Optimum Propeller Interaction Analysis of Harbourtug With Azimuth Thruster

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Abstract. Determine the safety of tug operation at sea, especially in narrow shipping areas such as port areas, it is necessary to pay attention to the maneuverability of ships and the performance of the ship's steering system. In ship maneuvering, a specially designed thruster with 360 degrees side thrust with a small turning angle is needed in order to produce a good ship movement performance. In this study, the authors designed a tugboat propeller ka-series four blades. The propeller can move 360 degrees so that the distribution of power is evenly distributed in all directions. The system is expected to provide extra thrust when needed in the process of maneuvering and docking the ship. Equipped with hydraulics used to quickly lift and lower the thruster and pull it back into the hull when not in use. The analysis results show that each propeller variation such as the difference in thrust value, torque value and resulting efficiency. From the analysis model, the highest thrust value was obtained in the first propeller model with a variation of P/D 1, AE/A0 0.45 valued at 306201.4. The lowest torque value is generated in the third propeller model with a variation of P/D 0.6, AE/A0 0.65 value at -22400.2 Nm. Harbourtug requires a high thrust value, so it is advisable to use the first Propeller model with variations of P/D 1, AE/A0 0.45 The highest efficiency value is obtained in the first propeller model valued at 0.7151.

1. Introduction
Transportation is the activity of moving people or objects from one place to another which takes place in a space. Transportation acts as a support for economic, social, cultural and political activities, so it can strengthen national unity and integrity. The development of transportation is influenced by the nature and level of human life, so it is said that transportation is the cause and effect of the progress of human civilization. Sea transportation mode is more efficient and profitable to carry weight in large quantities for archipelagic areas such as Indonesia [1].

Ships are an important means of sea transportation in the maritime world to promote trade from within and outside the country which has a higher economic value. Increased transportation activities also have an impact on increasing marine incidents and accidents in Indonesia which must be the concern of all parties, not only ship owners but also government, related agencies and the community [2]. Many aspects affect the success of ship operations, namely hull planning, ship engineering system planning, propulsion system planning, calculation of ship maneuverability and other planning [3].

Ships can operate properly if they have a propulsion system design that can overcome total resistance that occurs in order to maintain the service speed as planned [4]. One of the components of the ship propulsion system is a propeller. The propeller transfers powered by changing the rotational
force of the propeller into thrust to move the hull with the mass of water by rotating the axial blades on the shaft [5]. The development of the propeller design of course aimed at making the speed of a ship more optimal and effective[6].

Optimization of the propulsion system which is one of the most important parts of a ship because it is closely related to speed. The propulsion system located at the stern of the ship will have a significant impact on the flow from the ship. The irregular distribution of the flow to the propeller can have an influence on the existing propulsion speed [7]. A tugboat is a type of guide ship commonly used to tow and push large ships to enter the port pool area [8].

In the following section, reviews of previous studies of propeller performance scaling methods in general was presented. Next, the specific cases investigated in this study and the methodology used were discussed, followed by the main results. Therefore, in order to assist in proper mooring or berthing operations, a large amount of energy is required that is generated from the propeller thrust.

2. Study area and parameter description

2.1. Characteristics Propeller
An object to be able to move requires a thrust to move the object. Likewise, a ship moving in the waters requires a thrust force that functions to push the ship to be able to move against the forces which in the world of education are called the resistance force of the media through which it passes. Meanwhile, the thrust required to fight this resistance force is known as the propulsive force. In general, the characteristics of the propeller in the open water test as represented in the KT - KQ - J diagram [9]. Each type of ship propeller has different characteristics of performance curves. So that the study of the propeller characteristics of a ship cannot be generalized to the whole shape or type of propeller. The equation model for the performance characteristics of a ship's propeller as follows:

\[ K_T = \frac{T}{\rho n^2 D^4} \]  
\[ K_Q = \frac{Q}{\rho n^2 D^5} \]  
\[ J = \frac{V_a}{nD} \]

Where KT is the thrust coefficient, KQ is the torque coefficient, J is the advance coefficient, Va is the speed of advance, D is the diameter propeller, N is the rotational speed, T is the thrust propeller, Q is the torque propeller, \( \rho \) is the density of the fluid.

2.2. Ducted Propeller
The duct thrust produced arises from the suction force on the curved duct surface. Ducted propellers generally comprise two principal components. The first is an annular duct having an aerofoil cross-section. The second component is a special case of a non-ducted propeller in which the design of the blades has been modified [10]. The propellers for these units can be of either the fixed or controllable pitch type.

Ducted propellers, sometimes referred to as kort nozzles by way of recognition of the Kort Propulsion Company’s initial patents and long association with this type of propeller, have found application for many years where high thrust at low or zero ship speed is required as in towing and trawling situations. In these situations, the duct generally contributes a half of the propulsor’s total thrust at zero ship speed commonly referred as bollard pull condition [9]. However, this relatively large contribution by the duct falls to more modest proportions with increasing ship speed toward the
free running condition, then at very high speeds the propulsor thrust receives a negative contribution from the duct[11].

2.3. Azimuth Thruster
Azimuth Thruster is the configuration, which is used in marine vessels to provide necessary thrust in desired direction which give ships better manoeuvrability than fixed propellers and rudder systems. Azimuth thrusters have been in common use for many years and are configured in either non-ducted or ducted propeller arrangements. These units fall into two distinct classes: the first is where a propeller is mounted on a rotatable pod beneath the ship and the second is the Voith Schneider or Kirsten-Boeing propulsion concept, the second where a propeller is mounted on a pod beneath the ships [12].

2.4. Controllable Pitch Propeller
The propeller blades are controlled to provide more manoeuvrability to change the blade pitch, the shaft speed can be maintained constant by engaging the generator thereby reducing the variable number of operations. The controllable pitch propeller has found application in most of the propeller types and arrangements so far outlined in this chapter, with the possible exception of the podded propulsors, contrarotating and tandem propellers. The total set of characteristics comprises sets of KT and KQ versus J curves comprising the design pitch angle. When analysing the performance of a controllable pitch propeller at off-design conditions, use should not be made of fixed pitch characteristics beyond say 5 or 10 degrees from design pithe effects of section distortion [9]. Different with the single line for fixed pitch propellers, the performance characteristics can be considered as surface forming.

The controllable pitch propeller needs to have greater mechanical complexity. It has several important advantages like maneuver through pitch adjustment and in cases where constant speed engines are used and operational changes can be achieved without accelerating and slowing down the propulsion engine system [13]. In the case of a controllable pitch propeller, there is a limit to the extent of the blade area due to the requirement of passing blade to obtain full reversibility of the blades [14].
3. Methodology

The methodology of this study consisted of several stages as presented on Figure 1.

![Figure 1. Research flowchart.](image)

3.1 Collecting Data
In this step, the necessary supporting data is collected, including lines plan drawings, general arrangements and other data required according to the analysis carried out, namely maneuver. Apart from that, rules from the class and other supporting data are also needed.

3.2 Resistance Calculation
The calculation steps of the vessel resistance related to the pod body, body-strut interface, and the effect of lift are carried out to stir the propeller flow in succession. This calculation is performed to determine the required power, as well as the dimensions of the thruster to be designed. The Holtrop method is an algorithmic method that is useful for predicting the resistance of tankers, general cargo, fishing vessels, tugs and container ships.

3.3 Propeller Selection
Selection of the specification and type of thruster must consider the calculation of the power of the thruster and also the calculation of all ship resistance using the Holtrop method with the help of
maxsurf resistance software. Based on the calculation, the specification can be searched through the thruster catalog according to the required power.

3.4 Designing the Optimal Propeller
In this study using the main propeller data in modeling the Propcad software. After finding the optimal propeller type and design, it is necessary to analyzing data.

3.5 Variation Data Analysis
Analysis in open water condition and analyses the distribution of fluid flow behind the propeller. The variation used are $\text{Ae} / \text{Ao}$ value, the $P / D$ value and $J$ value.

4. Result
4.1 Model Design
In this study using the main propeller data in modeling the PropCad software. PropCad is software for the geometric modeling of marine propellers, it can generate transverse and profile views, pitch distribution, geometric information, as well as the basic propeller parameters. the results of the visualization of the geometric design as shown in Figure 2.

4.2 Analysis of propeller performance
Propeller model is analyzed for thrust and torque values using the CFD method, giving variations to the predetermined variables. The fixed variable of this study is the propeller, while the variables varied are the $\text{Ae} / \text{Ao}$ value, the $P / D$ value and $J$ value.

4.2.1 Propeller data analysis 1
The obtained streamline results for $P/D$ 1 and $\text{Ae}/\text{A0}$ 0.45 were presented on Figure 3, 4, 5, 6, 7 and 8.

Figure 2. Propeller Ka-series Geometric.

Figure 3. Streamline Result of Ka4-45 with $J$ 0.1, $P/D$ 1 and $\text{Ae}/\text{A0}$ 0.45.
Figure 4. Streamline Result of Ka4-45 with J 0.3, P/D 1 and Ae/A0 0.45.

Figure 5. Streamline Result of Ka4-45 with J 0.5, P/D 1 and Ae/A0 0.45.

Figure 6. Streamline Result of Ka4-45 with J 0.7, P/D 1 and Ae/A0 0.45.

Figure 7. Streamline Result of Ka4-45 with J 0.9, P/D 1 and Ae/A0 0.45.
Figure 8. Streamline Result of Ka4-45 with J 1.1, P/D 1 and Ae/A0 0.45.

4.2.2 Propeller data analysis 2

The obtained streamline results for P/D 0.8 and Ae/A0 0.55 were presented on Figure 9, 10, 11, 12, 13 and 14.

Figure 9. Streamline Result of Ka4-45 with J 0.1, P/D 0.8 and Ae/A0 0.55.

Figure 10. Streamline Result of Ka4-45 with J 0.3, P/D 0.8 and Ae/A0 0.55.

Figure 11. Streamline Result of Ka4-45 with J 0.5, P/D 0.8 and Ae/A0 0.55.
Figure 12. Streamline Result of Ka4-45 with J 0.7, P/D 0.8 and Ae/A0 0.55.

Figure 13. Streamline Result of Ka4-45 with J 0.9, P/D 0.8 and Ae/A0 0.55.

Figure 14. Streamline Result of Ka4-45 with J 1.1, P/D 0.8 and Ae/A0 0.55.

4.2.3 Propeller data analysis 3
The obtained streamline results for P/D 0.6 and Ae/A0 0.65 were presented on Figure 15, 16, 17, 18, 19 and 20.

Figure 15. Streamline Result of Ka4-45 with J 0.1, P/D 0.6 and Ae/A0 0.65.
Figure 16. Streamline Result of Ka4-45 with J 0.3, P/D 0.6 and Ae/A0 0.65.

Figure 17. Streamline Result of Ka4-45 with J 0.5, P/D 0.6 and Ae/A0 0.65.

Figure 18. Streamline Result of Ka4-45 with J 0.7, P/D 0.6 and Ae/A0 0.65.

Figure 19. Streamline Result of Ka4-45 with J 0.9, P/D 0.6 and Ae/A0 0.65.
Figure 20. Streamline Result of Ka4-45 with J 1.1, P/D 0.6 and Ae/A0 0.65.

4.2.4 Propeller variation

The result of variation the values efficiency, thrust and torque were presented on Table 1, 2 and 3.

Table 1. Variation on the first propeller model.

| J  | Va (m/s) | Va (knot) | Vr (m/s) | Thrust (N) | Torque (Nm) | KT | KQ | 10 KQ | EFF (%) |
|----|----------|-----------|----------|------------|-------------|----|----|-------|--------|
| 0.1| 1.81     | 3.51836   | 39.82495 | 306201.4   | 64523.1     | 0.4349 | 0.0633 | 0.6328 | 10.94% |
| 0.3| 5.43     | 10.5551   | 40.15265 | 263467.2   | 56662.6     | 0.3742 | 0.0556 | 0.5558 | 32.16% |
| 0.5| 9.05     | 17.5918   | 40.80016 | 211002.5   | 47502.2     | 0.2997 | 0.0466 | 0.4659 | 51.21% |
| 0.7| 12.67    | 24.6285   | 41.7526  | 153330.5   | 37608.2     | 0.2178 | 0.0369 | 0.3689 | 65.80% |
| 0.9| 16.29    | 31.6653   | 42.98971 | 26102.3    | 91208.2     | 0.1278 | 0.0256 | 0.2560 | 71.51% |
| 1.1| 19.91    | 38.7020   | 44.48774 | 11747.7    | 11747.7     | 0.0193 | 0.0115 | 0.1152 | 29.31% |

Table 2. Variation on the second propeller model.

| J  | Va (m/s) | Va (knot) | Vr (m/s) | Thrust (N) | Torque (Nm) | KT | KQ | 10 KQ | EFF (%) |
|----|----------|-----------|----------|------------|-------------|----|----|-------|--------|
| 0.1| 1.81     | 3.5184    | 39.8250  | 251464.6   | 44170.1     | 0.3571 | 0.0433 | 0.4332 | 13.13% |
| 0.3| 5.43     | 10.5551   | 40.15265 | 202428.4   | 37096.1     | 0.2875 | 0.0364 | 0.3638 | 37.75% |
| 0.5| 9.05     | 17.5918   | 40.80016 | 143619.6   | 28811.6     | 0.2040 | 0.0283 | 0.2826 | 57.47% |
| 0.7| 12.67    | 24.6285   | 41.7526  | 77935.8    | 19072.1     | 0.1107 | 0.0187 | 0.1871 | 65.95% |
| 0.9| 16.29    | 31.6653   | 42.98971 | -2672.1    | 6847.4      | -0.0038 | 0.0067 | 0.0672 | 0.00%  |
| 1.1| 19.91    | 38.7020   | 44.48774 | -10837.1   | -9594.2     | -0.1539 | -0.0094 | -0.0941 | 0.00%  |

Table 3. Variation on the third propeller model.

| J  | Va (m/s) | Va (knot) | Vr (m/s) | Thrust (N) | Torque (Nm) | KT | KQ | 10 KQ | EFF (%) |
|----|----------|-----------|----------|------------|-------------|----|----|-------|--------|
| 0.1| 1.81     | 3.51836   | 39.8250  | 176819.6   | 25590.8     | 0.2511 | 0.0251 | 0.25   | 15.93% |
| 0.3| 5.43     | 10.5551   | 40.1527  | 126728.8   | 20229.9     | 0.1800 | 0.0198 | 0.20   | 43.33% |
| 0.5| 9.05     | 17.5918   | 40.8002  | 64674.8    | 13342.4     | 0.0919 | 0.0131 | 0.13   | 55.88% |
| 0.7| 12.67    | 24.6285   | 41.7526  | 13997.5    | 4535.2      | 0.0199 | 0.0044 | 0.04   | 49.82% |
| 0.9| 16.29    | 31.6653   | 42.98971 | -115873.7  | -7077.3     | -0.1646 | -0.0069 | -0.07  | 0.00%  |
| 1.1| 19.91    | 38.7020   | 44.48774 | -245143.8  | -22400.2    | -0.3482 | -0.0220 | -0.22  | 0.00%  |
4.2.5 Variation comparison graph

The result of comparison the values efficiency, thrust and torque were presented on Figure 21, 22 and 23.

**Figure 21.** Torque value comparison graph.

**Figure 22.** Thrust value comparison graph.

**Figure 23.** Efficiency value comparison graph.
4.2.6 Propeller visual design
The obtained three variation propeller designs with two views were presented on Figure 24, 25, 26, 27, 28 and 29.

![Figure 24](image)
Figure 24. The first propeller visual model perspective view.

![Figure 25](image)
Figure 25. The first propeller visual model front view.

![Figure 26](image)
Figure 26. The second propeller visual model perspective view.

![Figure 27](image)
Figure 27. The second propeller visual model front view.

![Figure 28](image)
Figure 28. The third propeller visual model perspective view.

![Figure 29](image)
Figure 29. The third propeller visual model front view.

4.2.7 Summary report
From the simulation running results on Table 1, Table 2 and Table 3 shows the thrust and torque values at different propeller variations:

1. On the first propeller model has the highest thrust value of 306201.4 compared to other variations of the model.
2. On the third propeller model has the lowest torque value of -22400.2 Nm compared to other variations of the model.
3. On the first propeller model has the highest percentage of efficiency at 71.51% compared to other variations of the model.
5. Conclusion
To minimize the use of engine power on the ship, selecting the propeller from the resulting performance and analyzed the efficiency of the propeller design that has been produced in order to be able to move a tugboat 32.8 meters at a specified speed.

From the 18 variations of the model, the highest thrust value was obtained in the first Propeller model with a variation of P / D 1, AE / A0 0.45 valued at 306201.4. The lowest torque value is generated in the third Propeller model with a variation of P / D 0.6, AE / A0 0.65 value at -22400.2 Nm. Harbourtug requires a high thrust value, so it is advisable to use the first Propeller model with variations of P / D 1, AE / A0 0.45 The highest efficiency value is obtained in the first propeller model valued at 0.7151. Adding variations in propeller data with different blade ratios is suggested for further research.

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REFERENCES
[1] Jinca 1953- M Y (Muhammad Y, 2011 Transportasi laut Indonesia : analisis sistem & studi kasus / M. Yamin Jinca Surabaya: Brilian Internasional.
[2] Ralahalu K A and Jinca M Y, 2013 The Development Of Indonesia Archipelago Transportation Int. Ref. J. Eng. Sci. 2, 9 p. 12–18.
[3] Jinca M Y, 2012 PELAYARAN KAPAL-KAPAL TRADISIONAL 24 p. 218–231.
[4] ITTC, 2008 Dictionary of Ship Hydrodynamics.
[5] Zhang G Zhao Y Li T and Zhu X, 2014 Propeller Excitation of Longitudinal Vibration Characteristics of Marine Propulsion Shafting System Shock Vib. 2014 p. 1–19.
[6] Utami S D Haripamudya H and Kurniawan S B, 2020 Study of passenger vessels design in Berau Regency, East Kalimantan, Indonesia for public transportation IOP Conf. Ser. Earth Environ. Sci. 557, 1.
[7] Nurhadi R Chrismianto D and Rindo G, 2017 Analisa Bentuk Variasi Propulison Module Pada Sistem Propulsi Azipod (Azimuthing Podded Drive) Berbasis Computational Fluid Dynamic (CFD) J. Tek. Perkapalan; Vol 5, No 1 Januari.
[8] Trimulyono A, 2015 Analisa Efisiensi Propeller B-Series Dan Kaplan Pada Kapal Tugboat Ari 400 Hp Dengan Variasi Jumlah Daun Dan Sudut Rake Menggunakan Cfd Kapal 12, 2 p. 112–120.
[9] Carlton J S, 2019 Propeller Performance Characteristics .
[10] Bhattacharyya A Krasilnikov V and Steen S, 2016 A CFD-based scaling approach for ducted propellers Ocean Eng. 123 p. 116–130.
[11] Ariana I M, 1997 Optimasi penggunaan propeller sebagai penggerak kapal dan pembangkit tenaga listrik pada KLB Maruta Jaya 900 DWT: laporan penelitian Jurusan Teknik Sistem Perkapalan, Fakultas Teknologi Kelautan, Lembaga Penelitian, Institut Teknologi Sepuluh Nopember.
[12] Manngård M et al., 2019 Estimation of propeller torque in azimuth thrusters IFAC-PapersOnLine 52, 21 p. 140–145.
[13] Bhattacharyya A Krasilnikov V and Steen S, 2016 Scale effects on open water characteristics of a controllable pitch working within different duct designs Ocean Eng. 112 p. 226–242.
[14] Anthony I Ekwere W Ogbonnaya E and Ejabefio K, 2013 Design Procedure of 4-Bladed Propeller West African J. Ind. Acad. Res. 8, 1 p. 13–24.