International Journal Of Engineering Research And Development
e- ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 18, Issue 3 (May.-June. 2022), PP. 16-24

Hydrodynamics Comparison of V-shaped and U-shaped Hulls of 5 GT Fishing Vessels Based on the Characteristics of Southern Java Waters

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ABSTRACT
The fishery sectors in Indonesia have enormous potential including capture fishery potential of US$ 15.1 billion/year, marine aquaculture potential of US$ 46.7 billion/year, and aquaculture potential of US$ 10 billion/year. With abundant marine natural resources, the development program of Indonesia should notice the increasing number and quality of fishing vessels. A good fishing vessel design has to consider the aspects of efficiency, feasibility standards, and fishermen's safety. To achieve feasibility and safety standards, the design process has to concern the characteristics of the waters where the fishing vessel operates. The Southern Java waters are waters that have high waves with Hs ranging between 1.5 to 2 m. Therefore, a hydrodynamic comparison of the hull between the V-shaped and U-shaped was carried out, including the evaluation of resistance prediction, stability, and seakeeping to obtain the best vessel design criteria. The investigation was carried out using the numerical method with the Computational Fluid Dynamics (CFD) approach. The results showed that the V-shaped is better than the U-shaped because it produces lower resistance while the stability and seakeeping performance are better.

Keywords*: hydrodynamics, Southern Java waters; 5 GT fishing vessel; resistance, stability, seakeeping.*

Date of Submission: 13-06-2022 Date of Acceptance: 27-06-2022

I. INTRODUCTION

Indonesia is an archipelagic country that has abundant natural marine resources. The potential of fishery resources, including capture fishery, marine aquaculture, public fishing waters, and others, are estimated to reach US$ 82 billion/year. Based on KKP data (2018), the potential for capture fishery reaches US$ 15.1 billion/year, the potential for marine aquaculture reaches US$ 46.7 billion/year, the potential for public fishing waters reaches US$ 1.1 billion/year, the potential for aquaculture potential reaches US$ 10 billion/year, the potential for freshwater aquaculture reaches US$ 5.2 billion/year, and the potential for marine biotechnology reaches US$ 4 billion/year. In addition, the fishing industry also provides many employment opportunities. The fishery sectors can absorb 5.35 million direct workers, consisting of 2.23 million marine fishermen, 0.47 million public water fishermen, and 2.65 million fish raisers (Pursetyo, et. al., 2015).

Because Indonesia has abundant marine natural resources, the development of Indonesia should be oriented towards the maritime sectors, especially the fishery sectors. One of the most important fishery sectors is fishing vessels. According to (Kepmen KKP, 2019) a fishing vessel can include a vessel, boat, or other floating equipment that is used to catch fish, support fishing operations, fish cultivation, fish transportation, fish processing, fishery training, and fishery research. In addition, a fishing vessel is used by fishermen as transportation to the fishing ground and carrying the fish catch to the collection store. A fishing vessel and fishing gear including a net, hand line, fish cooler, GPS, and lighting are vital equipment in catching fish.

Small fishing vessels ranging from 1 to 5 GT are vessels that are mostly used by fishing communities in Indonesia, such as the fishermen in Puger District, Jember Regency, East Java. According to (Yasim, et. al., 2021) one of the fishing community settlements with a high population is in Puger District, Jember Regency. However, fishing vessels used by fishermen so far have not passed through a design process but have been built only based on experience. Moreover, the fishing ground area of Puger namely the Southern Java waters, is famous for high waves and strong winds. Therefore, accidents happen frequently such as vessel capsizing and vessel destruction due to being hit by high waves, as mentioned by Utami (2020).

A good processing design for a fishing vessel should consider many aspects such as efficiency, feasibility standards, and fishermen's safety. Moreover, the innovation aspect in the implementation of appropriate technology should also be considered to keep up with the modern technology that is rapidly increasing. In terms of hull design innovation, there are 2 types of hull vessels that are used, namely V-shaped and U-shaped. According to (Basir, et. al., 2015) there is a chine effect on ship resistance where the V-shaped hull has less resistance than the U-shaped hull. While from the stability aspect, according to (Fadillah, et. al., 2019) the U-shaped hull is better than the V-shaped hull, but from the seakeeping aspect, the V-shaped hull is better. According to (Hakim, 2015), the U-shaped hull has the opportunity, number, and pressure of slamming that is greater than the V-shaped hull, but the U-shaped hull has a longer fatigue life than the V-shaped hull.

Based on these studies, it is known that the V-shaped and U-shaped hulls have their respective strengths and weaknesses. However, to achieve feasibility and safety standards, the design process should concern the characteristics of the waters where the fishing vessel operates. The Southern Java waters are waters that have high waves with Hs ranging between 1.5 to 2 m (Kurniawan and Khotimah, 2015). Therefore, a hydrodynamic comparison of V-shaped and U-shaped hulls based on the sea state of the Southern Java waters was carried out to obtain the most suitable vessel design. The hull design would be attempted as efficiently as possible to reduce the vessel's resistance but still have good hydrodynamic performances including stability, seakeeping, and endurance. A fishing vessel with a capacity of 5 GT was chosen because this study is aimed to provide small fishermen in Puger District, Jember Regency with a good fishing vessel design that is expected to help increase catch fishing.

II. MATERIAL AND METHODS

A numerical method with a Computational Fluid Dynamics (CFD) approach was used in this study. The study begins by designing the hull of the fishing vessel with 2 variations in the hull form which are V-shaped and U-shaped. The capacity of the fishing vessel design is 5 GT. After that, a comparative analysis of the vessel resistance produced by the V-shaped and U-shaped was carried out. Resistance is one of the crucial parameters because it affects the engine power required to move the vessel at the speed designed. According to (Leksono, et. al., 2018) the prediction of fishing vessel resistance is more accurate when using the Van Oortmerssen method. This method can predict the resistance of small vessels such as tug boats, fishing vessels, stern trawlers, pilot boats, etc. at a 95% confidence level, the average error in power prediction at a certain speed range is less than 18%.

To calculate the vessel resistance prediction by Van Oortmerssen methods, can use the following formula: (Van Oortmerssen, 1971)

$$R_T = (C_1 f_1 + C_2 f_2 + C_3 f_3 + C_4 f_4)\Delta + (C_F + \Sigma\Delta C_F)\frac{1}{2}\rho v^2 S \qquad (1)$$

where :

The value of $C_1 f_1$ through $C_4 f_4$ is the resistance coefficient obtained from reading the tables and graphs in the reference (Van Oortmerssen, 1971), C_F is the frictional resistance coefficient according to the ITTC formula and determined based on the length and speed of the ship. $\Sigma\Delta C_F$ is the sum of the allowances for hull roughness, bilge keel resistance, additional resistance due to steering blade and air resistance, as given in Table 1.

Table 1. Allowances for additional frictional resistance (Van Oortmerssen, 1971)

Allowances for :	ΔC_F
Roughness all-welded hull	0.00035
Steering resistance	0.00004
Bilge keel resistance	0.00004
Air resistance	0.00008

While S is the wetted surface area, if unknown, can be approximated by means of the formula:

$$S = 3.223\Delta^{2/3} + 0.5402\, L_D \Delta^{1/3} \qquad (2)$$

After analyzing resistance prediction, the next step is to analyze stability. Vessel stability is the ability of a vessel to right up after a stinging motion caused by the influence of external forces acting on the vessel. The external forces can come from currents, waves, wind, etc. The important points in the vessel stability analysis as shown in Figure 1.

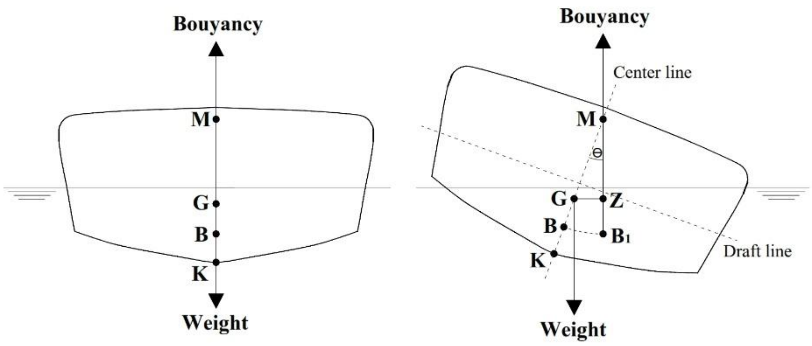

Figure 1. Vessel's equilibrium principle

According to (Yulianti, et. al., 2017), the center of gravity (G) indicates the location of the vessel's center of weight, which is the resultant point of the vessel's weight pressing downwards. The center of buoyancy (B) indicates the location of the vessel's center of floating, which is the resultant point of whole forces pushing upwards from the submerged part of the vessel. The metacenter point (M) is a pseudo-point as a boundary where G should not pass it so that the vessel always has positive stability. When the vessel heels to an angle (Θ), the center of buoyancy (B) now shifts to (B_1). The lever between the G and B_1 in this condition produces a moment that brings the vessel back to its original upright position. This moment is called the Righting Moment (MR), and the lever that indicates separation between the vertical lines passing through G and B_1 is called the Righting Lever (GZ).

Calculation of vessel stability can use the formula from A.N Krylof (Fadillah, et. al., 2019) with the equation:

$$FB = g\Delta = \rho g \nabla \quad (3)$$

where :

FB = *buoyancy*, *g* = gravity, Δ = displacement of vessel, ∇ = displacement volume, ρ = density.

To calculate the righting lever can use the following formula:

$$GZ = yB\varphi \cos\Theta + zB\varphi - KG \sin\Theta \quad (4)$$

where :

$yB\varphi$, $zB\varphi$ are center coordinates of buoyancy.

To calculate the righting moment at every angle of inclination, can use the formula:

$$MR = g\Delta.GZ \quad (5)$$

After analyzing stability, the next step is to analyze seakeeping on the V-shaped hull and U-shaped hull. Seakeeping is the movement of the vessel that occurs due to excitation from external factors, especially waves. In seakeeping, the vessel can experience 2 types of motions. The first is a rotational motion consisting of rolling, yawing, and pitching. The second is a translational motion consisting of heaving, swaying, and surging (Bhattacharyya, 1978; Djatmiko, 2012), which can be illustrated in Figure 2.

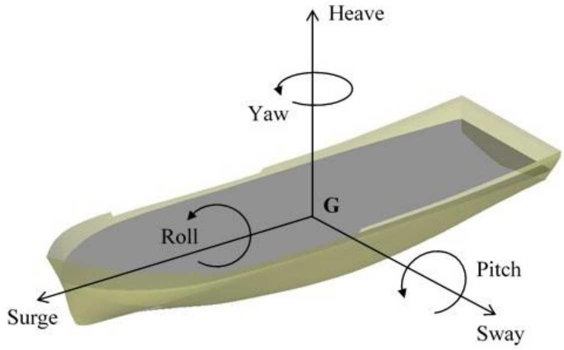

Figure 2. Various vessel motions based on the axis

When the vessel moves, there are additional forces as a response to the movement of the vessel, including added mass inertial force, damping force, restoring force, and exciting force. The investigation of the seakeeping performance in this study uses the strip theory method. Strip theory is a seakeeping analysis method that considers a vessel consisting of a number of 2-D sectional slices, which are rigidly connected to each other. Each of 2-D sectional slices is treated hydrodynamically as if it were a segment of an infinitely long floating cylinder. However, strip theory only applies to long and slender bodies of vessels. According to the experiment results revealed by (Lloyd, 1998), strip theory can be applied successfully to floating objects with L/B ratio ≥ 3.

In the seakeeping analysis, the motions that are reviewed are motions that only can be responded to by the vessel, namely heaving, rolling, and pitching. The results of the seakeeping investigation can be shown in the Response Amplitude Operator (RAO) graph. According to (Chakrabarti, 2005), RAO is a transfer function that is used to analyze external loads such as waves on the movement of a marine building structure or vessel, which is presented in the response graph. The response has an amplitude which can be sourced from motion, tension, or vibration. According to (Djatmiko, 2012) the RAO value can be calculated using the formula:

$$\text{RAO} = \frac{Xp\ (\omega)}{\eta(\omega)} \quad (6)$$

where :

Xp(ω) = Amplitude of vessel motion (e.g. surge, sway, heave, roll, pitch, yaw)

η (ω = Amplitude of incident wave

Seakeeping investigation requires a sea state data where the vessel operates. According to (Romadhoni, 2017; Bai and Jin, 2016) wave calculation model in archipelagic and coastal waters conditions can use the Joint North Sea Wave Project spectrum (JONSWAP) with the following formula:

$$S(\omega) = \frac{\alpha g^2}{\omega^5} \exp\left[-1.25\left(\frac{\omega}{\omega_m}\right)^{-4}\right]\gamma^{\exp\left[-\frac{(\omega-\omega_m)^2}{2\sigma^2 \omega_m{}^2}\right]} \quad (7)$$

where,

$\gamma = 3.3$

$\sigma = 0.07\ and\ 0.09$ for $\omega > \omega_m$ respectively

$\alpha = 0.076\bar{x}^{(-0.22)}$

$\omega_m = 2\pi \frac{3.5\bar{x}^{(-0.33)} g}{V_{w10}}$

V_{w10} = wind speed 10 m above the sea level

III. RESULTS AND DISCUSSION

Fishing Vessel Design

The design of the 5 GT fishing vessel is focused only on the hull shape, especially the submerged part, to investigate the hydrodynamic performances. Then, the hydrodynamic performances of the V-shaped hull and the U-shaped hull would be compared. The data for the 5 GT fishing vessel design is shown in Table 2.

Table 2. Principal dimension of 5 GT fishing vessel design

Parameter	Hull Form		Unit
	U-shaped	V-shaped	
Lenght over all (LoA)	10.27	10.27	m
Lenght water line (Lwl)	9.66	9.71	m
Breadth (B)	2.40	2.60	m
Draft (T)	0.60	0.60	m
Height (H)	1	1	m
Coefficient block (Cb)	0.52	0.42	
Volume of carane (V)	8.28	7.07	m^3
Fish hold capacity	6.41	6.11	m^3
DWT	6.61	5.37	tons

In terms of the principal dimension comparison of 2 shapes of fishing vessel designs, as shown in Table 2, it can be seen that the U-shaped is better than the V-shaped because it has larger both volume displacement and fish hold capacity even though the main dimension tends to be smaller, especially the breadth parameter.

The hull design of U-shaped and V-shaped are shown in Figure 3. This figure shows that the hull design of V-shaped is slimmer than U-shaped. This causes the V-shaped design to have a smaller volume than the U-shaped hull.

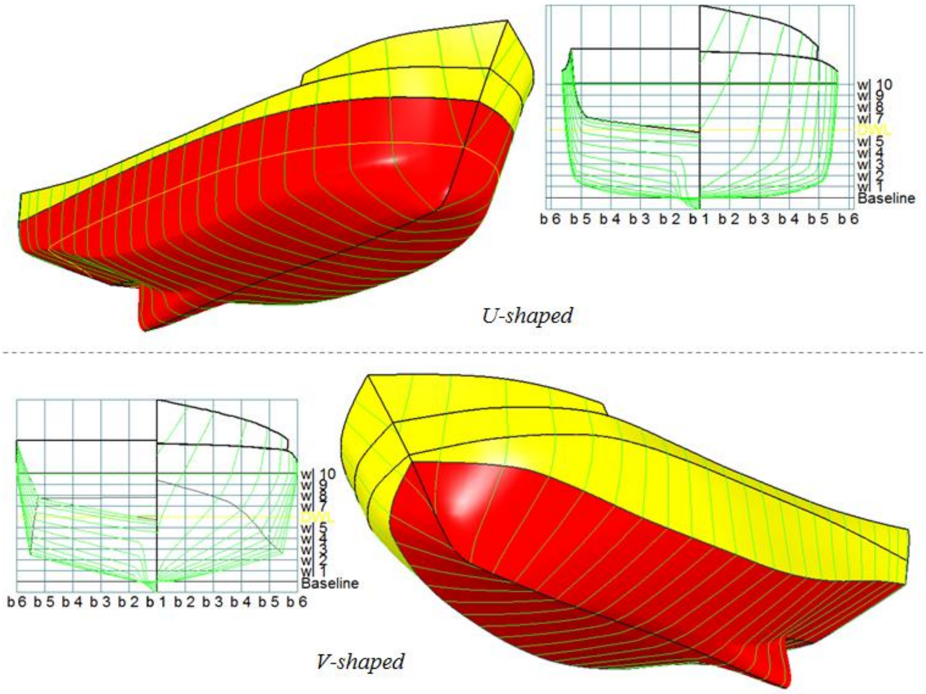

Figure 3. The hull design of 5 GT fishing vessel

Analysis of Resistance Prediction Results

Prediction of fishing vessel resistance in this study using the Van Oortmerssen method because it has high precision when applied to small ships. Calculating vessel resistance was performed by Maxsurf Resistance software, then validated with manual calculation using equation 1. The results show that the resistance predicted by Maxsurf Resistance software has been validated in good agreement with manual calculations. The results of the 5 GT fishing vessel resistance predictions are shown in the graph as in Figure 4.

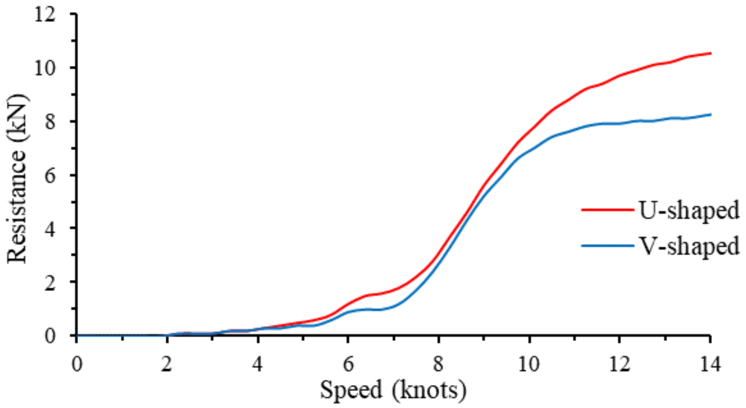

Figure 4. Comparison of 5 GT fishing vessel resistance results

Based on the resistance prediction results as shown in Figure 4, it can be seen that the 5 GT fishing vessel design on the V-shaped hull has less resistance than the U-shaped hull. The resistance difference is relatively small in the beginning but tends to increase along with increasing speed, especially at the speed above 10 knots. However, the service speed of 5 GT fishing vessel is designed in the range between 8 to 10 knots, so that based on the resistance graph it is known that the difference of vessel resistance in this speed range is still relatively small, which is 0.4 kN at 8 knots, 0.4 kN at 9 knots and, 0.7 kN at 10 knots. Therefore, it is necessary to investigate the stability and the seakeeping of this fishing vessel to determine which one has the best hydrodynamic performance.

Analysis of Stability Results

Stability investigation was carried out on several variations of load-cases to analyze vessel stability in empty conditions, operational conditions, and full load conditions based on the stability criteria issued by the International Maritime Organization (IMO, 2002). Stability investigation results of the 5 GT fishing vessel on the V-shaped and U-shaped hulls can be seen in Table 3, which shows that the vessel stability of the 5 GT fishing vessel on both the V-shaped hull and the U-shaped hull have met the stability criteria issued by (IMO, 2002).

Table 3. Intact stability checking based on IMO criteria (2002)

Stability Criteria (IMO, 2002)		V-shaped		U-shaped	
Parameter	**Requirement**	**Actual**	**Status**	**Actual**	**Status**
Area 0^0 to 30^0 (m.deg)	≥ 3.151	8.00	Accepted	6.36	Accepted
Area 0^0 to 40^0 (m.deg)	≥ 5.157	13.13	Accepted	10.70	Accepted
Area 30^0 to 40^0 (m.deg)	≥ 1.719	5.14	Accepted	4.33	Accepted
GZ_{max} at 30^0 or greater (m)	≥ 0.2	0.54	Accepted	0.46	Accepted
Angle of GZ_{max} (deg)	≥ 25	46.36	Accepted	47.27	Accepted
GM_0 (m)	≥ 0.15	1.07	Accepted	0.83	Accepted

The stability results analysis shown in this paper are only in full load conditions due to space limitations. The full load conditions mean the vessel departure from fishing activity, wherein this condition is considered that the fish hold is filled 100%. The value of KG for the fishing vessel on the V-shaped hull is 0.45 m and the U-shaped hull is 0.416 m. The stability results are presented in the GZ curve as shown in Figure 5. The KG value indicates righting lever magnitude when the vessel is heeling. As is known, the greater value of GZ causes the greater result of righting moment (MR).

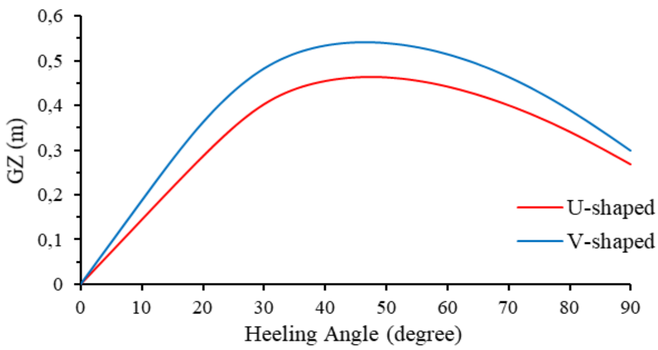

Figure 5. Comparison of 5 GT fishing vessel stability results

Figure 5 shows a comparison of the stability capability of 5 GT fishing vessels between the V-shaped hull and the U-shaped hull where the maximum righting lever (Max GZ) of the V-shaped fishing vessel is 0.54 m at heeling angle of 46.36 deg, while the U-shaped fishing vessel has Max GZ of 0.46 m at heeling angle 47.27 deg. Furthermore, in Figure 5 it can be seen that overall the GZ value of the V-shaped fishing vessel is greater than the GZ value of the U-shaped fishing vessel. This indicates that the stability of V-shaped is better than U-shaped because the larger GZ value will result in the larger MR.

Analysis of Seakeeping Results

Seakeeping simulation was carried out based on the characteristics of the Southern Java waters, precisely in the fishing ground area of Puger, Jember Regency, Indonesia. According to (Kurniawan and Khotimah, 2015) the significant wave heights (Hs) of Southern Java waters are ranged between 1.5 m to 2 m in December to February, ranged between 1.25 m to 1.5 m in March to May, ranged between 1.5 m to 2 m in June to August, and ranged between 1.5 m to 2 m in September to November. Based on these data, a seakeeping simulation was carried out using 4 wave parameters, including Hs 1.25 m, Ts 5.56 s; Hs 1.5 m, Ts 6.12 s; Hs 1.75 m, Ts 6.61 s; and Hs 2 m, Ts 7.08 s.

Seakeeping simulation was also carried out on 4 headings, which are head sea (180 deg), bow quartering sea (135 deg), beam sea (90 deg), and following sea (0 deg). In addition, the simulation varies 5 speeds, which are 0 knots (static), 7 knots, 8 knots, 9 knots, and 10 knots. The results of the seakeeping are then evaluated with seakeeping criteria of the fishing vessel according to (Tello, at. al., 2011) including vertical acceleration at work deck < 0.2 g (rms), lateral acceleration at working deck < 0.1 g (rms), roll < 6 deg (rms), and pitch < 3 deg (rms).

In this paper, the results are only presented the analysis of seakeeping in wave condition Hs 1.5 m because this Hs represents most waves that occur in one year in the Puger waters area, Jember Regency, Indonesia. The seakeeping results in heading head sea with 8 knots of vessel speed are shown in Figure 6.

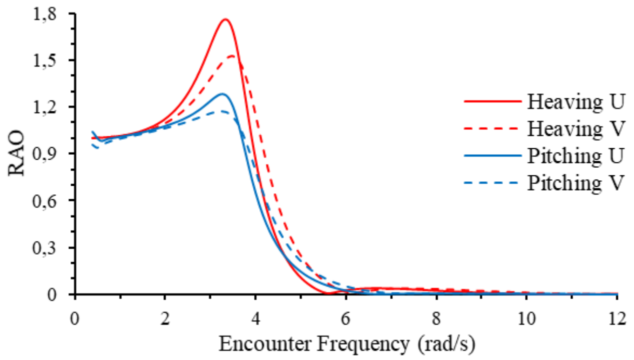

Figure 6. Comparative vessel motion in head sea direction

In Figure 6 it can be seen that the vessel motion on heading head sea is better produced by the V-shaped hull compared to the U-shaped hull. More detail can be seen in the graph that the U-shaped has a greater response motion than the V-shaped, both in heaving and rolling motion. While the seakeeping performance is rated based on the resulting motion response, which is the smaller motion response when the vessel is operating, the better the results of seakeeping performance. Therefore, the seakeeping performance of the vessel based on Figure 6 is considered that the V-shaped hull is better than the U-shaped hull.

Furthermore, from the seakeeping results it can be known that the 5 GT fishing vessel with V-shaped only operates maximally at the speed of 8 knots in wave condition Hs 2 m. At the speed of 9 knots or above, the V-shaped hull does not meet the requirements more because its vertical acceleration is 0.22 g, which exceeds the seakeeping criteria (Tello, at. al., 2011). Meanwhile, the 5 GT fishing vessel with U-shaped only can operate maximally at the speed of 7 knots on the same conditions. At the speed of 8 knots or above, the U-shaped hull does not meet the seakeeping criteria because it has a vertical acceleration of 0.21 g which exceeds the standard criteria. However, in the aspect of pitch motion, both V and U hull shapes of the 5 GT fishing vessel have met the criteria, which is below 3 deg.

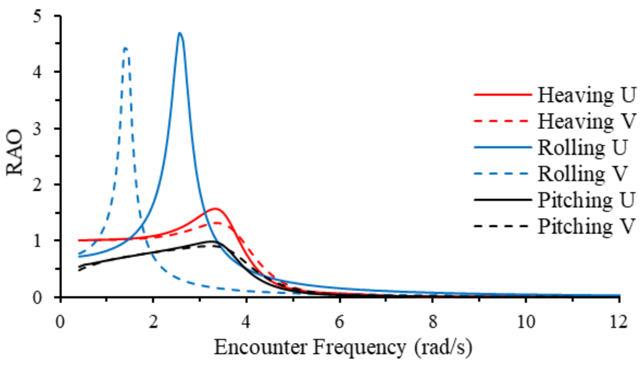

Figure 7. Comparative vessel motion in bow quartering sea direction

The seakeeping results on the heading bow quartering sea with wave condition Hs 1.5 m and vessel speed of 10 knots are shown in Figure 7. From the results, it is known that the 5 GT fishing vessel with V-shaped has good seakeeping performance at the speed of 10 knots where all the seakeeping criteria are met. While on the 5 GT fishing vessel with U-shaped can only meet all the seakeeping criteria at the speed of 8 knots. In Figure 7 it can also be seen that the motions response of the fishing vessel V-shaped hull, which are heave motion, roll motion, and pitch motion, have a smaller value than the motions response of the U-shaped hull. Therefore, the seakeeping performance of the 5 GT fishing vessel V-shaped hull is considered to be better than the U-shaped hull.

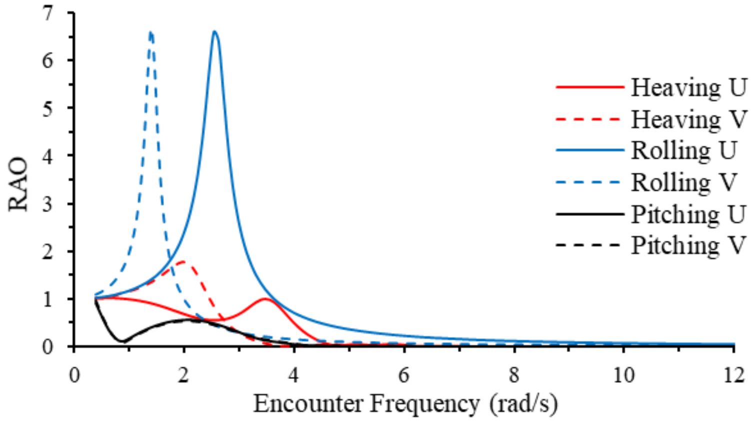

Figure 8. Comparative vessel motion in beamsea direction

The seakeeping results on the heading beam sea are shown in Figure 8. From the results, it is known that at wave heights above Hs 1.5 m, the 5 GT fishing vessel both V and U-shaped hulls fail to meet seakeeping criteria (Tello, at. al., 2011). This is because the roll motion produced by the 5 GT fishing vessel with V-shaped is 10.95 deg (rms) and the U-shaped is 13.22 deg (rms), which is smaller than the roll motion requirement of 6 deg (rms). Even so, this 5 GT fishing vessel is still considered safe when heading high waves of 1.5 m in the beam sea direction because the Max GZ angle of the vessel is greater than the rolling angle, which is 46.36 deg for the V-shaped hull and 47.27 fort the U-shaped hull. However, this fishing vessel is not recommended heading high waves from the beam sea direction for a long time because it has high potential to cause motion sickness. In addition, in Figure 8 it can be seen that the overall seakeeping performance of the 5 GT fishing vessel with V-shaped hull is a little bit better than the U-shaped hull because it has a better roll motion response.

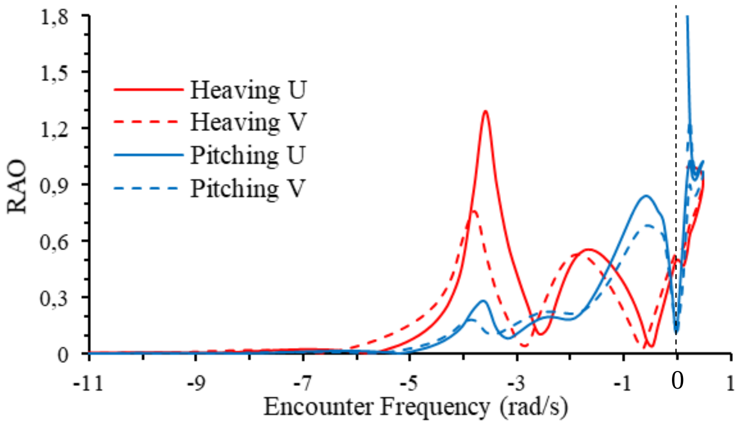

Figure 9. Comparative vessel motion in following sea direction

The seakeeping results on heading following sea are almost as similar as the results of the seakeeping results on heading head sea, but the results on heading following are smaller because the wave direction is linear with the vessel movement. The seakeeping results for the heading following sea are shown in Figure 9. In this figure, it is known that the seakeeping performance produced by the 5 GT fishing vessel V-shaped is better than the U-shaped because the V-shaped hull has motions response including heave motion and roll motion which are smaller than the U-shaped hull. In addition, from the seakeeping results on heading following sea, it is known that the 5 GT fishing vessel with V-shaped has a vertical acceleration of 0.17 g (rms) or meets the seakeeping criteria on conditions of wave height Hs 2 m and vessel speed of 10 knots, while the vessel with U-shaped can meet the seakeeping criteria at speed of 9 knots which has a vertical acceleration of 0.196 g (rms). Thus, it can be concluded that the seakeeping performance of the 5 GT fishing vessel with V-shaped hull is considered to be better than the U-shaped hull.

IV. CONCLUSION

Based on the analysis of the resistance prediction, stability, and seakeeping results from the 5 GT fishing vessel on 2 types of hulls, which are V-shaped and U-shaped, it can be concluded that the 5 GT fishing vessel with the V-shaped hull has better hydrodynamic performance than the U-shaped hull. This can be seen from the analysis of resistance prediction results that in the service speed range between 8 to 10 knots, the V-shaped hull has less resistance than the U-shaped hull with the differences of 0.4 kN at the speed of 8 knots, 0.4 kN at the speed of 9 knots, and 0.7 kN at the speed of 10 knots. The analysis of stability results also shows that the stability of the 5 GT fishing vessel with the V-shaped hull is better than the U-shaped hull where the Max GZ of the V-shaped hull is 0.54 m at the heeling angle of 46.36 deg, while the Max GZ of the U-shaped hull is 0.46 m at the heeling angle of 47.27 deg. As is known, a larger GZ value will affect a larger MR result when the vessel is heeling.

The seakeeping results also show better motion response on the 5 GT fishing vessel of V-shaped. It can be seen in the whole results of seakeeping investigation both on heading head sea (180 deg), bow quartering sea (135 deg), beam sea (90 deg), and following sea (0 deg) which are the motion response of the V-shaped hull is smaller than the U-shaped hull. As is known, the motion response indicates the seakeeping performance, where the smaller of motion response when the vessel is operating, the better of seakeeping performance. Therefore, it is considered that the hydrodynamic performance of the 5 GT fishing vessel of V-shaped is better than the U-shaped. However, the U-shaped hull does not have any strengths. In the aspect of dimension comparison, the fishing vessel with the U-shaped hull is better than the V-shaped hull because it has a larger displacement volume and bigger fish hold capacity in the relatively equal main dimension.

Acknowledgements

A big thanks to the Chancellor of the Jember University and the Chair of the Institute for Research and Community Services Jember University (LPPM Jember University) who have supported in funding research. Also, the research team “Keris Perkapalan” would like to thank the Dean of Engineering Faculty and the Head of Naval Engineering Department for supporting and providing the research facilities.

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