Study of the Effect of Displacement Changes of the Polbeng 2 Vessel on Ship Performance Using the Wyman Method

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Abstract

The development of the Polbeng 2 vessel research is a study of the Polbeng 2 ship, which was designed in 2022 and completed in construction in 2023. The Polbeng 2 vessel has been operating for approximately two years. During its operation, in 2025, the ship experienced severe damage to its main engine, which led to the recommendation of replacing it with a new one. The original engine, with a power output of 71 HP, was replaced with an engine of 15.78 HP, considering that the vessel is only intended for research purposes, performance testing, and educational activities. The smaller engine was selected because it was the only one available in the Department of Naval Architecture. The change in the ship's engine naturally caused variations in the vessel's displacement, draft, and performance at the same operating speed. The author conducted the ship performance calculations using the Wyman Method in the Maxsurf Student Version program to analyze the effect of displacement changes from 2.692 tons to 2.625 tons. The results indicate that this change had an impact on the vessel's draft and performance, showing a 2.2% decrease in engine power.

Keywords : Main Engine, Power Engine, Ship Performance, Wyman Method

1. INTRODUCTION

The "Polbeng 2" vessel, developed by the Department of Naval Architecture at the Bengkalis State Polytechnic in 2023, has played an important role as both a practical training facility and a means of maritime transportation for the academic community. As a multifunctional vessel, Polbeng 2 was designed to simulate real operational conditions, allowing students to apply hydrodynamic and propulsion system theories through hands-on practice. However, after two years of operation, the maintenance team discovered a decline in engine performance—characterized by frequent sudden shutdowns and inconsistent thrust power—as well as severe engine damage, which necessitated a complete engine replacement since repairing it would be equivalent to installing a new one.

This decline in engine performance not only disrupts learning efficiency—since practical sessions cannot be conducted as scheduled—but also poses safety risks during vessel operation [1]. Meanwhile, deformation and wear on the stern have worsened the flow characteristics in the wake region, resulting in an increased wave resistance coefficient and a reduction in the ship's maximum speed [2]. These conditions indicate the necessity for comprehensive technical intervention: engine rehabilitation to restore power output and propulsion system reliability, as well as flow optimization to minimize hydrodynamic drag [3].

The replacement of the main engine on the Polbeng 2 vessel affects the ship's displacement, as the new engine has a lower power output compared to the original one. There is a specific reason for using a smaller engine: since the Polbeng 2 vessel is primarily intended for educational and research purposes within the Department of Naval Architecture, the replacement engine utilized is the one available in the department's inventory. Although the engine power is lower, it allows the vessel to remain operational for training and experimental use, even though a reduction in ship speed and changes in the wetted surface area are expected to occur.

Based on the issues experienced by the Polbeng 2 vessel, the author suggests conducting a study on the changes in ship displacement resulting from the engine replacement by using the Maxsurf Student Version, specifically applying the Wyman Resistance Method to calculate the ship's resistance. Through this study, it is expected to determine the percentage of engine power change at the same ship speed and to enhance students' understanding that ship performance analysis can be examined from various problems arising from specific vessel conditions.

2. REVIEW OF LITERATURE

This research is supported by a literature review that discusses theories, findings, and practices related to ship hydrodynamics, total ship resistance, engine rehabilitation, and stern redesign methodology. The literature review is divided into several subsections, as follows:

Resistance is the force that opposes the forward motion of a ship, and as a result of this resistance, a thrust force is required to propel the vessel. When sailing, a ship experiences several types of resistance due to interactions between the hull and the surrounding sea environment (Harvald, 1983). These resistances include wave-making resistance, air resistance, and frictional resistance. In addition to these, there are also other forms of resistance encountered during navigation, commonly referred to as added resistance, one of which is roughness resistance. Roughness resistance occurs as a result of surface roughness, such as that caused by corrosion and fouling on the ship's hull.

The calculation of the total ship resistance is carried out to determine the engine power required for the vessel. This ensures that the ship can operate at the desired speed as specified by the owner (owner's requirement). In this study, the ship's resistance is determined using the Wyman Method, which employs an empirical calculation approach, and the analysis is conducted using the Maxsurf Student Version – Resistance software. The selection of this method is based on the fact that the vessel's characteristics meet the criteria required for applying the Wyman Method in resistance estimation. The use of the Maxsurf Resistance software is relatively straightforward: the ship's design file is opened in the Maxsurf Student Version – Resistance program, the desired calculation method is selected, and the software then processes the resistance and speed estimation for the designed vessel.

The following is the empirical formula of the Wyman Method:

The Wyman Method is one of the ship resistance calculation methods available in the Maxsurf Student Version – Resistance (Hullspeed) software. This method was developed based on Wyman's empirical formula, which originated from experimental tests conducted on displacement hull vessels such as merchant ships, warships, passenger ships, and fishing vessels. The main objective of this method is to estimate the total resistance of a ship at various speeds, particularly for vessels operating at low to moderate speeds (displacement mode).

A. Basic Principles of the Wyman Method

The Wyman Method is based on dividing the total ship resistance into several main components, as described below:

1. Frictional Resistance (Rf)
   Frictional resistance can be determined or influenced by several factors, including:
   a. It is caused by the friction between water and the surface of the ship's hull.
   b. It is calculated using the ITTC (International Towing Tank Conference) 1957 formula.

2. Wave-Making Resistance (Rw)
   Wave-making resistance is the resistance acting on the ship due to the impact of water waves interacting directly with the hull when the vessel moves at a certain speed. This resistance occurs as a result of:
   a. The formation of surface waves generated by the ship's movement.
   b. The influence of the hull form and the vessel's speed.
3. Viscous Pressure Resistance (Rv)
   Viscous pressure resistance is caused by the viscosity of water, which produces additional pressure around the hull due to non-uniform flow behavior along the ship's surface.
4. Air Resistance (Ra)
   Air resistance is the type of resistance acting on the ship due to the presence of superstructures located above the water surface, which are directly exposed to the airflow as the vessel moves at a certain speed. This resistance generally occurs as a result of:
   a. The aerodynamic drag acting on the ship's upper structures.
   b. It typically accounts for about 2–5% of the total resistance.
   c. Based on the analysis of various ship resistance components, the total resistance of a vessel can be expressed as:

$$R_T = R_f + R_w + R_v + R_a \qquad (1)$$

Where:
R_T= Total Resistance
R_f= Frictional Resistance
R_w= Wave-Making Resistance
R_v= Viscous Pressure Resistance
R_a= Air Resistance

B. Propulsion Power Requirement Calculation

The calculation of the main propulsion power requirement is carried out to ensure that the ship can operate according to the design specifications. The process is as follows:

Effective Horse Power (EHP)

Effective Horse Power (EHP) is the amount of power required to propel a ship against its total resistance at the service speed. The value of EHP can be calculated using the formula derived from Lewis (1988) as follows:

$$EHP = \frac{R_T \times V}{75} \qquad (2)$$

Where:
EHP= Effective Horse Power (HP)
R_T= Total Resistance (kgf)
V= Ship Speed (m/s)
75 = Conversion factor from kg·m/s to horsepower

Delivered Horse Power (DHP)

Delivered Horse Power (DHP) is the power transmitted to the propeller at the service speed, after accounting for the losses in power transmission from the shaft to the propeller. The value of DHP can be calculated using the formula derived from Lewis (1988) as follows:

$$DHP = \frac{EHP}{\eta_D}$$

$$\eta_D = \eta_H \times \eta_R \times \eta_O \qquad (3)$$

Where:

EHP= Effective Horse Power (kW / HP)

η_D= Propeller Efficiency

η_H= Hull Efficiency

η_R= Relative-Rotative Efficiency

η_O= Open-Water Efficiency

Brake Horse Power (BHP)

Brake Horse Power (BHP) is the total power produced by the main engine before mechanical losses occur in the transmission system. It can be expressed as:

$$BHP = DHP + (X\% \times DHP) \qquad (4)$$

Where:

X= Correction factor (includes the effect of engine room location and operational area adjustments).

C. Regression Method

Regression is a set of statistical techniques used to model the relationship between a continuous dependent variable (target) and one or more independent variables (predictors). The main objectives are prediction and/or understanding the influence of predictor variables on the target variable.

Types of regression (briefly summarized) include the following:

1) Simple Linear Regression — 1 predictor, model: $y = \beta_0 + \beta_1 x + \varepsilon$. (5)
2) Multiple Linear Regression — multiple predictors: $y = \beta_0 + \beta_1 x_1 + \ldots + \beta_p x_p + \varepsilon$. (6)
3) Polynomial Regression — handles nonlinear relationships by including power terms (e.g., x^2, x^3). (7)
4) Ridge Regression / L2 Regularization — reduces overfitting and multicollinearity by adding $\lambda \sum \beta_j^2$.
5) Lasso / L1 Regularization — performs both regularization and variable selection by adding $\lambda \sum \mid \beta_j \mid$. (8)
6) Elastic Net — a combination of L1 and L2 regularization. (9)
7) Logistic Regression — for binary categorical targets (despite the name “regression,” it outputs probabilities).
8) Nonlinear Regression — uses nonlinear parametric models (e.g., exponential models) and requires iterative fitting methods.
9) Tree-Based / Ensemble Regression (Random Forest, Gradient Boosting) — nonparametric models effective for complex or nonlinear relationships.

Basic assumptions (for classical linear regression):

a) Linearity: The relationship between predictors and the target is linear (or can be made linear via transformation).
b) Independence: Residuals/errors are independent of each other.
c) Homoscedasticity: The variance of residuals is constant across all levels of predictors.

d) Normality of Residuals: Residuals are normally distributed (important for inference and p-values).
e) No severe multicollinearity: Predictors are not highly correlated with one another.

If these assumptions are violated, use transformations, weighted least squares, regularization methods, or nonlinear/nonparametric models.

C. Metode Regresi

Regresi adalah rangkaian teknik statistik untuk memodelkan hubungan antara variabel dependen (target) kontinu dan satu atau beberapa variabel independen (prediktor). Tujuannya: prediksi dan/atau pemahaman pengaruh variabel-variabel prediktor terhadap target dan jenis-jenis regresi (ringkas) antara lain :

1) Regresi linear sederhana — 1 prediktor, model: $y = \beta_0 + \beta_1 x + \varepsilon$. (5)
2) Regresi linear berganda — banyak prediktor: $y = \beta_0 + \beta_1 x_1 + \ldots + \beta_p x_p + \varepsilon$. (6)
3) Regresi polinomial — menangani hubungan nonlinear dengan memasukkan pangkat (e.g. x^2, x^3). (7)
4) Regresi ridge / L2 — regularisasi untuk mengurangi overfitting dan multikolinearitas (menambahkan $\lambda \sum \beta_j^2$).
5) Lasso / L1 — regularisasi yang bisa melakukan seleksi variabel (menambahkan $\lambda \sum \mid \beta_j \mid$). (8)
6) Elastic Net — gabungan L1 + L2. (9)
7) Regresi logistik — target kategorikal biner (meskipun namanya "regresi", output probabilitas).
8) Regresi nonlinier — model parametrik nonlinear (mis. model eksponensial) dan metode fittingnya bukan closed-form.
9) Regresi pohon / ensemble (Random Forest, Gradient Boosting) — nonparametrik, kuat untuk hubungan kompleks/tidak linier.

D. Asumsi dasar (untuk regresi linear klasik)

1) Linearity: hubungan antara prediktor dan target bersifat linier (atau bisa dibuat linier dengan transformasi).
2) Independence: residual/error independen.
3) Homoskedastisitas: varians residual konstan di seluruh rentang prediktor.
4) Normalitas residual: residual berdistribusi normal (penting untuk inferensi/p-value).
5) Non-multikolinearitas yang parah: prediktor tidak sangat berkorelasi satu sama lain.

Jika asumsi dilanggar, gunakan transformasi, weighted least squares, regularisasi, atau model nonlinier/nonparametrik.

3. METHOD

This study employs a quantitative and experimental approach, with the research stages to be carried out as follows:

3.1. Problem Analysis

The problem analysis involves identifying and observing issues found in the *Polbeng 2* vessel, which has been in operation for approximately two years. During this period, the ship has encountered several problems, the most significant being severe engine damage that necessitates replacing the main engine, resulting in the vessel being temporarily out of operation.

3.2. Data Collection

Data collection involves gathering information related to the replacement of the ship's engine and measuring the weight of both the old and new engines to determine changes in the *Polbeng 2* vessel's draft. Additionally, this stage includes comparing the maximum speed performance of the new engine with that of the old one.

3.3. Research Design

This study adopts an integrated pretest–posttest design, combining the existing ship design to analyze the impact of the engine replacement. The aim is to observe the vessel's performance characteristics and implement these changes into the ship's design model to examine variations in draft and determine the decrease in the *Polbeng 2* vessel's displacement. Consequently, the engine replacement is expected to affect the vessel's performance and result in a reduction in speed.

3.4. Research Location

The research will be conducted at the facilities and laboratories of Politeknik Negeri Bengkalis, as well as directly on the *Polbeng 2* vessel operating in the waters surrounding the campus. This setup allows for system testing under both real operating conditions and controlled laboratory simulations. Additionally, the mini shipyard workshop will serve as the location for repair and maintenance activities on the *Polbeng 2* vessel.

3.5. Model Simulation

The simulation of the existing ship design model considers the impact of replacing the engine with one of lower power, which naturally leads to changes in the ship's displacement, draft, and a reduction in speed. The performance simulation of the *Polbeng 2* vessel is divided into two main parts as follows:

a. Using the regression method to determine changes in the ship's draft.

b. Using the Wyman method within the *Maxsurf Student Version* program to analyze the vessel's performance by examining the ship's speed and calculating the percentage difference in engine power between the *Polbeng 2* before and after the engine replacement.

3.6. Research Results

The results of this study will examine the impact of the *Polbeng 2* engine replacement on the vessel's performance, specifically focusing on the decrease in ship speed and changes in draft. The research method outlines the workflow or stages of the study, which can be illustrated in **Figure 1**.

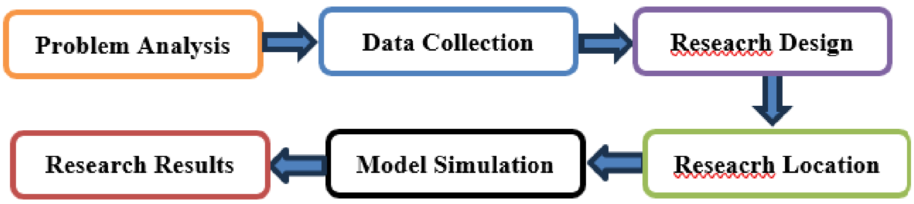


Figure 1. Research Flowchart

4 RESULT & DISCUSSION

4.1. Kondisi Kapal Polbeng 2

The current condition of the *Polbeng 2* vessel shows severe damage to its main engine after approximately two years of operation. The damage occurred because the engine used was a reused unit from the original engine, with a power capacity of 72 PS (equivalent to 71 HP) and a weight of 250 kg. With this power output, the vessel was initially capable of reaching a speed of around ±15 knots [4]. The use of this engine was considered efficient since the Department of Naval Architecture already possessed two engines that could be utilized for the vessel, even though they were land engines. The available engines were the first and second units, each with a power output of 16 PS or 15.78 HP. Because the first engine suffered severe damage, it will be replaced with the second engine, which has a power output of 15.78 HP. This replacement will inevitably affect the vessel's condition, engine power, and overall performance. Therefore, this study focuses on analyzing changes in the ship's draft resulting from the engine replacement on *Polbeng 2*.

The discussion regarding changes in the ship's draft requires determining the displacement of the vessel when using the first engine, followed by identifying the corresponding draft. Then, when the engine is replaced with the second engine (16 PS), the new draft must be calculated. This analysis is approached through a simple calculation method based on the ship's displacement, which can be determined as follows:

a. Main ship dimensions data
b. Engine weight data
c. Initial ship displacement

Ship data can be seen in Table 1 and Figure 2.

Table 1. Main dimensions data of the Polbeng 2 vessel

No.	Dimension	Value
1.	Length Overall (LOA)	9,50 Meters
2.	Depth	1,00 Meters
3.	Breadth (Beam)	1,663 Meters
4.	Draft	0,405 Meters
5.	Block Coefisien (Cb)	0,302
6.	Ship Speed	15 Knots

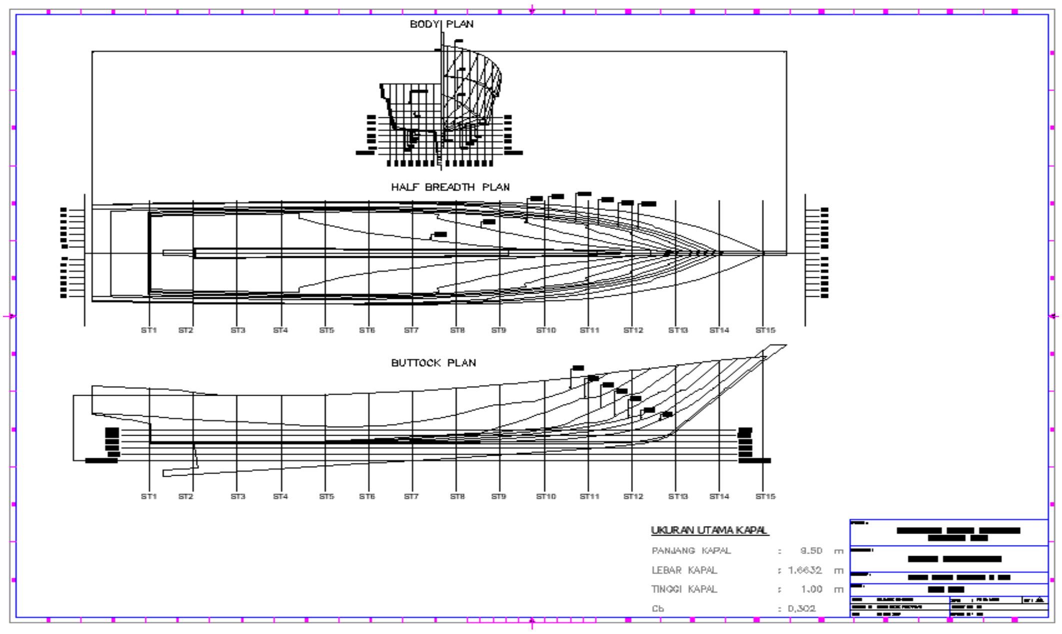


Figure 2. Lines Plan of the *Polbeng 2* Vessel

The ship's displacement value can be obtained from the Calculate Hydrostatics data in the *Maxsurf Student Version* program, as shown in Table 2. Based on Table 2, the vessel's displacement is 2.692 tons. Following the replacement of the main engine—from 71 HP to 15.78 HP—it is necessary to conduct an analysis of the draft change using the linear regression method, since the main engines have different weights. The original engine weighed 250 kg, while the replacement engine weighs 185 kg. This difference results in a change in the ship's displacement to 2.627 tons, as shown in Table 3. Likewise, the vessel's draft also changes, as presented in Table 4 and illustrated in Figure 3.

Table 2. Hydrostatic Data of the *Polbeng 2* Vessel

No	Measurement	Value	Units
1	Displacement	2,692	Ton
2	Volume (displacement)	2,626	m^3
3	Draft Amidships	0,405	m
4	Immersed depth	0,986	m
5	WL Length	8,340	m
6	Beam Max exten	1,695	m
7	Watted Area	18,699	m^2
8	Max. Sect. area	0,520	m^2
9	Waterpl. Area	11,158	m^2
10	Prismatic Coeff	0,605	

Table 3. Hydrostatic Values After Draft Modification

No	Measurement	Value	Units
1	Displacement	2,625	Ton
2	Volume (displacement)	2,561	m^3
3	Draft Amidships	0,399	m
4	Immersed depth	0,980	m
5	WL Length	8,296	m
6	Beam Max exten	1,692	m
7	Watted Area	18,539	m^2
8	Max. Sect. area	0,510	m^2
9	Waterpl. Area	11,065	m^2
10	Prismatic Coeff	0,605	

Tabel 4. Penentuan sarat kapal akibat perubahan mesin kapal

No.	Draft	Displacement
1	0.1	0.3705
2	0.15	0.5232
3	0.2	0.7909
4	0.25	1.1510
5	0.3	1.5930
6	0.35	2.0920
7	0.4	2.6380
8	0.45	3.2270
9	0.5	3.8580

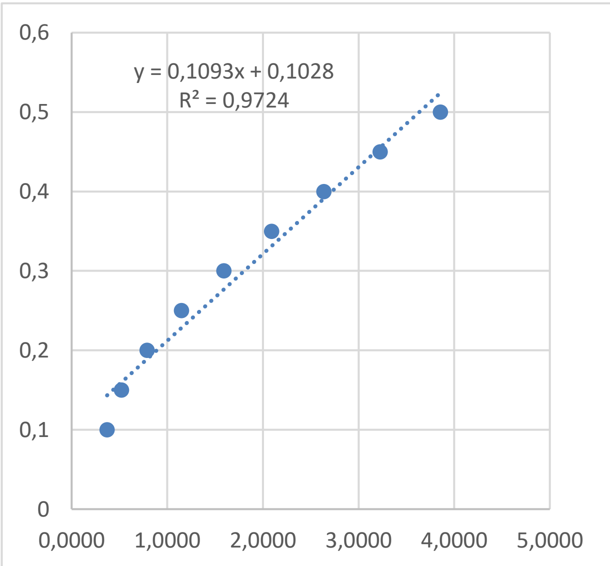


Figure 3. Draft Regression Values of the *Polbeng 2* Vessel

Based on Table 4 and Figure 3, the change in draft due to the engine replacement can be calculated using a numerical approximation formula, as follows:

$$\text{Draft} = 0.1093 \times \text{Displacement Change} + 0.1028$$
$$= (0.1093 \times 2.627 \text{ tons}) + 0.1028$$
$$= 0.3899 \text{ meters}$$

Thus, the vessel's new draft after the engine replacement is 0.3899 meters. The change in the vessel's draft results in modifications to the hydrostatics calculated for the ship model on the computer, so the ship data can be presented as in Table 3, and there is also a change in the ship's resistance due to the different wetted surface area. Therefore, to analyze the effect of the Polbeng 2 draft change resulting from the displacement variation, the resistance must be evaluated at the same speed to determine the difference in required engine power. This analysis is presented in Table 5 and Figure 4 for the draft of 0.405 meters.

Table 5. Comparison of Engine Power and Speed at a Draft of 0.405 Meters

NO	Ship Speed (Knot)	Power Engine (Hp)
1	1	0.044
2	2	0.349
3	3	1.179
4	4	2.795
5	5	5.459
6	6	9.434
7	7	14.98

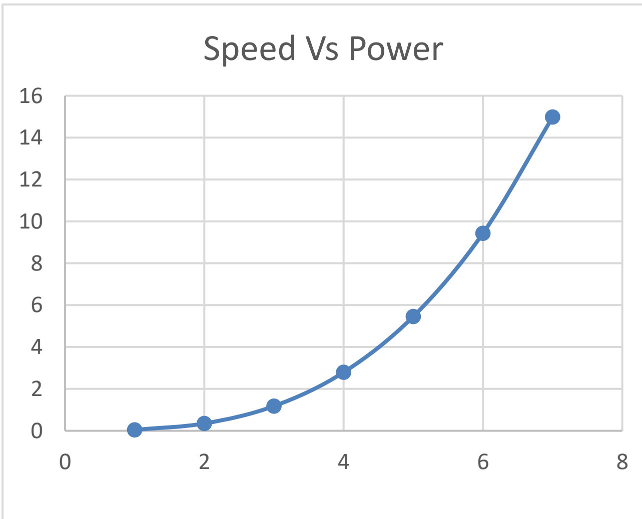
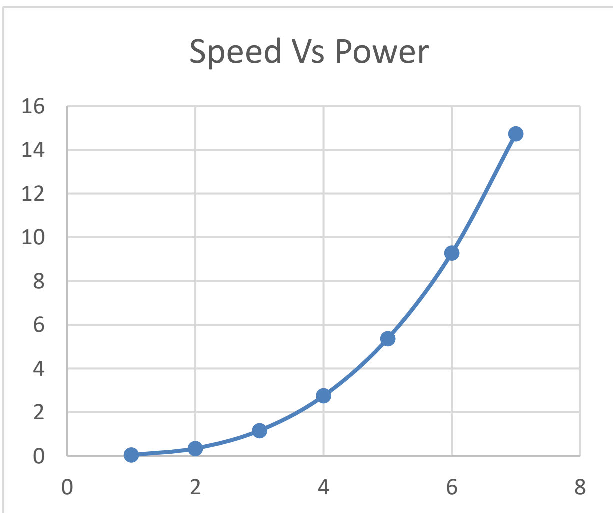


Figure 4. Speed Vs Power Engine

Sedangkan untuk nilai kecepatan dan power engine terhadap perubahan sarat kapal Polbeng 2 menjadi 0,3989 meter dapat dapat di lihat pada Tabel 6 dan Gambar 5.

Tabel 5.6 Nilai perbandingan Power Engine dengan kecepatan pada sarat 0,3989 meter

NO	Kecepatan Kapal Knot	Power Engine (Hp)
1	1	0.043
2	2	0.344
3	3	1.16
4	4	2.749
5	5	5.369
6	6	9.277
7	7	14.731



Gambar 5. Speed Vs Power Engine

The analysis resulting from the ship's engine replacement indicates a change in the vessel's draft and a decrease in both resistance and engine power by 2.2%.

5 CONCLUSION

The research study on the *Polbeng 2* vessel, which experienced engine failure and required an engine replacement, can be concluded as follows:

a. The replacement of the *Polbeng 2* vessel's main engine from 71 HP to 15.7 HP resulted in a change in the ship's displacement from 2.962 tons to 2.625 tons.
b. The *Polbeng 2* vessel also experienced a change in draft, which—based on linear regression analysis—was found to decrease from 0.405 meters to 0.3899 meters.
c. At a vessel speed of 7 knots, the *Polbeng 2* showed a 2.2% difference in engine power output after the engine replacement.

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