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Project on Determining Vehicle Power in Submarine Vehicle Design Using Regression Analysis to Enhance Students Understanding of Simple Pendulum Concepts

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Abstract

This study aims to determine vehicle power in submarine vehicle design using regression analysis and enhance Students understanding of the simple pendulum concept. In this experiment, tests were conducted to analyze the relationship between various variables such as speed, force, and vehicle mass in relation to the power generated. The regression analysis results revealed a significant correlation between the applied force on the vehicle and the speed achieved, which was then used to calculate the required power for submarine vehicle design. Additionally, the study seeks to provide students with a deeper understanding of fundamental physics concepts, particularly the simple pendulum, by applying these concepts in the context of submarine vehicles. This research is expected to contribute to physics education and practical applications in vehicle design through regression-based analysis.

Keywords: Vehicle Power, Submarine Vehicle Design, Regression Analysis, Simple Pendulum, Student Understanding.

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INTRODUCTION

Indonesia is an archipelagic nation, with two-thirds of its territory consisting of ocean, covering an area of approximately 5.9 million km². This includes 3.2 million km² of territorial waters and 2.7 million km² of Exclusive Economic Zone (EEZ) [1]. Given the vast expanse of Indonesian waters, the potential for diverse marine natural resources is immense [2]. However, exploring resources on the ocean floor requires specialized seabed vehicles capable of operating at extreme depths, which are beyond the reach of conventional submarines. The limitation of conventional submarines lies in their restricted diving capabilities due to increasing hydrostatic pressure at greater depths [3], [4]. Therefore, research into designing more efficient seabed vehicles is crucial for Indonesia, as the world's largest maritime nation.

This study focuses on the power requirements for seabed vehicles to move stably at specific depths. This involves the principles of fluid dynamics, where a vehicle moving underwater encounters various drag forces that must be countered with sufficient propulsion force. To accurately calculate power requirements, an analytical method is needed to accommodate the various factors affecting the vehicle's motion [5], [6]. One such method is regression analysis, which predicts the relationship between propulsion force, speed, and drag force. In physics education, particularly on topics such as fluid dynamics and the motion of objects in liquids, many students face difficulties understanding concepts like propulsion force, drag force, and the relationship between an object's mass and its velocity [7]. One fundamental concept that is often challenging to grasp is the relationship between an object's weight and its terminal velocity, as well as how this relationship applies to horizontal motion in a fluid [8]. Additionally, students frequently struggle with understanding the concept of power or the energy required to move an object through a fluid.

Previous studies have explored various approaches to explain these concepts to students. Kawuri et al. [5] investigated the drag force experienced by objects falling into water, finding that heavier test objects achieved higher terminal velocities. This study laid the groundwork for subsequent research examining the relationship between gravitational force and drag force during an object's motion in a fluid. Furthermore, Marshel [9] expanded on this research by examining the propulsion force required for horizontal motion of

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objects in liquids. The study concluded that the power of a vehicle can be calculated as the product of propulsion force and constant velocity.

However, this approach still has limitations in the context of student education. Laboratory experiments often require expensive equipment and materials that are not always accessible in schools. Additionally, students tend to memorize formulas without understanding the underlying concepts of the physical phenomena. Traditional teaching methods frequently fail to engage students in hands-on experiments that allow them to grasp the relationships between the concepts being taught [10]. For instance, in topics such as propulsion force and power of underwater vehicles, many students struggle to connect these concepts with fundamental materials like simple harmonic motion in pendulums. Furthermore, teaching methods that emphasize theory and rote memorization often result in a lack of student engagement and a superficial understanding of the concepts. This research offers a solution through an experiment-based project that integrates the concept of a simple pendulum with regression analysis to determine the power of an underwater vehicle. In this project, students are involved in conducting experiments using hollow steel spheres as test objects in water, representing a miniature model of an underwater vehicle [11]. Students measure various variables, such as object mass, terminal velocity, and propulsion force, then analyze the data using regression methods [12]. Consequently, students not only learn to understand the concepts of simple harmonic motion and fluid dynamics theoretically but also gain hands-on experience in applying these concepts to the design of underwater vehicles.

The purpose of this research is to enhance Students understanding of fundamental physics concepts such as fluid dynamics, propulsion forces, and power through a practical approach using simple pendulum experiments. Furthermore, this study aims to help students bridge the gap between theoretical and practical concepts, enabling them to comprehend real-world applications of physics theories in the context of maritime technology and underwater exploration. Through this research, students are expected to gain a clearer understanding of fundamental physics concepts as applied in marine exploration technology and to develop better data analysis skills through the use of regression analysis. Additionally, this project aims to motivate students to develop a greater interest in learning physics and its real-life applications, particularly in the maritime field.

METHOD

Preparation Stage

The experiment was conducted in various natural water sources with different flow velocities. Prior to the experiment, test objects were prepared, consisting of 9 test objects with three different radii sizes: 3 balls with a radius of 1.55 cm, 3 balls with a radius of 1.9 cm, and 3 balls with a radius of 2.15 cm (**Figure 1**). Additionally, the necessary equipment for conducting the experiment was prepared, including a protractor, digital scale, stopwatch, measuring cylinder, caliper, thread, and writing tools.

Figure 1. Nine Hollow Steel Test Objects Consisting of 3 Small Balls, 3 Medium Balls, and 3 Large Balls

Experiment Implementation Stage

The experimental procedure began by attaching or tying the test objects with thread. Next, a glass drainage channel was filled with a sufficient amount of water to allow the experiment to proceed. The tied test object was then immersed in the water within the drainage channel, starting with the test object with the smallest radius. The water flow velocity was adjusted until the test object reached a state of equilibrium. Once the test object achieved equilibrium, measurements were taken of the angle Ø between the suspension string and the vertical line. The next step involved calculating the weight of the test object in water (W) to determine the effect of buoyancy. This procedure was repeated for each subsequent test object, following the same steps of immersing the object, measuring the angle, and calculating the weight in water. The experiment was also repeated at four different water flow velocities for each test object to obtain more comprehensive data regarding the impact of flow velocity variations on the measurement results.

Data Processing and Analysis Stage

To measure the effectiveness of the physics experiment project in enhancing Students understanding, an evaluation was conducted through several stages. First, a pre-test was administered to assess Students initial understanding of basic physics concepts, particularly those related to fluid dynamics, driving force, and power of vehicles in water. The test consisted of 10 multiple-choice questions and 2 essay questions, designed to assess both fundamental theoretical concepts and their application in the experimental context. During the experiment, observations were made to assess student engagement. These observations aimed to record how students participated in the experiment, collected data, and engaged in group discussions [13]. The observation results served as qualitative data to evaluate Students understanding based on their active involvement in the experimental activities. After the experiment was completed, a post-test was administered with questions similar to the pre-test to evaluate the improvement in Students understanding [14]. The comparison between the pre-test and post-test results was analyzed to identify score changes, indicating the level of understanding gained after participating in the experiment project.

The next stage is data processing and analysis, which includes two main aspects: the analysis of experimental results and the evaluation of Students understanding. In the analysis of experimental results, the driving force acting on the test object is calculated using Stokes' equation, based on the equilibrium condition achieved during the experiment. The angle Ø is measured directly, and the result is compared with the theoretical calculation using Stokes' equation for validation. Additionally, the power of the underwater vehicle is calculated based on the measured angle Ø and the variation in water flow speed. For the analysis of Students understanding, the results of the pre-test and post-test are analyzed using descriptive statistics and paired t-tests.

RESULT AND DISCUSSION

Fabrication of Test Objects

The test objects are hollow steel spheres, made from two half-sphere steel plates with a plate thickness of 1 mm, which are welded together to form a complete sphere. The hollow steel sphere is filled with small steel balls to achieve the desired mass and density. The density of the test object is slightly higher than the density of water to make the object buoyant in water, as the water flow speed in this experiment is much smaller compared to the speed of the object moving in the water [15]. The water flow velocity, whether in a hydraulic laboratory or in nature, necessitates the determination of the appropriate density for the test object. If the test object is too small, it will rise to the surface due to the water flow; if it is too heavy, the water flow will not be able to push the object or the angle Ø will be too small. In this study, nine test objects were created, consisting of three different radius sizes: three spheres with a radius of 1.55 cm, three spheres with a radius of 1.9 cm, and three spheres with a radius of 2.15 cm. The mass and density values of these spheres are listed in **Table 1**.

Table 1. Test Object Sizes Used

Object Number	Radius (cm)	Mass (g)	Density (kg/m³)
Object 1	1.55	19.50	1,250.80
Object 2	1.55	33.68	2,160.36
Object 3	1.55	49.00	3,143.04
Object 4	1.9	33.82	1,177.17
Object 5	1.9	49.00	1,705.53

Object Number	Radius (cm)	Mass (g)	Density (kg/m³)
Object 6	1.9	90.29	3,142.71
Object 7	2.15	49.00	1,177.04
Object 8	2.15	89.50	2,149.89
Object 9	2.15	130.72	3,140.04

In **Table 1**, there are test objects with different radii but the same mass, specifically for objects 3, 5, and 7. The test objects with different radii but the same density are found in objects 1, 4, and 7, which have a density of 1.177 g/cm³, and objects 3, 6, and 9, which have the same density of 3.14 g/cm³. The test objects with the same radius are each made in 3 variations, with different masses and densities, to examine whether the cross-sectional area, mass, and density of the test objects influence the magnitude of the driving force acting on the test object. The image of the test objects is shown below.

Determination of the deviation angle (Ø) and driving force on the test object.

The study is conducted to determine the magnitude of the driving force/drag force exerted on a test object moving through water at a constant speed or a test object submerged in water flowing at a constant speed. As the speed of the vehicle moving in water increases, the drag/force exerted by the water on the vehicle also increases. When a driving force is applied to the vehicle, it will initially accelerate at a certain rate. As the vehicle's speed increases, the drag force from the water will become greater, causing the vehicle's acceleration to decrease and eventually approach zero, reaching a constant speed known as terminal velocity. At this constant speed, the resultant force on the vehicle is zero, meaning the driving force is equal to the drag force from the water.

The value of the driving force (F) can also be determined in another way, by suspending the test object and then immersing it into a water flow with velocities of 0.42 m/s, 0.5 m/s, 0.58 m/s, and 0.67 m/s, until the test object reaches equilibrium, as shown in **Figure 2** [16].

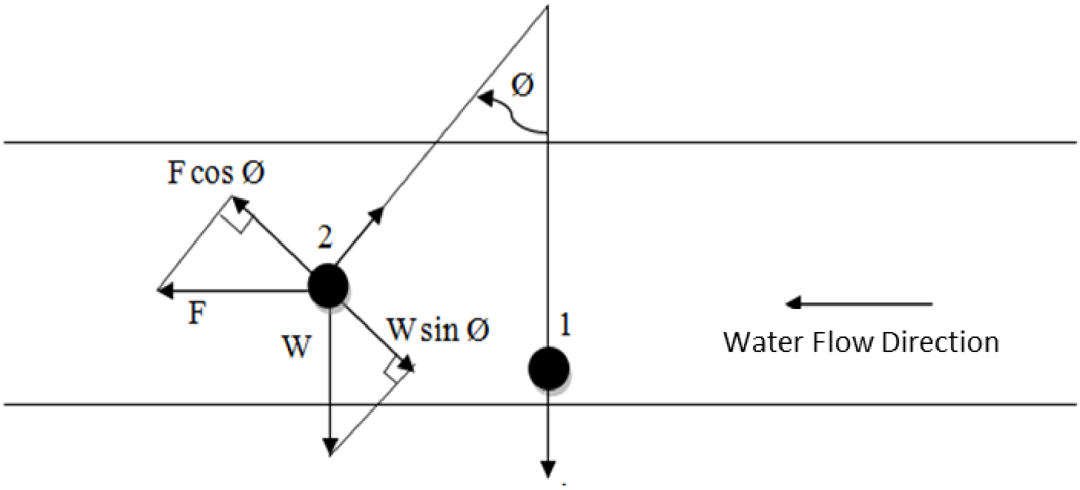

Figure 2. The Equilibrium Position of the Test Object After Being Moved by the Water Flow

Based on **Figure 2**, the driving force $F = W \tan Ø$, where W is the weight of the test object in water. The magnitude of the deflection angle (Ø) and the resulting driving force are as follows.

Table 2. Magnitude of the deflection angle Ø obtained from the experimental results.

Object Number	Ø			
	v = 0.42 m/s	v = 0.50 m/s	v = 0.58 m/s	v = 0.67 m/s
Object 1	74	76	78	79
Object 2	20	23	27	30
Object 3	13	15	18	22
Object 4	27	29	33	36
Object 5	18	20	23	27
Object 6	8	10	12	15
Object 7	22	24	27	31
Object 8	12	14	16	18

Note: The angles obtained are in degrees.

Table 3. Magnitude of the Driving Force (F)

No	F (m/s (N))			
	v = 0.42	v = 0.50	v = 0.58	v = 0.67
1	0.134	0.154	0.181	0.198
2	0.120	0.140	0.168	0.191
3	0.111	0.129	0.156	0.194
4	0.169	0.184	0.215	0.241
5	0.156	0.175	0.204	0.245
6	0.124	0.156	0.188	0.237
7	0.194	0.214	0.244	0.288
8	0.186	0.219	0.251	0.285
9	0.135	0.180	0.203	0.249

The results of the study show that for test objects with the same radius, an increase in density results in a smaller angle (Ø) and a constant driving force. This indicates that the density of the object does not affect the magnitude of the driving force. The variables that influence the magnitude of the driving force are the radius (or cross-sectional area in the direction of motion) and the velocity of the object moving in water.

Determination of the Equation Relating the Horizontal Driving Force (F) to the Radius of the Test Object (r) and the Flow Velocity (v) Using Multiple Log-Linear Regression.

Determination of the equation relating the driving force (F) to the radius of the test object (r) and the flow velocity (v) based on the experimental data presented in the table below.

Table 4. Experimental Results Based on the Experiment.

Flow velocity (m/s)	Log v	Radius of object (m)	Log r	Average driving force (N)	Log F
0.42	-0.377	0.0155	-1.810	0.123	-0.911
0.42	-0.377	0.0190	-1.721	0.150	-0.823
0.42	-0.377	0.0215	-1.668	0.170	-0.769
0.50	-0.301	0.0155	-1.810	0.146	-0.835
0.50	-0.301	0.0190	-1.721	0.179	-0.747
0.50	-0.301	0.0215	-1.668	0.203	-0.693
0.58	-0.237	0.0155	-1.810	0.169	-0.771
0.58	-0.237	0.0190	-1.721	0.208	-0.683

The results of the multiple linear regression on the logarithmic data using SPSS software are as follows.

$$Log\ F = 1{,}275 + log\ v + log\ r \qquad (1)$$

By applying the antilogarithm, the results are obtained as follows

$$F = 10(1{,}275 + log\ v + log\ r)$$
$$F = 101{,}275.10(log\ v).10(log\ r)$$
$$F = 18{,}836vr$$

Determination of Vehicle Power in Water

The power of the vehicle is equal to the magnitude of the driving force FFF (Equation 3) multiplied by the desired or planned speed of the vehicle. If the cross-sectional area of the vehicle has a radius of 5 m (assumed to be circular) and is required to move at a speed of 100 km/h or 27.778 , the required driving force is $F = 18{,}836rv = (18{,}836)(5)(27{,}778) = 2616.132N$. The desired vehicle must have a power of $F \cdot v = (2616.132N)(27.778m/s) = 72{,}670.916W$ hp. Since 1 hp = 745.670 W, the required electrical power for the vehicle is $(745.670)(745.670)W = 54{,}188{,}521.80W = 54.188.52kW$.

Results of Student Categorization and Provided Answers

The results of categorization and the answers provided are presented in **Table 3** and **Table 5**.

Table 5. Number of Student Respondents in Malang City

Category	Number of Respondents	Percentage
	Age	
15	52	52%

Category	Number of Respondents	Percentage
16	48	48%
Total	**100**	**100%**
	Gender	
Female	58	58%
Male	42	42%
Total	**100**	**100%**

Based on data obtained from 100 tenth-grade students in Malang City, the age distribution of respondents shows that the majority of students are 15 years old, with 52 students or 52% of the total respondents, while the remaining 48 students or 48% are 16 years old. In terms of gender, there are 58 female students (58%) and 42 male students (42%). These results indicate that the research sample is fairly balanced in terms of age distribution, with a predominance of 15-year-olds, and reflects greater participation from female students compared to male students.

Table 6. Average Scores of Pre-test and Post-test for Each Question

No.	Question	Pre-test	Post-test
1	Concept of Buoyant Force on Objects in Water	58%	78%
2	Effect of Water Flow Velocity on Frictional Force	55%	80%
3	Calculation of Driving Force on Objects in Water	50%	75%
4	Relationship Between Angle Ø and Equilibrium of Objects	60%	82%
5	Application of Stokes' Law in the Experiment	52%	77%
Average		**55%**	**78.4%**

From the data above, there was an average increase of 23.4% from the pre-test to the post-test, indicating an improvement in student understanding after conducting the experiment. Question number 4, regarding the relationship between angle Ø and the equilibrium of the object, showed the highest improvement, at 22%. Question number 3, about calculating the driving force, showed the lowest improvement, at 25%.

Results of the Normality Test and t-Test

The results of the normality test and t-test can be seen in **Table 7**.

Table 7. Results of the Normality Test and t-Test

Variable	Probability	Cut Off	T Value (1.96)	P value
X (Pre-test)	0.185*	0.05	12.25	0.0005
Y (Pre-test)	0.239*	0.05		
X (Post-test)	0.291*	0.05		
Y (Post-test)	0.226*	0.05		

Note: * Indicates passing the normality test with a significance level greater than 0.05

The very small p-value (<0.05) indicates that there is a significant difference between the pre-test and post-test results, suggesting that this experimental project is effective in improving Students understanding of the physics concepts being studied.

Discussion

In this study, the experimental results indicate that the density of the test object does not significantly affect the driving force. This can be observed in test objects with different densities that produced similar driving forces, especially for objects with the same radius. For example, the test object with a density of 3.14 g/cm^3 (objects 3, 6, and 9) and the test object with a density of 1.177 g/cm^3 (objects 1, 4, and 7) showed that the driving force generated was not influenced by density differences, but was more affected by the radius size and the flow velocity of the water. This is in line with the decrease in the deflection angle (Ø), which becomes smaller as the density of the test object increases. Based on the experimental results, the larger the radius size of the test object (or the cross-sectional area in the direction of motion), the greater the driving force required to maintain the movement of the test object in water. This is evident in test objects with larger radii, such as objects 7, 8, and 9, which required a greater driving force compared to smaller test objects. For instance, the test object with a radius of 2.15 cm demonstrated a higher driving force than the object with a radius of 1.55 cm.

The flow velocity of the water also plays a significant role in determining the driving force generated. The higher the flow velocity of the water, the greater the drag force encountered by the test object, which in turn increases the driving force required to maintain a constant speed. In this experiment, the test objects placed in water at a velocity of 0.67 m/s showed a greater driving force compared to those at a lower velocity of 0.42 m/s. This result indicates that the driving force is directly proportional to the flow velocity, meaning that the higher the flow velocity, the greater the driving force needed to reach terminal velocity. From the results of the multiple log-linear regression for vehicles aiming to move at high speeds, the required driving force increases as the size of the vehicle and the flow velocity increase. Based on the equation obtained, the required power for a vehicle moving in water at a speed of 100 km/h was calculated. The calculation showed that for a vehicle with a cross-sectional area of 5 m and a speed of 27,778 m/s, a driving force of 2,616.132 N and a power of 72.67 hp (equivalent to 54.19 kW) are required. This calculation demonstrates the amount of power needed for the vehicle to move at that speed in water.

The results of the categorization and the answers provided by the students indicate a significant improvement in their understanding of the physics concepts studied. Based on the pre-test and post-test data, the average score increased by 23.4%, with the highest improvement observed in the question concerning the relationship between the deflection angle and the equilibrium of the object. This suggests that the experiment had a positive impact in enhancing Students understanding of concepts such as buoyant force, friction, and other principles in fluid mechanics. The normality test showed that the distribution of pre-test and post-test data followed a normal distribution, with p-values greater than 0.05. Additionally, the t-test results demonstrated a significant difference between the pre-test and post-test, indicating that the experiment successfully improved Students understanding.

A study by Elmenshawy et al. [17], which examined the effect of the shape and size of objects on the driving force in fluid flow, found a significant relationship between the driving force and physical parameters such as object shape and size. This supports our findings, which identify that the driving force on a hollow steel ball is influenced by factors such as the object's radius and the water flow velocity. This research confirms that variations in physical parameters play a role in modulating the driving force acting on objects in fluid flow. Another study that aligns with our findings is that by Yue et al. [18], which explored Students understanding of dynamic fluid concepts in the context of hands-on experiments. The study found that students tend to better understand the concept of the driving force when they are directly involved in experiments with real objects. This finding reinforces our research, where direct observation of experimental objects, such as hollow steel balls, allows students to tangibly observe the relationship between the driving force and the motion of the object in water, leading to a deeper understanding of related physics concepts.

Theoretically, the research by Christov [3], which discusses the application of Newton's laws in fluid flow experiments, provides a foundation supporting our findings. The study states that the driving force in fluids is directly proportional to variables such as flow velocity and object size, which is consistent with our results, where the driving force is influenced by the object's radius and water flow velocity. This finding confirms that the relationship between force and flow variables can be analyzed using fundamental physics principles, particularly Newton's laws of motion.

CONCLUSION

The results of the study indicate that the density of the vehicle does not affect the magnitude of the driving force required for the vehicle. The variables that influence the driving force are the radius or cross-sectional area parallel to the motion and the velocity of the object in water. The equation obtained from the multiple log-linear regression is $F = 18.836vr$. The power required for the vehicle can be measured as the driving force multiplied by the expected constant velocity. Based on the experiments conducted, students were able to understand that a test object, such as a hollow steel ball with a density slightly higher than water, moves with a driving force dependent on the object's radius and the velocity of the water flow. The density of the test object does not affect the driving force, but the size of the radius and the flow velocity play a crucial role in generating the required force. From the multiple log-linear regression results, a relationship between the driving force and the water flow velocity was identified, which can be used to calculate the driving force needed for the vehicle to move at a specific velocity. In conclusion, fundamental physics principles such as force, density, and flow velocity significantly influence the motion of objects in a fluid, which can be applied to the design of vehicles or other systems.

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