# Development of Optimum Design B-Series Propeller with Engine Propeller Matching, A Case Study 60-Meters Patrol Boat

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***Abstract*—in preliminary ship design and ship propulsion systems, it is important to have a simple method of determining the optimization of the propeller diameter and propeller efficiency, as the minimum input data to arrive at a rough estimate of performance. This problem can be solved using propeller diagrams of the open water test series or polynomial regression. This research will introduce an optimization method for the design of the B series. The propeller design process, which was carried out as a single objective function using the MatLab code numerical method, encountered problems due to cavitation, required propeller thrust and engine propeller matching. Engine propeller matching is the matching of engine power, the hull and the propeller to achieve design speed with optimal efficiency. This research focus on case study results of testing a patrol boat with a length of 60 m. By using a computer program, this 60m patrol boat is able to reach a speed of 23.5 knots using a B5-92 and an engine power of 2935 kW with an efficiency of 64.2%. Using the DESPPC program, the 60m patrol boat is able to reach a speed of 23.5 using a B5-989 and an engine power of 2927 kW with an ETA-O efficiency of 64.5%. It can be concluded that the small computer program can be used as a B-Series propeller optimization method. For future research, this method will be developed for the other series based on polynomial regression such as Gawn series and Kaplan series.**

***Keywords*—**B series, engine propeller matching, optimation, single objective, small computer program.

## I. INTRODUCTION

Two methods can be used in preliminary propeller design. The first theoretical used propeller design methods using a computer without the geometry constraints seen in series propellers [1]. The second is to use an open water series diagram [2]. In the preliminary design process of a ship and ship propulsion system, it is important to have a simple method to the determination of propeller efficiency, that requires a minimum of input data to arrive at a rough performance estimate. In such cases, propeller series can be used. This research focuses on B series propeller. The B series is one of the most commonly used series because however, in practice, the B series data is among the most widely applied in the industry[3].

In this study, a simple method for optimum design propeller used the small computer program based on numerical code has been developed. The propeller design specifically to find a simple procedure for determination of optimum propeller efficiency, applying experimental results from tests with the B series propellers polynomials. The small computer program is handled as a single objective function, experiencing several problems such as cavitation, engine propeller matching, required propeller thrust and advance coefficient.

## II. METHOD

The preliminary design propeller problem has been tackled as a multi-purpose limited optimization problem [4][5]. In this study, the problems included cavitation, thrust requirement and engine propeller matching. There are two main steps for the B series propeller leading to a simple optimization problem. The first is selection of the best open water efficiency of each blade. Step two is comparing all the efficiency values and take the best value. Two main ways of dealing with 'multi-purpose' problems, both leading to a single goal optimization problem is chosen and the other is defined as constraints and sum of all objectives forms the optimization objective function [6]. This efficiency open water test optimization all blades can be seen in formula no 1 [7]:

$$\text{Find } X=\begin{Bmatrix}\eta_{o3}\\ \eta_{o4}\\ \eta_{o5}\\ \eta_{o6}\\ \eta_{o7}\end{Bmatrix} \quad (1)$$

where:

X is optimum propeller efficiency of the propeller type

Ƞ is efficiency of different type of propeller

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Z is the number of blades One easy way of optimization is to develop a small computer program that calculates $K_T$ and J as functions for each blade number, blade area, and pitch ratio.

In this study using 3 main constraints, namely the efficiency of open water test, cavitation and engine propeller matching. In addition to the best efficiency, it is necessary to consider the avoidance of cavitation. Another thing that is not less important is the power required by the propeller must be matched with the power generated by the engine.

### *A. The Wageningen B-Series propeller*

The Wageningen series is the most comprehensive series which has been tested by Troost [8]. It contains more than 120 propellers it includes 2 - 3 - 4 - 5 - 6 and 7 bladed propellers with blade areas ranging from 0.30 ~1.05. For each blade area and blade number, pitch ratios in the region P/D = 0.5 ~ 1.4 was tested [9] [10] as in table 1.

The Open water characteristics in Reynold 2 x $10^6$ numbers can be seen in formula no 11:

$$K_Q = \sum_{n=1}^{47} C_n (J)^{S_n} (P/D)^{t_n} (A_E/A_O)^{u_n} (Z)^{v_n} \tag{3}$$

$$K_Q = \sum_{n=1}^{39} C_n (J)^{S_n} (P/D)^{t_n} (A_E/A_O)^{u_n} (Z)^{v_n} \tag{4}$$

where, $C_n$ is the regression coefficient of the thrust and torque coefficients. The values of the coefficients and exponents in Eq. (3) and (4) are given in (6).

The efficiency value of all blades will be calculated for each pitch per diameter ratio and Blade area ratio. Then the best efficiency value will be obtained for each blade. The next step is to compare the best efficiency values so that each blade gets the best efficiency.

TABLE 1.
WAGENINGEN B-SERIES OF PROPELLERS.

| Z | Blade Area Ratio | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 0.30 | | | | | | | | | | | | | | |
| 3 | | 0.35 | | | 0.50 | | | 0.65 | | | 0.80 | | | 1.00 | |
| 4 | | | 0.40 | | | 0.55 | | | 0.70 | | | 0.85 | | | 1.05 |
| 5 | | | | 0.45 | | | 0.60 | | | 0.75 | | | | | |
| 6 | | | | | 0.50 | | | 0.65 | | | 0.80 | | | | |
| 7 | | | | | | 0.55 | | | 0.70 | | | 0.85 | | | |

The maximum load on the B series propeller occurs around 0.75R. Therefore, the Reynolds number of the radius is used as a representative for all propellers. Reynolds number 2 x 106 has been taken as a reference Reynolds number to represent the experimental results B series. Meanwhile, when the test was carried out with a lower Reynolds number, the test results were corrected for this difference. If the calculation result of the Reynolds propeller number at 0.75R is greater than 2 x 106, it is necessary to make corrections by adding to $\Delta K_T$ and $\Delta K_Q$.

$$Rn_{0.75R} = \frac{C_{0.75R} * \sqrt{[V_A^2 + (0{,}75\pi\, n\, D)^2]}}{v} \tag{5}$$

where, $C_{0.75R}$ is the blade chord length at 0.75R and $V_A$ is the advance velocity in m/s.

### *B. Optimum function*

Optimal goals in the design propeller is the maximum propeller efficiency ($\eta_{max}$) [12]. That marine propeller efficiency can be calculated as follows:

$$\eta = \frac{J}{2\pi} \cdot \frac{K_T}{K_Q} \tag{6}$$

The optimum design used in the small computer program in this research is the highest efficiency value. Cavitation can affect the performance of the propeller, so cavitation needs to be avoided in the preliminary process of propeller design. Cavitation in the propeller cannot be eliminated but can be avoided. One way to avoid cavitation is to increase the blade area ratio suggested by Keller 1966 [13].

$$\left[\frac{A_E}{A_O}\right]_{min} = \frac{(1.3 + 0.3Z)T}{(P_O - P_v)D^2} + K \tag{7}$$

where :
T is Thrust (N or kN)
Z is the number of blades
$P_O$-$P_V$ is pressure at centerline in the propeller in N per $m^2$(or kN per $m^2$)
K is a constant varying from 0 (for transom stern naval vessels to 0.2 (for high powered single-screw vessel)

### *C. Engine propeller matching*

Matching point is a point of intersection between engine characteristics and propeller load characteristics so that all the power generated by the propulsion engine will be absorbed by the propeller [14]. At engine speed n, is the point of rotation of the driving motor that according to propeller load conditions. The power generated by the driving motor is the same as the power absorbed by the propeller. All motor power is absorbed completely by the propeller. This results in no wasted motor power. So that it will provide optimal consequences on the use of material consumption fuel from the ship's propulsion motor to the desired design speed of the ship.

The indicator that can be seen on the ship is the engine indicator speed (rpm, or rps) and boat speed (knots, or mile/hour). While the propeller load indicator does not exist, there is only the propeller rotation indicator. So the determination of the operating speed of the driving motor in the propeller design is the key to optimization in the design of the ship's overall propulsion system.

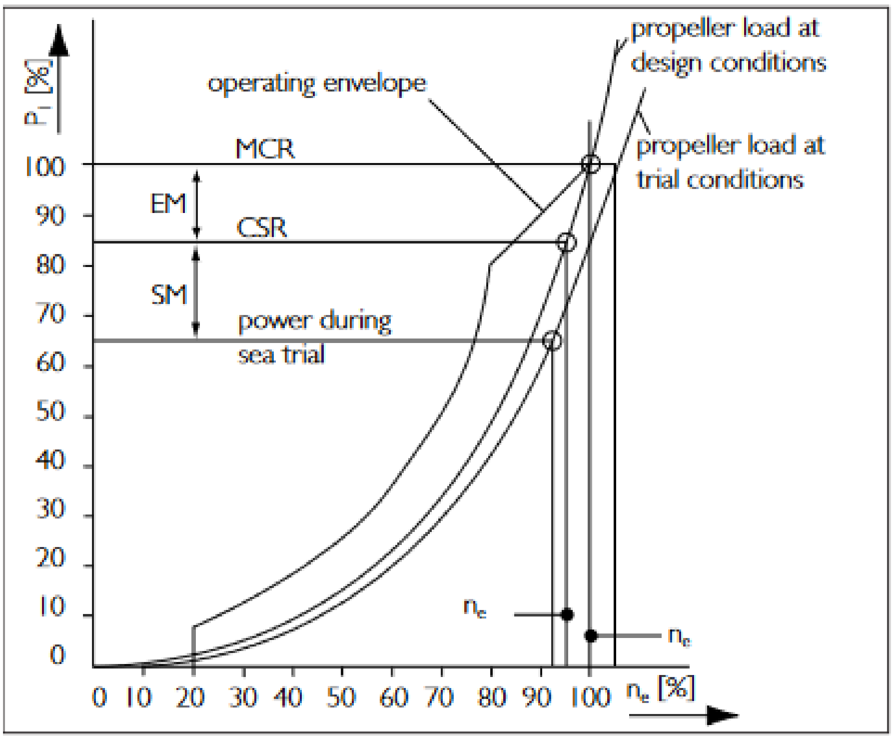


**Figure. 1.** Engine Propeller Matching [14].

Equal to the power produced by the engine and the resulting ship speed close to (exactly) the planned ship service speed. Propeller characteristics are as in Figure 1

$$\alpha = \frac{1}{2}\rho * WSA * CT \tag{8}$$

$$T_{SHIP} = \frac{\alpha * V_A^2}{(1-t)(1-w)^2} \tag{9}$$

$$T_{PROP} = K_T * \rho * n^2 * D^4 \tag{10}$$

$$T_{SHIP} = T_{PROP}$$

$$K_T = \frac{\alpha * V_A^2}{(1-t)(1-w)^2 * \rho * n^2 * D^4} \tag{11}$$

where :
WSA:Wetted Surface area(m$^2$)
CT : Resistance Coefficient
P : Specific gravity of seawater(1025 Kg/m$^3$)
$T_{ship}$ : Thrust required ship(N or kN)
$T_{prop}$ : Thrust required by propeller(N or kN)
$V_A$ : Advanced Velocity(m/s)
$K_T$ : Coefficient Thrust Propeller
n: : Rotation of propeller in m/s
D : Diameter Propeller(m)
T : Thrust deduction factor
W : Wake fraction

## III. Result and Discussion

### *A. Flow chart Small computer program*

The small computer program has been developed specially to find the optimum characteristics of any B-series propellers used numerical method.

There are 3 main constraints in making the Small computer program, namely $K_{Tdesign}$, minimal $A_EA_O$ and Reynolds number. $K_{Tdesign}$ is needed to get thrust in accordance with $K_T$ requirements. In addition, the $K_T$ design will be related to Engine Characteristics. It is at this point of intersection that the Engine Propeller Matching will be obtained. A minimum $A_EA_O$ is required to reduce the risk of cavitation. Reynolds number is needed to determine the magnitude of $\Delta K_T$ and $\Delta K_Q$. The optimum value is obtained from the highest ETA-O Efficiency value in each blade. Then the optimum value of 1 blade is obtained. The detail numerical method is summarized in the flowchart in Figure 2.

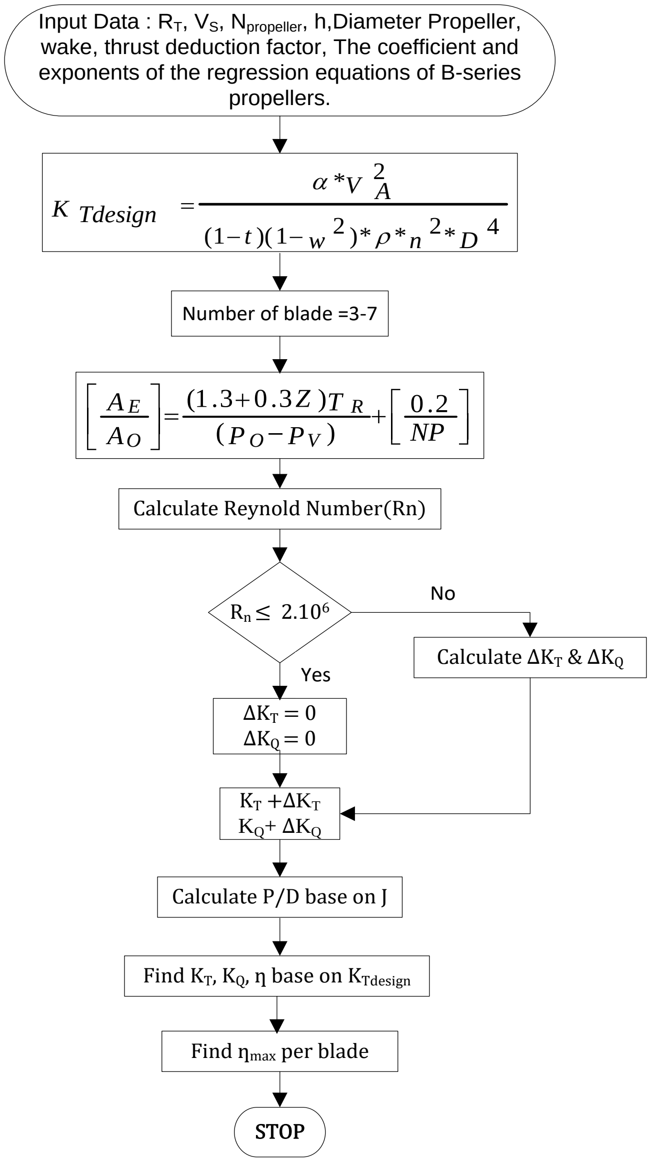


**Figure 2.** Flowchart small computer program for B-Series marine Propellers.

*B. Case study 60-meters patrol Boat*

The 60 meters patrol boat, according to operational needs are warships that are prepared as multirole vessels, as fast patrol boats, combatants, and Combat SAR which has agile speed and maneuverability and can be operated optimally in archipelagic seas. [15][16]. Main Functions 60 Meter Patrol Boat has the ability as a fast missile boat as well as a patrol ship killer with the special hit and run capabilities in attacking and destroying targets. The 60m Patrol Boat was chosen to be designed using the MatLab Program based on Polynomial Regression and Engine Propeller Matching so that it is expected to get a speed according to the design speed of 23 knots.

The main dimension of the 60 m patrol boat as in table 2.

TABLE 2
MAIN DIMENSION OF 60 METERS PATROL BOAT.

| No. | Item | Symbol | Score | Unit |
|---|---|---|---|---|
| 1 | Design Speed | Vs | 23 | Knot |
| 2 | Displacement volume moulded | Δ | 450.2 | $m^3$ |
| 3 | Length over all | LoA | 59.543 | m |
| 4 | Length on waterline | Lwl | 54.032 | m |
| 5 | Engine | PE | 3000 | kW |
| 6 | Breadth | B | 8.100 | m |

| | | | | |
|---|---|---|---|---|
| 7 | Depth | D | 4.900 | m |
| 8 | Draught on FP | $T_F$ | 2.570 | m |
| 9 | Draught on AP | $T_A$ | 2.570 | m |
| 10 | Mass density of seawater | ρ | 1025 | ton/m$^3$ |
| 11 | Wetted surface area bare hull | S | 467 | m$^2$ |
| 12 | Block coefficient | $C_B$ | 0.391 | |
| 13 | Mid ship section coefficient | $C_M$ | 0.563 | |
| 14 | Prismatic coefficient | $C_P$ | 0.694 | |

The problem is finding the optimal characteristics (P / D, J / $K_T$, $K_Q$, ETA, n_Blade, $A_E$ / $A_O$) of all B types of twin screw propellers. The diameter of the propeller (D) is limited to the specified value according to an acceptable line 60 meters patrol boat to avoid vibrations. Ship speed ($V_S$) and ship resistance ($R_T$) are given from the model test results of the 60-meters patrol boat. Based on the main dimensions as presented in Table 2 and the ship's lines plan, a ship model is made as in Figure 3

TABLE 3
MAIN DIMENSION OF MODEL 60 METERS PATROL BOAT

| No | Item | Symbol | Score | Unit |
|---|---|---|---|---|
| 1 | Length Over All | LOA | 3.962 | m |
| 2 | Length on Water Line | LWL | 3.654 | m |
| 3 | Draught surface | T | 0.539 | m |
| 4 | Displacement (submerge) | Δ | 0.326 | kg |
| 5 | Displacement surface | Δ | 0.171 | kg |

Ship model material : *fiberglass*
Scale model : λ = 15.03

The interaction between the hull and the propeller produces a wake fraction and thrust deduction factor. The estimation of these two factors greatly influences the estimation of engine power (Brake Horsepower) and propeller design. Self-propulsion test is very important in determining wake fraction (w) and thrust deduction factor(t). The test was carried out in a towing tank. In addition, the test results of this model are for ideal trial conditions (no currents, winds and waves). The results of the ship's self-propulsion test are shown in table 4.


**Figure. 3.** Testing the self-propulsion model at a load of 2.57 meters, Vs = 25 knots

TABLE 4
SHIP RESISTANCE DATA AND PROPULSIVE COEFFICIENT
OF THE MODEL 60 METERS PATROL BOAT
(T=2.6M, V=454M$^3$, D=466TS, 0% SEA MARGIN

| VS (Knot) | RT (kN) | t | w | EtaR |
|---|---|---|---|---|
| 23 | 257 | 0.058 | 0.047 | 1.002 |
| 24 | 271 | 0.058 | 0.047 | 1.002 |
| 25 | 288 | 0.058 | 0.047 | 1.002 |
| 26 | 301 | 0.058 | 0.047 | 1.002 |
| 27 | 314 | 0.058 | 0.047 | 1.002 |
| 28 | 328 | 0.058 | 0.047 | 1.002 |
| 29 | 341 | 0.058 | 0.047 | 1.002 |
| 30 | 355 | 0.058 | 0.047 | 1.002 |
| 31 | 368 | 0.058 | 0.047 | 1.002 |

### *C. Developed Small Computer Program*

The Small Computer program is specifically designed to calculate the optimal performance of each propeller B-series polynomials using MatLab Code. The input computer program data as in table 5. The results of calculations using a small computer program are shown in Figure 4.

TABLE 5
INPUT DATA COMPUTER PROGRAM

| Input Data | Lower Limit | Upper Limit | Unit |
|---|---|---|---|
| Ship Resistance(RT) | 257 | 368 | kN |
| Ship speed | 23 | 31 | knot |
| Number of Propeller Blades (Z) | 3 | 7 | |
| The diameter of propeller(D) | 1.800 | 1.800 | m |
| Specific gravity of seawater | 1025 | 1025 | kg/m$^3$ |
| Grafity | 9.8 | 9.8 | m/s |
| Vapour pressure | 1700 | 1700 | Pascal |

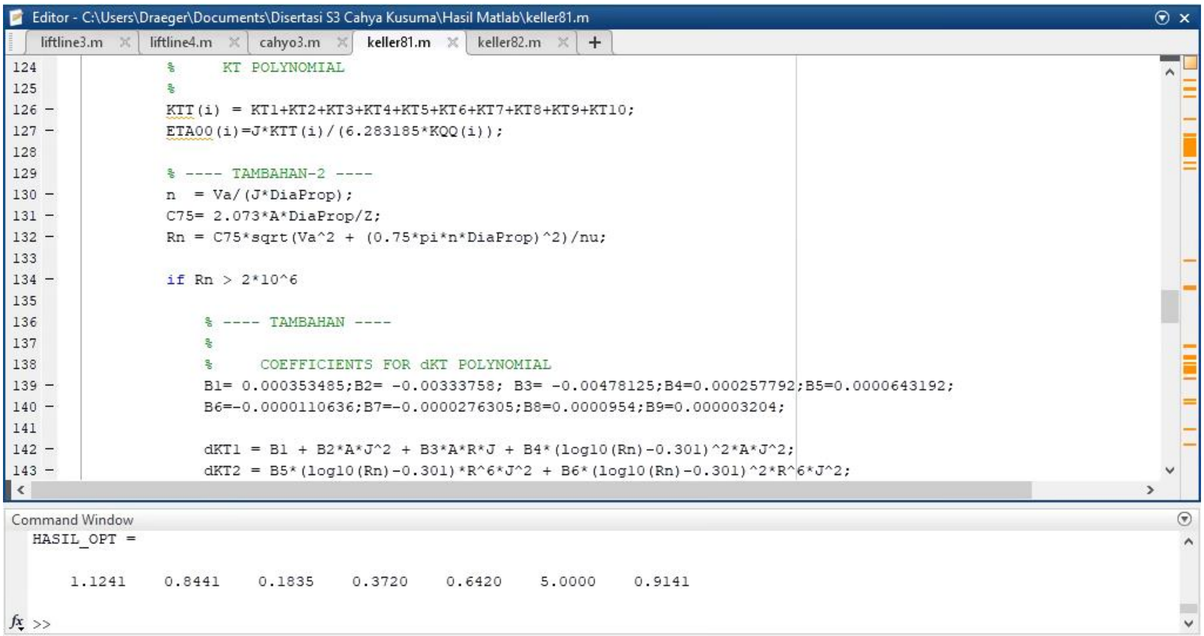


**Figure. 4.** The results of calculation using a Matlab program at a speed of 24.1 knots, 5 blades.

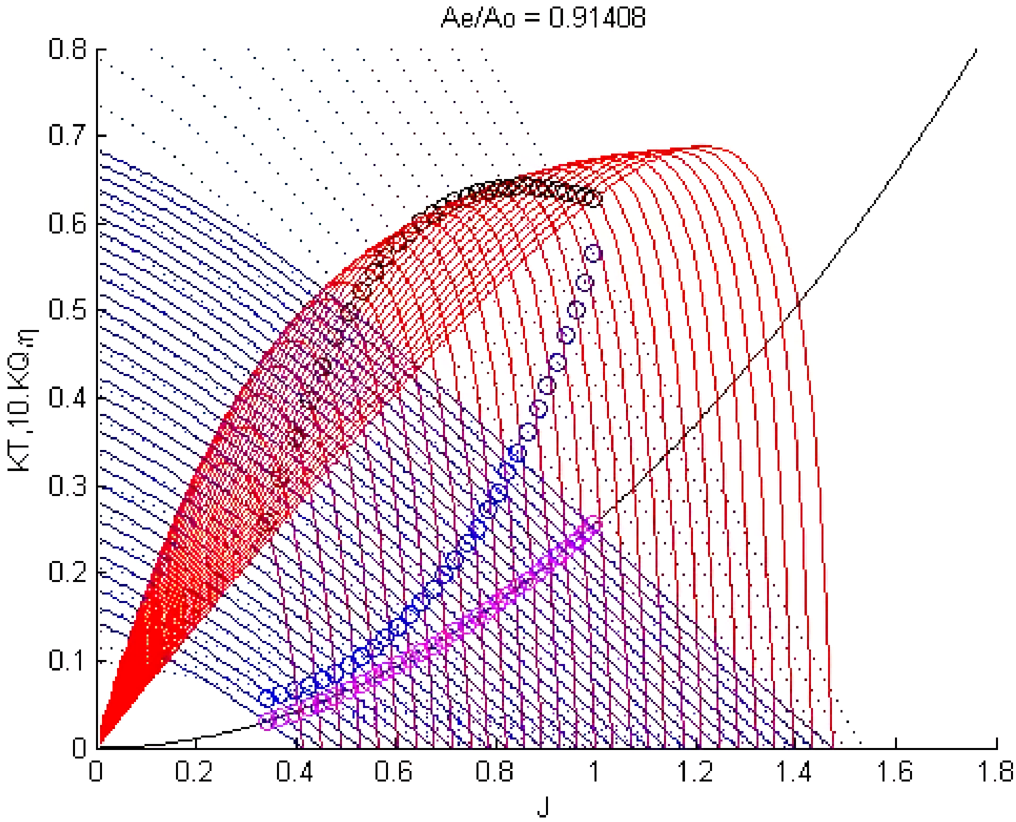


**Figure. 5.** The optimum result of.diagram open water test at 23.5 knots used 5 blades propellers.

MatLab has been used in ship optimization, including Ship Power Plant Simulation [17], the propulsion plant of a large container ship[18] Engine simulation[19], the ship propulsion system[20] and Contra rotating propeller[21]. The output result developed the small computer program as in table 6.

From table 6. The maximum capability of the B series by using the existing engine is a speed of 23.5 knots, at B5-92 P / D 1.1241 with an engine power of 2937 kW with efficiency 64.2%. The optimum of open water test diagram as in Figure 5.

TABLE 6.
OUTPUT RESULT OF THE DEVELOPED SMALL COMPUTER PROGRAM

| VS | VS | RT | N | 10KQ | PB | B series | | | |
|---|---|---|---|---|---|---|---|---|---|
| knot | m/dt | KN | RPS | | kW | ETA-0 | P/D | BAR | Z |
| 23.0 | 11.83 | 252.0 | 8.52 | 0.367 | 2844 | 64.57 | 1.12 | 0.88 | 5 |
| 23.1 | 11.88 | 253.9 | 8.53 | 0.367 | 2859 | 64.53 | 1.12 | 0.88 | 5 |
| 23.2 | 11.94 | 255.8 | 8.54 | 0.368 | 2878 | 64.45 | 1.12 | 0.89 | 5 |
| 23.3 | 11.99 | 257.7 | 8.55 | 0.370 | 2897 | 64.37 | 1.12 | 0.90 | 5 |
| 23.4 | 12.04 | 259.6 | 8.56 | 0.371 | 2917 | 64.28 | 1.12 | 0.90 | 5 |
| 23.5 | 12.09 | 261.5 | 8.57 | 0.372 | 2937 | 64.20 | 1.12 | 0.92 | 5 |
| 23.6 | 12.14 | 263.4 | 8.58 | 0.429 | 3401 | 64.13 | 1.23 | 0.96 | 6 |
| 23.7 | 12.19 | 265.3 | 8.59 | 0.431 | 3422 | 64.04 | 1.23 | 0.96 | 6 |
| 23.8 | 12.24 | 267.2 | 8.60 | 0.432 | 3445 | 63.99 | 1.23 | 0.97 | 6 |
| 23.9 | 12.30 | 269.1 | 8.61 | 0.461 | 3686 | 63.91 | 1.26 | 0.98 | 6 |
| 24.0 | 12.35 | 271.0 | 8.62 | 0.434 | 3486 | 63.88 | 1.23 | 0.99 | 6 |
| 24.1 | 12.40 | 272.7 | 8.65 | 0.435 | 3529 | 63.88 | 1.23 | 0.99 | 6 |
| 24.2 | 12.45 | 274.4 | 8.68 | 0.436 | 3578 | 63.77 | 1.23 | 1.00 | 6 |

*D. MARIN program DESPPC*

MARIN program DESPPC is a preliminary design program created by MARIN for the propeller B series.

Used 60m patrol boat data input, the maximum speed obtained for all types of B series is 23.5 knots are shown in Table 7.

TABLE 7.
OUTPUT RESULT MARIN PROGRAM DESPPC

| Ship Parameter | Value | Unit |
|---|---|---|
| Design Speed | 23.5 | Knot |
| Number of Propeller Blade (Z) | 5 | |
| Diameter of propeller(D) | 1.8 | meter |
| $A_EA_O$ | 0.989 | |
| PDRA | 1.010 | |
| Power Engine | 2927 | KW |
| ETA-O | 64.5 | % |

The results of the DESPPC Program can be as follows:

MARIN program DESPPC Performance Prediction of Displacement Ships Page 1
****************************************************
PATROL BOAT 60M SARAT2.6M

****************************************************

Main particulars
----------------

| | | | |
|---|---|---|---|
| LWL | : | 55.20 | [m] |
| LPP | : | 53.71 | [m] |
| B | : | 7.23 | [m] |
| VOL | : | 467 | [$m^3$] |
| TF | : | 2.60 | [m] |
| TA | : | 2.60 | [m] |
| Trim | : | 0.00 | [m] |

Hull ratios based on LPP
------------------------

| | | | |
|---|---|---|---|
| LWL/B | : | 7.429 | [-] |
| B/T | : | 2.781 | [-] |
| SLDR | : | 6.923 | [-] |
| TRIM | : | 0.00 | [Degr] |
| IE | : | 27.0 | [Degr] |

Hull form coefficients based on LPP

| | | | |
|---|---|---|---|
| CB | : | 0.463 | [-] |
| CM | : | 0.632 | [-] |
| LCB | : | -0.054 | [%LPP] |
| CWP | : | 0.827 | [-] (based on LWL) |
| CP | : | 0.732 | [-] |

-----------------------------------
Bulbous bow and transom stern
-----------------------------------

| | | | |
|---|---|---|---|
| ABULB | : | 0.0 | [$m^2$] |
| HBULB | : | 1.30 | [m] |
| ATRANS | : | 5.1 | [$m^2$] |

Wetted surface hull
-------------------

| | | | |
|---|---|---|---|
| S | : | 460 | [$m^2$] |

Appendages
----------

| | | | |
|---|---|---|---|
| SAPP | : | 2.1 | [$m^2$] |
| 1+K2 | : | 3.00 | [-] |

MARIN program DESPPC Performance Prediction of Displacement Ships Page 2
****************************************************
PATROL BOAT 60M SARAT2.6M
****************************************************

Propeller design conditions
--------------------------

| | | | |
|---|---|---|---|
| Design speed | : | 23.00 | [knots] |
| Propeller diameter | : | 1.800 | [m] |
| Minimum revolutions | : | 500.0 | [1/Min] |
| Maximum revolutions | : | 600.0 | [1/Min] |
| Addition to AEA0 | : | 0.100 | [-] |

Main propeller data

| | | | |
|---|---|---|---|
| Number of props | : | 2 | [-] |
| Number of blades | : | 5 | [-] |
| Clearance prop. tip | : | -0.41 | [m] |
| Propeller roughness | : | 0.000030 | [m] |
| Diameter | : | 1.800 | [m] |
| AEA0 | : | 0.989 | [-] |
| PDRA | : | 1.010 | [-] |

Propeller type: B-series propeller
Miscellaneous
-------------

| | | | |
|---|---|---|---|
| Aftbody hullform (CSTERN) | : | -10.0 | [-] |
| Aperture configuration (CSC) | : | 10.0 | [-] |

Water depth not provided

General data
------------

| | | | |
|---|---|---|---|
| CA-Calculated | : | 0.000627 | [-] |
| Addition to CA | : | 0.000000 | [-] |
| Hull roughness | : | 0.000150 | [m] |
| Addition to wake | : | 0.000 | [-] |
| Bare hull formfactor | : | 11.826 | [-] |
| Specific mass water | : | 1025.0 | [kg/m3] |
| Temperature water | : | 30 | [Degr C] |
| Addition to thrust ded. | : | 0.000 | [-] |

MARIN program DESPPC Performance Prediction of Displacement Ships Page 3
****************************************************
PATROL BOAT 60M 2.6M
****************************************************
Resistance deep water (calm water)
---------------------------------

| VS | R-FRIC | R-WAV | R-BULB | R-TRANS | R-APP | R-ALL | R-TOT |
|---|---|---|---|---|---|---|---|
| [knt] | [kN] | [kN] | [kN] | [kN] | [kN] | [kN] | [kN] |
| 20.0 | 40.2 | 83.5 | 0 | 14.0 | 0.6 | 15.7 | 161.3 |
| 20.5 | 42.1 | 92.4 | 0 | 13.6 | 0.6 | 16.5 | 172.9 |
| 21.0 | 44.0 | 101.4 | 0 | 13.1 | 0.6 | 17.3 | 184.5 |
| 21.5 | 46.0 | 110.3 | 0 | 12.5 | 0.6 | 18.2 | 196.1 |
| 22.0 | 48.0 | 119.2 | 0 | 11.9 | 0.7 | 19.0 | 207.6 |
| 22.5 | 50.1 | 128.2 | 0 | 11.1 | 0.7 | 19.9 | 219.1 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 23.0 | 52.2 | 137.1 | 0 | 10.2 | 0.7 | 20.8 | 230.6 |
| 23.5 | 54.4 | 146.1 | 0 | 9.3 | 0.8 | 21.7 | 242.1 |
| 24.0 | 56.5 | 155.0 | 0 | 8.2 | 0.8 | 22.6 | 253.4 |
| 24.5 | 58.8 | 163.7 | 0 | 7.0 | 0.8 | 23.6 | 264.6 |
| 25.0 | 61.0 | 172.4 | 0 | 5.6 | 0.9 | 24.6 | 275.6 |

MARIN program DESPPC Performance Prediction of Displacement Ships Page 4
****************************************************
PATROL BOAT 60M SARAT2.6M
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Interaction deep water (calm water)
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| VS | R-TOT | THRUST | W | T | ETA-H | ETA-R | ETA-0 | ETA-D |
|---|---|---|---|---|---|---|---|---|
| [knt] | [kN] | [kN] | [-] | [-] | [-] | [-] | [-] | [-] |
| 20.0 | 161.3 | 173.0 | 0.055 | 0.068 | 0.987 | 0.986 | 0.649 | 0.631 |
| 20.5 | 172.9 | 185.5 | 0.055 | 0.068 | 0.986 | 0.986 | 0.648 | 0.630 |
| 21.0 | 184.5 | 197.9 | 0.055 | 0.068 | 0.986 | 0.986 | 0.647 | 0.629 |
| 21.5 | 196.1 | 210.4 | 0.055 | 0.068 | 0.986 | 0.986 | 0.646 | 0.628 |
| 22.0 | 207.6 | 222.8 | 0.055 | 0.068 | 0.986 | 0.986 | 0.646 | 0.628 |
| 22.5 | 219.1 | 235.1 | 0.055 | 0.068 | 0.986 | 0.986 | 0.645 | 0.627 |
| 23.0 | 230.6 | 247.4 | 0.055 | 0.068 | 0.986 | 0.986 | 0.645 | 0.627 |
| 23.5 | 242.1 | 259.7 | 0.055 | 0.068 | 0.986 | 0.986 | 0.645 | 0.627 |
| 24.0 | 253.4 | 271.9 | 0.055 | 0.068 | 0.986 | 0.986 | 0.644 | 0.626 |
| 24.5 | 264.6 | 283.9 | 0.055 | 0.068 | 0.986 | 0.986 | 0.642 | 0.624 |
| 25.0 | 275.6 | 295.7 | 0.055 | 0.068 | 0.986 | 0.986 | 0.638 | 0.620 |

MARIN program DESPPC Performance Prediction of Displacement Ships Page 5
****************************************************
PATROL BOAT SARAT2.6M
****************************************************
Propulsion deep water (calm water)
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| VS | THRUST | ETA-D | CAVP | CAVN | N | PE | PS |
|---|---|---|---|---|---|---|---|
| [knt] | [kN] | [-] | [-] | [-] | [1/Min] | [kW] | [kW] |
| 20.0 | 173.0 | 0.631 | 1.000 | 1.000 | 427.3 | 1659 | 2657 |
| 20.5 | 185.5 | 0.630 | 1.000 | 1.000 | 439.9 | 1823 | 2924 |
| 21.0 | 197.9 | 0.629 | 1.000 | 1.000 | 452.3 | 1993 | 3200 |
| 21.5 | 210.4 | 0.628 | 1.000 | 1.000 | 464.5 | 2169 | 3486 |
| 22.0 | 222.8 | 0.628 | 1.000 | 1.000 | 476.5 | 2350 | 3781 |
| 22.5 | 235.1 | 0.627 | 1.000 | 1.000 | 488.2 | 2536 | 4085 |
| 23.0 | 247.4 | 0.627 | 1.000 | 1.000 | 500.0 | 2729 | 4397 |
| 23.5 | 259.7 | 0.627 | 0.999 | 1.002 | 512.5 | 2927 | 4714 |
| 24.0 | 271.9 | 0.626 | 1.000 | 1.005 | 525.6 | 3129 | 5046 |
| 24.5 | 283.9 | 0.624 | 1.004 | 1.010 | 539.4 | 3335 | 5401 |
| 25.0 | 295.7 | 0.620 | 1.010 | 1.016 | 553.8 | 3545 | 5777 |

Output results of the developed small computer program and DESPPC are shown in Table 8.

TABLE 8.
DEVELOPED PROGRAM MATLAB VS THE DESPPC PROGRAM.

| Item | Developed Program | DESPPC | Unit | Validation (%) |
|---|---|---|---|---|
| Vs | 23.5 | 23.5 | knot | 0.00 |
| Number of Blades | 5 | 5 | | 0.00 |
| ETA-O | 64.2 | 64.5 | % | 0.47 |
| D | 1.8 | 1.8 | m | 0.00 |
| Blade Area Ratio | 0.920 | 0.989 | | 7.50 |
| P/D | 1.12 | 1.01 | | 10.00 |
| n | 514.0 | 512.5 | RPM | 0.29 |
| PE | 2936 | 2927 | kW | 0.31 |

## IV. CONCLUSION

Using a computer program based on MatLab program, the 60m patrol boat is able to reach a speed of 23.5 knots, using the B5-92 P/D 1.1241 engine power of 2936 KW ETA-O 64.2%. Validation was carried out using the DESPPC program, the 60m patrol boat was able to reach a speed of 23.5 using the B5-989 P/D 1.01 Engine power 2927 KW ETA-O 64.5%. Based on the validation data carried out in table 8, the percentage value of validation of ship speed is 0%, Number of Blades is 0%, ETA-O is 0.47%, Propeller diameter is 0%, Blade Area Ratio is 7.5%, Pitch per diameter ratio is 10%, propeller rotation is 0.29% and engine power is 0.31%. All validation parameters are below 10%, so it is concluded that a small computer program based on the Numerical method using MatLab code can be used as an initial design for the B-series propeller. Based on the speed design, it is concluded that the B series is capable of propelling a 60m patrol boat

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## REFERENCES

[1] J. Dang, H. J. J. Van Den Boom, and J. T. Ligtelijn, “The wageningen C- and D-series propellers,” *FAST 2013 - 12th Int. Conf. Fast Sea Transp.*, 2013.

[2] C. Jeng-Horng, S Yu Shan, Basic design of a series propeller with vibration consideration by generic alghoritm, J.Mar.Sci. Technol.12(2007) 119-129.

[3] E. Benini, Multi-objective design optimization of B-screw series propellers using evaluationary algoritm design, J. Mar. Sci. Technol. 40(2003) 229-238.

[4] J.-B.Suen, J.-S Kouj, Genetic algoritm for optimal seies propeller design, in : Proceeding of Third International Conference on Marine Technology, ORDA 99, Poland, 1999.

[5] M.M. Karim, M Ikehata, A genetic algoritm (GA)-based optimization technique for the design of marine propeller, in Proceeding of the Propeller/shafting Symposium, Virginia Beach, USA 2000.

[6] H. Schneekluth, V. Bertram, Ship Design for Efficiency and Economy, Butterworth, Heinemann, 1998.

[7] S.S. Rao, Optimization Theory and application, second edition, Wiley Estern Limited India, 1991.

[8] J. S. Carlton, *Marine Propellers and Propulsion*, *2nd edition*, vol. 163. 2010.

[9] Van Lammeren Wpa, Van Manen JD, and Oosterveld MWC, “Wageningen B-Screw Series,” Soc Nav Archit. Mar Eng Trans, 1969.

[10] P. U. B. Type and E. Price, *Report no. W13011-1-RD wageningen B-Screw Series : Open Water, Bp-1/J and Bp2-1/J Diagram(Small Scale)*, 1978th ed. Nethderland, 1978.

[11] M. W. C. Oosterveld and P. van Oossanen, “Further Computer-Analyzed Dat of the Wageningen B-Screw Series.,” Int. Shipbuild. Prog., vol. 22, no. 251, pp. 251–262, 1975.

[12] M.M. Gaafary, Computerized method for propeller design of optimum diameter and rpm, in: 13th Congress of IMAM, Istanbul, Turkey, October 2009.

[13] *SNAME - Principles of Naval Architecture VOL II .pdf*. 2n.d.revision, pp 183 (1988)

[14] D Stapersma & Hk Woudi– Matching propulsion engine with propulsor, 2014, Journal of Marine Engineering & Technology, https://doi.org/10.1080/20464177.2005.11020189

[15] C Kusuma, IM Ariana, B Ali, Redesign KCR 60m Bow with Axe Bow Type To Reduce Ship Resistance, C Kusuma, IM Ariana, B Ali. IOP Conference Series: Earth and Environmental Science 557 (1), 012033, 2020

[16] C Kusuma, I M Ariana ,W H Nugroho , E B Djatmiko ,A A Masroeri and Sutardi, Design Propeller Of Fast Missile Boat 60 M By Using Gawn Series, IOP Conf. Series: Materials Science and Engineering 1052 (2021) 012026 IOP Publishing doi:10.1088/1757-899X/1052/1/012026, 2021

[17] Kharroubi K, Söğüt OS. Modelling of the propulsion plant of a large container ship by the partition of the cycle of the main diesel engine. Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment.2020;234(2):475-489. doi:10.1177/1475090219876515, 2020

[18] Jun-rui Jia, Research on Ship Power Plant Simulation System Based on LabVIEW and MATLAB Mixed Programming, 2nd International Conference on Automation, Mechanical Control and Computational Engineering, AMCCE 2017

[19] Gerasimos Theotokatos, Marine Engine/ Ship Propulsion System Simulation, Department of Naval Architecture, Ocean & Marine Engineering University of Strathclyde November 2015

[20] Gerasimos Theotokatos and Vasileios Tzelepis, A Computational study on the performance and emissions parameters mapping of a ship propulsion system, Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment, DOI:10.1177/1475090213498715 Corpus ID: 59131960, 2015

[21] Dimitrios Laskos, Design and Cavitation Performance of Contra-Rotating Propellers, thesis document Department of Mechanical Engineering, Massachusetts Institute of Technology, 2010.