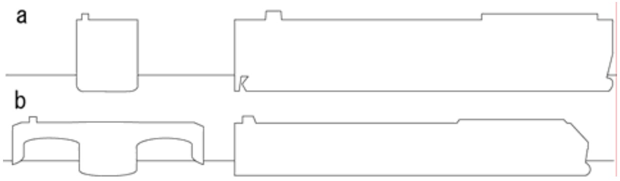

Fig.9 Front and side profiles of (a) mono-hull PCC and (b) trimaran PCC

Fig.10 shows the predicted resistance X_{H0} in calm water at β=0. The measured wind force of the trimaran and estimated ones of the mono-hull are shown in Figs.11~13.

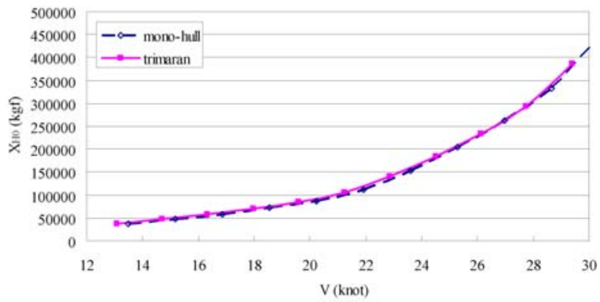

Fig.10 Predicted resistance X_{H0} in calm water at β =0

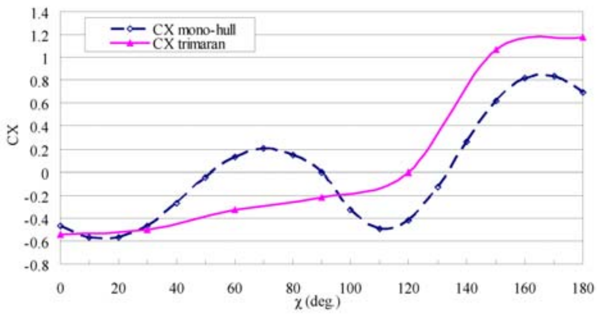

Fig.11 Longitudinal wind force coefficients of mono-hull PCC and trimaran PCC.

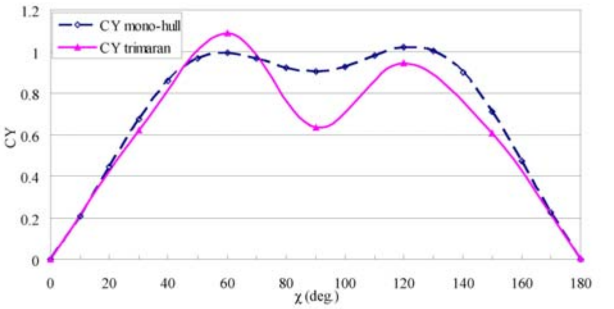

Fig.12 Lateral wind force coefficients of mono-hull PCC and trimaran PCC.

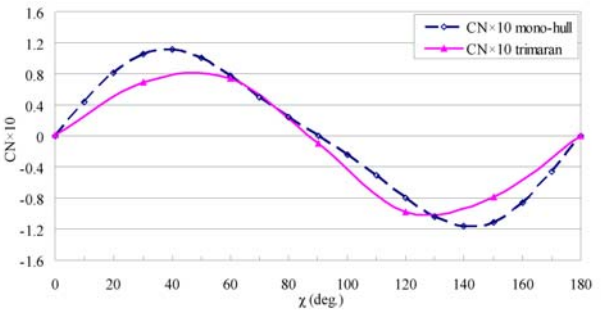

Fig.13 Yaw wind moment coefficients of mono-hull PCC and trimaran PCC.

5.4 Calculated Results

The calculated results for the drift angle, rudder angle and steady advance speed of the ship, β, δ and V in strong winds are shown in Figs.14~16. The true wind velocity U_W is set to 20 m/s. The direction of the true wind χ is also set from 0 to 180 degrees for every 30 degrees.

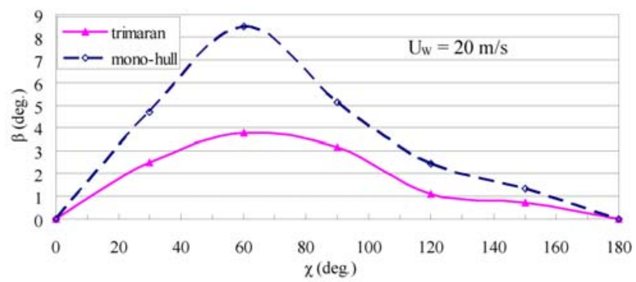

Fig.14 Calculated results of drift angles for mono-hull PCC and trimaran PCC.

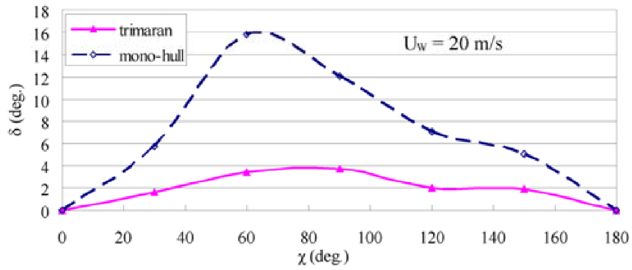

Fig.15. Calculated results of rudder angles for mono-hull PCC and trimaran PCC.

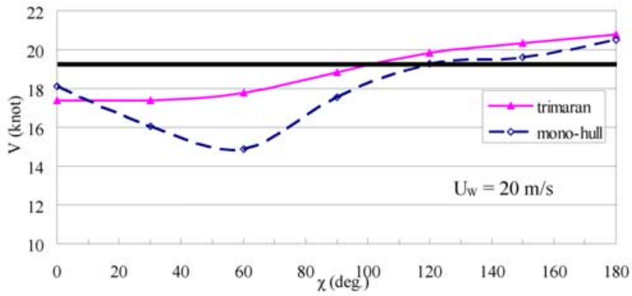

Fig.16 Calculated results of ship speed loss for mono-hull PCC and trimaran PCC.

As shown in Fig.14, in all wind directions, the drift angles of the trimaran are smaller than those of the mono-hull. The maximum drift angle of the trimaran is 4deg, although that of mono-hull is about 8deg. in 60deg. of wind direction.

The calculated results of rudder angles, shown in Fig.15, demonstrate that rudder angles of the trimaran are smaller than those of the mono-hull in all wind directions.

As shown in Fig.16, in almost all wind directions, the ship speed losses of the trimaran are smaller than those of the mono-hull. This good performance of the trimaran is caused because the drift and rudder angles of the trimaran are smaller than that of the mono-hull as previously mentioned.

6 Conclusions

In the present study, size and displacement, effective horse power/car and performance of a trimaran PCC in strong wind are investigated. Following conclusions have been obtained.

1) The displacement of a trimaran PCC can be reduced compared with a mono-hull one because of reduction of ballast water and hull plate thickness.

2) The EHP/car of a trimaran PCC is smaller than that of

a mono-hull PCC.
3) The L/B of the main-hull of a trimaran whose resistance is minimum is 10~14 for 1000 capacity of cars, 6 for 6000 capacity of cars at 20 knots.
4) The drift and rudder angle of a trimaran PCC is much smaller than that of a mono-hull one.
5) The speed loss of a trimaran PCC is smaller than that of a mono-hull PCC.

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