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Analysis of Monohull Design Characteristics as Supporting Vessel for the COVID-19 Medical Treatment and Logistic

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Abstract

The world is being hit by a health crisis by the COVID-19 pandemic which has infected peoples across the globe. The cases of COVID-19 in Indonesia itself continue to increase every day. The transportation sector is one of the sectors that have experienced numbers of direct impacts as a result of large-scale social restriction in form of preventive regulation. Furthermore, this phenomenon causes health agencies to experience difficulties in distributing logistics for handling COVID-19, especially in water areas. In the era of the Industrial Revolution 4.0, various society aspects and industrial processes are digitally connected to increase productivity, especially for COVID-19 treatment and logistic handling. This research was conducted to analyze several proposed monohull-unmanned ship prototypes which are expected to be a proposed solution to assist COVID-19 countermeasure. A series of stability and motion analyses is conducted, then the results are assessed to conclude the best design among the proposed design options. Results of the study indicated that compared to three variations of hull types, design of the Model III has excellent characteristics of ship stability, hull resistance and seakeeping. These analysis parameters are considered as main criteria in the ship's requirements since patient and logistic have to be transported safely to the designated location according to the given mission in assisting COVID-19 handling and treatment.

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1. Introduction

Since the end of 2019, the world has been hit by a health crisis as the COVID-19 pandemic has infected millions in different continents. As per 13 January 2021, there have been 90,335,008 confirmed cases of COVID-19, including 1,954,336 deaths based on the report of the World Health Organization WHO (2021). This virus is able to spread quickly in a quite easy way. In terms of virus expansion, commodities distribution needs to be continued to ensure sustainability of economy and industry. The distribution is mostly through sea as 71% of the earth's surface is covered by oceans Genda (2016). Nevertheless, the transportation system is one of the sectors that has experienced heavy impacts as a result of the Large-Scale Social Restriction regulation which is addressed to restrict virus expansion. The cases of COVID-19 in Indonesia itself continue to increase every day. This causes health agencies to experience difficulties in distributing logistics for handling COVID-19, and makes health agencies to experience difficulties in distributing logistics for COVID-19 handling, especially to disadvantaged, remote, outermost, and border zones.

In the last 5 years, the Industrial Revolution 4.0 is marked as a digital revolution, which is a digitally connected industrial process. In the midst of the COVID-19 pandemic, the Indonesian government has started to pay attention to development of the maritime technology sector through the Ministry of Education and Culture of the Republic of Indonesia by holding competitions to improve innovative ship design, especially advanced types. This competition requires participants to research, design, and build unmanned ships. Unmanned Surface Vehicles (USV) are marine crafts that are capable to conduct unmanned operation Liu et al. (2016). An Unmanned Surface Vehicle (USV) has many advantages and has been widely used for the military for many years, i.e., for patrol on the maritime territory, shipping commodities in the inter-island route, transportation, and scientific research purposes Chang et al. (2020); Dabit et al. (2020); Graves et al. (2020); Kim (2020); Ma et al. (2021); Wang et al. (2021). Design of the ships, including USV considers various aspects, e.g. safety Prabowo et al. (2020a,b), comfortableness Niklas and Pruszko, (2019); Gutsch et al. (2020), and efficiency Adland et al. (2018); Esmailian et al. (2019).

Research and development target of USV technology in this work is addressed to obtain a hull design with satisfying criteria of stability, resistance and seakeeping in accordance with the competition regulation and conditions of the water territories in Indonesia. Given the characteristics of sea waves in Indonesian waters, they have different conditions and an uncertain climate. Therefore, prototype testing is needed so that the USV operation is more effective. In accordance with the expected target in this work, the best ship prototype is expected to be projected into a ship to help handle COVID-19. This will later support the distribution of health facilities throughout the archipelago in Indonesia to help accelerate the handling of COVID-19.

2. Literature Review

This research will be aimed at developing unmanned ship technology. It is projected that later unmanned vessels that have high stability, low resistance, and good seakeeping characteristics can be created in accordance with the conditions of the territorial waters in Indonesia. The vessel designs are also addressed to support the distribution of health facilities throughout the archipelago in Indonesia in the context of COVID-19 handling. Stability, resistance and seakeeping are important factors to consider when designing a vessel hull. Stability is a characteristic or tendency of a ship to return to its original position or to straighten up again due to external forces. This characteristic is affected by ship shape, payload, draft, and buoyancy. In this analysis, the wave pattern produced by the hull, center of gravity (COG) of the hull, and center of buoyancy (COB) can be obtained. In this study, the stability test was conducted by analyzing the GZ curve with the maximum value of GZ. During hull operation (sailing process), there will be resistance from the fluid it passes. This resistance will also be the main influence on the ship's performance. With the innovation of the hull design model, the best design will allow a relatively small resistance value to be obtained so that it can maximize the performance of the ship itself. Seakeeping is the ability of a ship to survive at sea in any condition. This capability is a vital aspect when it comes to shipping design. In obtaining treatment of waves, ship hulls experience two types of motion, namely translational and rotational movements. Translation movement (linear) is a straight, regular motion according to its axis, this motion includes surging, swaying, and heaving. On the other hand, the rotational movement is the rotation of the ship, which includes rolling, pitching, yawing. These movements indicate the quality of the ship in response to the wave spectrum. This study focused on the performance testing under the heaving, rolling, pitching movements.
3. Methodology

In this study, the design method uses the comparison ship approach. Harvald (1992) states that one of the methods that can be used in ship design is the comparison method, in which a sailed ship is used as a reference for designing and developing. The method is used to select the best hull design which is preferred as this method does not require complicated calculations. This is because, in the original shipbuilding process, the designs are made by experts or by experienced companies in the world maritime industries so the possibility of defects was minimal. The use of parametric design and optimization techniques in the marine industry has constantly increased over the last decade with are applications being related to the performance and energy efficiency of the hull form Skoupas et al. (2019).

3.1. Ship data

The research was conducted using a ship prototype design and using monohull variations that have through the comparison ship method stage, namely Model I, Model II, and Model III. These models are results of design development from 2018 to 2020 based on regulation of the national unmanned ship competition Kemendikbud, (2020). The principal data for the Model I, Model II, and Model III ships are presented in Table 1.

| Parameters                  | Values                        |
|-----------------------------|-------------------------------|
|                             | Model I | Model II | Model III |
| Length Overall (m)          | 0.760   | 0.980    | 1.160     |
| Length Waterline (m)        | 0.730   | 0.950    | 1.081     |
| Draft (m)                   | 0.060   | 0.058    | 0.060     |
| Beam (m)                    | 0.300   | 0.300    | 0.320     |
| Depth (m)                   | 0.100   | 0.092    | 0.100     |
| $C_s$ (-)                   | 0.328   | 0.367    | 0.345     |
| Displacement (kg)           | 4.479   | 6.126    | 7.228     |

After the ship design process, which begins with the design of the ship prototype lines plan of each type, begins with managing the design grid in the form of sections, buttocks, and waterlines. For each of the design of the Model I, Model II, and Model III, a lines plan was made to determine the shape of the ship. The ship is then modeled into a three dimensional (3D) design with isometric views with an adjusted scale. The illustration of the isometric views is shown in Fig. 1.

![Fig. 1. Rendered 3D hull design: (a) Model I; (b) Model II; (c) Model III.](image)

3.2. Ship stability assessment

Stability testing is the ship's ability to be upright again after experiencing a certain roll/tilt. Stability in general, is divided into static stability (Equation 1) and dynamic stability (Equation 2).
\[ P. h = P. FS - P. GFS \sin \gamma \]  

(1)

\[ ED = \int_{\gamma=0}^{\gamma'=\gamma} S3 \, dy \]  

(2)

where \( S3 \) is \( P.h \) in static stability; and \( G \) is the center of gravity.

### 3.3. Hull resistance analysis

Ship resistance is an important factor that must be considered when building a ship's hull. One method of calculating resistance is Savitsky which is stated in the following equation.

\[ D = \Delta \tan \tau + \frac{D_f}{\cos \tau} \]  

(3)

where, \( D \) is the total drag/resistance; \( \tau \) is the trim angle; and \( D_f \) is the friction component.

### 3.4. Seakeeping characteristic

Assuming the oscillatory movements are linear and hormonal, the six differential equations for the coupling motion are written as follows.

\[ \sum_{n=1}^{6} [(M_{jk} + A_{jk})\dot{\xi}_k + B_{jk}\zeta_k + K_{jk}\zeta_k] = F_{je^{jwt}}; j, k = 1, \ldots, 6 \]  

(4)

where \( M_{jk} \) is the mass matrix and moment of inertia of the marine building (there is a matrix of hydrodynamic added mass coefficients and the number of hydrodynamic damping coefficients); \( K_{jk} \) is the matrix of strength coefficients or hydrostatic force and moment; \( F_j \) is the matrix of the excitation force (\( F_1, F_2, F_3 \)) and the moment of excitation (\( F_4, F_5, F_6 \)) in the complex function (expressed by \( e^{jwt} \)); \( F_1 \) is the excitation force which causes the motion surge; \( F_2 \) is the excitation force causing the sway motion; \( F_3 \) is the excitation force causing the heave motion; \( F_4 \) is the moment of excitation which causes the roll motion; \( F_5 \) is Moment of excitation causing pitch motion; and \( F_6 \) is moment of excitation causing yaw motion.

### 4. Result and Discussion

#### 4.1. Ship Stability

Stability analysis is carried out to determine the stability of the hull of the ship, which model has the best stability for the use of ships for inter-island logistics. The stability criteria that must be met are under different loading conditions to ensure a minimum level of safety Mauro et al. (2019). The term of stability stretches to the tendency of a body or system to return to its original state after it has suffered a small disturbance Rawson amd Tupper (2001). The following data is the results of the ship stability test (see Table 2). The GZ curve graph based on the stability calculation is presented in Fig. 2.

| Ship Model | GZ (cm) | 0°  | 10°  | 20°  | 30°  | 40°  | 50°  | 60°  | 70°  | 80°  | 90°  |
|-----------|--------|-----|------|------|------|------|------|------|------|------|------|
| Model I   | 0.022  | 2.505 | 3.789 | 4.085 | 3.880 | 3.394 | 2.725 | 1.933 | 1.064 | 0.152 |
| Model II  | 0.089  | 2.393 | 3.573 | 3.601 | 3.181 | 2.534 | 1.751 | 0.887 | -0.012 | -0.920 |
| Model III | 0.001  | 2.126 | 3.865 | 4.622 | 4.566 | 4.097 | 3.366 | 2.432 | 1.343 | 0.173 |
The calculation results are then compared in terms of the ship's roll degree and the GZ curve. Based on the results, the design slope (peak point) of the Model I ship prototype is 30° with the maximum GZ value is 4.085 cm. This means that the maximum ship model can return to its original position is 30°. If it exceeds that angle, the ship may return to its original position but in slower time period. Results of the Model II ship is 24.55° with the maximum GZ value is 3.687 cm which means, for this ship model, the maximum ship can return to its original position safely is 24.55°. If it exceeds this angle and reach negative GZ value, the ship is predicted cannot return to its original position. As for the Model III, maximum degree of the prototype ship is 33.63° with the maximum GZ value is 4.673 cm.

Based on the results of stability analysis, it can be concluded that from all the tested models (Models I, II, and III), the smallest stability characteristic is the model II ship with 24.55° and the maximum GZ value is 3.687 cm. The best value is shown by the Model III ship with 33.63° and the maximum GZ value is 4.673 cm. Model III has the largest angle so that the ship will be safer and more stable during operations.

4.2. Ship Resistance

In analyzing ship resistance, there are various calculation approaches, including Savitsky and Holtrop. In terms of the comparison data between the deployed methods and numerical calculation, the difference is approximately 14% for the Savitsky's mathematical model and 2% for the Holtrop's regression-based method Julianto et al. (2020).

This research was conducted to determine the design with the least resistance. The following data is results of the resistance test for all proposed models (see Table 3) and graphical form is displayed in Fig. 3.

| Speed Parameters (Knot) | Resistance I (N) | Resistance II (N) | Resistance III (N) | Power I (W) | Power II (W) | Power III (W) |
|-------------------------|------------------|------------------|-------------------|-------------|-------------|--------------|
| 0                       | 0                | 0                | 0                 | 0           | 0           | 0            |
| 5                       | 8.182            | 6.869            | 9.182             | 23.382      | 19.634      | 26.242       |
| 10                      | 12.774           | 14.232           | 17.260            | 73.019      | 81.355      | 98.664       |
| 15                      | 23.790           | 25.885           | 30.394            | 203.982     | 221.940     | 260.606      |
| 20                      | 40.128           | 43.017           | 49.944            | 458.752     | 491.775     | 570.969      |
| 25                      | 61.352           | 65.290           | 75.422            | 876.734     | 933.009     | 1,077.790    |
| 30                      | 87.294           | 92.522           | 106.581           | 1,496.931   | 1,586.594   | 1,827.674    |
Based on the comparative data, the hull resistance shows that at the speed of 30 knots, the Model I has a resistance of 87.294 N and the required power is 1,496.931 W; Model II experienced a resistance of 92.522 N and the required power is 1,586.594 W; while in Model III, it has a resistance of 106.581 N and the required power is 1,827.674 W. Based on these data, each model or year has an increase in resistance, this can be due to changes in competition regulations from year to year (the Models I, II, and III were designed based on technical regulations of 2018, 2019 and 2020, respectively) so that it can affect results of the calculation. Based on the data, it is also obtained that the faster the ship, the more resistance will be experienced. It can be concluded that the prototype I design has less resistance than the prototype II and III designs. Thus, the required power of the prototype I design is smaller than the other prototype designs. With a smaller resistance, the ship is more optimal when sailing on the water, and with less fuel is required, it is projected that the engine operation can be more optimal.

4.3. Seakeeping characteristic

Results of the seakeeping analysis are divided into several parts, namely response amplitude operator (RAO) of heaving, pitching, rolling, and added resistance. In the studies of planning hulls, the key objective is to improve the sailing performance Bi et al., (2019). The following graph is the test results according to the ship motion with angle of the wave directions 90°, 135°, and 180°. The response amplitude operator of the heaving motion data is shown in Fig. 4, response amplitude operator of the rolling motion is shown in Fig. 5, response amplitude operator of the pitching is shown in Fig. 6, and response amplitude operator of the added resistance graph shown in Fig. 7.
The used wave heading used is 90° (beam seas) from the side of the ship, 135° (bow quartering seas) from the oblique direction of the ship, and 180° (head seas) from the front of the ship. In terms of heaving, rolling, and pitching motion, Model I, Model II and Model III have varying values. The direction of arrival of the waves at 90° has a very striking difference in values, while the direction of arrival of the waves at 135° and 180° has a slight difference. The results of the motion show that the shape of the hull is very influential on the hull motion of the ship. The 180° rolling graph shows 0 value because at the angle of arrival the waves 180° do not cause the ship to roll. Apart from heaving, rolling, and pitching, there is an RAO added resistance graph that shows the frequency of additional resistance due to hull movement. Judging from the presented data, the design of Model III is more stable or less affected by waves because it has a relatively smaller value than other designs.
5. Conclusions

Based on results of the conducted studies for the prototype ship (Model I, Model II, and Model III), it is found that the stability test of the Model III design with an angle of 33.63° and the maximum GZ value is 4.673 cm, which has better stability than the designs of Model I and Model II. Then, in terms of the ship resistance test, the Model I design has a smaller resistance, i.e., 87.294 N, and the required power is 1,496.931 W compared to other proposed designs. In the seakeeping test, the design of model III is concluded to be more stable or less affected by waves and more resistant to all conditions in the water, because it has a relatively lower RAO value of heaving, rolling, and pitching at waves of 90°, 135°, and 180° and has a smaller added resistance value. Thus, the best design is obtained which the Model III design is expected to be projected to assist COVID-19 logistic and treatment handlings.

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