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The Selection of Fast Patrol Boat (FPB) Propeller Ship to Optimize Machine Usage of MTU 16V 595 TE 70l Using Harvald Guldhamer Method and Engine Propeller Matching (EPM)

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Abstract

To actualize a large, strong and professional Navy force, the Fast Patrol Boat ship repowering Diesel engine without replacing the ship propeller was done. Harvald Guldhamer Method and Engine Propeller Matching methods were used to obtain optimum results on the propulsion system and determine ship resistance. The analysis refers to machine diagram performance of MTU 16V 595 TE 70L The calculation result was used as an alternative comparison to Wageningen propeller series type B 4-85 at 91.975% propeller load with speed of 25 knot. It was still in a work area propeller engine which was outside of work machine area of 89,650%. Based on the fact that the propeller wageningen series type B 4-70 was still in the propeller engine working area of 94.909% propeller load, it can be concluded that there was a suitability between the power characteristics of the machine with propeller power.

Keywords: Ship Resistance, Power Boats, Propeller, Ship Propulsion, Engine propeller matching.

1. Introduction

Fast Patrol Boat (FPB) is a type of ship that have combat capability, limited great strike power and ideal avoidance speed to hide among the islands [1].

This paper have any literature to support the research about it, for example paper with title An Approximate Method For Calculation of Mean Statistical Value of Ship Service Speed on a Given Shipping Line , Useful in Preliminary Design Stage [2]. Experimental Investigation on Stern-Boat Deployment System and Operability For Korean Coast Guard Ship [3]. Performance of VLCC Ship with Podded Propulsion System and Rudder [4]. Introduction to Naval Architecture [5]. Basic Ship Theory [6]. Practical Ship Design [7]. Ship Resistance and Propulsion : Practical Estimation of Ship Propulsive Power [8]. Practical Ship Hydrodynamics [9]. Effect of Fluid Density on Ship Hull Resistance and Powering [10]. Ship Design and Contruction [11]. Resistance Propulsion and Steering of Ship [12]. Predictive Analysis of Bare-Hull Resistance of a 25,000 Dwt Tanker Vessel [13]. Resistance and Propulsion of Ships [14]. Hydrodynamic of Ship Propellers [15]. Ship Design for Efficiency and Economy [16]. Design of Propulsion Systems for High-Speed Craft [17]. Amethod of Calculation of Ship Resistance on Calm Water Useful at Preliminary Stages of Ship Design [18]. Increase of Ship Fuel Consumption Due to the Added Resistance in Waves [19]. An Inventigation Into The Resistance Components of Converting a Traditional Monohull Fishing Vessel Into Catamaran Form [20]. Simulation of a Free Surface Flow over a Container Vessel Using CFD [21]. Empirical Prediction of Resistance of Fishing Vessels [22]. Designing Constraints in Evaluation of Ship Propulsion Power [23]. Coefficients of Propeller-hull Interaction in Propulsion System of Inland Waterway Vessels with Stern Tunnels [24]. Cost optimization of marine fuels consumption as important factor of control ship's sulfur and nitrogen oxides emissions [25]. Numerical Investigation of the Influence of Water Depth on Ship Resistance [26]. The Wageningen Propeller Series [27]. Principles of Naval Architecture Second Revision [28]. Marine Propulsion [29].

The current condition did not meet the combat capability as expected in terms of weaponry and machinery. There was speed reduction, the original cruising speed was 25 knots, and the actual speed was only 20 knots only. Thus, it was necessary to analyze the vessel by using propeller matching engine process, in which the process of propeller matching engine was expected to have compatibility between power engine characteristics with propeller power [30].

This Paper is organized as follows. Section 2 review about the basic ship theory. Section 3 gives result and 4 discussion of research. Finally, in section 5 present conclusion of this paper.

2. Research Methodology

2.1. Technical Concept

In the selection of propellers according to the characteristics of the ship's propulsion engine, it is expected to have great combat capability and have such conditions:

1. High Accuracy, It allows the tactical and technical information to deliver quickly so that decisions can be obtained accurately and rapidly.
2. High Acquacition, This ensures control over the threat better, it requires the sewaco system and platform to be reliable.
3. High Speed, With the speed and agility of the vessel,

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it allows to conduct amore dynamic and combat capability.

2.2. Propulsion System of The Ship
The ship propulsion system, which is the exact matching between prime mover (diesel engine, gas turbine, steam turbine) and propeller from ship [31]. Matching completion is not only seen from the engine or propeller point of view, but both are an integrated problem. In FIG. 1 there is provided a definition of the variables in terms of power, torque, and velocity

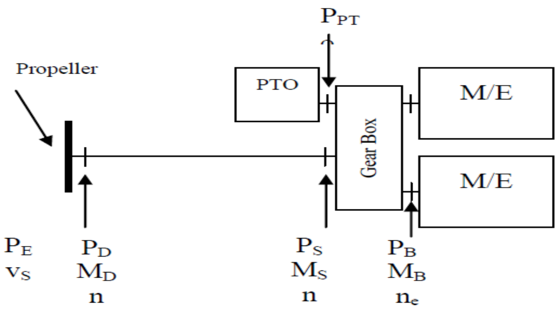

Fig. 1. Variable related with Matching Problems

2.3. Ship Resistance
The ship's resistance (R) at a certain velocity is the fluid force acting opposite the movement of the vessel. The resistance will be the same as the fluid force component working parallel to the axis of the ship's movement.
The required power (effective power) to drive the ship in water or to draw the vessel at speed Vs is:

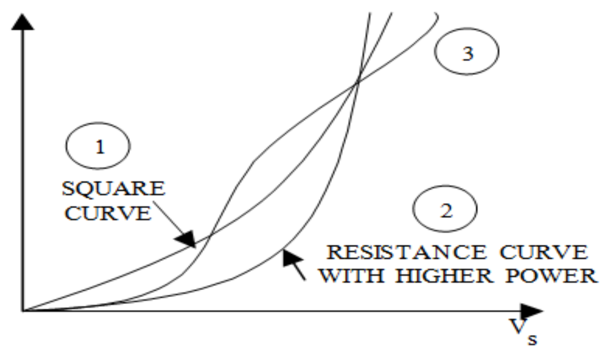

Fig. 2. Resistance-Speed Curve
Notes: (1) Quadratic relationship of Fn = 0,1-0,2, (2) High speed ship, (3) Type, planning craft, swath ship

This is true only for relatively low velocity ships with froude number of (Fn = 0,1-0,2) and depends on the hull shape [32]. For high speed vessels, ship resistance is no longer a quadratic relationship of speed or with the rank of more than two.

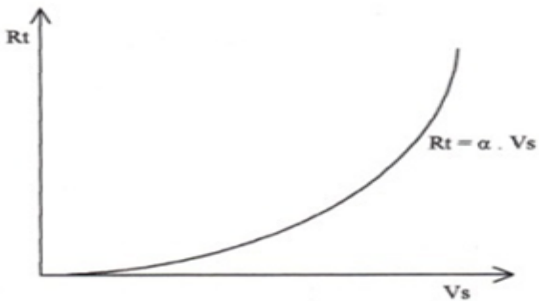

Fig. 3. The Relationship Between Total Resistance and Speed of The Ship

2.4. Displacement
Displacement is the weight of liquid displaced by the hull under the water surface. When the vessel floats in the balance state/motionless then the downward pressure equal to the pressure of the liquid to the hull. Thus the overall weight of the vessel and its contents at that time equal to the weight of liquid displaced by the hull immersed in a liquid in which the vessel is located [8].

Displacement : Lwl x B x T x CB x density of sea water (ton)

2.5. Volume Displacement
The volume of liquid displaced by the hull under the surfacewater where the ship is located [8].

Volume displacement: LWL x B x T x CB

2.6. Selection of The Main Engine
In the selection of the main engine, it is necessary to calculate the need of power engine. There are several indicators that need to be sought in order toobtain the desired results, those are effective horse power (EHP), thrust horse power (THP), delivery horse power (DHP), shaft horse power (SHP) dan brake horse power (BHP) [8]:

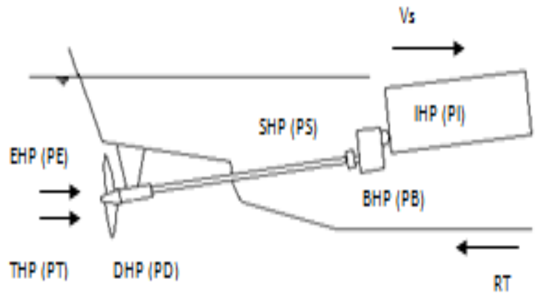

Fig. 4. Ship propulsion system

2.7. Propeller
In propeller selection, there are some characteristics that must be considered and will be the main consideration, namely: propeller type, propeller diameter, pitch ratio and the number of propeller propeller blade.

The propeller type selection with the most optimal level of efficiency, can be found using the Bp-δ diagram.
The steps in propeller selection is as follows:

a. Bp Calculation

$$Bp = \frac{Np \times \sqrt{P_d}}{Va^{5/2}} \quad (1)$$

b. Cut off the Bp with optimum line propeller of efficiency.
c. (P/D)o and δo value interpretation
d. Do value determination

$$Do = \frac{\delta o \times Va}{Np} \quad (2)$$

e. Determination of Db value (behind the hull. For ship using
Single Screw D_B = 0,95 . Do and Double Screw D_B=0,97 . Do

f. δ_B Calculation

$$\delta_B = \frac{D_B \times Np}{Va} \quad (3)$$

g. Cut off the initial Bp with δ_B. This condition was already in behind the hull.
h. $(P/D)_B$ and Efficiency Interpretation

2.8. Engine Propeller Matching
The matching process between the propulsion engine and the propeller is an essential process for obtaining optimal conversion between fuel and thrust under operating conditions which ensures the working safety of the propulsion and propeller motors. Matching process is not only done from the side of the motor only or from the side of the propeller, but must be handled as a whole. The matching process is basically based on power characteristics vs rpm or torque vs rpm of diesel engines and propellers. Similarly, the torque generated by the driving force multiplied by the ratio of the reduction gear, and it shall be proportional to the propeller torque of the same rotation. Since the characteristics are shown in graphical form, in the application matching is finding intersection (data domain point, torque and rpm are the same) of the curve. Then the parameters of the motor and propeller are adjusted so that the desired intersection can be obtained. The propeller matching engine process becomes complex with changes in its service conditions. They are the changes in ship resistance due to fouling of ships, weather and ship-laden changes.

2.9. Method of Research
Fast Patrol Boat (FPB) and MTU 16V 595 TE 70L engine resistance analysis to propeller with supporting theory.
Propeller analysis would be selected against optimum installed engine power. The method used in this research is literature study, field study, maxsurf program calculation, engine propeller matching and numerical calculation [33]

3. Result and Discussion

3.1. Calculation of Ship Resistance
In the calculation of ship resistance, beside using formulas that exist in the resistance ship book with the help of excel program on the computer, maxsurf program was also used for comparison so that the accurate results could be obtained.

3.2. Propeller Selection
The calculation results to find the efficiency of Wageningen serieswas performed using the data presented below:

Table 1. Propeller Wageningen Series Calculation Results

Type Propeller	B4-40	B4-55	B4-70	B4-85	B4-100
1/Jo	2,08	2,11	2,09	2,02	1,94
δ	210,6329114	213,670886	211,6455696	204,557	196,4557
eff	57,503 %	57,109 %	56,100 %	54,803 %	53,215 %
P/D	0,751	0,745	0,770	0,823	0,871
P	1,171 m	1,178 m	1,206 m	1,246 m	1,266 m
D	5,114 ft	5,188 ft	5,139 ft	4,967 ft	4,770 ft
	1,559 m	1,581 m	1,566 m	1,514 m	1,454 m
D_B	5,012 ft	5,084 ft	5,036 ft	4,867 ft	4,675 ft
	1,528 m	1,550 m	1,535 m	1,484 m	1,425 m
D_{max}	1,553 m	1,553 m	1,553 m	1,553 m	1,553 m
δ_B	206,420	209,397	207,413	200,466	192,527
1/Jo	2,038	2,068	2,048	1,980	1,901
$(P/D)_B$	0,764	0,761	0,780	0,850	0,890
eff_B	58,450 %	57,904 %	56,902 %	55,065 %	54,270 %

3.3. Recalculation of Ship Power Needs
This was performed to find out whether the above propeller efficiency was still sufficient to the main engine power. Because in the calculation of power needs before, the assumption ηp = 0.6 was still used. Then, the efficiency obtained of propeller B4-70 was 56.9%. So it can be concluded that the basic assumptions of power requirements for engine selection still meet the available BHPSCR = 10673.026 HP (sufficient).

3.4. Cavitation Calculation
The calculation of cavitation needs to be done in order to ensure a free propeller of cavitation that causes fatal damage to the propeller. Determining the relationship between the ship's resistance and the speed of the vessel will be implemented in the form of the relationship between KT (Thrust coefficient) and J (Advance Coefficient).

Table 2. Relationship Between Kt and J in Trial Condition (Clean Hull)

J	KT *trial*
0,1	0,011379
0,2	0,045516
0,3	0,102412
0,4	0,182066
0,5	0,284478
0,6	0,409648
0,7	0,557576
0,8	0,728263
0,9	0,921708
1	1,137911
1,1	1,376872

The relationship between KT and J above was the relationship obtained in the trial condition (Clean Hull), to get the operation point of the propeller at the service condition then the sea margin price must also be considered. The price of sea margin would affect the size of the ship's resistance, therefore the relationship between KT and J would also change. The amount of sea margin suitable for cruise ships was 15% - 30% for Asia-pacific [14].

Furthermore, based on the data that had been obtained, graph of the relationship between KT and J on the condition of trial (Clean Hull) can be made as presented below:

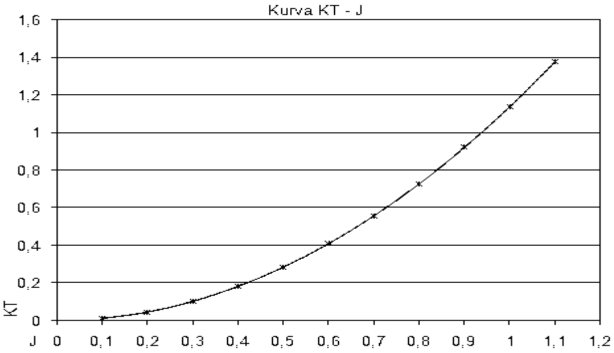

Fig. 5. Relationship between Kt and J on Trial Condition (Clean Hull)

3.5. Propeller Characteristic

In designing the characteristics of propeller type B series 4-70 Wageningen series for fix propeller was used.

Table 3. Graph open Water Propeller B4-70 Interpretation Results

P/D = 0,78			
J	KT	10 KQ	Efisiensi
0,000	0,350	0,430	0,000
0,100	0,320	0,400	0,130
0,200	0,288	0,365	0,252
0,300	0,250	0,328	0,368
0,400	0,210	0,280	0,471
0,500	0,169	0,231	0,568
0,600	0,120	0,182	0,627
0,700	0,070	0,131	0,621
0,800	0,0250	0,078	0,432
0,900	0,000	0,027	0,000
1	0	0	0
1,1	0	0	0

Then, a curve graph between KT - KQ - J - ηo on open water test B4-70 in the table above was made and presented in the figure below:

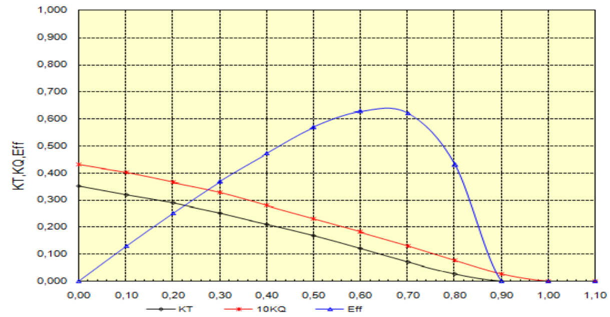

Fig. 6. $K_T - K_Q - J - H_o$ Curve in Open Water Test B4-70

3.6. Engine-Propeller Matching

The graph of resistance KT-J characteristic with open water test curve B4-70 was presented as follows:

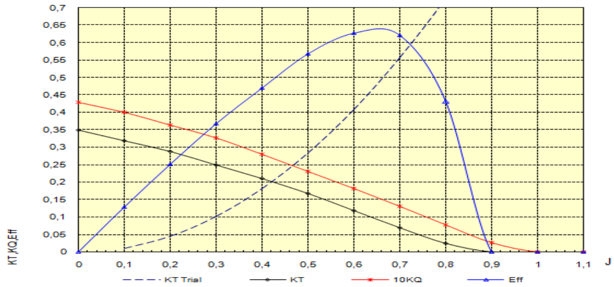

Fig. 7. K_T–J Curve with Curve in Open Water Test B4-70

3.7. The Calculation of Delivered Power in Trial Condition (Clean Hull).

Based on the table delivered power on the above trial conditions, it could be described in the form of diagrams below:

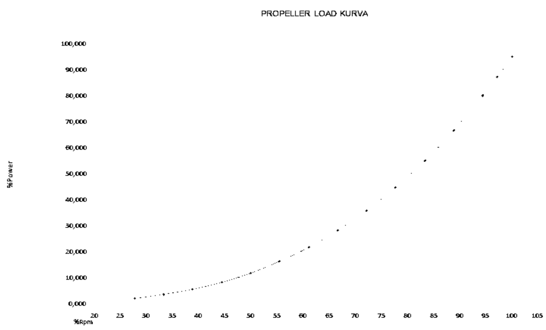

Fig. 8. Propeller B4.70 Load Curve

Table 4. Delivered Power in Trial Condition (Clean Hull)

Rps	Rpm propeller	Rpm M/E	Q trial	Pd trial (HP)	Pb trial (HP)	%Rpm	% Trial Power
3,933	235,96	500	3377,168	104,2582	108,5570208	27,778	2,034
4,719	283,15	600	4863,121	180,1581	187,5865319	33,333	3,515
5,506	330,34	700	6619,248	286,0844	297,8804651	38,889	5,582
6,292	377,54	800	8645,549	427,0414	444,6495572	44,444	8,332
7,079	424,73	900	10942,023	608,0336	633,1045453	50	11,864
7,865	471,92	1000	13508,670	834,0653	868,4561663	55,556	16,274
8,652	519,11	1100	16345,491	1110,1409	1155,915157	61,11	21,660
9,438	566,30	1200	19452,485	1441,2648	1500,692255	66,667	28,121
10,225	613,50	1300	22829,653	1832,4415	1907,998197	72,222	35,754
11,011	660,69	1400	26476,994	2288,6752	2383,04372	77,778	44,655
11,798	707,88	1500	30394,508	2814,9704	2931,039561	83,333	54,924
12,585	755,07	1600	34582,196	3416,3315	3557,196457	88,889	66,658
13,371	802,27	1700	39040,057	4097,7628	4266,725145	94,444	79,953
13,764	825,86	1750	41370,303	4470,0687	4654,382266	97,222	87,218
14,158	849,46	1800	43768,092	4864,2688	5064,836362	100	94,909

4. Discussion

Engine load characteristics obtained from the main engine data MTU 16V 595 TE 70L was described as follows:

Table 5. Engine Load Characteristic Data

Rpm ME	Power (Kw)	Power (Hp)	% Power	% Rpm
500	0	0	0	27,778
500	400	543,8485	10,1910828	27,778
600	566	769,5456	14,42038217	33,333
700	760	1033,312	19,36305732	38,889
800	950	1291,64	24,20382166	44,444
900	1170	1590,757	29,8089172	50
1000	1425	1937,46	36,30573248	55,556
1100	1700	2311,356	43,31210191	61,111
1200	1970	2678,454	50,1910828	66,667
1300	2300	3127,129	58,59872611	72,222
1400	2615	3555,409	66,62420382	77,778
1500	2960	4024,479	75,41401274	83,333
1600	3355	4561,529	85,47770701	88,889
1700	3740	5084,983	95,2866242	94,444
1750	3925	5336,513	100	97,222
1800	3925	5336,513	100	100
1800	0	0	0	100

Then, the data for propeller load characteristics of the MTU machine 16V 595 TE 70L was described as follows:

Table 6. Propeller Load Characteristic Data

Rpm ME	Rpm propeller	Propeller Power (Kw)	Propeller Power (HP)	% Power	% Rpm
500	235,9604	95	129,164	2,420382	27,778
600	283,1524	130	176,7508	3,312102	33,333
700	330,3445	210	285,5204	5,350318	38,889
800	377,5366	315	428,2807	8,025478	44,444
900	424,7286	450	611,8295	11,46497	50
1000	471,9207	625	849,7632	15,92357	55,556
1100	519,1128	760	1033,312	19,36306	61,111
1200	566,3049	1060	1441,198	27,00637	66,667
1300	613,4969	1350	1835,489	34,3949	72,222
1400	660,689	1700	2311,356	43,3121	77,778
1500	707,8811	2090	2841,608	53,24841	83,333
1600	755,0731	2533	3443,92	64,53503	88,889
1700	802,2652	3050	4146,845	77,70701	94,444
1750	825,8613	3300	4486,75	84,07643	97,222
1800	849,4573	3610	4908,232	91,97452	100

Based on the data about the main engine above, we could make the engine envelopecurve to be plotted with propeller load B4-70. This was done to determine whether the selected stapler and propeller had been matched or matched. Here is the curve of the basic machine data above:

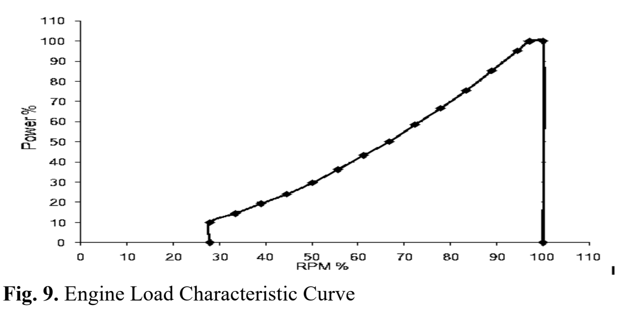

Fig. 9. Engine Load Characteristic Curve

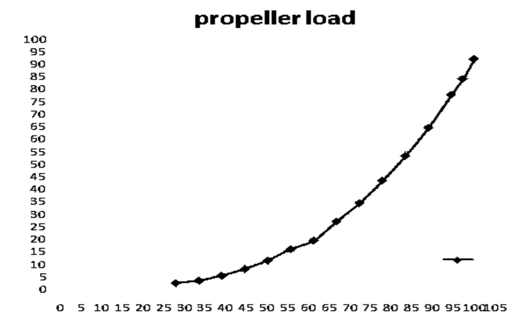

Fig. 10. Propeller Load Characteristic Curve

Furthermore, the engine and propeller load characteristics curve abovewass plotted with the result of propeller load calculation from the selected propeller that was propeller type B4.70. The plot was described as follows:

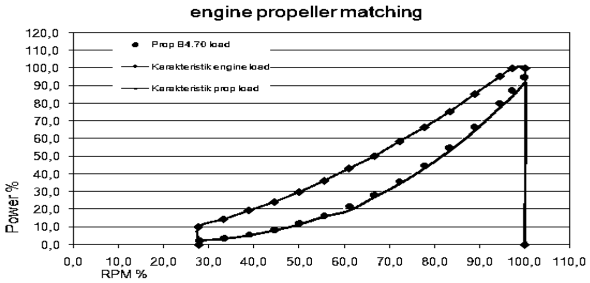

Fig. 11. Engine-Propeller Curve

The results of the engine-propeller matching curve readings could be expressed as follows:

Table 7. Interpretation Results of Engine Curve - Propeller Matching

Analysis	% Rpm	Power (Hp)	% of power
Engine Load	100 %	5336,513	100 %
Propeller Load	100 %	4908,232	91,975 %
Propeller B4.70 Load	100 %	5064,836	94,909 %

5. Conclusion

Based on the calculation results data above, the Propeller load of 5064.836 Hp and the power percentage of 94.909% were obtained. When compared to the propeller load characteristics of the MTU 16V 595 TE 70L 4908.232 machine with the power percentage of 91.975%, then wageningen series type B4.70propeller meets the propeller work area. The power margin above 90% in a clean hull condition indicated that it is very capable to keep the ship service conditions as expected at a maximum speed of 25 knots.

6. Acknowledgements

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Nomenclature

R	Ship Resistance
Vs	Speed of The Ship
P_E	R.Vs
P_D	Delivered Power
η_P	$\eta_H.\eta_O.\eta_R$
T	Thrust Force Propeller
P_S	Shaft Power
V_A	Speed of Advance
Q	Torque Propeller [N.m] in Open Water Condition
P_B	Brake Power
n	RPM Propeller per Second [s-1]
η_T	Total Efficiency
η_H	Hull Efficiency = (1-t) / (1-w)
t	Thrust Deduction Factor
i	Gear Ratio : i = n/ne
w	Wake Fraction
η_D	Propeller Efficiency in a Mounted State in The Back of The Ship
η_O	Open Water Propeller Efficiency
η_R	Relative Rotative Efficiency
η_S	Axis Efficiency
η_M	Mechanical Efficiency
η_{gear}	Gear Efficiency
P_{PTO}	Power Take Off
$\boldsymbol{\omega}$	Angular Speed of Propeller Axis [s-1] $=2\pi.n$
n_e	Rotational Speed of Engine (Prime Mover), [s-1]