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CALCULATION AND OPTIMIZATION OF FORCE AND POWER ON AUTONOMOUS SURFACE VEHICLE (ASV) AS MEANS OF MARINE ACCIDENT RESCUE

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ABSTRACT

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The strategic regional position makes Indonesia a world transportation crossing route with various modes of transportation through Indonesian territory to reach other islands, countries, or even continents. For this reason, a solution is needed to reduce the number of fatalities and injuries due to ship accidents that may occur. By reducing the evacuation time to a minimum, it will be possible to minimize the number of casualties and injuries if the ship has an accident. Considering that, in terms of usability and benefits, the Autonomous Surface Vehicle (ASV) can be an alternative as a form of Search and Rescue (SAR) ship. Based on the results of the ASV Ship design that suits these needs, a force and power analysis was carried out in accordance with the applicable theory. Of the two designs with a monohull shape and with different hull variations, with the main dimensions of the ASV Sang Nagari (LH=4.55 m, LWL=4.348 m, B=1.272 m, D=0.804 m T=0.45 m) and ASV Sang Nadibumi (LH=4.55 m, LWL=4.311 m, B=1.352 m, D= 0.802 m, T=0.4 m) obtained a displacement of 1.063 tons and a resistance of 1 kN for ASV Sang Nagari and 1.202 tons and a resistance of 2.6 kN for ASV Sang Nadibumi at a standard speed of 10 knots. Based on the results of the force analysis, it is concluded that the two ASVs have two forces in static conditions, that is weight force and upward lift force (FBouyant). Based on the results of the efficiency of ASV Sang Nagari has a higher efficiency of 0.002% with 56.422% than ASV Sang Nadibumi with 56.420%. The ASV linear model made from linearization has the properties of a controllable and observable, so this model can be applied to navigation and control systems.

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1. INTRODUCTION

Indonesia is the largest archipelago in the world with approximately 17,500 (seventeen thousand five hundred) islands and a total area of approximately 8 (eight) million square kilometers. An area of 1.8 (one point eight) million square kilometers of Indonesian territory is surrounded by territorial waters of which an area of 6.1 (six point one) million square kilometers is the exclusive economic zone (EEZ) [1]. The strategic regional position region makes Indonesia a crossing point for world transportation, with various modes of transportation through Indonesian territory reaching other islands, countries, or even continents. This strategic position results in higher mobility, so the chance of accidents is increasing. Ship accidents are events experienced by ships that can threaten the safety of ships and/or human life in the form of a) sinking ships, b) burning ships, c) ship collisions, and d) ship aground **[1]**.

According to the 2017 Transportation Safety Investigation Performance Outcomes **[2]**, there were 34 ship or shipping transportation accidents occurring in 2017 with various types of accidents. Moreover, from these ship transportation accidents, a high number of casualties and injuries were obtained due to long or late evacuation actions. The National Search and Rescue Agency, formerly known as the National Search and Rescue (SAR) Agency (Basarnas), has sea SAR transportation facilities to carry out search and rescue tasks. Sea SAR Transportation Facilities are conveyances used to carry out these tasks. These facilities cover various types of ships ranging from rescue ships, rescue boats, hovercraft, rigid inflatable boats (RIB), rubber boats, and rafting boats **[3]**.

However, it is necessary to evaluate the evacuation handling of passengers and crew members during marine transportation or ship accidents. By reducing the evacuation time to a minimum, it will be possible to minimize the number of casualties and injuries if the ship has an accident. Considering that, in terms of usability and benefits, the Autonomous Surface Vehicle (ASV) can be an alternative as a form of SAR ship. Along with the development of ASV technology **[4]**, **[5]** its application has gradually expanded in various sectors. In Indonesia, the development of Autonomous Surface Vehicle (ASV) technology is quite fast **[6]**, **[7]**. An Unmanned Surface Vehicle (USV) or ASV is a ship robot that can move automatically from one point to another **[8]**, **[9]**. This automatic movement uses position estimation of ASV **[10]**. Several studies have been carried out regarding the estimation of positions and optimization, such as the one applied to AUV using Ensemble Kalman Filter **[11]**, **[12]** and Square Root Ensemble Kalman Filter (SR-EnKF) method. This research refers to the technological independence of strengthening the national water transportation industry in the National Search and Rescue sector. Research is needed in order to increase technological innovation, especially the concept of design and system of Unmanned Vessels.

The target to be achieved is a better procedure for handling the evacuation of passengers and crew members during a sea transportation accident and reducing the evacuation time to a minimum. The main objective of this research is to produce calculations and analysis of the power system and in-depth technical mechanics of this Unmanned Ship. Hopefully, in the future, this research report can be continued and developed until one day, the dream of the desired evacuation handling procedure can be achieved with this alternative.

2. METHODS

2.1 Definition of Autonomous Surface Vehicle (ASV)

An Autonomous Surface Vehicle (ASV) or Unmanned Surface Vehicle (USV) is a remotely controlled or autonomous vehicle that performs tasks without direct control by an operator. ASV is one type of Autonomous Vehicle (AV) or Unmanned Vehicle (UV) that operates on the water surface.

Figure 1. ASV illustration

Mechanics

1) Mass, Force, and Weight [13]

$$P = \frac{m}{\nabla} \quad (1)$$

$$Fg = \ m\,.\,g \quad (2)$$
$$Fg = \ m\,.\,g = W \quad (3)$$

Where :

m : Mass (kg or g)

g : Gravitational acceleration = 9,81 m/s^2

∇ : Volume (m^3 or cm^3)

2) Newton's Law Motion I [14]

$$\sum F = 0 \quad (3)$$

3) Equilibrium Equation [14]

$$\sum F = 0 \quad (4)$$

$$\sum M = 0 \quad (5)$$

4) Hydrostatic Force [6]

$$F_{Bouyant} = p \;\; g \;\; \nabla \quad (6)$$

2.2 Ship Construction System

In the field of shipping, ship construction is a component of the ship building consisting of the ship's body and superstructure. The ship construction system is divided into two parts of the discussion: ship geometry and ship displacement [15].

1) *Mass Displacement [kg]*

$$\Delta = L_{WL} \;\; B \;\; T \;\; C_b \; \rho \quad (7)$$

2) *Weight Displacement [N]*

$$\Delta = L_{WL} \;\; B \;\; T \;\; C_b \; \rho \;\; g \quad (8)$$

3) *Volume Displacement [m^3]*
$$\nabla = C_B\ B\ \ T \tag{9}$$

2.3 Resistance and Ship Propulsion Systems

Ship propulsion is achieved through the conversion, transmission, and use of energy in a sequence of events that includes the development of power in the prime mover, the transmission of power to the propeller, the development of thrust on the moving surface of the propeller blades, and the transmission of thrust to the ship structure in that way to propel the ship in the water.

1) *Effective Horse Power (EHP)*
$$EHP = R_T\ \ v \tag{10}$$

2) *Delivery Horse Power (DHP)*
$$DHP = EHP/\eta D \tag{11}$$

3) *Break Horse Power (BHP)*
$$BHP\ =\ DHP\ +\ (A\ \%\ \ DHP) \tag{12}$$

The research stages in this paper can be written as follows

1) The initial stage in this research is problem identification
2) Next, there is a literature study and data collection
3) Next is the search for the ship platform design
4) Force calculation and analysis
5) Power calculation and analysis

2.4 Autonomous Surface Vehicle Modelling

The following are the equations of the ASV motion system with translational (surge and Sway) and rotational motions (Yaw) as follows [5], [7]:

$$(m - X_{\dot{u}})\dot{u} = X_{|u|u}|u|u + (1-h)X_{prop} + (m + X_{vr})vr\ +\ (mx_G + X_{rr})r^2 + X_{\delta\delta}\delta^2 + X_{ext} \tag{13}$$

$$(m - Y_{\dot{v}})\dot{v} + (mx_G - Y_{\dot{r}})\dot{r} = -(m - Y_{ur})ur + Y_{uv}uv +\ Y_{|v|v}|v|v + Y_{|v|r}|v|r + Y_{\delta}\delta\ + Y_{ext} \tag{14}$$

$$(mx_G - N_{\dot{v}})\dot{v} + (I_z - N_{\dot{r}})\dot{r}\ = -(mx_G - N_{ur})ur + N_{uv}uv + N_{|v|v}|v|v + N_{|v|r}vr + N_{\delta}\delta + N_{ext} \tag{15}$$

The ASV motion equations are in the form of a nonlinear model to be linearized into a linear model, then optimized through controllable and observable checking in the linear model in the results and discussion section below.

3. RESULTS AND DISCUSSION

3.1 Ship Platform Design

The design of the Unmanned Vessel consists of the following parts:

Table 1. Operational Requirements

Main Task and Functions	Marine Rescue
Operational Area	Sea
Speed	10 – 15 knots
Capability	all day
Crew	5 people

Monohull design vessel with a Deep 'V' Hull shape that tapers to form a simple V.

Table 2. ASV SANG NAGRI

L_H	LWL	B	D	T
4.55 m	4.348 m	1.272 m	0.804 m	0.45 m

Monohull design ship with a Deep 'V' Hull shape with a V angle larger than that of Sang Nagari and having Chine around the ship.

Table 3. ASV SANG NADIBUMI

L_H	LWL	B	D	T
4.55 m	4.311 m	1.352 m	0.802 m	0.4 m

Lines Plan

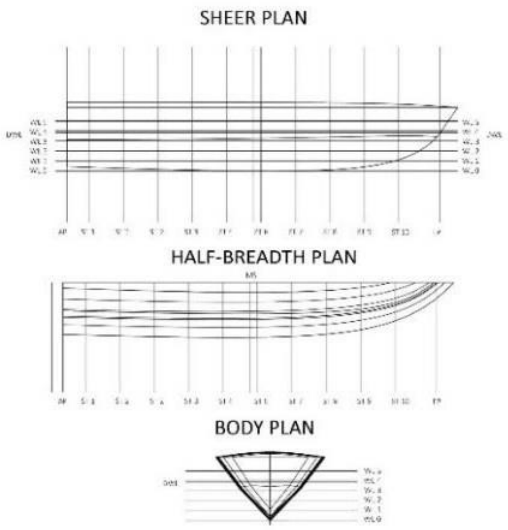

Figure 2. Lines Plan of ASV Sang Nagari

Of the available plans, a line plan can then be obtained. This design is arranged in such a way that it has the same characteristics as a certain outcome (have the same main measures, displacement (Δ), CB, and LCB). To see whether the design surface is smooth or not, the Maxsurf Modeler Advanced Software has provided views from several angles, that is, front view (Body Plan), side view (Sheer Plan), and top view (Breadth or HalfBreadth Plan. These lines from various points of view will later be used as a line plan. The following is a line plan of the designs available as in **Figure 2** and **Figure 3**.

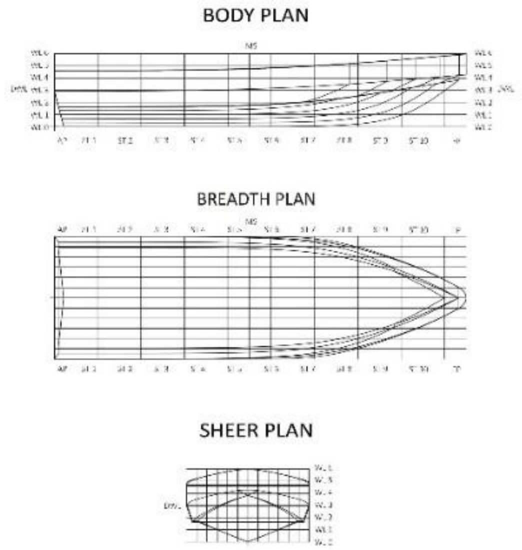

Figure 3. Lines Plan of ASV Sang Nagari

a. Force Calculation and Analysis

1) Center Point Determination

- ASV Sang Nagari

  LCG : -0.165 m (center point of *Midship* (MS))

- ASV Sang Nadibumi

  LCG : -0.173 m (center point of *Midship* (MS))

2) Static Force Analysis with Free Body Diagram

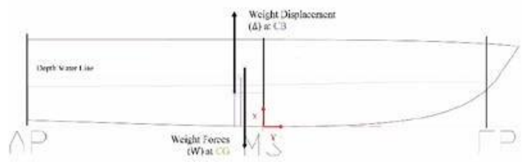

Figure 4. Centered Horizontal Static Force of ASV Sang Nagari

After determining the center point and analyzing the static forces that occur, the next step is to model the Free Body Diagram as a form of mechanical interpretation in force analysis. **Figures 4** to **7** provide Free Body Diagrams created based on determining force points and static force analysis. In a detailed image, it can be seen that **Figure 4** depicts the Horizontal Static Force of ASV Sang Nagari. **Figure 5** represents the Vertical Static Force of ASV Sang Nagari.

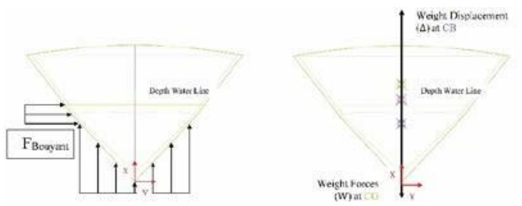

Figure 5. Vertical Static Force of ASV Sang Nagari

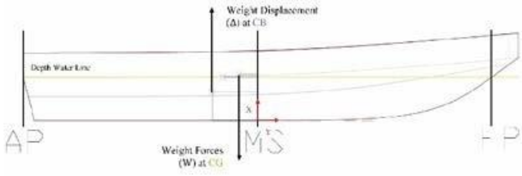

Figure 6. Centered Horizontal Static Force of ASV Sang Nadibumi

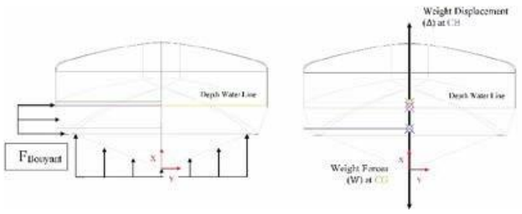

Figure 7. Vertical Static Force of ASV Sang Nadibumi

3) Force Calculation

Then, what is done after the previous stages is to determine the amount of force that occurs when the Unmanned Ship is in a static state (at rest or no acceleration (a = 0)) and balanced (Equilibrium) according to Newton's first law and balance equation. The available forces are:

$$\uparrow + \sum F = 0 \quad (16)$$
$$\uparrow + \sum Fx = 0 \quad (17)$$
$$\uparrow + \sum Fx = W - \Delta(N) \quad (18)$$
$$W = \Delta(N) \quad (19)$$

So, it can be concluded that the weight force or gravity (W) is equal to the Mass Displacement (Δ (N)). From the forces described in the previous point, the amount of force can be obtained using the formula available in the Basic Theory. Then, the formula substitution is done.

Bouyant Force

$$F_{Bouyant} = p \ g \ \nabla \quad (20)$$

Volume Displacement

$$\nabla = L_{WL} \ B \ T \ C_B \quad (21)$$

So,

$$F_{Bouyant} = p \ g \ \nabla \quad (22)$$
$$F_{Bouyant} = \rho \ g \ L_{WL} \ B \ T \ C_B \ \rho \quad (23)$$
$$F_{Bouyant} = \Delta(N) \quad (24)$$

Then, subsitute **Equation (16)**.

$$F_{Bouyant} = W \quad (25)$$

So, it can be concluded that the Bouyant Force ($F_{Bouyant}$) is equal to the Mass Displacement ((N)) and Weight Force (W).

4) Ship Displacement Calculation

Known from Maxsurf Modeler Advanced software, the Coefficient Block (Cb) on ASV Sang Nagari and Sang Nadibumi is respectively 0.417 and 0.503. Then, the displacement calculation is done.

Table 4. Results of Displacement Calculation

Calculation	*Volume Displacement* (∇)	*Mass Displacement* ($\Delta\Delta$ (kg))	*Weight Displacement* ($\Delta\Delta$ (N))
ASV SangNagari	1.037 m^3	1.063 ton	10.435 kN
ASV SangNadibumi	1.172 m^3	1.202 ton	11.791kN

b. Power Calculation and Analysis

1) Calculation of Ship Resistance and Propulsion Power

The calculation of resistance for this unmanned ship is obtained with Maxsurf Resistance software. This Unmanned Vessel Resistance Calculation Method uses the Holtrop method.

Table 5. Results of Resistance and Propulsion Power calculation

Calculation	Speed	*Sang Nagari*	*Sang Nadibumi*
Ship Resistance [kN]	5 knot	0,3	0,8
	10 knot	1	2,6
	15 knot	1,8	4
Effective Horse Power (HP)	5 knot	0,575	1,534
	10 knot	3,836	9,974
	15 knot	18,358	23,017
Delivery Horse Power (HP)	5 knot	0,886	2,364
	10 knot	5,912	15,372
	15 knot	15,963	35,474
Brake Horse Power (HP)	5 knot	1,019	2,719
	10 knot	6,799	17,678
	15 knot	18,358	40,795

2) Selection of Main Motor and Energy Source

Since the selected propulsion system is an electric propulsion system, the selected motor is an electric motor, and the selected energy source is a battery. The minimum power required by propulsion for Sang Nagari is 18.358 HP or 24.618 kW, and that for Sang Nadibumi is 40.795 HP or 54.707 kW. So, the motor sought is a motor with input power exceeding BHP or the minimum power required for the propulsion system.

Table 6. Motor Specifications for both ASVs

Torqeedo Deep Blue Specifications	*40R Outboards (ASV Sang Nagari)*	*80R Outboards (ASV Sang Nadibumi)*
Input Power (continous) [kW]	27,6	55,1
Propulsive Power [kW]	16,2	32,4
Comparable Petrol Outboards(Shaft Power) [HP]	40	80
Maximum overall Effieciency [%]	54	54
Nominal Voltage [V]	360	360
Max. Continous Performance [kW]	55	55
Capacity [30,5]	30,5	30,5

Table 7. Battery Specifications for both ASVs

SONY Lithium-Ion US18650VTC6 Rechargeable Batteries	
Capacity [mAh]	3000
Nominal Capacity [mAh]	3120
Nominal Voltage [V]	3,6

Calculation of Energy Source Consumption

Table 8. Battery consumption calculation on speed variation

Calculation of speed	ASV Sang Nagari		ASV Sang Nadibumi	
	Battery life (minute)	Maximum Distance (km)	Battery life (minute)	Maximum Distance (km)
15 knots	28.900	13.380	32.169	14,894
10 knots	16.055	8.920	20.910	9,929
5 knots	4.816	4.460	6.433	4.964

3) Power Analysis

After calculating the propulsion power, a power analysis can be carried out by comparing the effective thrust and the brake thrust (transmitted thrust) that occurs on each ship design using the basic concept of efficiency (η).

$$\eta = \frac{P_{output}}{P_{input}} \cdot 100\% \tag{26}$$

with Poutput is BHP and Pinput is EHP. So,

$$\eta = \frac{BHP}{EHP} \cdot 100 \tag{27}$$

Then substituted, with each speed variation. Then, the graph modeling is made.

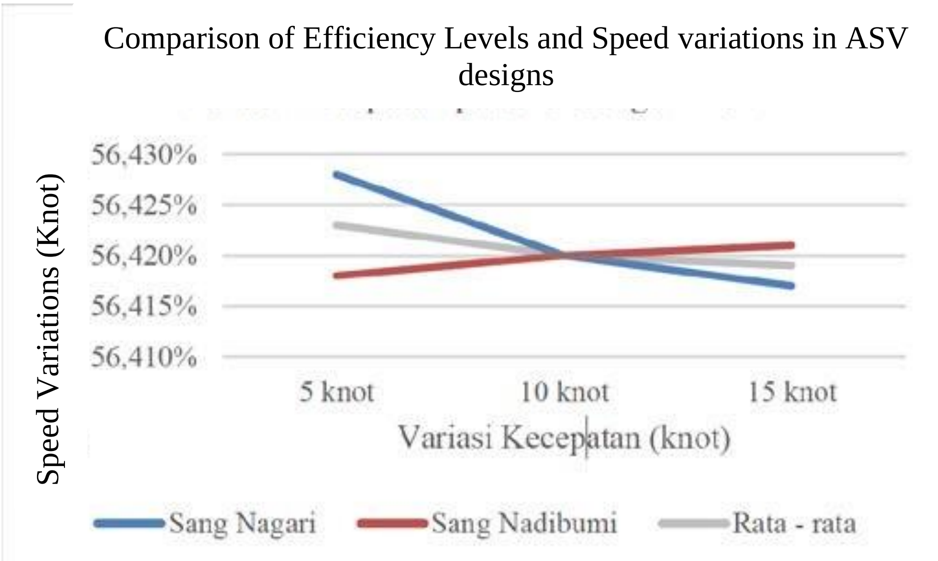

Figure 8. Graph of comparison of efficiency rate and speed variation of both ASVs

Then, the average total efficiency of the two ASVs was compared.

Table 9. Calculation of the average of total efficiency rate

Calculation	*Sang Nagari*	*Sang Nadibumi*
Average total Effiency ($\bar{\eta}$) [%]	56.422%	56.420%

3.2 Linearization of ASV Nonlinear Model

The linear model desired is obtained as follows.

$$\dot{x}(t) = A\,x(t) + Bu(t) \tag{28}$$

$$y(t) = Cx(t) + Du(t) \tag{29}$$

To determine (t), a Jacobi matrix can be formed as given below:

$$J_{x1} = \begin{bmatrix} \frac{\partial \Sigma_X}{\partial u} & \frac{\partial \Sigma_X}{\partial v} & \frac{\partial \Sigma_X}{\partial r} \\ \frac{\partial \Sigma_Y}{\partial u} & \frac{\partial \Sigma_Y}{\partial v} & \frac{\partial \Sigma_Y}{\partial r} \\ \frac{\partial \Sigma_N}{\partial u} & \frac{\partial \Sigma_N}{\partial v} & \frac{\partial \Sigma_N}{\partial r} \end{bmatrix} \quad (30)$$

From its differential derivation, it is obtained

$$A = J_{x2} = \begin{bmatrix} K_1 & 0 & 0 \\ 0 & K_2 & K_3 \\ 0 & K_4 & K_5 \end{bmatrix} J_{x1} \quad (31)$$

So that the obtained J_{x2} is

$$A = J_{x2} = \begin{bmatrix} A_{11} & A_{12} & A_{13} \\ B_{21} & B_{22} & B_{23} \\ C_{31} & C_{32} & C_{33} \end{bmatrix} \quad (32)$$

with

$$A_{11} = K_1 2\bar{u}X_{|u|u} \quad (33)$$

$$A_{12} = K_1\bar{r}(m + X_{vr}) \quad (34)$$

$$A_{13} = K_1((m + X_{vr})\,\bar{v} + 2\bar{r}(mx_G + X_{rr})) \quad (35)$$

$$B_{21} = K_2(-\bar{r}(m - Y_{ur}) + Y_{uv}\bar{v}) + T_3(-\bar{r}(mx_G - N_{ur}) + \bar{v}N_{uv}) \quad (36)$$

$$B_{22} = K_2\left(\bar{u}Y_{uv} + 2\bar{v}Y_{|v|v} + \bar{r}Y_{|v|r}\right) + K_3(\bar{u}N_{uv} + 2\bar{v}N_{|v|v} + \bar{r}N_{|v|r}) \quad (37)$$

$$B_{23} = K_2\left(-\bar{u}(m - Y_{ur}) + \bar{v}Y_{|v|r}\right) + K_3(-\bar{u}(mx_G - N_{ur}) + \bar{v}N_{|v|r}) \quad (38)$$

$$C_{31} = K_4(-\bar{r}(m - Y_{ur}) + Y_{uv}\bar{v}) + K_5(-\bar{r}(mx_G - N_{ur}) + \bar{v}N_{uv}) \quad (39)$$

$$C_{32} = K_4\left(\bar{u}Y_{uv} + 2\bar{v}Y_{|v|v} + \bar{r}Y_{|v|r}\right) + K_5(\bar{u}N_{uv} + 2\bar{v}N_{|v|v} + \bar{r}N_{|v|r}) \quad (40)$$

$$C_{33} = K_4\left(-\bar{u}(m - Y_{ur}) + \bar{v}Y_{|v|r}\right) + K_5(-\bar{u}(mx_G - N_{ur}) + \bar{v}N_{|v|r}) \quad (41)$$

Next, for the Jacobi Control matrix, a partial derivation is performed as follows.

$$J_{u1} = \begin{bmatrix} \frac{\partial \Sigma_X}{\partial X_{prop}} & \frac{\partial \Sigma_X}{\partial \delta} & \frac{\partial \Sigma_X}{\partial \delta} \\ \frac{\partial \Sigma_Y}{\partial X_{prop}} & \frac{\partial \Sigma_Y}{\partial \delta} & \frac{\partial \Sigma_Y}{\partial \delta} \\ \frac{\partial \Sigma_N}{\partial X_{prop}} & \frac{\partial \Sigma_N}{\partial \delta} & \frac{\partial \Sigma_N}{\partial \delta} \end{bmatrix} \quad (42)$$

Thus, the control Jacobi matrix obtained is as follows.

$$B = J_{u2} = \begin{bmatrix} K_1 & 0 & 0 \\ 0 & K_2 & K_3 \\ 0 & K_4 & K_5 \end{bmatrix} J_{u1} \quad (43)$$

$$B = J_{u2} = \begin{bmatrix} a_{11} & 0 & 0 \\ 0 & b_{22} & b_{23} \\ 0 & c_{32} & c_{33} \end{bmatrix} \tag{44}$$

Information:

$a_{11} = K_1(1-h)$
$b_{22} = K_2 Y_\delta + K_3 N_\delta$
$b_{23} = K_2 Y_\delta + T_3 N_\delta$
$c_{32} = K_4 Y_\delta + K_5 N_\delta$
$c_{33} = K_4 Y_\delta + K_5 N_\delta$

So, the linearization result of the nonlinear model is

$$\begin{bmatrix} \dot{u} \\ \dot{v} \\ \dot{r} \end{bmatrix} = J_{x2} \begin{bmatrix} u \\ v \\ r \end{bmatrix} + J_{u2} \begin{bmatrix} X_{prop} \\ \delta \\ \delta \end{bmatrix} \tag{45}$$

$$\begin{bmatrix} \dot{u} \\ \dot{v} \\ \dot{r} \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{13} \\ B_{21} & B_{22} & B_{23} \\ C_{31} & C_{32} & C_{33} \end{bmatrix} \begin{bmatrix} u \\ v \\ r \end{bmatrix} + \begin{bmatrix} a_{11} & 0 & 0 \\ 0 & b_{22} & b_{23} \\ 0 & c & c_{33} \end{bmatrix} \begin{bmatrix} X_{prop} \\ \delta \\ \delta \end{bmatrix} \tag{46}$$

The system is said to be controlled if the rank of the controllability matrix is equal to the dimension of the system. The controllability matrix is formed from matrix A and matrix B. The controllability matrix is as follows.

$$Controlable = (B|AB|A^2B| \dots |A^{n-1}B) \tag{47}$$

The dimension of the system is $n = 3$, so that

$$Controlable = (B|AB|A^2B|A^2B) = 3 \tag{48}$$

So, the system is controlled because it has rank = 3.

The system is said to be observable if the rank of observability is equal to the dimension of the system. The observability matrix is formed from matrix A and matrix C, and the observability matrix is as follows.

$$Observable = \begin{pmatrix} C \\ CA \\ CA^2 \\ \vdots \\ CA^{n-1} \end{pmatrix} \tag{49}$$

The dimension of the system is $n = 3$, so

$$Observable = \begin{pmatrix} C \\ CA \\ CA^2 \end{pmatrix} \tag{50}$$

So, the system is observed because it has rank = 3.

4. CONCLUSION

After the analysis, the conclusions that can be drawn are as follows:

1. The results of the Unmanned Vessel design, starting from Operational Needs, Design Limitations, and Main Size according to Section IV point A are obtained.
2. The ASV linear model made from linearization has the properties of a controllable, and observable, so this model can be applied to navigation, guidance and control systems.
3. Analysis of static forces on unmanned ships results in static ships having 2 forms of force, that is weight force (gravity) and lift force (FBouyant) and displacement calculations done is in accordance with point B.
4. Calculation of resistance and propulsion power and component selection is carried out as at point C.
5. Power analysis results in the conclusion that ASV Sang Nagari produces an efficiency of 56.422%, higher than that ASV Sang Nadibumi produces, that is, an efficiency of 56.420% by using the same battery usage.

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