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The Study on Stability and Seakeeping Characteristics of the Glass Bottom Boat Trimaran in Karimunjawa Island

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Abstract. Recently the diversity of fish populations in the waters Karimunjawa Island is only appreciated by those who have the ability to play diving and snorkeling. It is due to the unavailability of a vehicle that is specially made to delight in the fascination of the underwater panorama. One of the alternative solutions is using the glass bottom boat technology which is using transparent bottom that might look out the underwater scenery instead of swimming and snorkeling. The paper has focused on the study of intact stability and seakeeping characteristics of glass bottom boat trimaran in Karimunjawa Island. The intact stability characteristics will be investigated at the various load cases and weight distribution configurations which are influenced by the passenger positions and fuel tank condition. Regarding the seakeeping performance analysis, the ITTC-Bretschneider will be adopted as the wave spectrum at the wave parameters defined from the operational environment. The influence of the parameters on the stability and seakeeping of the glass bottom boat trimaran are presented and discussed.

1. Introduction

Jepara regency is one of the regencies in Central Java province. The Jepara regency district borders are the Java Sea in the west and the north, Pati and Kudus Regency in the east, as well as Demak district in the south. Jepara regency also includes the Karimunjawa Island, located in the Java Sea. Jepara district located in the eastern north coast of Central Java, where the western and northern parts bounded by the sea. The eastern part of the District is a mountainous region.

Jepara regency also includes the Karimunjawa Islands, which is a cluster of islands in the Java Sea. Two of its largest island is the Karimun and Kemujan Island. Most of the area is protected under Karimunjawa Marine Conservation. The public transportation to the islands served by a ferry that departed from the Port of Jepara and the small airport is available for the small plane that may be used in private or emergency conditions.

Karimunjawa, a group of islands in the Java Sea, a few miles northwest of the city of Jepara, Central Java, is a paradise for coral reefs, mangroves, and coastal forests. Karimun Islands, which has a land area of 1,500 hectares and waters covering an area of 110,000 hectares, is an excellent habitat for nearly 400 species of marine fauna. Ecological environment in Karimun until now relatively still preserved. Since the 27 islands in the archipelago of Karimunjawa, only five are inhabited, while 22 other islands are original, beautiful and a virgin. The inhabited islands are Karimunjawa, Kemujan, Nyamuk, Parang, and Genting. On March 15, 2001, The Karimunjawa Island was declared as a National Park by the

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Government of Karimunjawa Jepara regency to protect the natural wealth of coral reefs, mangroves, coastal forests and marine fauna of the archipelago. Some of the endangered species is live comfortably in Karimunjawa Islands, including white-bellied sea eagle, hawksbill and green turtles, as well as approximately 242 species of ornamental fish.

Panorama and the natural resources are owned by the Karimun Islands often tempt tourists to come to the island despite having a long journey. They usually visit the island of Menjangan. Menjangan Besar is an island that is used for breeding center sharks, turtles, and eagles. The visitors who have more guts can also swim or do snorkeling accompanied by dozens of sharks, and watch the beautiful underwater panorama, see **Figure 1**.

Figure 1. Tourist attraction in Karimunjawa

Nowadays the beauty of the underwater panorama is usually only enjoyed by those who can swim, snorkel and dive. It is due to the unavailability of a vehicle that is specially made to enjoy the beautiful underwater panorama, for tourists who cannot swim and dive. One of the alternative solutions is using the glass bottom boat technology which is using transparent bottom that might look out the underwater scenery instead of swimming and snorkeling. Therefore the glass bottom trimaran design is proposed and studied to have the optimum hull form and seakeeping performance to support the tourism activities in Karimunjawa.

Based on the condition, the paper has focused on the study of intact stability and seakeeping characteristics of glass bottom boat trimaran in Karimunjawa Island. The intact stability characteristics will be investigated at the various load cases and weight distribution configurations which are influenced by the passenger positions and fuel tank condition. Regarding the seakeeping performance analysis, the ITTC-Bretschneider will be adopted as the wave spectrum at the wave parameters defined from the operational environment.

2. Literature Reviews

Hullform trimaran is a design concept that has been developed from a boat equipped with two outriggers on the right and left aside. Trimaran design advantage is endurance capability that allows the ship to be driven at high speeds even faster than a speedboat. The trimaran also offers the ability to deal with the conflicting requirement to provide sufficient hydrostatic restoring moment to achieve adequate transverse stability, which is the primary function of the outriggers or side hulls, especially, vital for a ship when damaged and partially flooded. However, the main advantage trimaran design that is considered as a glass bottom hull form is a larger area and the flexibility for the design of the particular main deck and bottom part than a monohull. Additionally, trimaran design is possible to provide wider view access at the bottom part which is not blocked by demi-hull like on the catamaran hull form. The trimaran proposed design may be seen in **Figure 2**.

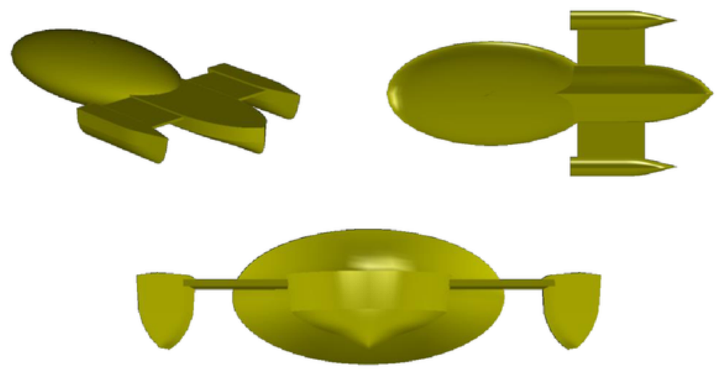

Figure 2. The trimaran hull form for the glass bottom boat

In this study of glass bottom technology development, the commonly reviewed articles were related to the trimaran technology/multihull and hull form development procedure. It is due to the glass bottom boat that would be developed using the trimaran hull form. Konstantin I. Matveev, [1], conducted a study on the aerodynamic characteristics of the hybrid model trimaran. Investigation of the aerodynamic behavior of the hybrid trimaran which consists of three wave-piercing hull planning and wing-shaped superstructure was made. The use of interceptors on the pressure side of the wing has significantly augmented the aerodynamic lift force.

Ming-Chung Fang, [2], performs the parametric studies of the trimaran wave loads on ships. Analysis based wave spectra carried out to determine the setting side of the hull during sailing trimaran wave conditions. The magnitude of the significant wave loads, including shear force, bending moments and moments of torque in each different location in the main hull and the cross deck with consideration stagger and clearance were derived using spectral analysis. This study provides information for setting hull side by considering the wave loads on ships trimaran.

Xu Min, [3], conducted a study on the numerical optimization to ship trimaran hull side. Based on the Green's function and potential theory of three-dimensional, this study provides significant value to the wave loads, including shear forces and bending moments vertically at each different location on the main hull, as well as bending moments transverse to the connection structure and the main hull. Parametric optimization on wave loads for the layout and hull length different side also performed. The results of this study are very useful for the design and optimization of a new type of trimaran.

Hafez, K. A., [4], to investigate the effect of variation comparison stagger at high-speed trimaran hydrodynamic interference. Methods slender body which is the software used to calculate Hullspeed symmetry series resistance trimaran on the water surface calm and deep waters. Each series consists of 4681 trimaran configuration derived by considering 151 staggers. Three series trimaran being studied are AMECRC, Wigley, and NPL.

Su Yu-Min, [5], conducts studies and numerical experiments on hydrodynamic performance of the trimaran planing type channel. Numerical studies were made using RANS-VOF solver to analyze the performance of hydrodynamic channel type trimaran planing. A series of experiments on the hydrodynamic towing tank was made, to get the movement behavior and performance barriers trimaran sailing. The study indicates that the resistance was decreased significantly due to the influence of a combination of hydrodynamic and aerodynamic lift, while the peak of high-speed resistance is reached.

Lv Jian, [6], undertakes the analytical studies on the response of the bottom panel due to the slamming loads. The response of bottom panel was studied analytically by using elastic Euler-Bernoulli beam as a cross-sectional representation of the bottom panel. The slamming pressure was modeled as a high-intensity peak which is followed by a constant lower pressure, at a constant velocity along the beam. The study shows that the maximum deflection and bending moment occurs when slamming loads on transverse beams approaching the lowest natural frequency of the beam. At high-speed slamming, the bottom panel response was decreased. The high-intensity peak pressure is not the cause of the structural response to be enlarged. However, the total peak load slamming has a significant effect on the response of the structure. The slamming load on the low motion was not influenced significantly. However, the load case was influenced substantially by the rapid motion.

A. F. Zakki, A. Windyandari, D. M. Bae, [7], the development of new type free-fall lifeboat using FSI Analysis. The results of the study provide the parameters for numerical analysis of the acceleration response induced by slamming load during water entry phase in the launching process.

D. Chrismianto, et. al., [8], the use of optimization analysis and computational fluid dynamics was applied to the development of the submarine hull form. The parametric model of submarine hull form was proposed using the cubic bezier curve and curve-plane intersection method. The results show that the submarine hull shape might be generated with some variation of the input parameters.

3. Intact Stability and Loading Conditions

The Archimedes principle states that a body immersed in fluid experiences an upthrust equal to the weight of the fluid displaced. Since the glass bottom boat trimaran is a floating body, the boat floating freely in still water experiences a downward force due to gravity is known as the weight. The boat is in equilibrium, while the weight has the same magnitude and the same line action with the buoyancy force. Otherwise, the boat would move until the equilibrium position achieved.

The boat might be inclined in any direction. Any inclination might be considered as made up of an inclination in the transverse plane and inclination in the longitudinal plane. In equilibrium and stability calculations the transverse inclination is known as the heel, and the longitudinal inclination called trim. The equilibrium position and intact stability characteristics of the glass bottom trimaran boat were estimated, considering the loading conditions that describe the operational conditions of the boat.

The loading conditions of the trimaran boat were determined based on the number of occupants and the configuration of the occupant positions during the evacuation process. Therefore, the loading conditions in the equilibrium and intact stability calculations are:

a. Condition I: Departure Full Occupant (LCG =-0.287 m from midship)
b. Condition II: Departure 50% Occupant (LCG =-0.059m from midship)
c. Condition III: Arrival 100% Occupant (LCG =-0.426 m from AP)
d. Condition IV: Arrival 50% Occupant (LCG =-0.119 m from AP)
e. Condition V: Lightweight Condition (LCG=0.223 m from midship)

The intact stability calculations have been made using Krylov's method, considering the same load case with the loading condition that was used for the equilibrium calculations. No free surfaces in boat units were considered. The center of gravity for the lightweight/empty condition was considered at midship. For the cases of the calculations using the loading conditions, the center gravity was adapted following the weights distribution of the occupant positions.

4. Wave spectrum on Seakeeping Analysis

The ship response for the certain speed in the regular wave is described in Response Amplitude Operator (RAO) curve. Strip Theory Method has used this study with several speeds 0 to 6 knot and 180o for the heading of the wave. For calculation of ship response to the irregular wave can describe with Response Spectrum as shown in Equation 1.

$$S\zeta r\ (\omega) = RAO2 \times S\zeta\ (\omega) \qquad (1)$$

$S\zeta\ (\omega)$ is noted as Wave Spectrum. The Bretschneider or ITTC formula with two parameters is used as shown in Equation 2. The first parameter is Significant Wave Height (Hs) and the second parameter is Average Period (Tav). The several Hs and Tav are shown in **Table 1**.

$$S_{ITTC\zeta}(\omega) = \frac{A}{\omega^5} \mathrm{EXP}\left(\frac{-B}{\omega^4}\right) \quad (2)$$

where :

ω = wave frequency (rad/sec) $A = 172{,}75 \frac{H_s{}^2}{T_{ave}{}^4}$ $B = \frac{691}{T_{ave}{}^4}$

Table 1. The height of Significant Wave (Hs) and Average Period (Tav).

Hs (m)	Tav (s)
0,25	1,931
0,50	2,731
1,00	3,862

The area under the Response Spectrum is called m0 as shown in Equation 3. The average and height of significant ship motion are described in Eq. 4 and Eq.5. The calculation of the average and height of significant velocity and acceleration are available in Eq. 6 and Eq. 7 by combining with Equation 4 and 5 with substituting the value of $m_{0,2,4}$.

$$m_0 = \int_0^\infty S_{\zeta r}(\omega)\ d\omega \quad (3)$$

$$(\zeta)av = 1{,}253\ \sqrt{m_0} \quad (4)$$

$$(\zeta)s = 2\ \sqrt{m_0} \quad (5)$$

$$m_2 = \int_0^\infty \omega^2\ S_{\zeta r}(\omega)\ d\omega \quad (6)$$

$$m_4 = \int_0^\infty \omega^4\ S_{\zeta r}(\omega)\ d\omega \quad (7)$$

The results of seakeeping calculation are evaluated according to criteria. The criteria of seakeeping that used are General Criteria for Fast Small Craft [9] as showed in **Table 2**.

Table 2. General Criteria for Fast Small Craft, [9]

No	Standard	Value
1	Single amplitude average pitch, (θ)av	3°
2	Significant heave acceleration, $(a_z)s$ for no people working on deck	≤ 0,4g

5. Results and discussion

5.1. The Glass Bottom Boat Trimaran Stability

The results GZ curve for each load case is showed in **Figure 3**. The criteria evaluation is showed in **Table 3**. The GZ curve is a moment arm that use to return the ship to an initial condition after roll motion. The positive value of GZ indicates the ship can return to the initial condition. On the other hand, the negative value of GZ indicates the ship cannot return to the initial condition.

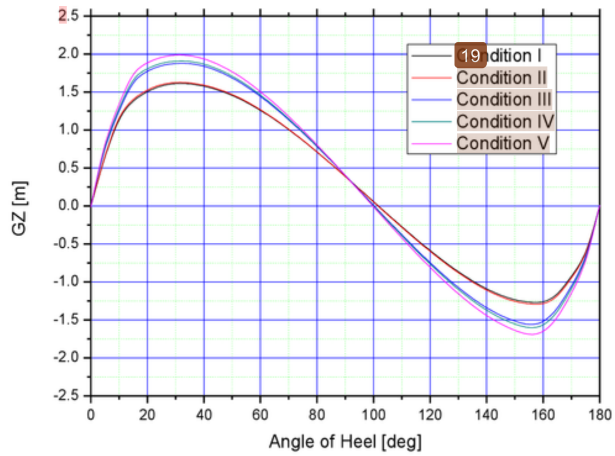

Figure 3. GZ curves of the glass bottom boat trimaran

Table 3. Criteria Evaluation for GZ Curve

Criteria	Value	Condition I	Condition II	Condition III	Condition IV	Condition V
Angle of Maximum GZ	25 deg	31.8 deg	31.4 deg	32.3 deg	32.3 deg	31.4 deg
Initial GMt	0.15 m	7.73 m	7.89 m	9.10 m	9.37 m	9.89 m

As showed in Figure 3 and Table 3, the boat has the positive value of GZ over 90o of heel angle in every load case. It indicates that the boat has a good stability. For criteria evaluation, the boat passes the criteria

5.2. The Seakeeping Characteristics.

Ship response in the regular ship is described in RAO Curve. The minimum response for the ship occurs when the peak of RAO curve is low. **Figure 4** and **Figure 5** show the heave and pitch RAO curve with the different speed.

RAO for each motion is constant with speed. The increasing speed of the vessel, the peak RAO has increased as well. The results of criteria evaluation were available in **Table 4** and **Table 5**.

Table 4. Criteria Evaluation for Single Amplitude Average Pitch (Degree)

Hs [m]	Standard	0 knot	1.5 knot	3 knot	6 knot	12 knot
0.25	< 3	2.7×10-4	2.3×10-4	2.0×10-4	1.5×10-4	1.0×10-4
0.50	< 3	9.4×10-4	8.6×10-4	7.9×10-4	6.8×10-4	5.1×10-4
1.00	< 3	2.1×10-3	2.0×10-3	1.9×10-3	1.8×10-3	1.7×10-3

Table 5. Criteria Evaluation for Significant Heave Acceleration (g) for No People Working on Deck

Hs [m]	Standard	0 knot	1.5 knot	3 knot	6 knot	12 knot
0.25	< 0.4	1.02×10-5	2.04×10-5	2.04×10-5	1.02×10-5	1.02×10-5
0.50	< 0.4	2.04×10-5	2.04×10-5	2.04×10-5	2.04×10-5	3.06×10-5
1.00	< 0.4	3.06×10-5	4.08×10-5	4.08×10-5	5.10×10-5	8.16×10-5

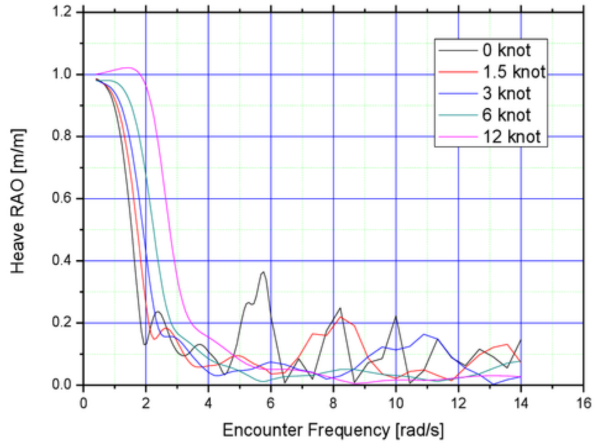

Figure 4. Heave RAO

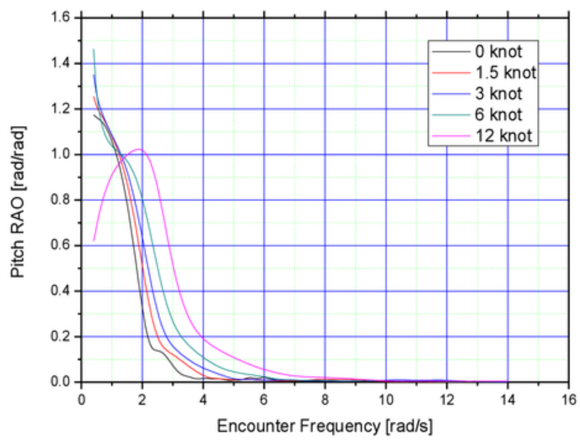

Figure 5. Pitch RAO

As showed in **Table 4** and **Table 5**, for average amplitude pitch the trimaran boat is passed the criteria for condition 0-12 knot and height of significant wave 0.25 – 1 m. Based on the seakeeping analysis, it is concluded that the trimaran boat is reliable for the Glass Bottom Hullform to support tourism activities in Karimunjawa Islands.

6. Conclusion

The calculation of stability analysis shows that trimaran boat has the positive value of GZ over 90o of heel angle in every load case. The trimaran boat can return to the initial condition in roll motion. It indicates that the trimaran boat has a good stability.

The seakeeping analysis shows that for average amplitude pitch the trimaran boat was accepted by the criteria. It indicates that trimaran boat might be used as an alternative hull form for Glass Bottom Boat to support tourism activities in Karimunjawa islands.

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