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Experimental Study on Seakeeping Performance of a Catamaran with Asymmetric Demi-Hulls

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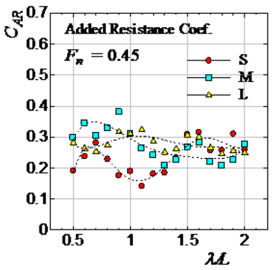
Graphical abstract



Abstract

To capture the seakeeping performance of a catamaran with asymmetric demi-hulls, tank tests were carried out in regular head waves using a scaled model with 2.036 m in length. The lateral space between the demi-hulls was changed in the tests as *W/B*=2.55, 2.90 and 3.25, where *W* denotes breadth overall and *B* the breadth of the demi-hull. Also, two models with different water lines of inside flat and outside round (IF-type) and of outside flat and inside round (OF-type) were used. OF-type is superior to IF-type in both ship motion and added resistance performances in waves at the design speed. In IF-type series, the smallest clearance, *W/B*=2.55 is the best in the added resistance performance.

Keywords: Catamaran; asymmetric demi-hull; seakeeping; tank tests; added resistance in waves

■1.0 INTRODUCTION

Catamarans are widely used as passenger ferry, etc. One of the two hulls of a catamaran is called a demi-hull. Most of the time, demi-hulls have symmetric waterlines as in mono-hull ships. However, catamarans with asymmetric demi-hulls have appeared recently, mainly for reasons of fuel efficiency[1,2,3].

Figure 1 shows an example of a catamaran with asymmetric waterline demi-hulls. The left hand side of Figure 1 is flat inside between the demi-hulls and round outside. The right hand side of Figure 1 is flat outside and inside round between the demi-hulls. In this paper, the former is called Inside Flat (IF) type and the latter Outside Flat (OF) type.

This paper discusses ship motions and added resistance of a catamaran with asymmetric demi-hulls in head waves. There are many studies on the performance of catamarans, but few dealing with the seakeeping performance of catamarans with asymmetric demi-hulls[4]. To capture the effect of the asymmetric demi-hull form on seakeeping, tank tests were conducted using ship models of IF and OF-types. Moreover, the effect of lateral clearance between demi-hulls was investigated. Test results are shown in this paper.

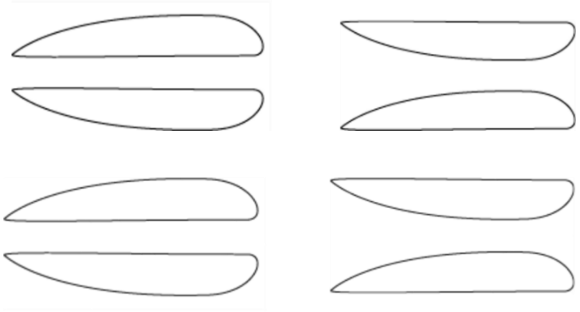


Figure 1 Waterlines of catamaran with asymmetric demi-hulls (left: IF, right: OF)

■2.0 OUTLINE OF TANK TESTS

2.1 Ship Model

The studied ship is a catamaran of 28 m in the length. Table 1 shows the principal dimensions of the ship. L_{pp} denotes the ship length between perpendiculars, L_{wl} the waterline length, B the breadth of demi-hull, d the draft and Δ the displacement volume. Figure 2 shows the body plan. Let IF-type be a standard in this paper. Note that we can make OF-type easily by replacing right and left demi-hulls. A ship model with 1/13.75 scale was used in the tank tests. Figure 3 shows a photograph of the ship model. Design speed of the ship is 14.5 knots, and the corresponding Froude number is F_n=0.45.

Table 1 Principal dimensions of a ship

Symbol	Fullscale	Model
L_{pp}	28.00 m	2.036 m
L_{wl}	28.80 m	2.095 m
B	4.00 m	0.291 m
d	3.34 m	0.243 m
Δ	249.2 m^3	0.0959 m^3

This ship model can change the lateral clearance between two demi-hulls in three conditions, S, M and L: S-condition has small clearance between demi-hulls, M middle and L large clearance. Table 2 shows the breadth overall in the three configurations. Figure 4 shows rear views of the ship models with three different hull clearances in IF-series. M-condition of OF-type is denoted by Mo here.

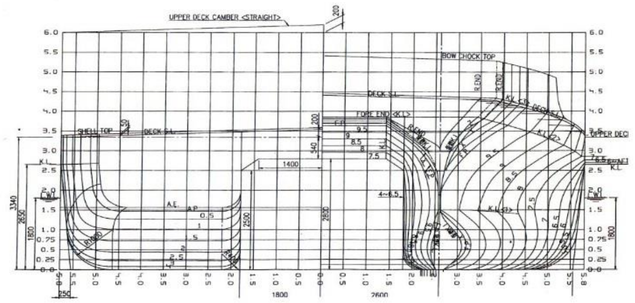


Figure 2 Body plan of the catamaran

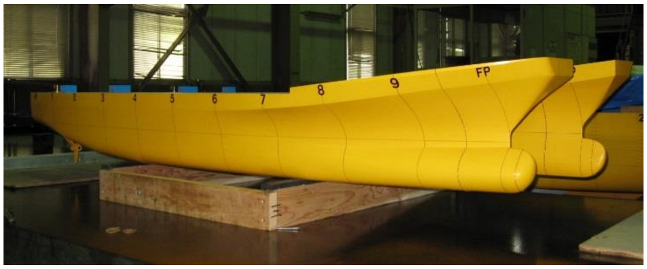


Figure 3 Catamaran model

Table 2 Breadth overall of three configurations

Symbol	Fullscale	Model
Small: S	10.20 m	0.744 m
Middle: M	11.60 m	0.844 m
Large: L	13.00 m	0.944 m

Figure 4 Rear views of ship models with three different hull clearances (top: S, middle: M, bottom: L)

2.2 Outline of Seakeeping Tests

Seakeeping tests in regular head waves were conducted in Hiroshima University towing tank. The test conditions were as follows:

- Froude numbers: F_n: 0.20, 0.35, 0.45
- Ratio of wave height to ship length H_w/L_{pp}: 0.015, 0.025 (30 mm, 50 mm in the model, respectively)
- Ratio of wave length to ship length λ/L_{pp}: 0.5 - 2.0, the interval is 0.1.

We recorded time histories of heave, pitch, surge motions, wave height and resistance in waves. Fourier transform technique was applied to obtain the amplitude of the motions and the phase difference to the incident waves. Heave amplitudes z_a are non-dimensionalized with wave amplitude h_a. Pitch amplitudes θ_a are non-dimensionalized with wave slope (Kh_a). Surge motions are not discussed in this paper.

The added resistance was obtained by deducting the resistance in still water from the mean resistance in regular waves. The added resistance R_{AR} is non-dimensionalized by the following formula:

$$C_{AR} = R_{AR}/(\rho g h_a^2 L_{wl})$$

where ρ is the water density and g is the acceleration of gravity.

Table 3 shows the non-dimensional radius of gyration in pitch κ_{yy} for ship models.

Table 3 Radius of gyration (κ_{yy}/L_{pp})

S (IF)	M (IF)	L (IF)	Mo (OF)
0.30	0.30	0.29	0.32

3.0 TEST RESULTS

3.1 Effect of Wave Height

Figure 5 shows the non-dimensional heave and pitch amplitudes, and added resistance in two different wave heights. All the results are for M-condition. The dash-line for added resistance is fitting curve approximated by a polynomial equation of the 5th degree.

Heave amplitude and added resistance decrease for larger wave height. For lower wave height (H_w/L_{pp}=0.015), the pitch amplitude of F_n=0.2 once decreases at λ/L_{pp}=1.2, increases drastically for larger waves and reaches a peak at λ/L_{pp}=1.6. For higher wave height (H_w/L_{pp}=0.025), we cannot see the clear drop at

λ/L_{pp}=1.2 and peak at λ/L_{pp}=1.6. When the wave height is high, significant wave-breaking at the fore part and waves hitting to the deck were observed in the tank tests. The breaking wave phenomena is probably the main cause for the difference of the motion response.

The wave height effect on the added resistance coefficient is remarkable. At F_n=0.2 and 0.45, added resistance of the low wave height is roughly two times larger than that of the high wave height. This differs from common theory which assumes added resistance proportional to wave height squared. This is probably due to the effect of wave breaking, but details require further investigations. The added resistance at F_n=0.2 and 0.35 has a typical characteristic and reaches a peak at around λ/L_{pp}=1.5. The characteristic for F_n=0.45 is unusual with its undulations over for λ/L_{pp}.

3.2 Effect of Hull Clearance

Figure 6 shows the non-dimensional heave, pitch and added resistance for three different hull clearances, S, M and L in H_w/L_{pp}=0.025. Heave is smallest in S-condition at all three Froude numbers. The reason should be that the heave damping force becomes large for small hull clearance. Pitch shows different tendencies at different Froude numbers. For example, for λ/L_{pp} > 1.5, pitch is smallest in S-condition at F_n=0.2, largest in S-condition at F_n=0.35, and almost the same in S, M and L conditions at F_n=0.45. The added resistance is smallest in S-condition except for short waves with λ/L_{pp} < 1.0 at F_n=0.2 and 0.35, and for long waves with λ/L_{pp} > 1.5 at F_n=0.45. The reason for the larger added resistance in S-condition in short waves is probably the effect of the wave reflection at the bow for smaller hull clearance.

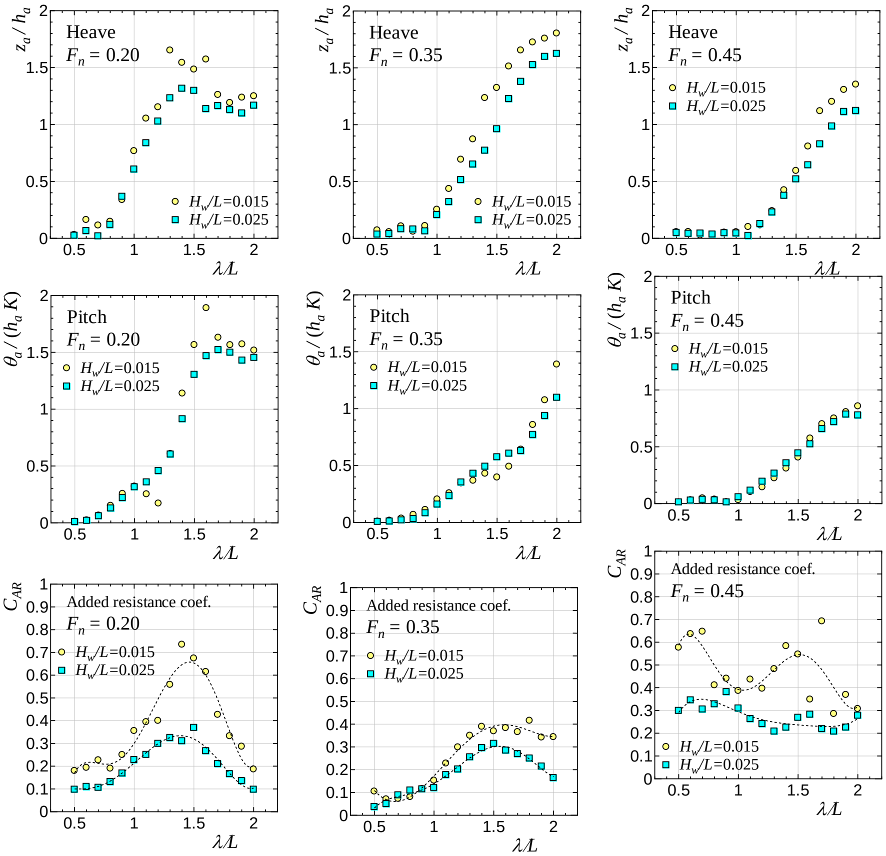


Figure 5 Wave height effect on heave, pitch amplitudes and added resistance coefficient for M-condition

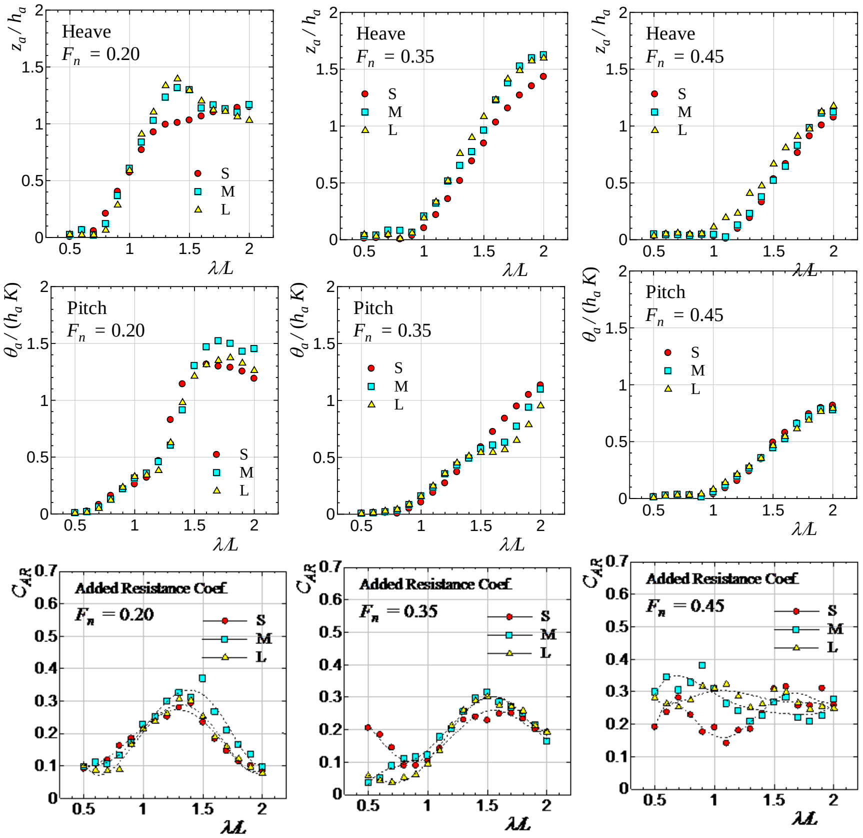


Figure 6 Demi-hull clearance effect on heave, pitch amplitudes and added resistance coefficient (IF-condition, H_w/L_{pp}=0.025)

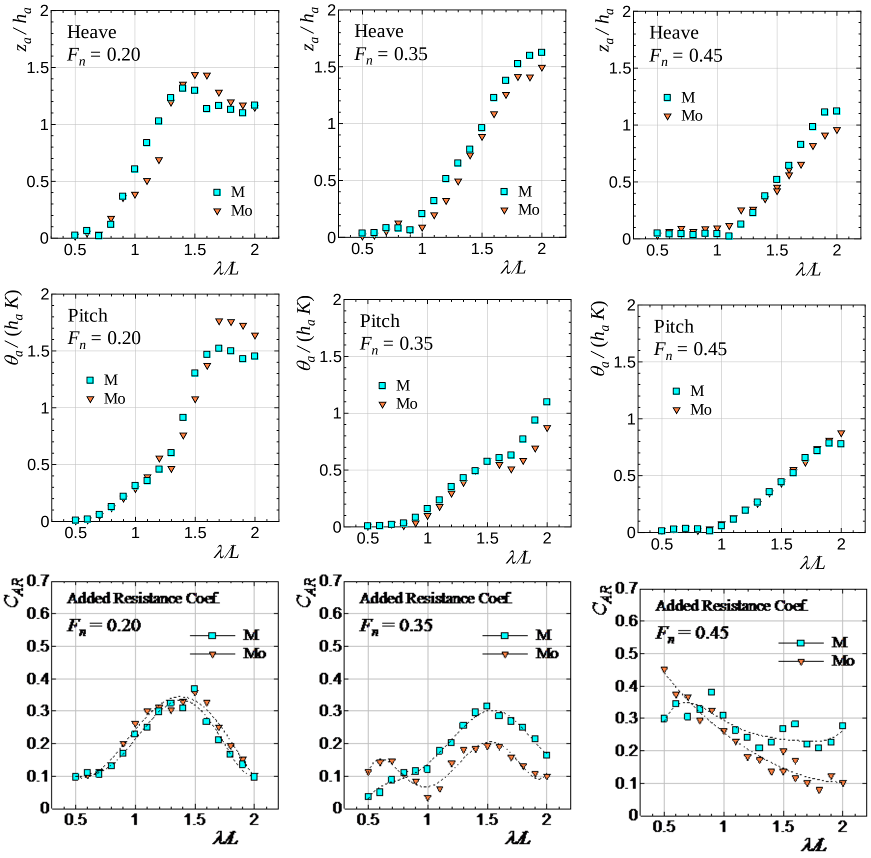


Figure 7 Effect of IF and OF water lines on heave, pitch amplitudes and added resistance coefficient (H_w/L_{pp}=0.025)

3.3 Effect of Waterline Tendency: IF and OF

Figure 7 shows the effect of IF and OF waterlines on heave, pitch and added resistance in H_w/L_{pp}=0.025. Heave in Mo-condition (OF-type) is smaller than that in M-condition (IF-type) except for $\lambda/L_{pp} > 1.4$ at F_n=0.2 and $\lambda/L_{pp} < 1.3$ at F_n=0.45. Pitch is smaller or almost the same in Mo-condition except for $\lambda/L_{pp} > 1.7$ at F_n=0.2. Added resistance is smaller in Mo-condition except for $\lambda/L_{pp} < 0.7$ at F_n=0.35 and 0.45. Added resistance for Mo-condition is smaller than for M-condition as overall tendency. Thus, Mo-condition is superior to M-condition in propulsive performance in waves.

■4.0 RESULTS IN IRREGULAR WAVES: SHORT-TERM PREDICTION

The short-term prediction in long-crested irregular head waves was carried out using the results of the ship motions and added resistance coefficient obtained in regular wave seakeeping tests. ISSC spectrum was used as a wave spectrum. Here, the test results in H_w/L_{pp}=0.025 were used for the prediction. The significant values of heave and pitch are denoted by $z_{1/3}$ and $\theta_{1/3}$, respectively. These are proportional to the significant wave height $H_{1/3}$. $R_{1/3}$ denotes the averaged added resistance in irregular waves. This is proportional to the square of the significant wave height $H_{1/3}$ and the unit is ton/m^2.

Figure 8 shows the prediction results of heave, pitch and added resistance in irregular waves for different conditions of S, M, L and Mo at F_n=0.45. The horizontal axis shows the averaged wave period T_{01}. For the significant value of heave, S-condition is the smallest for S, M and L conditions for all T_{01}. Further, Mo-condition is smaller than M-condition. The significant value of pitch is almost the same for S, M, L and Mo conditions. For the added resistance per squared significant wave height, S-condition is the smallest among S, M and L conditions, and Mo-condition is smaller than M-condition except for shorter wave period. Thus, Mo-condition (OF-type) is more superior to M-condition (IF-type) in overall seakeeping performance.

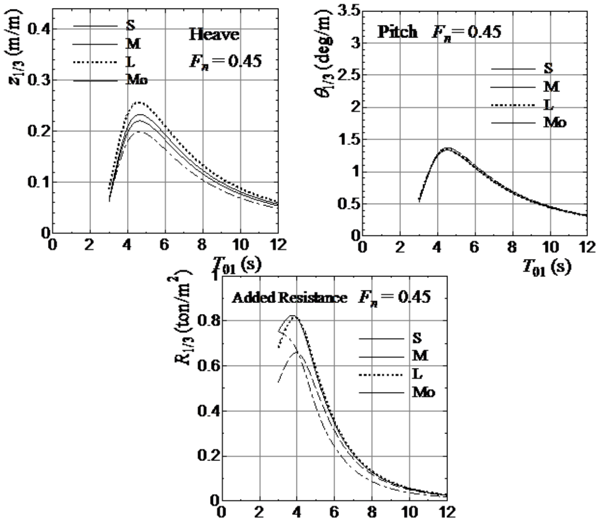


Figure 8 Heave, pitch motions and added resistance in irregular waves (F_n=0.45)

■5.0 CONCLUDING REMARKS

To capture the seakeeping performance of a catamaran with asymmetric demi-hulls, tank tests were carried out in regular head waves using a scaled model with 2.036 m in length. We investigated the effect of wave height, clearance of the demi-hulls, and type of the waterline of inside flat and outside round (IF-type) and of outside flat and inside round (OF-type) on the performance. The results obtained in this study are summarized as follows:

- The amplitudes of heave and pitch, and the added resistance coefficient decrease for higher wave height. The wave height effect on the added resistance coefficient is remarkable. The added resistance coefficient of low wave height (H_w/L_{pp}=0.015) is roughly two times larger than that of high wave height (H_w/L_{pp}=0.025). This is probably due to the influence of breaking waves and water on deck for high waves.
- Heave becomes smallest in S-condition. Pitch is almost the same among S, M and L conditions at the design speed F_n=0.45. Added resistance is smallest in S-condition for three different hull clearances. Mo-condition is superior to M-condition in added resistance performance.

Thus, added resistance coefficient changes significantly with hull clearance and waterline shape (IF/OF). In particular, OF-type is superior to IF-type for overall seakeeping performance. Further research shall elucidate the mechanism of such changes.

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