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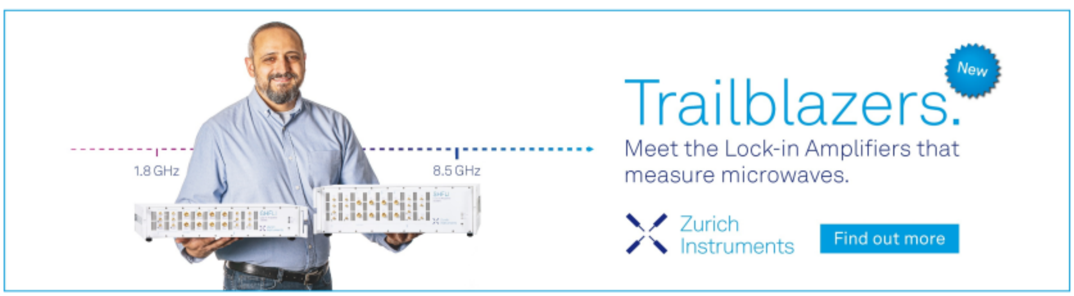

Suitability of Propulsion System of KL. Barombong After Length Increase

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Abstract. KL Barombong is a training vessel for BP2IP Barombong seafarers cadets. The vessel length has been increased by around 8 meters and was equipped with 2 x 445 kW main engines and 2 propulsion systems (twin screws) which have not been changed. Planning and selecting the capacity of the main engine must meet the vessel resistance dan speed criteria. Therefore, the recalculation of the required power was based on the post-modification condition. From the present study, it can be proved theoretically that the planning of propulsion systems in the ship can be applied in real-time and according to the desired requirements. The used matching calculation was the Holtrop method. From the results of these calculations, it can be seen that the ship was capable of moving at a speed of 11.5 knots with the power of the main engine in its possession, and to reach the operating speed, the engine power required was 961.45 kW.

INTRODUCTION

Determining the ship's engine power is one of the crucial early steps in designing a ship. This process considers several factors such as ship resistance, ship speed, ship dimension, and shape, etc. Therefore, the change in one or more of these factors will theoretically change several factors as well such hydrodynamic characteristics and loading capacity aspects [1]. The most imprortant change is the required engine power [2]. However, when the required power is obtained from the calculation, the power of the chosen engine is usually increased by 15% of tolerance for safety, fouling, and other technical factors. Therefore, in case of dimension increase, the installed engine might be still able to be used to obtain the ship service speed [3].

Training ship or in Bahasa, it is called "Kapal Latih (KL)" Barombong, as shown in Fig. 1, is a ship that is operated mainly for marine training and practice ("praktek laut" abbreviated as prala), especially for the Maritime Science Education and Training Center (BP2IP) Barombong sailor cadets. The ship is also sometimes are operated for social activities in various regions in the country. Recently, KL Barombong has been redesigned by increasing the length of the hull from 35m to 43m, and building and renovating the deck and space of the ship, so that it can accommodate more marine practice cadets (prala). Certainly, with the addition of the length of the hull, the engine load on the ship will increase as well, thus affecting the speed of the ship. However, considering the cost and other technical difficulties, after adding the hull length, the main engine power (main engine) on the ship remains the same as the previous engine power. The ship engine was replaced with a new one but the same engine power as the old one.

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FIGURE 1. Training Vessel (KL) Barombong

Considering that this modification requires good planning regarding changes in the main size of the ship, namely in the form of design modification drawings and calculation ship speed data that will be generated after experiencing an additional hull length, the present study investigated the effect of this length increase to engine load and ship speed. By increasing the length of the ship, it is necessary to see the speed of the ship due to this increase. Moreover, to calculate the speed, it is necessary to compute the ship resistance. The present study employed Holtrop's method in computing the ship resistance.

LITERATURE REVIEW

Ship Resistance

The resistance of the ship at a speed is the fluid force acting on the ship in such a way as to oppose the vessel's movement. The resistance is the same as the component of the fluid force working parallel to the axis of motion of the ship. The resistance of the ship is influenced by several variables such as speed, length of the ship, the wet surface area of the ship, acceleration due to gravity, and density of water. The total resistance can be broken down into a number of different components as a result of several interacting factors [4].

Basically, ship resistance is divided into 2 (two) major parts, namely resistance above the free surface and resistance below the free surface. The resistance that is under the surface is that works on the part of the ship that is visible above the free surface. Here, the influence of the presence of air causes resistance. According to the International Towing Tank Conference (ITTC) 1957 the components working on the ship were briefly described, areR_F (Friction Resistance), R_R (Residual Resistance), R_V (Viskos Resistance), RP (Pressure Resistance), R_W (Wavemaking Resistance), R_{WP} (Wave Pattern Resistance), R_{WB} (Wave Breaking Resistance), and R_S (Spray Resistance) [5].

The environment also affects ship resistance, if the ship moves on limited water, the water barrier will be close enough to be able to affect ship resistance. Sometimes water also affects resistance, which is called the shallow water effect. In addition, on free shipping lines, ship resistance will experience changes.

Ship Resistance Calculation using Holtrop's Method

To calculate the ship resistance using Holtrops's method, several variables that need to be calculated are [6]:

a. Total resistance

In some ship calculation methods, there are several reviews based on the unit of agreement and not based on an experimental attempt or field data collection, such as estimating the value of the puffed bow resistance which only observes the puffed bow separately. On this basis, J. Holtrop and G.G.J. Mennen made a method by relying on the accuracy of calculations in data collection and statistical processing, which is why this method is also known as the Statistical Effective Power Prediction Method, abbreviated as the Statistical Ship Resistance Method.

To calculate the total ship resistance in the Holtrop method, it is defined by the following formula:

$$RT = RF\ (1+k1) + RAP + Rw + RB + RTR + RM \quad \text{(kN)} \tag{1}$$

where

RT	= total resistance (kN)	
RF	= friction resistance (kN)	
RAP	= additional parts resistance (kN)	
Rw	= wave resistance (kN)	
RB	= bulbous resistance (kN)	
RTR	= transom resistance (kN)	
RM	= resistance of model (kN).	

b. Lift and drag force

When the ship is moving, several forces work parallel to the ship's movement, namely the ship resistance (R) and the ship thrust (T). The thrust of the ship is generated by the propeller of the ship due to the pressure of water on the propulsion device. This propulsion device is known as ship propulsion, and one of the most commonly used propellers is a propeller. A propeller is ship propulsion that uses motor (mechanical) power, where the power generated by the motor is distributed through the shaft to the propeller. The amount of power provided by the motor drive from the motor can be defined as follows:

IHP is the power produced by each engine cylinder
BHP is the engine power measured at the crankshaft.
SHP is engine power that is transferred by the motor to the propeller shaft
DHP is the power on the ship's propeller after experiencing a reduction due to torque moments,
THP is the power generated by the rotation of the propeller on its axis due to lift, where
EHP is the power needed to move the ship.

Wake

Froude's number of wake (w) is the difference between the speed of the ship and the velocity of flow to the propeller, with the approximate formula given by Taylor as follows:

w= 0.5 Cb – 0.05 for single screw

w= 0.55 Cb – 0.20 for twin-screw

Thrust Deduction Fraction

The thrust required to propel the ship at speed (V) will be greater than the resistance (Rt) that the ship would experience if it was towed at the same speed as that speed. This loss of thrust (T-Rt) is expressed in the fraction of the thrust T and is called the thrust deduction fraction (t) [7].

$$T=Rt/((1-t)) \quad or \quad Rt = (1 - t)T \tag{2}$$

According to the results of the experiments conducted by Schoenher, the relationship between t and w can be formulated for a ship that uses two propellers as follows:

If use bossing, $t = 0.025\ w + 0.014$ (3)
If use shaft bracket, $t = 0.7\ w + 0.06$ (4)

Blade Efficiency

a. Hull efficiency(ηh)

The hull efficiency is the ratio between the power provided by the propeller (THP) and the effective power of the ship, and in relation to the wake and trust deduction factors [8].

$$(nh) = \frac{(1-t)}{(1-w)} \tag{5}$$

b. Relative rotation efficiency (ηrr)

Propeller which is open in water (open water) with the same flow rate at an advanced speed, will have open water efficiency as follows

$$(nrr) = \frac{T.Va}{2\pi.N.Q_0} \tag{6}$$

where Q_o is the torque measured in open water conditions when the propeller produces a thrust T and at a certain rotation N.

c. Propulsion efficiency

Propulsion efficiency can be formulated as follows :

$$nD = \frac{EHP}{DHP} \tag{7}$$

RESEARCH METHODOLOGY

Research Object

This research was conducted on a ship named KL. Barombong.

Research Data

- The main dimension of the training vessel (KL) Barombong can be seen in Table 1.

TABLE 1. The main dimension of training vessel (KL) Barombong

Dimension	Before (m)	After (m)
LOA	36.6	45.1
LBP	34	42.5
B	8	8
H	5.2	5.2
T	2.4	2.4
v	12 knots	12 knots

- Propeller data are shown in Table 2.

TABLE 2. The propeller of the training vessel (KL)Barombong

Parameters	Fixed Pitch Propeller
Number of blades	4 blade
Shaft length	5050 mm
Shaft diameters	127 mm
Propeller diameters	1333 mm
Pitch	1.007 m
Ae/Ao	0.85
P/D	0.75

- The main engine specifications of Training Vessel(KL) Barombong are as follows:
  - Brand : Mitsubishi
  - Type : S6A3-MPTK
  - Engine Speed : 1900 rpm
  - BHP : 455 Kw / 605 Hp
  - GearBox : 1 : 48
  - Fuel Type : Diesel oil

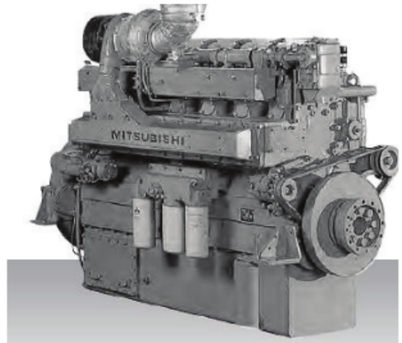

FIGURE 2. The engine of the training vessel (KL)Barombong

RESULTS AND DISCUSSION

Ship Resistance Calculation

Calculation main input data

- Block Coefficient (Cb) = 0.72
- Midship Coefficient (Cm) = 0.95
- Waterline Coefficient (Cwl) = 0.86
- Prismatic Coefficien (Cp) = 0.76
- Δ (Displacement) = 696.72 ton
- ∇ (Volume) = 674.67 m^3
- LCB = -0.42 % LBP
- A_s = 66.48 $m^2 h_B$
- AT = 0
- S_{wind} = 76.67 m^2
- C_{stern} = 10of each engine condition
- Reynold number (Rn) = 2486534
- Froude number (Fn) = 0.29

➢ *Friction resistance (R_F)*

$$R_F = (1 + k_1) \times C_F \times 0.5 \times \rho \times S \times v^2 \quad (8)$$

- Determine LR
  $L_R = L\,(1 + Cp + \frac{0.06 \times Cp \times \%LCB}{4Cp-1}) = 77.2826$
- Determinevalue of coefficient 12 (C_{12})
  $C_{12} = (T/L)^{0.2228446} = 0.522462$
- Determine value of coefficient 13 (C_{13})
  $C_{13} = 1 + 0.003 \times C_{stern} = 1.03$
- Determine value of hull factor ($1 + k_1$)
  $1 + k_1 = C_{13}\,(0.93 + C_{12}\,(B/L_R)^{0.92497}\,(0.95\text{-}Cp)^{-0.521448}\,(1 - Cp + 0.025 \times \%\,LCB)^{0.6906} = 1.01776$
- Area of hull under the water (S)
  - According to E.R Mumford /Sv. Harvald
    $S_1 = 1.025 \times LWL\,(Cb \times B + 1.7\,T) = 445.801\ m^2$
  - According J.A Normand
    $S_2 = LWL\,(1.5\,T + (0.09 + Cb)B) = 445.536\ m^2$

– According D.W Taylor

$S_3 = LWL\ (1.7\ T + 0.7\ B) = 427.856\ m^2$

– According Dr. Yamagata

$S_4 = LWL \times B\ (1.22\ T/B + 0.46)\ (Cb + 0.765) = 453.74\ m^2$

$S_{mean} = (S_1 + S_2 + S_3 + S_4)\ /\ 4$

$= (445.801 + 445.536 + 427.856 + 453.74)\ /\ 4 = 443.23\ m^2$

$S_{APP} = 15\ \% \times S_{mean}$

$= 15\ \% \times 443.23\ m^2 = 66.48\ m^2$

$S = S_{mean} + S_{APP}$

$= 443.23\ m^2 + 66.48\ m^2 = 509.714\ m^2$

- Coefficient of Friction (C_F)

  $C_F = \frac{0.075}{(\log Rn - 2)^2} = 0.002387$

So the total friction resistance is:

$R_F = 1.019852 \times 0.002387 \times 0.5 \times 1.025\ kg/m^3 \times 509.714\ m^2 \times (6.173\ m/s)^2$

$= 23.537\ kN$

➢ *Additional resistance (R_{APP})*

Additional resistance is computed by the following formula:

$$R_{APP} = (1 + k_2) \times C_F \times 0{,}5 \times \rho \times A_s \times v^2 \quad (9)$$

where the additional parts $(1 + k_2)$ is determined by the following formula:

$$(1 + k_2) = \sum E_2 / \sum E_1 \quad (10)$$

TABLE 3. Determine value $1 + k_2$

Parts	Exist=1, No=0	Factor	Product
Rudder behind stern	1	1.3	1.3
Rudder behind skeg	1	1.5	1.5
Twin screw balance rudders	1	2.8	2.8
Shaft bracket	1	3	3
Skeg	1	1.5	1.5
Strut bossing	1	3	3
Hull bossing	1	2	2
Shaft	1	2	2
Stabilizer fins	0	2.8	0
Dome	0	2.7	0
Bilge keels	1	1.4	1.4
$\sum E_1$	9	$\sum E_2$	18.5

so:

$(1 + k_2) = 18.5/\ 9 = 2.0555$

and then:

$R_{APP} = 2.0555 \times 0.002358 \times 0.5 \times 1.025\ kg/m^3 \times 66.48\ m^2 \times (6.173 m/s)^2 = 6.310\ kN$

➢ *Wave resistance (R_w)*

Wave resistance is computed using the following formula:

$$R_W = C_1 \times C_2 \times C_5 \times \nabla \times \rho \times \exp\ \{m_1 \times F_n^d \times m_2 \times \cos\ (\lambda \times F_n^{-2})\}/1000 \quad (11)$$

where

- *Coefficient C_1*

  $C_1 = 2223105 \times C_7^3 \times (T/B)^{1.07961} \times (90 - I_E)^{-1.37565} = 2.251$

where

Angle of Entrance $(i_E) = 9.8^o$

$C_7 = B/L = 0.1809$

- *Coefficient C_2*

  $C_2 = \exp(-1.89\sqrt{C_3}) = 1$

where

$$C_3 = \frac{0.56 \times A_{BT}^{1.5}}{BT\,(0.31\sqrt{A_{BT}} + T_F - h_B)} = 0$$

- *Coefficient C_5*

  $C_5 = 1 - (0.8 \times A_T) / (B \times T \times C_m) = 1$

- *Coefficient m_1*

  $$m_1 = \frac{0.0140407 \times L}{T} - \frac{1.75254 \times \nabla^{1/3}}{L} + \frac{4.7932 \times B}{L} - C_{16}$$
  $$= -0.128$$

where

$$C_{16} = 8.07981\,C_p - 13.8673\,C_p^2 + 6.984388\,C_p^3 = 0.856727$$

- *Coefficient m_2*

  $m_2 = C_{15} \times C_p^2 \exp(-0.1 \times F_n^{-2}) = 0.312$

where

$$C_{15} = \frac{LWL^3}{\nabla} = \frac{(44.2)^3}{597.69} = 1.69385$$

- *Value of λ*

  $\lambda = (1.446 \times C_p^2) - (0.03\,L/B) = 0.930$

Therefore, thewave resistance (R_W) is:

$= 18.41\ kN$

➢ *Transom resistance(R_{TR})*

Resistance of transom (R_{TR}) can be calculated using a formula:

$$R_{TR} = 0.5 \times \rho \times A_T \times v^2 \times C_6 \qquad (12)$$

where

- *Coefficient C_6*

  $C_6 = 0.2\,(1 - 0.2\,F_{nT}) = 0.109$

where

$$F_{nT} = \frac{v}{\sqrt{2 \times g \times A_T / (B + B \times C_{WP})}} = 2.405$$

So the transom resistance is:

$R_{TR} = 10.641\ kN$

➢ *Air resistance (R_A)*

Air resistance (R_A) can be calculated using the following formula:

$$R_A = 0.5 \times \rho \times S_{wind} \times v^2 \times C_A \qquad (13)$$

where

- *Coefficient C_4*

  $C_4 = 0.04$ when $\frac{T_F}{LWL} > 0.04$

- *Coefficient of air resistance (C_A)*

The value of coefficient air resistance is divided into two parts which are :

$$C_{A1} = 0.006\,(L + 100)^{-0.16} - 0.00205 + 0.003\sqrt{\frac{LWL}{7.5 \times C_b}} \times C_2 \times (0.04 - 0.04) = 0.000658425$$

$C_{A2} = (0.105 \times K_s^{1/3} - 0.005579) / L^{1/3}$ (where $K_s = 150\ \mu m = 150 \times 10^{-6}$)

$= -1.20236E\text{-}08$

$C_A \, total = C_{A1} + C_{A2}$
$= 0.000658413$

So the total air resistance is

$= 1.630 \, kN$

➢ *Total resistance (R_{TOT})*

The total resistance can be calculated using a formula :

$$R_{TOT} = (R_F + R_{App} + R_W + R_{TR} + R_A)/1000 \; (KN)$$
$$= 23.537 + 6.310 + 18.41 + 10.641 + 1.630 = 60.95 \; KN$$

Using the same procedure above, both resistance before the addition of length and after the addition was calculated for various ship speeds as shown in Table 4. From the table, it can be seen that at the speed of 12 knots before the addition of length the obtained resistance of 50.68 Kn and after experiencing the addition of length is 60.95Kn. Which means there was an increase of 16.85%.

TABLE 4. Resistance result by Holtrop's method

V		Modification		Addition	
		Rt (kN)Before	Rt(kN)After		
knot	m/s			kN	%
10	5.144	38.13	45.32	7.19	15.86
11	5.658	44.25	52.90	8.65	16.35
12	6.173	50.68	60.95	10.27	16.85
13	6.687	57.38	69.41	12.03	17.33
14	7.202	64.25	78.22	13.97	17.86

Calculation of Wake (w), Thrust Deduction Fraction (t), Advanced Speed (Va), and Thrust (Th)

Using the formulas described in Section 2, the Wake (*w*), Thrust Deduction Fraction (*t*), Advanced Speed (*Va*), and Thrust (*Th*) were also calculated. The calculation results are shown in Table 5.

TABLE 5. Calculation results of the wake, thrust deduction fraction, advanced speed, and thrust

V	BEFORE				AFTER			
	W	t	V_a	T_h	W	t	V_a	T_h
m/s	-	-	m/s	kN			m/s	kN
5.144	0.174	0.182	4.25	51.85	0.196	0.197	4.14	56.44
5.658	0.174	0.182	4.67	59.59	0.196	0.197	4.55	65.88
6.173	0.174	0.182	5.10	71.35	0.196	0.197	4.96	75.91
6.687	0.174	0.182	5.52	76.02	0.196	0.197	5.38	86.45
7.202	0.174	0.182	5.95	84.58	0.196	0.197	5.79	97.43

Propeller Loading Characteristics

For cargo ships with and behind the engine, the selection of propellers used in the propulsion system is oriented towards the type of Wageningen B-series with the diameter and number of blades that already exist. In this case, using a propeller with specifications shown in Table 2.

Correlation of Resistance and Propeller of Ship

The correlation equation between ship and propeller resistance can be modeled based on the propeller loading characteristics using open water. Resistance per displacement is a function of velocity. The ship resistance characteristics can be presented as an order 2 polynomial equation with equations

$$R_T = \alpha_1 V^2 + \alpha_2 V + c \tag{14}$$

Next is the equation of propeller thrust as follows:

$$T = \frac{\alpha_1 \left(\frac{V_a}{(1-w)} \right)^2 + \alpha_2 \left(\frac{V_a}{(1-w)} \right) + c}{(1-t)} \tag{15}$$

The other equation of propeller thrust can be formulated as are following:

$$T = \rho K_T D_P^2 n^4 \tag{16}$$

where

$$K_T = K^* . J^2 \tag{17}$$

$$K^* = \frac{\left\{ \alpha_1 + \alpha_2 (1-w) / V_a + c(1-w)^2 / V_a^2 \right\}}{(1-w)^2 (1-t) \rho D^2} \tag{18}$$

$$J^2 = \frac{V_a^2}{n^2 D^2} \tag{19}$$

By entering parameters wake *(w)*, thrust *(t)*, and advance ratio *(Va)*, the propeller loading characteristic is presented in Table 6, where thrust coefficient is the function of advance ratio *(*J)

TABLE 6. Correlation between K_T dan J

J	J^2	K_T SEATRIAL		K_T SEAMARGINE	
		Before	After	Before	After
0	0	0.000	0	0.000	0.00
0.1	0.01	0.007	0.01	0.008	0.01
0.2	0.04	0.028	0.03	0.032	0.04
0.3	0.09	0.063	0.08	0.073	0.09
0.4	0.16	0.113	0.14	0.129	0.16
0.5	0.25	0.176	0.21	0.202	0.24
0.6	0.36	0.253	0.30	0.291	0.35
0.7	0.49	0.345	0.41	0.396	0.48
0.8	0.64	0.450	0.54	0.518	0.62
0.9	0.81	0.570	0.69	0.655	0.79
1	1	0.703	0.85	0.809	0.97

Then the KT-J data are plotted onto the open water propeller curve to obtain the propeller operating point. In this step, an open water test chart is required for the selected propeller. After that, look for the respective values of the KT and 10KQ as shown in Fig. 3.

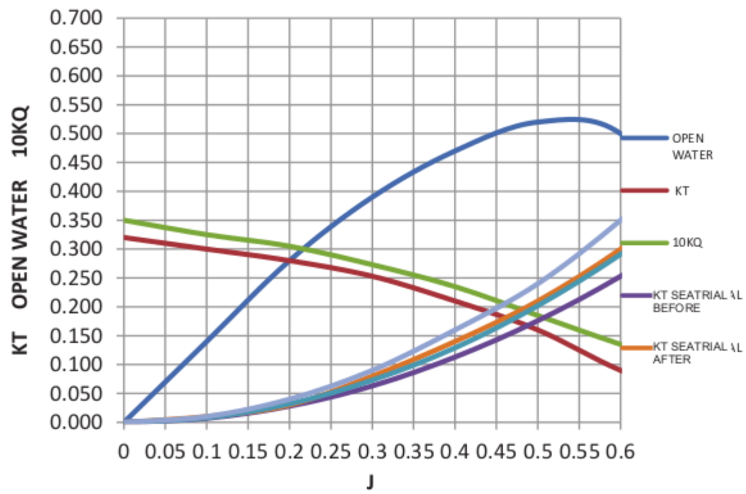

FIGURE 3. Open water test

Based on the reading of the chart above, the results are obtained.

TABLE 7. Parameter of KT, 10KQ, J and *ηo*

ITEM	SEA TRIAL		SEA MARGINE	
	Before	**After**	**Before**	**After**
J	0.485	0.463	0.470	0.445
KT	0.170	0.850	0.180	0.193
10KQ	0.850	0.197	0.190	0.210
Ho	0.52	0.51	0.50	0.49

By knowing the new propeller efficiency value, it can be corrected again for the power requirement of the main engine [9].

- Hull Efficiency (ηH)

$\eta H = (1 - t) / (1 - w) = 1.0637$

- Relative Rotative Efficiency (ηrr)

  $\eta rr = 1$

- Propeller Open Water Efficiency (ηo)

  $\eta o = 0.49$

- Effeciency Delivered (ȠD)

  $\eta_D = \eta H \times \eta o \times \eta rr = 0.489$

- Shaft Efficiency (ηs)

  $\eta s = 0.98$

- Propeller Behind Hull Efficiency (ηb)

  $\eta b = \eta o \times \eta rr = 0.49$

- Coefficient of Propulsion (ηp)

  $\eta p = \eta H \times \eta rr \times \eta o \times \eta s = 0.48$

- Calculate Speed of Advance (Va)

  Va = 4.65m/s

- Thrustof blade (Thrust)
  T = R/(1-t)= 75.91KN

- Calculate Thrust Horse Power (THP)[5]
  THP = T x Va= 376.776KW= 505.265HP

- Calculated Delivered Horse Power (DHP)
  DHP = EHP/ηD= 768.930KW= 1031.15HP

- Calculated Shaft Horse Power (SHP)
  SHP = DHP/ηs= 792.71KW= 1063.044HP

- Calculated Power Main Engine (BHP)
  BHPscr = SHP/0.98= 817.22KW= 1073.67HP
  BHPmcr= BHPscr/0.85= 961.45KW= 1263.14HP

TABLE 8. Engine power

ITEM		DHP (KW)	SHP (KW)	BHP (KW)
SEA TRIAL	Before	631.64	651.17	817.24
	After	738.77	761.63	923.74
SEA MARGINE	Before	650.78	670.91	842.00
	After	768.93	792.712	961.45

After obtaining a new driving motor power, the relationship between speed and BHP is:

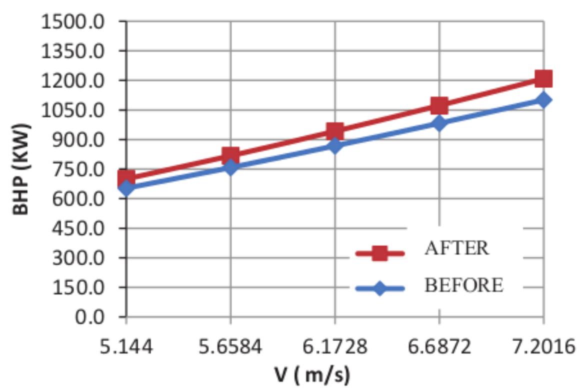

FIGURE 4. Correlation of speed to BHP

From the graph of the relationship between speed and BHP, it shows that to reach a speed of 12 knots the amount of main engine power needed is 961.45 Kw, while the installed engine power is 2x445 Kw or (890 kW). The graph shows that the maximum speed that can be achieved is 11.5 knots.

CONCLUSIONS

Based on the results of the discussion through the calculation of the resistance and propulsion of the ship for two conditions, namely before and after the addition of the length of the motorboat with the type and power of the main motor that was installed, it can be concluded that the ship before the length increase produces a ship resistance of 50.68 kN at a speed of 12 knots, and after experiencing an increase in the length of the ship resistance to 60.95 kN with a speed of 11.5 knots. Moreover, to achieve a service speed of 12 knots with the same propeller, the engine power (BHP) required is 961.45 kW.

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