Optimization of B-series propeller geometry dimension to improve traditional fishing ship performance

D Mulyana*, F Koeshardono, A Sudradjat and R Y Widiatmoko
Mechanical Engineering Department, Politeknik Negeri Bandung, Indonesia

*deni.mulyana@polban.ac.id

Abstract. The fishing ship propulsion system will affect the performance of the ship and impact the fishermen's income. A crucial factor is the level of efficiency produced by propellers mounted on fishing vessels. In B-series propellers, propeller efficiency can be optimized by varying the size of the geometric dimensions. This propeller optimization process can be done after the ship resistance value is known. In Cirebon waters, as in other regions in Indonesia, the selection of propellers by fishermen is still unclear. Most are only based on the availability of goods on the market, without looking at how big the actual ship resistance occurs. In this research, one of the fishing boats that will be built will be chosen to estimate the ships' resistance. After that, by considering the engine used as its driving source, the geometry dimensions that can produce the highest efficiency are sought. Estimation of ship resistance is sought by the Holtrop method, and propeller optimization is carried out with the help of software. From the results of this study, the value of ship resistance commonly used by Cirebon waters fishermen is 2.608 kN at an operational speed of 7 knots. Optimized propeller design provides a 6 percent increase in efficiency compared to previously used propellers.

1. Introduction

The method of fishing by people has been evolved from time to time. However, one thing in common that is found in every process of fishing in the sea, fishing ships. This equipment is needed when the area of the catchment is far from the shore. The other advantage of the ship is its ability to store a high quantity of fish. However, with various types of ships (sometimes called vessels), the definition of the fishing ship has to be cleared. The fishing ship, as described by Nomura and Yamazaki, is a floating facility that is used in fishery, including fishing in the high seas and deep seas, research, surveying, training, and supervising. The fishing ship has a distinct characteristic in speed, maneuvering, exploring capability, construction, and storage facility. Primary conditions in fishing are hull structural strength, supporting the operation, high stability, and complete facility for storage [1,2].

Fishing ships, mainly utilized by fishermen, especially in Cirebon (as the subject of this research) relatively small in size. Most of the ships, the mover is generated by using the propeller mounted at the back of the ship. In other word, the propeller in the fishing operation is crucial. As necessary as it may seem, the fishermen still using trial and error for choosing their propeller.

Overview of marine propeller analysis is explained by Yeo and Hau [3]. The design of ship propellers aided by the computer explained by Koronowicz et al [4]. The aim of the study itself is to increase efficiency. Wide Chord Tip is utilized with sufficient improvement in Lee et al [5]. The B-Series propeller is the most feasible, as explained by Favacho et al when implementing it in the Amazon region [6] and Anthony for Africa [7]. Yeo and Ong was utilizing B-Series in his study [8]. Different materials
could play a role in the design (in this case, composite) [8, 9]. The location of the propeller also played a significant role in increasing efficiency [10], as Chamanara et al explained [11]. The duct of propeller is also playing a significant role [12]. Optimization is the method to get the best result from B-Series, as explained by Jiang et al [13], Vesting et al [14], and Takekoshi et al [15]. The continuation of this paper is studied by Windyandari et al using Computational Fluid Dynamics [16]. Also, using the CFD to evaluate the performance is done by Tan et al [17] and Raj and Reddy [18].

2. Methodology
The first step in this study is by getting data. There is 2 type of data: Geometrical data and hydrostatic design of the ship. The object of the study is like in Figure 1 below.

![Figure 1. Fishing ship of Cirebon fishermen.](image)

In order to measure the ship, it has to be clearly defined what is to be measured. So, the dimension to be measured is shown in Figure 2. These dimensions are needed to estimate the hull resistance by using the software.

![Figure 2. The dimension of the ship.](image)

After the process of measuring, the data could be seen as the table below.

| No | Geometry Parameter | Unit | Value |
|----|-------------------|------|-------|
| 1  | $L_{OA}$         | m    | 18.40 |
| 2  | $L_{WL}$         | m    | 15.38 |
| 3  | $B_{OA}$         | m    | 4.33  |
| 4  | $B_{WL}$         | m    | 3.93  |
| 5  | $T_s$ or $D_s$   | m    | 1.2   |
| 6  | $I$              | m    | 0.5   |

With the use of the software by using the data in the table, the hull then recreated as Figure 3.
The following data needed is hydrostatic of the ship hull. After the process of measuring, the data is presented below.

**Table 2. Hydrostatic data of ship.**

| No | Parameter                              | Symbol | Unit   | Value  |
|----|----------------------------------------|--------|--------|--------|
| 1  | Total displaced volume                 | $\nabla$ | m$^3$  | 28.361 |
| 2  | Displacement                           | $\nabla$ | ton    | 29.070 |
| 3  | Wetted surface area                    | $A_{WS}$ | m$^2$  | 59.483 |
| 4  | Waterplane area                        | $A_{WL}$ | m$^2$  | 48.250 |
| 5  | Midship section area                   | $A_M$   | m$^2$  | 3.135  |
| 6  | Longitudinal center of buoyancy        | $LCB$   | m      | 8.675  |
| 7  | Longitudinal center of buoyancy        | $LCB$   | %      | -2.114 |
| 8  | Block coefficient                      | $C_{BWL}$ | -     | 0.3915 |
| 9  | Prismatic coefficient                  | $C_P$   | -      | 0.5884 |
| 10 | Midship coefficient                    | $C_M$   | -      | 0.6654 |
| 11 | Waterplane coefficient                 | $C_{WL}$ | -      | 0.7993 |

After those two data acquired, the next step is to estimate the hull resistance. There are three methods used which are:

- Holtrop Method
- Fung-Leibman Method
- Delft Series Method

From these 3, Holtrop is used. The boundary conditions in this estimation are as followed:

- The speed of the ship is between 2 knots to 9 knots
- Appendages, wave and wind data, is not included

After that, the total resistance, which includes the appendages, wave, and wind, is calculated. The value is 10%.
Figure 4. Relationship between velocity and total resistance-effective power.

The velocity of the fishing ship is 7 knot, so from the curve, the resistance is 2.608 kN, and effective power is 9.393 kW. By using the formula, the propulsion force to overcome is 3.36 kN. From that, the performance of the installed propeller could be estimated. B-series propeller polynomial regression equation by Oosterveld and van Oossanen could be used to get open.

Figure 5. Open water characteristic of the installed propeller.

From that data, the propeller is designed and optimized. The main focus of this study is the number of blades in the propeller, which are 3 and 4.

3. Results and discussion

Propeller optimization is worked by using the B-series propeller polynomial regression equation by Oosterveld and van Oossanen. It is included in the software made by Parson to get maximum open water efficiency that could generate propulsion force needed at a specified speed. The algorithm of optimization is Nead and Mead Simplex [19,20]. The result optimization for three blades of propeller is as Figure 6.

In this optimization process, the independent variables are propeller diameter, blade area ratio, and pitch ratio. Beside them, propeller rotational speed needed to generate certain propulsion forces becomes the independent variable. Burril’s back cavitation is 5 or 10 %.

From Figure 6, in the three blades, the optimum diameter is 0.8 m. The pitch becomes shorter than previously installed, which means increasing rotational speed.
Figure 6. Relationship between velocity and total resistance-effective power for three blades (left) and four blades (right).

With decreasing blade area ration, cavitation effect also decreased. Propeller efficiency is 0.616 when advancing coefficient 0.515. Compared to the installed propeller, there is a 6% increase in propeller efficiency.

From the same figure also, the diameter, pitch, and blade area ratio have the same value with previously installed propeller but with four blades. The efficiency of the propeller is 0.594 when advance coefficient 0.5526. There is a 2% increase in propeller efficiency compared to previously installed.

Figure 7. Optimized propeller for fishing ship.

4. Conclusion
From this study, it could be concluded that:

- Resistance estimation for the ship is 2.608 kN and the propulsion force needed is 3.36 kN.
- Optimization parameter for propeller as followed:
  - Propeller diameter ($D$) = 0.8 m
  - Blade number ($Z$) = 3
  - Pitch diameter ratio ($P/D$) = 0.82
  - Blade area ratio ($A_e/A_o$) = 0.31
- Open water efficiency as a product of optimization is 6% higher than previous installation
- Parameter $D$, $Z$, $P/D$, dan $A_e/A_o$ is used as a reference to design standard B-series propeller by calculating chord length, blade thickness, also ordinates of airfoil per blade section.
References

[1] Nomura M and Yamazaki T 1977 Fishing Technique (Tokyo: Japan International Cooperation Agency)

[2] Turbo M D 2004 Basic principles of ship propulsion [Online] Retrieved from: https://marine.man.eu/docs/librariesprovider6/propeller-aftship/basicprinciples-of-propulsion.pdf

[3] Yeo K B and Hau W Y 2014 Fundamentals of Marine Propeller Analysis Journal of Applied Sciences 14(10) 1078-1082

[4] Koronowicz T, Krzemianowski Z, Tuszkowska T and Szantyr J 2009 A complete design of ship propellers using the new computer system Polish Maritime Research 16(1) 29-34

[5] Lee C S, Choi Y D, Ahn B K, Shin M S and Jang H G 2010 Performance optimization of marine propellers International Journal of Naval Architecture and Ocean Engineering 2(4) 211-216

[6] Favacho B I, Vaz J R P, Mesquita A L A, Lopes F, Moreira A L S, Soeiro N S and Rocha O F L D 2016 Contribution to the marine propeller hydrodynamic design for small boats in the Amazon region Acta Amazonica 46(1) 37-46

[7] Anthony S, Ekwere W, Ogbonna Y E and Ejabefio K 2013 Design Procedure of 4-Bladed Propeller West African Journal of Industrial and Academic Research 8(1)

[8] Yeo K B and Ong C M 2014 Fixed-pitch Marine Propeller Geometry Design Journal of Applied Sciences 14(11) 1131-1138

[9] Taketani T, Kimura K, Ando S and Yamamoto K 2013 Study on performance of a ship propeller using a composite material The Third International Symposium on Marine Propulsors smp vol 13

[10] Prasad P and Lanka B B 2017 Design and Analysis of the Propeller Blade International Journal of Advances in Mechanical and Civil Engineering 4(2) 14-19

[11] Chamanara M, Ghassemi H, Fadavie M and Ghassemi M A 2018 Effects of the duct angle and propeller location on the hydrodynamic characteristics of the ducted propeller Ship Science and Technology 11(22) 41-48

[12] Santhosh Babu K P and Padmanabhan S 2017 Design of marine propeller blade with different blade sequences analyse the hydro formation under pressure hydrodynamic fill ARPN Journal of Engineering and Applied Sciences 12(17) 4996-5002

[13] Jiang J, Cai H, Ma C, Qian Z, Chen K and Wu P 2018 A ship propeller design methodology of multi-objective optimization considering fluid–structure interaction Engineering Applications of Computational Fluid Mechanics 12(1) 28-40

[14] Vesting F, Bensow R E, Johansson R, Gustafsson R and Costa N 2016 Procedure for application-oriented Optimisation of Marine Propellers Journal of Marine Science and Engineering 4(4) 83

[15] Takekoshi Y, Kawamura T, Yamaguchi H, Maeda M, Ishii N, Kimura K, ... and Fujii A 2005 Study on the design of propeller blade sections using the optimization algorithm Journal of marine science and technology 10(2) 70-81

[16] Windyandari A, Dwi H G and Suharto S 2018 Design and performance analysis of B-series propeller for traditional purse seine boat in the north coastal region of Central Java Indonesia Journal of Applied Engineering Science 16(4) 494-502

[17] Tan Y, Li J, Li Y and Liu C 2019 Improved Performance Prediction of Marine Propeller: Numerical Investigation and Experimental Verification Mathematical Problems in Engineering 1-10.

[18] Raj S S and Reddy P R 2011 Performance evaluation of composite marine propeller using L8 orthogonal array International Journal of Engineering Science and Technology 3(11)

[19] Fyson J (Ed.) 1985 Design of small fishing vessels (Farnham: Fishing News Books) pp 85-86

[20] Parsons M G 1975 Optimization methods for use in computer-aided ship design Proceedings of the First SNAME STAR Symposium