Study of Offshore Patrol Vessel Models for Seakeeping and Maneuvering Improvement using Anti-Rolling Fins

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Abstract. Offshore patrol vessel models using anti-rolling fins with variations of fin angle and shape are investigated in this study to improve the seakeeping and maneuvering performances, especially in the combat operation of the vessel. This study focused on the determination of the effect of adding fins to the seakeeping and maneuvering performances by optimizing fin angle and shape fitted on the ship hull. The 3D ship model with three variations of fin’s shape and four variations of the fin angle was analyzed using a numerical method of computational fluid dynamic (CFD) software. Result showed that fins type NAIAD 525, has the smallest average roll response occurs at 55 deg fin with motion amplitude 5.4E-05 deg. At the same fin angle, the average pitch amplitude reaches the smallest of 2.7E-03 deg. For PRAXIS type, the smallest average roll response occurs at 60 deg fin with motion amplitude 4.7E-05 deg. But for average pitch amplitude, the lowest value occurs at 45 deg of 2.7E-03 deg. And WESMAR type, the smallest average roll response occurs at 45 deg fin with motion amplitude 3.9E-05 deg. At the same fin angle, the average pitch amplitude reaches the smallest of 2.7E-03 deg. Turning maneuvers parameter of the vessel are comply with the IMO standard. The highest value of Tactical Diameter, which is 4.91 L, occurs in condition of no environmental disturbance, while the highest value of Advance occurs in wind disturbance condition with a value of 4.29 L.

1. Introduction

Undership fins are known as one of the additional parts to improve the ship stability. The use of undership fins is known to improve rolling motion performance and reduce ship resistance. Fin’s shape and also its angle, can significantly affect the ship performance. The 3D simulation may show the effect of fin’s shape and angle before building the prototype. Because of that, this study analyzes the effect of fixed fins undership on resistance and rolling motion of OPV vessels. In this study, simulation of the effect of undership fins whether it is able to reduce the resistance value and increase the rolling motion value of the ship, considering that the addition of undership fins is an Appendages Resistance are examined. In addition, the use of fins undership on OPV was expected to be able to reduce the rocking motion of ships caused by several natural factors, namely waves, wind, and sea currents.
2. Materials & Methods

2.1. Ship Characteristics

The control of the rolling motion produced by the fins depends on several variables including the density of the water, the moment arm of the fins, the relative velocity between the fins and the flow of water, the area of the fins, the lifting coefficient, and the angle between the fins and the fluid velocity [3]. To calculate the magnitude of the moment that occurs during the rolling motion, the following eq. 1&2 can be used.

\[ \text{Moment} = -\Delta GM \frac{1}{T} \phi \]  

(1)

\[ T \phi = 2\pi \left( \frac{k^2 x x}{g G MT} \right)^{1/2} \]  

(2)

The rolling motions that occur on the ship are shown in the figure 1.

![Figure 1. Rolling Motion on Ships](image)

To calculate the magnitude of the return arm and the enforcement moment, the following equations can be used as shown in eqs. 3 and 4

\[ GZ = GM \sin \theta \]  

(3)

\[ M_R = W \times GZ \]  

(4)

GZ is the return arm, GM is the metacenter height, \( \theta \) is the angle of inclination, \( M_R \) is the enforcement moment, and \( W \) is the ship's weight or displacement.

2.2. Ship Performance

2.2.1. Seakeeping

The ship's translational motion is divided into surge (straight motion in the direction of the X axis), sway (straight motion in the direction of the Y axis), and heave (straight motion in the direction of the Z axis). While the rotational motion is also divided into 3, namely roll motion (rotational motion on the X axis), pitch (rotational motion on the Y axis), and yaw (rotational motion on the Z axis) [2]. Six degrees of freedom of movement of the ship is shown through the Figure 2.
2.2.2. Ships Maneuvering
On the OPV maneuvering ability is very important, because good maneuverability will be useful in pursuing enemy missions and avoiding enemy attacks with great precision. [2] Turning maneuver/turning test is a test of ship maneuvers to determine the ship's ability to turn at a certain angle towards the portside or starboard. The result of the turning test is a turning trajectory parameter which will display a characteristic description of the ship's maneuvering [2]. Mathematical Maneuvering Group (MMG) model introduced by Yasukawa as shown by Figure 4 [3] consisted of Equations 1 to 3 can predict ship's maneuverability of the vessel. The polynomial expressed by Equations 4 to 6 are the approximation value of the hull forces and hull moment. The variables of the polynomial equations are the drift angle, $\beta$ and dimensionless turning rate, $r'$. The variables represent the hull derivatives of hydrodynamics coefficients of the hull.

\[
\begin{align*}
\text{Surge:} & \quad (m + m_x)u_G - (m + m_y)v_G r_G = X_H + x_R + X_w \\
\text{Sway:} & \quad (m + m_y)v_G - (m + m_x)u_G r_G = Y_H + y_R + Y_w \\
\text{Yaw:} & \quad (I_{xx} + I_{yy})r_G = (N_H + N_p + N_R + N_W) - x_G(Y_H + Y_p + Y_R + Y_W) \\
X_H + m_y v_G r_G & = 0.5 \rho L d U^2 (X_H^t + X_y^t \beta^2 + (X_y^t - m_y^t) \beta r' + (X_y^{tt} - x_G^t m_y^t) r'^2 + X_y^{t3}) \\
Y_H - m_x u_G r_G & = 0.5 \rho L d U^2 \{Y_H^t \beta + (Y_H^t - m_x^t) r' + Y_H^{tt} \beta^2 r' + Y_H^{t3} \beta^3 + Y_H^{t3} r'^2 + Y_H^{t3} \beta^3 \} \\
N_H & = 0.5 \rho L d U^2 \{N_H^t \beta + N_H^{tt} r' + N_H^{ttt} \beta^2 + N_H^{ttt} \beta^3 r' + N_H^{ttt} r'^2 \beta + N_H^{ttt} r'^3 \beta^3 \}
\end{align*}
\]
In this study, the maneuvering simulation uses prediction coefficients based on block coefficient, the ratio of L/B and d/B proposed by Kijima and Yoshimura [4]. The coefficient prediction are eligible for medium high speed vessels having block coefficient in between 0.51 to 0.65, L/B ratio range of 2.6 to 7.1, and d/L ratio from 0.25 to 0.46. The added mass and added mass moment of inertia are calculated according to Motora’s diagrams [5,6,7]. The effects of wind on ship maneuvering are calculated in the MMG model based on Fujiwara’s estimation of wind forces and moment [8] based on the variables shown in Figure 5.

![Figure 4. Wind force variables](image)

Referring to Yasukawa [9], a polynomial equation developed based on Kt-J diagram of the propeller can predicts the propeller force depending on propeller revolution and diameter as well as wake fraction and the trust deduction fraction. The rudder forces are predicted based on the rudder normal force and the hydrodynamic coefficients of interaction between ship hull and rudder. The turning ability of the vessel is simulated according to the ITTC procedure [10] and evaluated based on the IMO standard [11]. The water depth is more than four times the full-load draft at zero trim, sea states is less than 4, and maximum wind speed is Beaufort 5. The speed approaching the turning maneuver is at least 90% of the ship’s speed. The minimum turning trajectory is 540 degrees. Tactical diameter and advance as shown in Figure 5 should be less than 5L and 4.5L, respectively.

![Figure 5. Turning Maneuvering Track](image)
2.2.3. Fins Undership

This analysis was conducted with aims to compare the optimum angle and shape on standard undership fins to the effect of fins on resistance and rolling motion on OPV through simulation with CFD. Fin model to be used for simulation, as shown in the figure 6.

![Figure 6. Fin Stabilizer Model](image)

2.3. Methodology

Seakeeping and maneuvering performance are analyzed based on the 3D model with fins undership. The calculation of seakeeping and maneuvering using the Ansys Aqwa and Fluent Software is based on Computational Fluid Dynamic methods. The main dimensions of the OPV and the dimension of the fins are as seen in table 1 and 2. The effects of fins undership to the seakeeping and maneuvering are simulated in 3 types of fins and dividein 5 fins degree 25°, 45°, 55°, and 60°. The flow chart of this study is presented in Figure 7.

![Figure 7. The flow chart of the study](image)
3. Result and Discussion

3.1. Hull

Ship data used in numerical testing using Ansys Aqwa software are presented in table 1:

| Table 1. Hull Dimension |
|-------------------------|
| LOA (m) | B (m) | H (m) | T (m) | Δ (tons) | Vmax (kts) | Vs (kts) |
| 90 | 13.5 | 6.8 | 3.7 | 2700 | 28 | 20 |

Creating the shape of the hull that will be used as input to the program Ansys Aqwa using Maxsurf software. The design of the OPV ship model was carried out with Maxsurf Modeller software to create a 3D model of the OPV which is shown in Figure 8.

![Image of Offshore Patrol Vessel models obtained from Maxsurf Modeler](image)

**Figure 8.** Offshore Patrol Vessel models obtained from Maxsurf Modeler

3.2. Fins

The shape design of the OPV (Offshore Patrol Vessel) vessel with a displacement of 2700 tons is designed according to the general plan drawings on the OPV. The fin size data for the three models are presented in table 2.

| Table 2. Fins Dimension |
|-------------------------|
| Type of Fins | Area (m²) | A (mm) | B (mm) | C (mm) | D (mm) | E (mm) |
| NAIAD 525 | 1.49 | 982 | 1104 | 1838 | 427 | 214 |
| WESMAR RS1600 | 1.5 | 1025 | 954 | 1836 | 410 | 219 |
| PRAXIS EFS-15 | 1.5 | 930 | 1344 | 2215 | 538 | 276 |

The depiction of the fins undership model uses 3 types of undership fins, namely NAIAD 525, WESMAR RS1600, and PRAXIS EFS-15 as presented in figure 9.
Seakeeping performances are analyzed based on 3D models with variations in fins. Analysis can be done using the CFD method on the ANSYS software. Where it is necessary to do meshing and setting boundary conditions as a pre-processing step, then a solution can be carried out for data retrieval.

3.3. Propeller and Rudder

The $K_T$-$J$ diagram of the propeller matches with a polynomial equation as shown in Figure 10. The type of propeller equipped on the existing vessel is following.

- **Type**: Twin Screw FPP B3-45
- **Rake**: 15
- **Propeller rotation direction**: Right
- **Number of blades**: 3
- **Propeller diameter**: 2.5 m
- **Hub diameter**: 0.25 m
- **Design pitch ratio**: 0.677
- **Expanded blade area ratio**: 0.45
- **Maximum revolution**: 500 rpm
- **Thrust**: 2785 N
- **Torque**: 1132 Nm

![Figure 10. $K_T$-$J$ diagram](image)

The aspect ratio, $\Lambda$ of rudder installed in the existing vessel is 1.897 with the span or height of the area, $Sp$ is 2.168 m, and rudder area, $A$ is 2.478 m². The mean chord or mean breadth of rudder area, $Ch$ is 1.143 m, tip cord, $Ch_T$ is 0.941 m and root chord, $Ch_R$ is 1.345 m.
3.4. Seakeeping performance

Seakeeping analysis were performed in irregular waves for Indonesian water that represented by JONSWAP spectrum formulation with the peakedness parameter by 1.5. The peak period (Tp) and significant wave height (Hs) used are 15 sec. of 3 meters respectively. Ship condition that considered is in full load condition with speed 20 knots and operate at following sea condition only. 3 types of fin model, namely NAIAD, PRAXIS and WESMAR with 4 (four) different installed angle i.e. 25 deg., 45 deg., 55 deg. And 60 deg. Motions responses investigated are roll and pitch using 3D Panel Method by ANSYS AQWA software as presented in Fig. 11.

Figure 11. 3D Panel Model

With the various fin angle, the analysis results average amplitude of roll and pitch as shown in Figure 11 through Fig. 13 below. From the figures, the following information are obtained:

For NAIAD type, the smallest average roll response occurs at 55 deg fin with motion amplitude 5.4E-05 deg. At the same fin angle, the average pitch amplitude reaches the smallest of 2.7E-03 deg. (Fig. 12)

For PRAXIS type, the smallest average roll response occurs at 60 deg fin with motion amplitude 4.7E-05 deg. But for average pitch amplitude, the lowest value occurs at 45 deg of 2.7E-03 deg. (Fig. 13).

For WESMAR type, the smallest average roll response occurs at 45 deg fin with motion amplitude 3.9E-05 deg. At the same fin angle, the average pitch amplitude reaches the smallest of 2.7E-03 deg. (Fig. 14).

Figure 12. Average Amplitude for NAIAD Type
Figure 13. Average Amplitude for PRAXIS Type

Figure 14. Average Amplitude for WESMAR Type

3.5. Maneuvering performance
Three simulation results of turning maneuver conducted in the calm water, wind disturbance of 20 knots from East, and current disturbances of 1.5 knots to West shown in Figure 15 a, b, and c, respectively. The tactical diameters and advances of the maneuvers are comply the IMO requirements as presented in Table 4.

Figure 15. Speed and trajectory of 600 degrees turning in 3 (three) environmental conditions
Table 3. Turning parameters

| Parameters       | No Environmental Disturbances | Wind Disturbance | Current Disturbance |
|------------------|-------------------------------|------------------|---------------------|
| Tactical Diameter| 4.91 L                        | 4.67 L           | 4.38 L              |
| Advance          | 3.57 L                        | 4.29 L           | 3.48 L              |
| Status           | Passed                        | Passed           | Passed              |

Figure 16. Turning parameters (a) No Environmental Disturbance, (b) Wind Disturbance, (c) Current Disturbance

The detailed trajectory of the maneuvering presented in Figure 16 shows the movement of the vessel in every 5 seconds of total 270 seconds period. Simulations show that wind disturbance change the trajectory at the approaching stage and the current disturbs the trajectory after approaching stage.

4. Conclusion

The effectiveness of adding fins depends on the angle of installation, fins type NAIAD 525, has the smallest average roll response occurs at 55 deg fin with motion amplitude 5.4E-05 deg. At the same fin angle, the average pitch amplitude reaches the smallest of 2.7E-03 deg. For PRAXIS type, the smallest average roll response occurs at 60 deg fin with motion amplitude 4.7E-05 deg. But for average pitch amplitude, the lowest value occurs at 45 deg of 2.7E-03 deg. And WESMAR type, the smallest average roll response occurs at 45 deg fin with motion amplitude 3.9E-05 deg. At the same fin angle, the average pitch amplitude reaches the smallest of 2.7E-03 deg. Turning maneuvers parameter of the vessel are comply with the IMO standard. The highest value of tactical diameter, which is 4.91 L, occurs in conditions of no environmental disturbance, while the highest value of advance maneuver occurs in conditions of wind disturbances with a value of 4.29 L. The effect of the fins to maneuverability is the future work of this study.

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