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Roll Motion Analysis on Unmanned Surface Vehicle with Remote Controlled Weapon Station Models to Combat Piracy in Surabaya West Access Channel

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Abstract

The dense shipping activity in the Surabaya West Access Channel (SWAC) is accompanied by a high rate of piracy which had 13 cases during 2013–2018. An Unmanned Surface Vehicle (USV) with Remote Controlled Weapon Station (RCWS) was created to overcome this piracy, increase work effectiveness, and reduce potential casualties. This study aims to create a design of USV equipped with RCWS complies with the requirements then analyzes the stability and seakeeping (roll motion) because it is one of the most determining factors of the stability and safety of the ship. The research method in this study is a simulation process based on system engineering theory starting from the formulation of requirements, design making, and then simulation. Five design models are created and simulated to analyze their stability and seakeeping performance. The design results are a monohull USV equipped with an RCWS with the main dimension of 1.7 m long, 0.9 m wide, and 1.04 m high. The stability simulations conclude that Model 4 is the most stable platform with the highest peak value of GZ for 0.112 m in angle degree of 108.2°. The seakeeping simulations show that at wave heading 45°, model 3 has the highest RAO with the peak value of 4.703 at the frequency of 0.4 rad/s. At wave heading 90°, model 5 has the highest RAO with the peak value of 0.095 at the frequency of 0.4 rad/s. At wave heading 135°, model 1 has the highest RAO of 0.012 at the frequency of 0.581 rad/s.

1. Introduction

The geographical condition of Indonesia, which is at the intersection of two continents and two oceans, makes Indonesian waters a very strategic international sea trade route. Indonesia is one of the largest maritime countries globally, with a sea area that reaches 5.8 million km2 [1] which is more than 70% of the entire territory of Indonesia [2].

One of the busiest marine areas in Indonesian waters is the Surabaya West Access Channel (SWAC), with the number of ships crossing from 2008 to 2013 reaching 20,582 ships each year [3]. The high level of shipping activity in the SWAC area makes the risk of crimes that threaten maritime security possible, one of which is piracy. According to data from the ICC, International Maritime Bureau states that Indonesia is the country with the highest number of piracy cases in Southeast Asia, with 261 cases during 2015 – 2019 [4]. In SWAC itself, 13 cases of piracy were recorded from 2013 – 2018 [5].

Vessels have been traditionally considered as a human domain. The command and control that shall be given for the operation onboard will be different in the era of digitalization [6]. The development of the maritime sector within the aspects of defense and security is currently focused on the autonomous system. This autonomous industry matures as several initiatives at the international level have addressed cost, resilience, regulatory challenges.

The focus in the industry today is improving safety by minimizing the human role of hazardous work. Therefore, it can be assumed that there will be a significant increase in autonomous systems in the maritime domain in the future [7]. Taking this for granted, present concepts of unmanned vessels usually contain a shore-based control center that monitors the vessel's status, the navigational and technical processes and provides the necessary options of remote control [8].

The development of USV as an unmanned technology has promising prospects yet also challenges. With the support of more effective and affordable navigation equipment and a more robust and more reliable wireless communication system, the opportunities for developing USV technology are more significant than before. USV can be developed for various potential uses such as scientific research, environmental missions, exploration of marine resources, military use, and other applications [9].

On the other hand, the development of RCWS technology and the increasing interest of the military in the sophistication of defense equipment are driven by the potential for more excellent military capabilities while reducing risks for the armed forces and reducing operational costs and dependence on personnel. An autonomous weapon system that is very sophisticated and operates independently without human intervention, such as a weapon system with Artificial Intelligence (AI), has not been widely used.

With global recognition of the importance of maintaining human control over target selection and assault, semi-robotic technologies such as RCWS are likely to have greater military use in the future [10]. The potential use of these two systems is predicted to dominate the military world in the future. For that reason, developing and studying the integration of both is essential.

Previous researches have been done in designing USV for various purposes such as ocean exploration, traffic regulation, surveillance, monitoring, and hydrographic data collecting [11][12][13]. However, there is a lack of researches in designing USV which serve the military purpose, especially as a combatant vessel equipped with autonomous weaponry technology.

In order to face the threat of piracy in the dense shipping area, this research conducted modeling and simulation on the design of USV, which integrated with the RCWS as an effort to design a semi-robotic technology system to assist the tasks of the Indonesian Navy in securing the SWAC area. The selection of a mission to tackle piracy is based on the size of the pirate ship's body, categorized as relatively small, mostly using speedboats whose sizes vary from 7 m to 50 m [14][15].

In this paper, the research focuses on missions facing small pirate ships and not for large confrontation missions in large areas of the sea, such as protecting maritime defense and security from external enemy warships. The simulations are conducted on the effect of barrel positions on the stability and seakeeping performance of the ship in roll motion because the motion is one of the most determining factors of the stability and safety of the ship [16][17][18].

This research aims to create a design of USV equipped with RCWS that complies with the requirements, which are ideal in dealing with piracy in the SWAC area, and analyze the stability and seakeeping of roll motion through simulations.

2. Methods

In general, methods are based on a system engineering process and then simulation, illustrated in Figure 1.

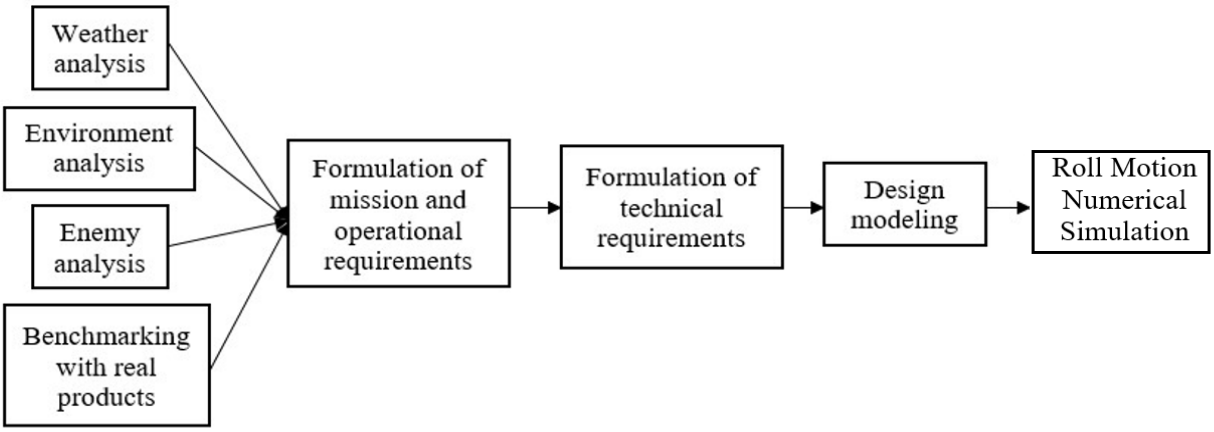

Figure 1. Methods

Research objects consist of real product of USV and RCWS which are USV PANDAWA-35 belong to *Sekolah Tinggi Teknologi Angkatan Laut Surabaya* (STTAL) and RCWS Sea Rogue acquired by PT Pindad Persero. These objects are used as the source for the design dimensions. Meanwhile, variables that are taken into account in this research are wind speed (knot); wave height (m); sea depth (m); dimension of the USV and RCWS, including length (m), breadth (m), height (m), and mass (ton); azimuth and elevation degree of RCWS; and wave headings.

In this study, the research constraints are as follows:

1. The USV and RCWS technical requirements are designed for the Surabaya Access Channel's work area and designed to face the type of pirates ship effectively.
2. The numerical simulation was carried out on USV and RCWS design with five different models, an unarmed ship model (model 1). Four of other ship models equipped with an RCWS with different configurations, which are barrel position at 0° (model 2), barrel position at 90° (model 3), at 170° azimuth (model 4), and 49° elevation (model 5).
3. Wave headings on the simulation are with angle variations of 0°, 45°, 90°, 135°, and 180°.

2.1. System Engineering Process Design

System engineering is simply a combination of units, products, and processes that can meet predetermined needs or goals. In general, it is applying a methodology built into the design, analysis, and development of complex systems to meet the needs [19]. To identify the needs in this study, the inputs for technical requirements are: 1) the mission and the operational requirements that are reviewed from data gathering regarding weather (wind speed data and wave height), 2) environment (sea depth), and 3) Enemies (pirate ship type and attack frequency). Afterward, the design of USV and RCWS will be created and developed based on the dimensions of the selected existing products with several configurations according to the technical requirements that have been made.

2.2. System Engineering Process Design

Stability is the ability of a floating structure to return to its original position after experiencing interference from internal or external factors, such as disturbances from the environment (waves and wind). There are two types of stability, namely horizontal stability and longitudinal stability. Horizontal stability means the structure is stable after experiencing a trim, while longitudinal stability means that the structure is stable after rolling. Three important aspects must be considered as part of stability, namely the center of gravity (G), the center of buoyancy (B), and the metacentric point (M). The illustrations of these notations can be seen in Figure 2.

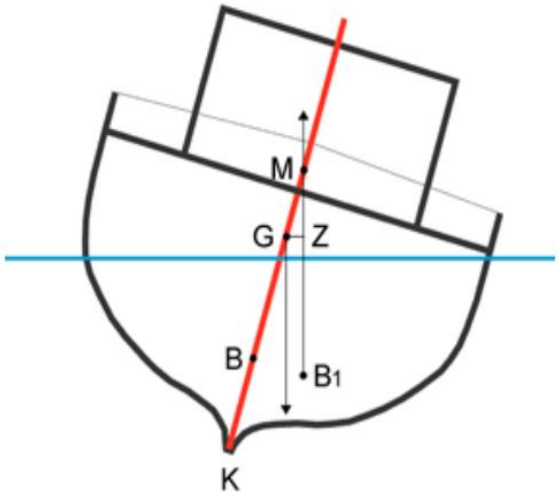

Figure 2. Roll Motion of a Ship

GM is the value of the distance between the center of gravity and the metacentric point. The higher the GM value, the ship's initial stability would increase. Meanwhile, GZ is a mathematical notation of righting arm. The value of GZ will increase as the tilt of the ship increases until a particular slope the GZ value reverses and decreases and then drop to zero, which the ship will capsize. The highest GZ value is called "Maximum GZ," while the tilt angle is called "Angle of Maximum Stability." Therefore, before the ship experiences a tilt as far as "Angle of Maximum Stability," the ship still has a high probability of returning to its original position [20].

Floating structures on the surface of the water will experience six degrees of freedom (6-DOF) which are divided into two categories, namely translational motion (surge, sway, and heave) and rotational motion (roll, pitch, and yaw) [21]. In this study, the motion that is taken into consideration is only the roll motion.

In terms of stability, there is a Response Amplitude Operator (RAO). RAO is information about the characteristics of the ship's motions that are generally presented in the form of a curve, where the abscissa is the frequency. The ordinate of the RAO is the ratio between the motion amplitude at a certain degree of freedom with the wave slope. RAO is also called a transfer function because it can transform wave loads into a spectrum response [22]. In general, RAO for rotational motion can be calculated with the following Equation [23].

$$RAO = \frac{\zeta k_0}{kw.\zeta_0} = \frac{\zeta k_0}{\left(\frac{\omega^2}{g}\right).\zeta_0} \quad (1)$$

where ζk_0 is the amplitude of the motion of the ship (rad), kw is a wave number, ω^2 is wave frequency, and ζ_0 is the wave slope (rad).

In the process, several steps are needed before carrying out the simulation process. The stages used are as follows:

1. **Modeling.** Models that have been created will be exported to be used for the simulation process to analyze their stability and seakeeping.
2. **Geometry Settings.** Geometry adjustments are made to determine the location of the center point of the axes used.
3. **Meshing.** Meshing is combining all parts that have been created, which are the models and the geometry adjustments.
4. **Data Input.** The data input process is carried out to provide additional information on the ship model so that the ship data in the model will be the same as the ship's condition and the actual environment. The data input process will also include a wave heading angle with angle variations of 0°, 45°, 90°, 135°, and 180°. Figure 3 illustrates the wave heading angle used in this study.

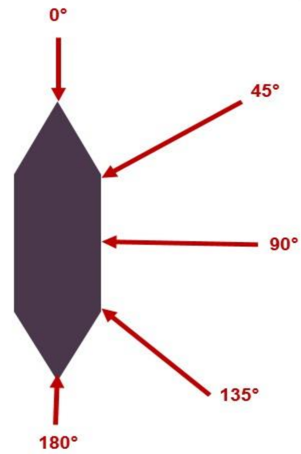

Figure 3. Wave Heading in USV Platform

5. **Hydrodynamic Diffraction.** Hydrodynamic diffraction is a simulation process in the Maxsurf Motion. The result of this simulation process is the Response Amplitude Operators (RAO) graph.

The method used in this research to analyze seakeeping performance is the linear strip theory method. In this method, specifically, the RAO of roll motion may be represented in the Eq. 2 concerning wave force and not wave slope. However, the two are assumed to be the same [24].

$$RAO_{roll} = \frac{\eta C}{F} = \frac{1}{\sqrt{(1-\lambda^2)^2 + 4\beta^2\lambda^2}} \quad (2)$$

where η is instantaneous roll displacement, C is hydrostatic restoring coefficient for roll, F represents exciting roll moment at the encounter frequency ω, β is non-dimensional damping coefficient for roll, and λ is the length of wavelength. The RAO is then modified for wave heading and apparent wave slope as shown in Eq. 3 [24].

$$RAO_{roll}(\mu) = RAO_{roll} \sin \mu \quad (3)$$

where μ is the angle of wave heading.

3. Results and Discussion

3.1. Technical requirements

In the design process, a requirement is a set of needs imposed on a new or a modified product, either before or during the product development cycle. Technical requirements are documentation of what a particular product or service should have and a statement that identifies the required attributes, capabilities, characteristics, or quality of the system to have value and usefulness.

In the system engineering approach, a set of requirements is used as input into the design stage of product development and the verification process. Before making the requirements, a feasibility study is carried out. The formulation of requirements can be broken down into identifying requirements (collecting and reviewing user needs), analysis, documenting requirements, and validation to ensure the requirements are correct [25].

Before creating technical requirements, the mission and operational requirements are formulated first. The formulation of missions and operational requirements is based on weather, environment, and enemy analysis. Weather data collection was carried out on December 9th, 2020, and December 31st, 2020. The weather data forecast was taken from the website of the Meteorological, Climatological, and Geophysical Agency (BMKG) with the SWAC being in Area code I.07 which can be seen in Figure 4, circled in red.

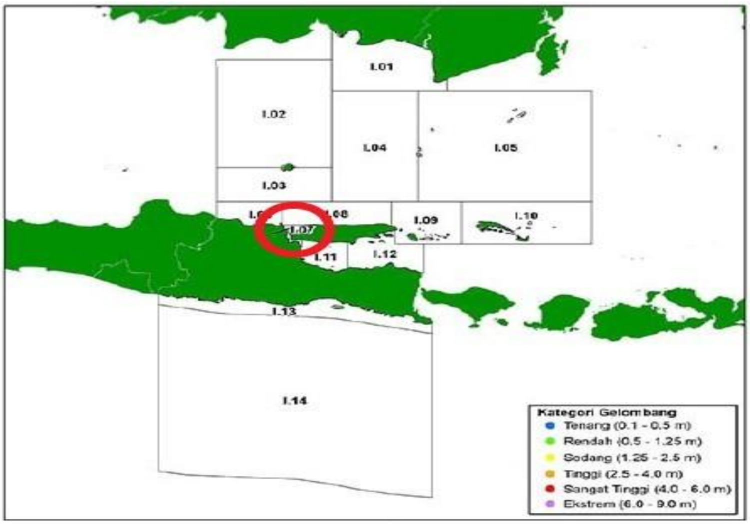

Figure 4. Surabaya West Access Channel Area

In weather analysis, it is necessary to analyze the height of sea waves classified into several categories. According to the World Meteorological Organization (WMO) Manual Code no.306 part A, the classification of sea waves (sea state) is shown in Table 1 [26].

Table 1. Sea State Classification

Category	Height of Wave (m)
Smooth	<0.5
Slight	0.5 – 1.25
Moderate	1.25 – 2.5
Rough	2.5 – 4
Very rough	4 – 6
High	6 – 9

In Table 2, the results of weather observations are shown in the form of wind and wave speeds during December 2020.

Table 2. the Results of Weather Observations in the SWAC During December 2020

Date	Wind speed (knot)	Wave category
Dec 9th 7 p.m – Dec 10th 7 a.m	9 – 23	Rough
Dec 10th 7 a.m – 7 p.m	7 – 20	Moderate
Dec 10th 7 p.m – Dec 11th 7 p.m	7 – 14	Moderate
Dec 11th 7 p.m – Dec 12th 7 p.m	5 – 12	Slight
Dec 13th 7 p.m – Dec 14th 7 a.m	5 – 14	Slight
Dec 14th 7 a.m – 7 p.m	3 – 12	Slight
Dec 14th 7 p.m – Dec 15th 7 p.m	3 – 12	Slight
Dec 15th 7 p.m – Dec 16th 7 p.m	3 – 9	Smooth
Dec 19th 7 p.m – Dec 20th7 a.m	5 – 15	Slight
Dec 20th 7 a.m – 7 p.m	5 – 14	Slight
Dec 20th 7 p.m – Dec 21th 7 p.m	5 – 14	Slight
Dec 21th 7 p.m – Dec 22th 7 p.m	5 – 16	Slight
Dec 25th 7 p.m – Dec 26th 7 a.m	3 – 7	Smooth
Dec 26th 7 a.m – 7 p.m	3 – 9	Smooth
Dec 26th 7 p.m – Dec 27th 7 p.m	3 – 8	Slight
Dec 27th 7 p.m – Dec 28th 7 p.m	3 – 10	Smooth
Dec 29th 7 p.m – Dec 30th 7 a.m	5 – 15	Slight
Dec 30th 7 a.m – 7 p.m	4 – 11	Slight
Dec 30th 7 p.m – Dec 31th 7 p.m	5 – 18	Moderate
Dec 31th 7 p.m – Jan 1st 2021 7 p.m	5 – 12	Slight

In the environment analysis, the data required is the length, width, and depth of the SWAC area. According to the Decree of the Minister of Transportation KP 455 of 2016, the length of the new SWAC area is 39.65 Nautical Miles (NM) or 73.5 Km with a minimum water depth of 13 m [27]. Meanwhile, in the enemy analysis, the targets that the USV and RCWS systems will face are pirate ships. The classification of small vessels can be divided into the following categories presented in Table 3 [28].

Table 3. Category of Small Vessels

Length of the vessel (m)	Speed (knot)
5	5
8	6.8
11	8
12	8.5
20	10.8
24	12
30	13.4

Based on the data description above, the mission requirements can be summarized as follows:

1. Able to operate in weather conditions with wind speeds of 3 - 23 knots, as well as smooth category wave heights (<0.5 m) to rough (2.5 - 4 m).
2. Able to operate in SWAC area with a minimum water depth of 13 m.
3. Capable of dealing with pirate ships with a vessel length of 5 - 30 m with a speed of 5 - 13.4 knots.

Operationally, the requirements designed for the USV and RCWS in this study are planned as follows:

1. Able to work well in day or night conditions with a minimum of 8 hours of endurance.
2. Operable for reconnaissance, quick hit reaction, and security patrols.
3. Has good platform stability and maneuverability.

Following the formulation of mission and operational requirements, the design will be based on USV products belonging to the *Sekolah Tinggi Teknologi Angkatan Laut Surabaya* (STTAL), namely PANDAWA-35 which has dimensions of L = 4 m; B = 2 m; and T = 0.5 m with trimaran hull type. As for the RCWS, it will be based on the RCWS Sea Rogue with the main dimension of 1.7 m long; 0.9 m wide; 1.04 m high; a total weight of 180 kg and azimuth ± 170°, elevation + 49° to -20°. The existing product of USV and RCWS that this research design is based on can be seen in Figure 5 and Figure 6, respectively.

Figure 5. USV PANDAWA-35

Figure 6. RCWS Sea Rogue

Technical requirements are compiled regarding the mission and operational requirements and the design process results, as previously explained. The technical requirements will be limited to the design aspects only and not calculate the overall ship system. The technical requirements made are:

1. The ship's dimensions are made based on the dimensions of PANDAWA - 35 with L = 4 m, B = 0.7 m, and T = 0.5 m.
2. The type of vessel will be designed to be monohull, in contrast to the reference vessel PANDAWA - 35, which has a trimaran design. A vessel with better maneuverability is desired for combat operation to chase the enemy vessel. Monohull vessels tend to have a smaller resistance than trimaran vessels resulting in better maneuverability [29].
3. The RCWS design will be made following the technical specifications on the RCWS Sea Rogue, with the dimensions of the approach following the original. RCWS Sea Rogue has a caliber and a greater angle of elevation and azimuth and better automation capabilities than weapons on the PANDAWA - 35, so it is more optimal in hitting the target.
4. The main engine for propulsion is based on PANDAWA – 35, a YAMAHA 85-PK motor with a mass of 111 kg and 8 hours.

3.2. Design Modeling

The drawing of the design is gradually started with the first drawing of the USV and the RCWS design was made then. The final stage is to combine both the USV and RCWS designs into a unified system. In this study, the RCWS will be placed right at the center of gravity of the USV to obtain a structural balance. The results of the USV design that have been equipped by RCWS are shown in Figure 7 and Figure 8.

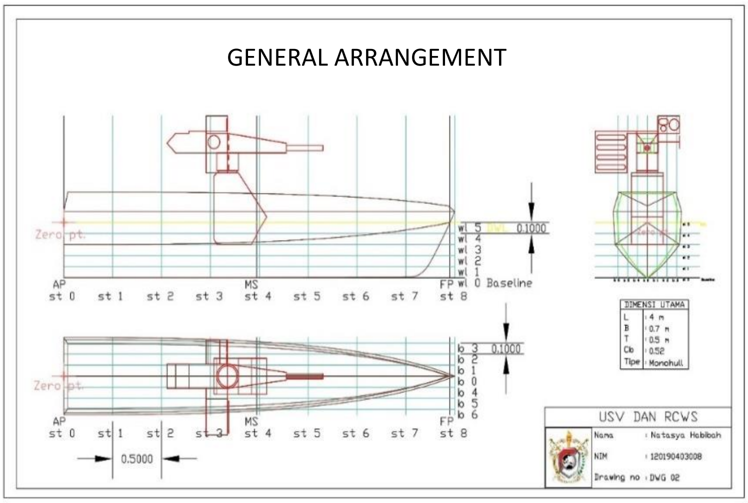

Figure 7. General Arrangement of USV and RCWS

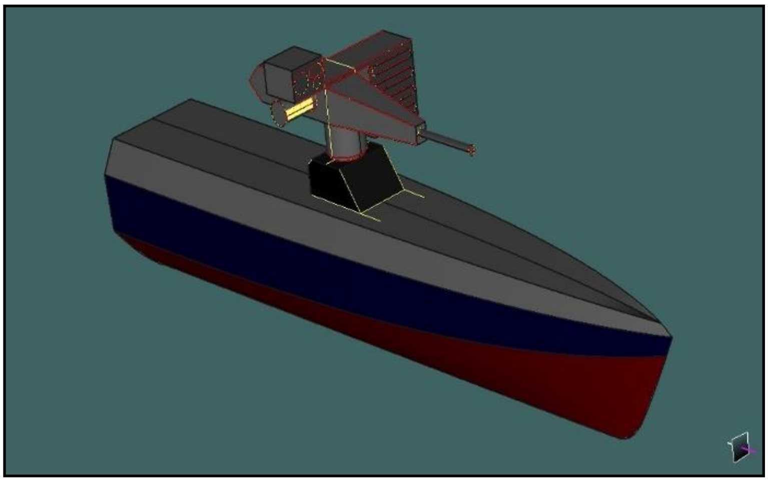

Figure 8. 3D Modeling of USV and RCWS

3.3. Simulation

The simulation was done with stability simulation and then continued with seakeeping simulation. In the simulation, several requirements entered into input which will be explained as follows:

1. There are five simulated models, namely: one of an unarmed ship model (model 1), as well as four of other ship models equipped with an RCWS with different configurations, which are barrel position at 0° (model 2), barrel

position at 90° (model 3), at 170° azimuth (model 4) and 49° elevation (model 5). All five models could be seen in Figure 9.

2. The simulated wave heading angles are 0°, 45°, 90°, 135°, and 180°, as described in Figure 3.
3. Input data for the environment is a wind speed of 23 knots and wave height of 4 m with a water depth of 13 m.
4. The simulated USV speed will follow the speed at PANDAWA – 35 with 28 knots.
5. The wave simulation spectra used in this research are the Pierson-Moskowitz, and JONSWAP simulated in irregular waves. Table 4 describes the inputs for both spectra.
6. The weight of the ship, weapons, and the motor will be taken into account with the distribution of mass describes as follows in Table 5.

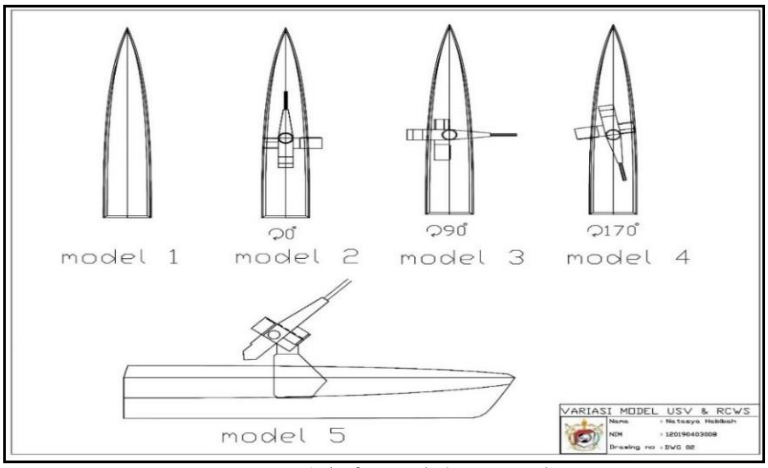

Figure 9. Models for Stability Simulation

Table 4. Wave Spectra Input

Type	Characteristic Height (m)	Modal Period (s)	Average Period (s)	Zero-Crossing Period (s)	Peak Enhancement Factor	Wind Speed (Knot)	m_0 (m^2)
Pierson-Moskowitz	2.99	8,64	6,68	6,18	1	23	0,558
JONSWAP	4	9,98	8,35	7,86	3,3	-	1,003

Table 5. Mass Distribution of the Vessel

Item	Quantity	Unit Mass (kg)	Total Mass (kg)	Unit Vol (m3)	Total Vol (m3)	Long. Arm (m)	Trans. Arm (m)	Vert. Arm (m)	Total FSM (kg.m)	FSM Type
Lightship	1	251.7	251.7			1.706	0	0.441	0	User Specified
RCWS	1	180	180			1.68	0.047	0.481	0	User Specified
Other components	1	180	180			1.68	-0.047	0.481	0	User Specified
Motor	1	111	111			0	0	0.2	0	User Specified
Total load case			722.7	0	0	1.431	0	0.424	0	
FS correction								0		
VCG fluid								0.424		

Before the seakeeping simulation, stability simulation was done for all the design models that have been made. The stability of the design was then analyzed with the result as follows in Figure 10.

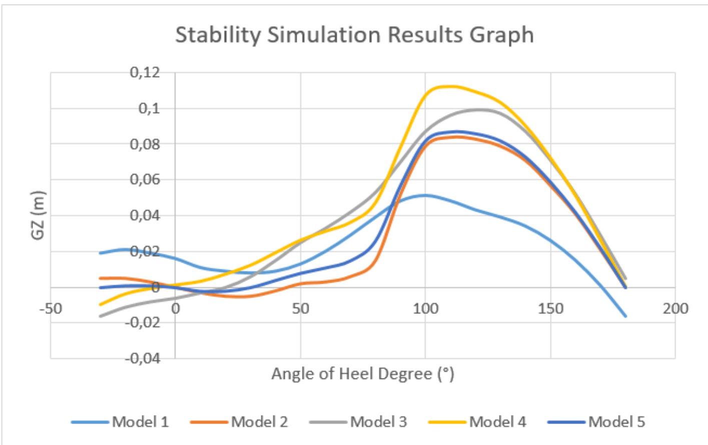

Figure 10. Stability Simulation Results

Based on the figure, the highest value of GZ belong to model 4, and the lowest belongs to model 1. Model 4 has the peak value of GZ for 0.112 m in angle degree of 108.2° before it decreases and drops to zero in angle 180°, which is the ship's condition finally capsized. Meanwhile, in Model 1, the peak value of GZ is 0.051 m in angle degree of 99.1° before it decreases and drops into zero. With its high value of GZ and the largest area below the line curve, Model 4 is the most difficult one to get to the heel. Meanwhile, Model 1 starts with the highest value of GZ, which means it has the most significant initial stability. However, model 1 also has the lowest value of GZ overall and the smallest area of the graph, meaning it will capsize easily than the others.

After the stability simulation, seakeeping simulations are carried out. The example of summary results of the seakeeping roll simulation in each spectrum for model 1 in all wave headings can be seen in Table 6 and Table 7. The results of the motion response of the ship or RAO are illustrated in Figure 11 – Figure 13.

Table 6. Summary Results of Seakeeping Roll Simulation for Pierson-Moskowitz Spectra in Model 1

Heading (deg)	m_0 (deg^2)	RMS (deg)	Significant amplitude (deg)	Modal (peak) T_0 (w_0)	Mean (centroid) T_bar (w_bar)	Mean zero crossing (peak) T_z (w_z)
0	0	0	0	-	-	-
45	4.8	2.19	4.38	26.104 (0.24)	318.625 (0.02)	82.690 (0.08)
90	0.00068	0.026	0.052	8.921 (0.70)	6.724 (0.93)	6.224 (1.01)
135	0.00003	0.0052	0.01	5.605 (1.12)	4.232 (1.48)	3.866 (1.63)
180	0	0	0	4.803 (1.31)	3.677 (1.71)	3.349 (1.88)

Table 7. Summary Results of Seakeeping Roll Simulation for JONSWAP Spectra in Model 1

Heading (deg)	m_0 (deg^2)	RMS (deg)	Significant amplitude (deg)	Modal (peak) T_0 (w_0)	Mean (centroid) T_bar (w_bar)	Mean zero crossing (peak) T_z (w_z)
0	0	0	0	-	-	-
45	3,98	1,99	3,99	26.104 (0.24)	238.888 (0.03)	79.208 (0.08)
90	0,0012	0,035	0,07	9.942 (0.63)	8.413 (0.75)	7.927 (0.79)
135	0,00007	0,0082	0,016	6.103 (1.03)	5.436 (1.16)	5.090 (1.23)
180	0	0	0	5.282 (1.19)	4.746 (1.32)	4.442 (1.41)

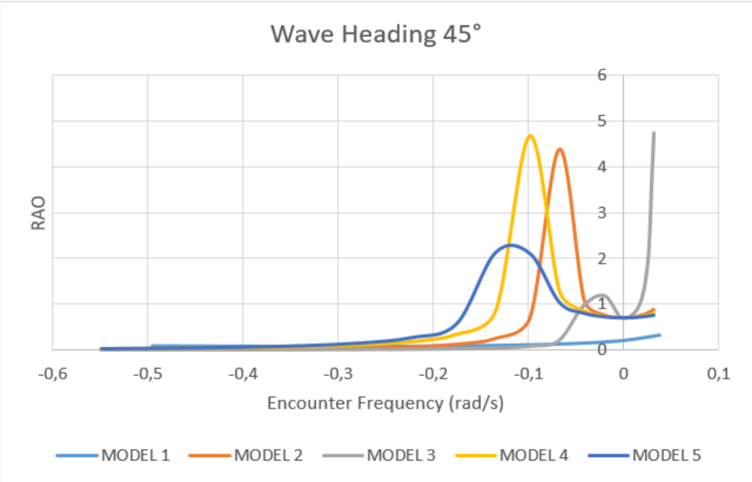

Figure 11. Seakeeping Simulation Results of Roll Motion in Wave Heading 45°

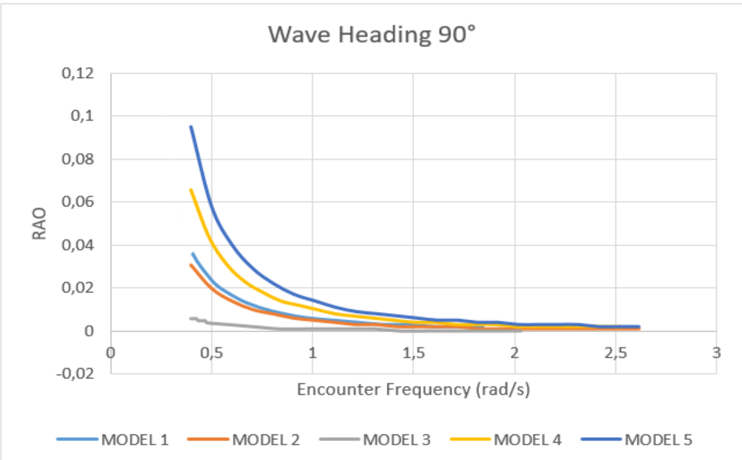

Figure 12. Seakeeping Simulation Results of Roll Motion in Wave Heading 90°

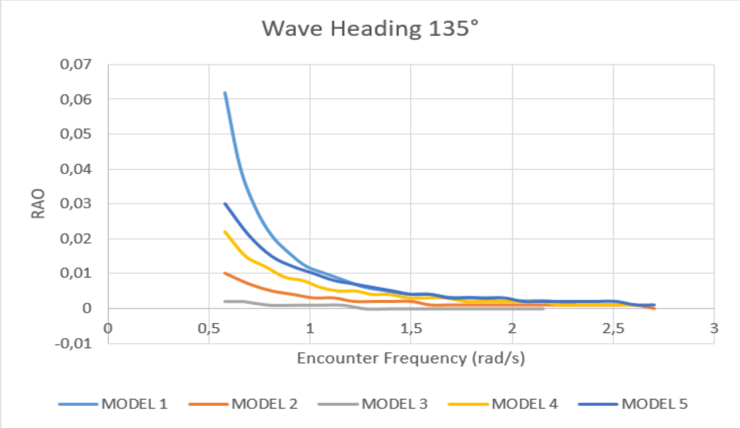

Figure 13. Seakeeping Simulation Results of Roll Motion in Wave Heading 135°

According to Figure 11, at wave heading 45°, model 3 already have the highest value of initial motion response of 4.703, which is the ratio between the amplitude of the motion at a certain degree of freedom with the wave slope, then the others at the frequency of 0.019 rad/s. Meanwhile, for Model 2 and 4, the motion response started flatter and steeply increase until it reaches the highest value of RAO at 4.37 in frequency -0,067 rad/s and 4.675 in frequency -0,098 rad/s, respectively. The lowest value of RAO belongs to Model 1, in which the graph tends to flatter and only slightly decrease from the initial frequency, which has the highest peak value of RAO at 1,089 in frequency 0.019 rad/s.

In Figure 12, at wave heading 90°, overall model 5 has the highest motion response with the peak value of 0.095 while model 3 has the lowest with the peak value of 0.006 both at an initial frequency of 0.4 rad/s. Similar to Figure 13 at wave heading 135°, model 3 also has the lowest motion response with the peak value of 0.002. While model 1 shows the opposite with a peak value of RAO at 0.012, both at an initial frequency of 0.581 rad/s.

The RAO value of 0 at the heading 0° and heading 180° for all the models was nullified or resulted in zero. According to formula 3, this happened because the RAO for a roll in specific wave headings is multiplied by the sine of the angle. Thus, in wave heading 0° and 180°, the value of RAOs is multiplied by zero resulting in null.

The seakeeping simulation results on the roll motion show that the amplitude of the ship motions gradually lessens because the graph shows a decrease after the peak point of each curve. Even though there was a slight increase after a decrease, but in the end, the graph continued to decline again until the RAO becoming the value of 0. The slight increase in the graphs is more likely to happen because there is an excitation frequency equal to the natural frequency of the USV structure so that resonance occurs. Resonance will enhance the amplitude of the ship's motion that increases RAO value before finally the RAO value decreases and the ship gradually reaches its balance again.

4. Conclusion

TUSV had been successfully designed with the monohull type with dimension adopted from USV PANDAWA – 35 and equipped with an RCWS based on the RCWS Sea Rouge with the main dimension of 1.7 m long; 0.9 m wide; 1.04 m high; a total weight of 180 kg and azimuth ± 170° with elevation + 49° to -20°. The stability simulations conclude that Model 4 is the most stable platform with the highest peak value of GZ for 0.112 m in angle degree of 108.2°. The seakeeping simulations show that at wave heading 45°, model 3 has the highest value of initial motion amplitude of 4.703 at frequency 0.4 rad/s, and the lowest value of RAO belongs to Model 1. At wave heading 90°, overall model 5 has the highest motion response with the peak value of 0.095 while model 3 has the lowest, both at the frequency of 0.4 rad/s. Similar to the result of Figure 13 at wave heading 135°, model 3 also has the lowest motion response, while model 1 shows the opposite with a peak value of RAO at 0.012, both at an initial frequency of 0.581 rad/s. In conclusion, in parallel with the dense shipping traffic with the increasing development of autonomous technology with the simulation results, this research could face the challenged and effectively solve the present need to combat piracy activities, as well as reducing potential human casualties, in the area of Surabaya West Access Channel.

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