Selecting Monohull, Catamaran and Trimaran as Suitable Passenger Vessels Based on Stability and Seakeeping Criteria

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Abstract: The current paper describes the selection of monohull, catamaran and trimaran in order to operate as passenger vessel for calm water and oblique wave conditions. The three modes were built and modified based on the previous models developed at ITS which was applied for river and coastal areas. The analysis is focused on the evaluation of stability and seakeeping criteria. The stability criterion is based on IMO regulation and the seakeeping criterion is solved using Maxsurf and CFD analysis. The whole results are compared each other together with comparative analysis with published data in order to find out the most suitable vessel mode for the indicative seawaters.

Key words: monohull, catamaran, trimaran, stability, seakeeping, CFD

1. Introduction

Multihull vessels have been centre of attention in the last thirty years for their applications as passenger vessels, sporting craft, and oceanographic research vessels [1] and [2]. Reference [3] later developed catamaran form for the application of fishing vessels. The reasons behind the progressive development are due to the advantages of multihulls (catamaran and trimaran) such as their ability to provide lower drag and hence the size of main engine compared to monohull of similar displacement, having wider deck area and better transverse stability [2].

Multihull vessels also show good seakeeping characteristics compared to monohull type of vessel. Reference [4] conducted research on the seakeeping characteristics of catamarans in deep water, whilst Reference [2] investigated the seakeeping characteristics of catamaran and trimaran for river and coastal operation at Indonesian waters. However, both of them discovered that the seakeeping characteristics of catamaran, in particular, are rather poor in oblique waves. This is attributed to the configuration of catamaran when heeling aside due to rolling motion, the stability of catamaran relies only on the demihull, which is still underwater.

There are several tools that can be used to investigate the seakeeping characteristics of ships, including catamaran and trimaran, namely: (1) theoretical investigation, (2) the use of experimental model test, (3) the use of commercial software – Seakeepers from Maxsurf, and (4) the use of CFD package – ANSYS AQWA. The current paper is focused on the stability evaluation and seakeeping analysis of monohull and multihulls.

2. Ship Hull Form

The current work used a modified model which is developed by [2]. The previous models were designed for calm water condition such as river and coastal waters. In fact, slight modification was made to make it fit with oblique wave condition. Complete investigation was also included with the seakeeping characteristics of monohull for comparison purposes with the multihulls.

Body plan of the monoull is shown in Figure 1 together with its principal particular in Table 1.

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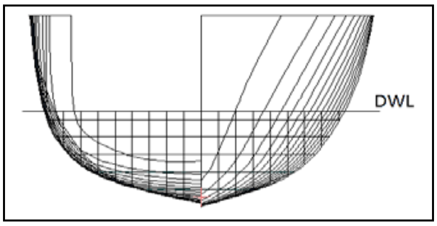

Figure 1 - Body plan of monohull

Table 1 Data particular of monohull

L (m)	B (m)	T (m)	V (knots)	C_P	L/B	B/T
68.55	11.93	3.24	20	0.79	5.75	4.10

Body plan of catamaran and trimaran were shown in Figures 2 and 3 and their particulars were given in Tables 2 and 3.

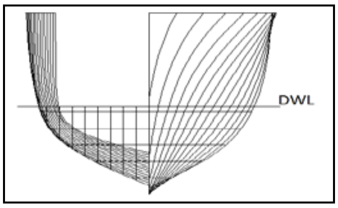

Figure 2 - Body plan of demihull catamaran

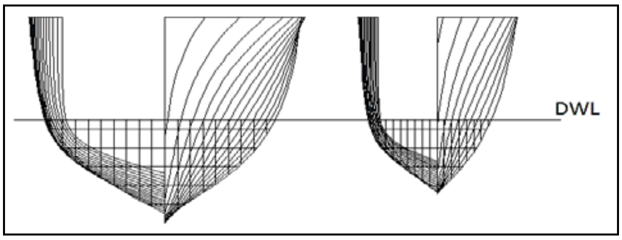

Figure 3 - Body plan of main-hull and side-hull of trimaran

Table 2: Data particular of demihull catamaran

L (m)	B (m)	T (m)	V (knots)	C_P	L/B	B/T
72.12	36.80	3.24	20	0.66	1.96	11.35

Table 3: Data particular of trimaran

L (m)	B (m)	T (m)	V (knots)	C_P	L/B	B/T
72.12	48.14	3.59	20	0.63	1.98	13.40

3. Stability Analysis

The term stability refers to the tendency of a body or system to return to its original state after it has suffered a small disturbance [5]. If a floating body is very stable it will return quickly to the upright and may produce motion sickness; if it is just stable a disturbance which is not small may cause it to capsize. The stability therefore must be just right in the range of conditions in which a vessel may find itself during its operation and life, even damaged or mishandled.

Transverse stability of a vessel depends on KB, BM. KG and GM. Since Metacentre (M) is at the intersection of vertical lines through the centres of buoyancy in the initial and slightly inclined positions, GM is the most important component.

The value of metacentre can be calculated as [5]:

$$KM = KB + BM \qquad (1)$$

Where:

$$KB = 0.535T$$

$$BM_T = \frac{C_W^2 B^2}{12TC_B} \qquad (2)$$

The empirical value of KB was given by [6]. The values of BM for monohull, catamaran and trimaran can be obtained from the data given in Tables 1 to 3.

For monohull:

$$BM_T = \frac{0.79^2 x\, 11.93^2}{12\, x\, 3.24\, x\, 0.79\, x\, 0.785} = 3.68 \text{ m}$$

For catamaran:

$$BM_T = \frac{0.79^2 x\, 36.8^2}{12\, x\, 3.24\, x\, 0.79\, x\, 0.785} = 35.05 \text{ m}$$

For trimaran:

$$BM_T = \frac{0.79^2 x\, 48.14^2}{12\, x\, 3.59\, x\, 0.79\, x\, 0.785} = 54.14 \text{ m}$$

Furthermore, the value of GZ at small angle (less than 15^0) and the righting moment are respectively:

$$GZ = GM\, x\, \sin\theta \qquad (3)$$

$$Righting\ Moment = W\, x\, GZ\, x\, \sin\theta \qquad (4)$$

The height of the initial metacentre above the keel (KM) depends upon a ship's underwater form. The vertical distance between G and M is referred to as the metacentric height. If G is below M, the ship is said to have positive metacentric height, and if G is above M the metacentric height is said to be negative.

Furthermore, during its voyage a ship can experience heeling and listing conditions [5]. A ship is said to be heeled when the ship is inclined by an external force, for example, when the ship is inclined by the action of the waves or wind. A ship is said to be listed when the ship is inclined within the ship, for example, when the ships is inclined by shifting a weight transversely within the ship. Catamaran and trimaran, which has higher BM, GM and GZ values, will have better characteristics on heeling and listing conditions.

4. Seakeeping Evaluation

Performance of ship at sea is popularly called seakeeping. This is among the most important factors when comparing competing vessels or types of vessel. This is due to the seakeeping criteria, which can influence important aspects such as passenger comfort, operational limits, speed loss and structural integrity [5].

Motion transfer functions for each vessel and wave energy spectra for the relevant sea area are necessary to perform spectral calculations. Reference [7] provides good information about wave spectrum of Indonesian water. This allows the calculation of statistical quantities such as the RMS values of the various motions and accelerations and the probabilities of an individual motion or acceleration exceeding a given value. This also assists ship designers to estimate vessel's seakeeping characteristics more realistic.

Seakeeping is simply known as the motions of ship at sea which is affected by external wave forces. Seakeeping is expressed as Figure 4 and consist of 3 sets of translational motions and 3 sets of rotational motions. The translational motions include heave, sway and surge, whereas rotational motions contain pitch, roll and yaw. Table 3 further describes the calculation of response of amplitude operator (RAO).

Examples of seakeeping estimation by using commercial software and CFD code were described. Three types of vessels were investigated: monohull, catamaran and trimaran. The tests were conducted at sea state 3 and 5 and represented calm water and oblique wave conditions.

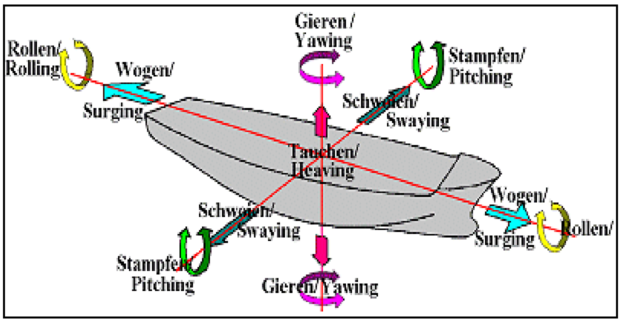

Figure 4 - 6 degrees of freedom of ship motions

Table 4 RAO equations of ship motion

No	Translational motion	RAO	No	Rotasional Motion	RAO
1	Surge	$(x_a/\delta_a)^2$	4	Roll	$(Ø_a/\delta_a)^2$
2	Sway	$(y_a/\delta_a)^2$	5	Pitch	$(\Theta_a/\delta_a)^2$
3	Heave	$(z_a/\delta_a)^2$	6	Yaw	$(\Phi_a/\delta_a)^2$

Surge and sway motions are motion of ship which accelerates and decelerates the motion of ship to move forward and backward from a certain position. Heave motion involves linear and vertical motion of going up and down. Similarly, pitch motion is also a motion which goes up and down but making a curve direction or a rotational motion. Roll motion involves motion from side to side of ship, whilst yaw motion involves rotational movement in vertical axis.

Based on the Second Law of Newton, the equation of motion of floating structure in 6 degrees of freedom can be expressed as follows:

$$F = Ma \tag{5}$$

Where:

F : resultant force on the structure

M : mass of structure

a : acceleration

Equation (1) can be written in other form, where the body acceleration (a) is the second differential of the body or structure position.

$$F = M\ddot{x} \tag{6}$$

Resultant of forces work on the structure consists of buoyancy and external forces. External forces comprise excitation and radiation forces. The mathematical equation can be written as follows:

$$FWJ + FRJ + FHSJ = M\ddot{x} \tag{7}$$

In order to estimate the seakeeping qualities of a vessel, the hydrodynamics responses of the vessel to hydrodynamics loading, must be known. At least two information, namely speed of vessel and wave angle of entrance, must be available [8]. Thus, the wave frequency within the operational area of the vessels can be found and this lead to the calculation of wave's magnitude. The behaviour of vessel is found based on the probability movement of the ship at the certain agreed level. The seawater condition is described using statistical model hence the wave height and wave energy will be known in relation with frequency and angle of entrance of the wave.

Furthermore, in order to estimate ship motion, the following items must be known: excitation force, added mass and damping radiation as functions of frequency and heading angle. Thus, the response amplitude operator (RAO), which is also known as transfer function, is obtained.

4.1 Heave Motion

Results from the calculation using ANSYS AQWA for each type of vessels at Froude Number (Fr) of 0.3 show that the trimaran at zero incidence has the most excessive heaving motion of about 0.43m. Similarly, the calculation using Maxsurf code also provided the same condition, in which the displacement is about 0.58m. Other type of hull forms (monohull and catamaran) produce less heaving motions at the values of 0.47m and 0.14m (using Maxsurf) and 0.12m and 0.21m (using AQWA), respectively.

Table 5 Heave motion at sea state 5and Fr 0.3

Tool	Vessel type	Heave at various wave angle (m) 0	45	90	135	180
Maxsurf	Monohull	0.47	0.55	0.72	0.63	0.57
	Catamaran	0.14	0.12	0.18	0.19	0.19
	Trimaran	0.58	0.28	0.25	0.23	0.24
AQWA	Monohull	0.12	0.43	0.56	0.16	0.44
	Catamaran	0.21	0.03	0.26	0.06	0.11
	Trimaran	0.43	0.17	0.36	0.15	0.13

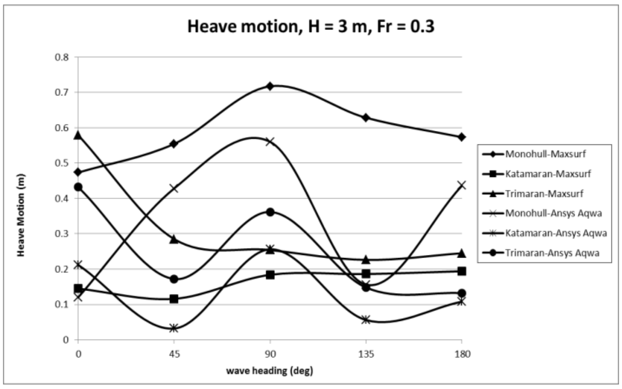

Figure 5 - Heave motion at sea state 5 and Fr 0.3

4.2 Pitch Motion

Results from the calculation using ANSYS AQWA for each type of vessels at Froude Number (Fr) of 0.3 demonstrate that the trimaran at zero incidence has the most excessive pitching motion of about 11.08 degrees at wave height about 5m (Figure 6).

Similarly, the calculation using Maxsurf code also provided the same condition, in which the displacement is about 11.77 degrees. Other type of hull forms (monohull and catamaran) produces less significant pitching motions.

Figures 5 and 6 demonstrated that the catamaran form has lower heave and pitch motions and this is attributed the effect of its width. The smaller the distance between hulls, the lower the response of heave and pitch. Monohull type of vessel, in general, has lower response at low frequency such as reported in [4].

Table 6 Pitch motion at sea state 5 and Fr 0.3

Tool	Vessel type	Pitch at various wave angle (degrees) 0	45	90	135	180
Maxsurf	Monohull	1.25	1.19	0.57	1.39	1.58
	Catamaran	1.78	0.86	0.55	0.75	0.86
	Trimaran	11.77	1.66	0.67	0.82	0.95
AQWA	Monohull	1.36	0.99	0.08	0.49	1.41
	Catamaran	0.94	0.56	0	0.63	0.49
	Trimaran	11.08	1.63	0.28	0.5	0.5

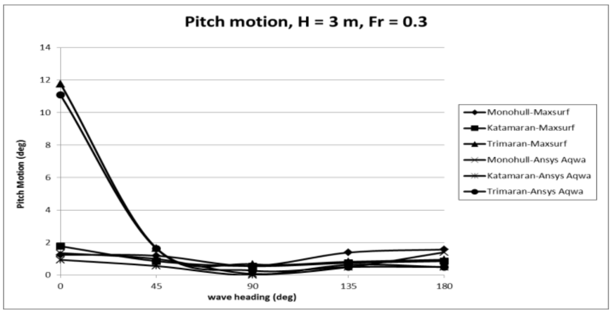

Figure 6 - Pitch motion at sea state 5 and Fr 0.3

The ship motion both for monohull and catamaran is significant when the direction of wave is from leeside (between 0 and 90 degrees) against the movement of ship. In details, Reference [9] stated that the motion of catamaran at S/L=0.2 was 18% lower than the motion of catamaran at S/L=0.4 at heading angle of 120 degrees. Fast catamaran has good characteristics at oblique wave condition and including at pitching motion condition. However, when wave comes from the side of vessel, the motion of catamaran is lower compared to the motion of monohull. This is believed to be due to the catamaran has relatively low rolling period [10].

4.3 Roll Motion

Results from the calculation using ANSYS AQWA for each type of vessels at Froude Number (Fr) of 0.3 demonstrate that the monohull at 90 degrees (beam sea condition) has the most excessive rolling motion of about 8.51 degrees at wave height about 5m (Figure 7).

Similarly, the calculation using Maxsurf code also provided the same condition, in which the displacement is about 8.61 degrees. Other type of hull forms (trimaran and catamaran) produces less significant pitching motion those are 1.14 and 4.07 degrees, respectively.

Table 7 Roll motion at sea state 5 and Fr 0.3

Tool	Vessel type	Roll at various wave angle (degrees) 0	45	90	135	180
Maxsurf	Monohull	0	4.16	8.61	5.13	0
	Catamaran	0	2.06	4.07	3.33	0

	Trimaran	0	1.97	4.41	3.11	0
Aqwa	Monohull	0	3.84	8.51	4.32	0
	Catamaran	0	0.8	1.14	0.8	0
	Trimaran	0	0.39	0.64	0.21	0

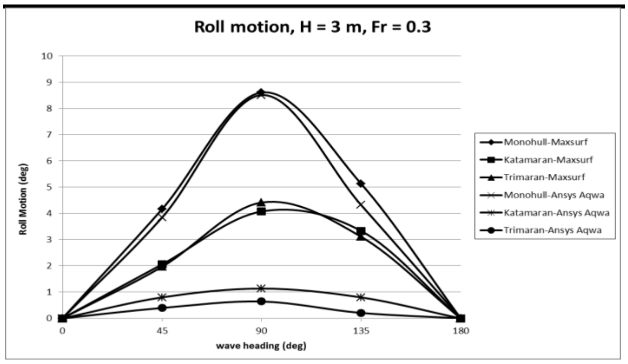

Figure 7 - Roll motion at sea state 5 and Fr 0.3

5. Conclusions

The current research has investigated the stability and seakeeping characteristics of monohull, catamaran, and trimaran. The stability analysis based on static stability was calculated using standard naval architecture criteria, whilst the seakeeping analysis was estimated using Maxsurf and ANSYS AQWA.

It is shown, from stability evaluation that both multihulls (catamaran and trimaran) has higher values of BM, GM and hence GZ thus causes the multihulls to be more stable than the monohull as well as providing better heeling and listing characteristics for the multihulls.

In terms of seakeeping, multihull vessels also demonstrate better characteristics on heave, pitch and roll motions. Both commercial softwares (Maxsurf and ANSYS AQWA) show similar results on the estimation of ship's seakeeping.

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